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Utilization of Household Organic Waste into Biogas and Integrated with IoT

Bintang Indra Maulana[1], Andhika Suryamiharja[2], Pradipa Catya Wisesa[3], Rendy Munadi[4], Sussi Sussi[5]
[1,2,3,4]Teknik Telekomunikasi, Fakultas Teknik Elektro, Telkom University, Bandung, Indonesia
[1]bintangindramaulana@student.telkomuniversity.ac.id, [2]iamdhikka@student.telkomuniversity.ac.id,
[3]pradipawisesa@student.telkomuniversity.ac.id , [4]rendymunadi@telkomuniversity.ac.id, [5]sussiss@telkomuniversity.ac.id

Abstract

The increase in population impacts several environmental sectors, particularly the use of natural gas energy for household needs, such as LPG (Liquefied Petroleum Gas). This has resulted in the depletion of natural gas reserves and a rise in LPG imports. Additionally, the growing population contributes to the accumulation of household waste, which can lead to excessive leachate production and greenhouse gas emissions. This issue is particularly concerning in developing countries like Indonesia due to its negative environmental impact. This research aims to provide a solution and contribute to reducing household waste accumulation by utilizing organic waste to create renewable energy in the form of biogas as an alternative to LPG. Biogas is produced through the fermentation of organic waste. Nutrient-rich fluids containing sugar can enhance the performance of methanogenic bacteria in biogas formation. In this study, we conducted nutritional testing on molasses and coconut water to determine which nutrients optimize biogas production efficiency by monitoring the pressure of the generated biogas. Generally, biogas comprises methane and carbon dioxide. It is important to note that excessive methane can lead to explosions, while high carbon dioxide levels contribute to greenhouse gas emissions. The quantities of methane and carbon dioxide produced during biogas generation can be influenced by temperature and humidity. Therefore, monitoring pressure, temperature, humidity, methane, and carbon dioxide levels in the biogas production process using the Internet of Things (IoT) is a prudent approach. The results indicate that a substrate mixed with molasses produces biogas at twice the pressure compared to coconut water. Furthermore, optimal biogas production with ideal methane and carbon dioxide levels occurs at temperatures between 25-35°C under high humidity conditions. This suggests that mesophilic methanogenic bacteria thrive in tropical climates.

Keywords: Biogas, methane, carbon dioxide, methanogenic bacteria, Internet of Things, temperature, humidity

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1. Introduction

Indonesia has the fourth-largest population in the world [1]. According to data from the Central Statistics Agency, Indonesia experienced an average population increase of approximately 2 million people per year from 2019 to 2022, as shown in Table 1.

Table 1. Indonesian Population Data

Year	2019	2020	2021	2022
Population (million)	270,6	273,5	275,8	277,7

This affects several environmental and economic sectors, particularly the use of natural gas for household needs, such as Liquefied Petroleum Gas (LPG). This has led to the depletion of natural gas reserves and an increase in LPG import levels [2]. This is supported by data recorded by the Ministry of Energy and Mineral Resources, as follows:

From Figure 1, the Ministry of Energy and Mineral Resources notes that natural gas production in Indonesia has decreased significantly since 2019 and will continue to decline until 2022.

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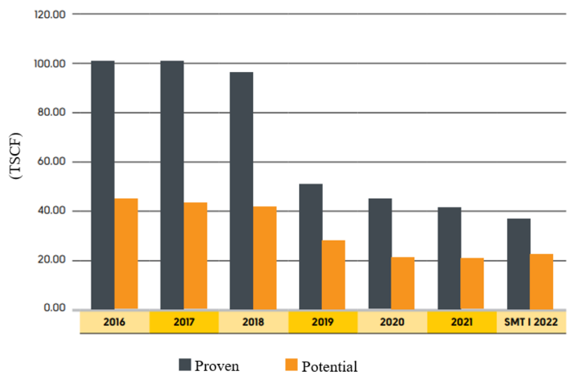

Figure 1. Indonesia's Natural Gas Reserves 2016-2022

The use of natural gas in Indonesia is divided among several sectors: 60-65% in the industrial sector, 20-25% in the electricity generation sector, 0,2-1% in the household sector, and the remainder in the transportation and commercial sectors. Consequently, the household sector, which receives only a 0,2-1% share of natural gas, impacts the amount of local LPG gas production, which cannot meet the needs of the Indonesian people. As a result, imports of LPG gas from abroad have increased, as noted in Figure 2 and Table 2.

Table 2. Comparative data on production, imports and demand for LPG gas in Indonesia

Parts	Year 2019	2020	2021	2022
Production (million tons)	1,94	1,92	1,9	1,99
Import (million tons)	5,71	6,4	6,34	6,74
Requirements (million tons)	7,77	8,02	8,36	8,56

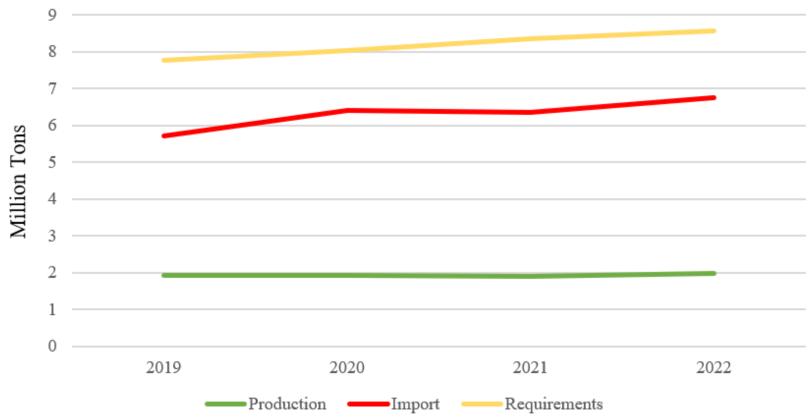

Figure 2. Comparison graph of production, imports and demand for LPG gas in Indonesia

Apart from that, the increasing population contributes to the growing accumulation of household waste. This is supported by data recorded in the Waste Management Information System by the Ministry of Environment and Forestry, which tracks waste accumulation in Indonesia annually as shown in Table 3.

Table 3. Total Waste Accumulation in Indonesia (2019-2022)

Year	Amount of waste accumulation (million tons)
2019	67,8
2020	69,8
2021	70,5
2022	72

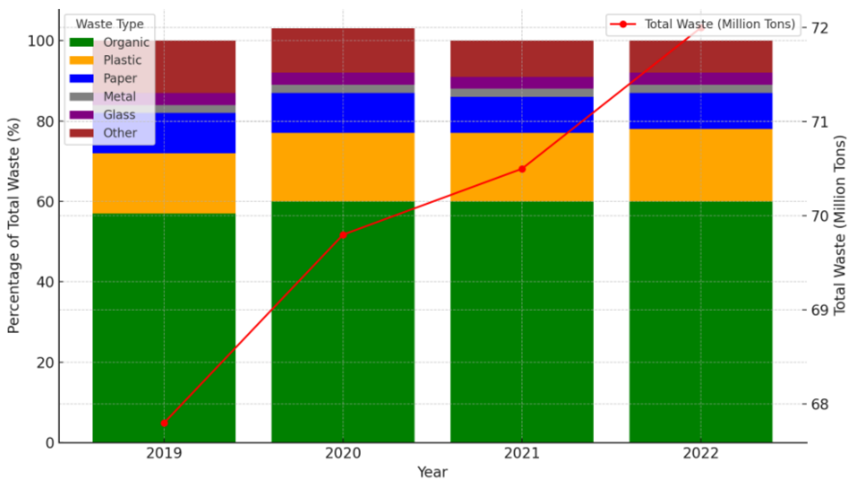

Figure 3. Waste Composition in Indonesia (2019-2022)

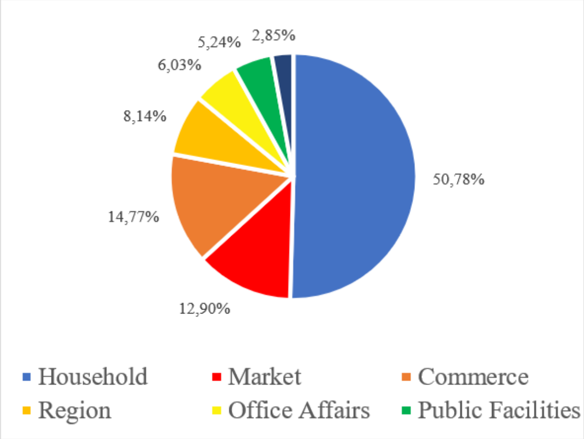

Figure 4. Sources of Garbage Accumulation in Indonesia

Figures 3 and 4 show that the average waste accumulation in Indonesia is approximately 38.2 million tons per year, predominantly consisting of organic waste, with households generating the largest share. Additionally, the Ministry of Environment and Forestry has reported annual achievements in waste management, indicating that 61.79% of waste, or about 23.6 million tons per year, is managed, while unmanaged waste accounts for 38.21%, or 14.6 million tons per year. This situation raises significant concerns, particularly among the populations of developing countries like Indonesia, due to its negative environmental impacts, such as excessive leachate production and greenhouse gas emissions [3].

In response to this phenomenon, the Indonesian government has made efforts to expand natural gas exploration and enhance the development of renewable energy [4]. This research aims to contribute to the advancement of renewable energy, particularly in the household sector. As previously mentioned, liquefied petroleum gas (LPG) is the most commonly used natural gas energy source in households. Additionally, households are the largest contributors to organic waste in Indonesia. This organic waste can be utilized to produce biogas as a renewable energy source, serving as an alternative to LPG.

Biogas is formed through a natural fermentation process that involves two types of fermentation: aerobic and anaerobic. The key difference between these two is that aerobic fermentation requires oxygen, whereas anaerobic fermentation does not [5]. Generally, the biogas formation process utilizes anaerobic fermentation, as it allows for production in an airtight environment, ensuring that the biogas generated maintains sufficient pressure for daily needs [6]. This fermentation process relies on bacterial activity, particularly methanogenic bacteria, to produce biogas. There are two categories of methanogenic bacteria: mesophilic methanogenic bacteria, which thrive at temperatures ranging from 25-35°C, and thermophilic methanogenic bacteria, which operate at temperatures ranging from 40-60°C [7]. To optimize the biogas production process, it is recommended to place the digester tube in a controlled temperature environment, such as indoors. Given that this research was conducted in Indonesia, where temperatures range from 30-35°C, testing focused on mesophilic methanogenic bacteria. Apart from temperature factors, methanogenic bacteria can also be influenced by the substrate used and nutritional factors [8]. Just like humans, bacteria also need nutrition to maximize their potential [9]. In previous research, using tofu liquid as a substrate along with molasses and coconut water as nutrients produced the following biogas pressure comparison:

Table 4. Biogas Pressure Comparison Between Molasses and Coconut Water As Bacteria Nutrition

No	Time	Biogas Pressure (psi)	
		Molasses	Coconut Water
1	Day 1	0	1
2	Day 2	0	2
3	Day 3	0	3
4	Day 4	1,7	3,5
5	Day 5	3,5	4

The data in Table 4 show that the nutrients used in biogas production significantly influence the pressure of the resulting biogas. This is particularly concerning because, regardless of the quantity of biogas produced, low pressure can hinder the ability to generate sufficient heat for cooking. Therefore, this research tested the same nutrients using a different substrate: household organic waste slurry or ground household organic waste.

Additionally, the selection of the digester tank design is a crucial consideration, as the chosen material should align with the specified requirements. Currently, there are three available types of digester tanks. The buried digester tank is commonly used due to its simple construction and utilization of readily available materials like cement, enabling a larger capacity. This design effectively regulates substrate temperature by being placed underground. However, it lacks flexibility [10]. Furthermore, a semi-permanent digester tank design has been implemented, which features stainless steel, a material renowned for its corrosion resistance. This innovative design boasts a capacity that is equivalent to its predecessor [11]. Unlike the permanently installed buried digester tank, this design allows for the movement of the digester tank for regular maintenance. However, the material used in this design tends to absorb heat. Consequently, the digester tank must be placed in a temperature-controlled indoor environment, which limits its mobility. The last design option is the portable digester tank, which is constructed using HDPE (High-Density Polyethylene) material [12]. This material is highly resistant to corrosion and does not absorb heat. Although this design has a relatively small capacity, its compact size provides advantages in terms of mobility, making it highly adaptable. A notable advancement in this design is its integration with a monitoring system that utilizes sensors [13], [14].

Biogas typically consists of around 50-70% methane and 25-50% carbon dioxide [14]. A high concentration of methane makes biogas highly flammable and vulnerable to potential explosiveness, while an increased level of carbon dioxide can contribute to the emission of greenhouse gases [15]- [17]. Therefore, it is crucial to monitor the biogas production process efficiently, including essential parameters such as temperature, methane content, and carbon dioxide content. This monitoring is necessary to achieve a high-quality standard of biogas production [18].

Biogas production can be efficiently monitored using the Internet of Things (IoT). The IoT is a communication system that connects electronic devices and enables effective biogas monitoring through the use of various sensors. The data collected from these sensors is then presented on a user interface for analysis and observation [19].

This research is being conducted in the village of Lebaksiu Kidul, Indonesia because of its significant potential for developing initiatives in compost production and organic waste utilization. The village was chosen due to the identified lack of knowledge, which is currently a major obstacle to effectively utilizing organic waste. As a result, it is expected that this research will open up new possibilities for organic waste utilization.

2. Research Methods

The research method is divided into two focuses: the evaluation of biogas production efficacy, which explores the optimal composition of substrates for biogas formation, and the examination of the relationship between temperature, humidity, and biogas productivity.

2.1 Effectiveness of Biogas Production

The assessment of biogas production efficiency is crucial to ensure that the resulting biogas has sufficient pressure for regular use. Therefore, it is important to carefully select a suitable biodigester in order to facilitate an optimal biogas generation process.

Taking into consideration various factors such as economic aspects, manufacturing feasibility, and sustainability considerations, the portable digester tank emerges as the most appropriate choice for this investigation. Its compact design, with a capacity of 250 litres, contributes to reducing production costs, easing maintenance procedures, and simplifying the installation of an Internet of Things (IoT)-based monitoring system.

That meets sustainability requirements. Figure 5 is the design of the biodigester used. When evaluating the effectiveness of biogas production, the parameters being examined include the compositions of the substrates under investigation. These compositions are described as shown in Table 5.

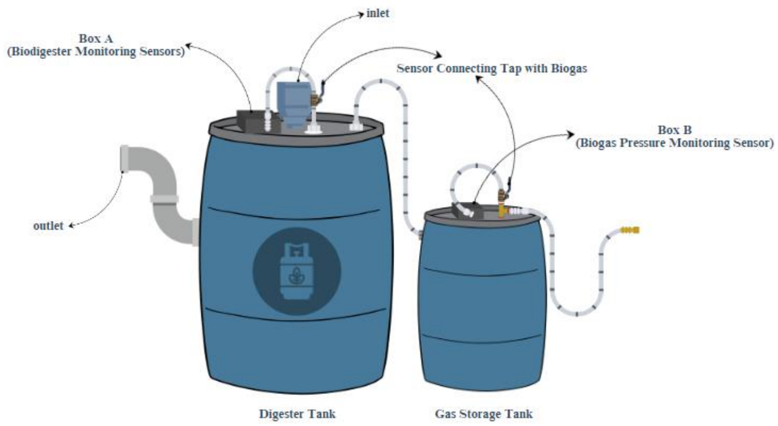

Figure 5. Design of the biodigester

Table 5. The compositions of substrates tested

No.	Materials	Compositions
1.	substrate with a mixture of household organic waste and water	1:1 or 1:2
	Em4 Bacterial Solution	1,6 ml/L substrate
	Molasses Solution	16 ml/L substrate
2.	substrate with a mixture of household organic waste and water	1:1 or 1:2
	Em4 Bacterial Solution	1,6 ml/L substrate
	Coconut Water	0,06 ml/ L substrate

The composition presented in Table 5 was formulated by building upon existing research, albeit by utilizing distinct substrate materials. Previous investigations used tofu liquid as the foundation, whereas the current study incorporates household organic waste as the substrate [9]. The research outcomes include biogas pressure readings recorded in PSI units by BMP180 sensors. These sensors are integrated with the Internet of Things (IoT) system to display the data through the Blynk application/web interface. The BMP180 sensor is installed inside Box A, as shown in the circuit Figures 6 and 7.

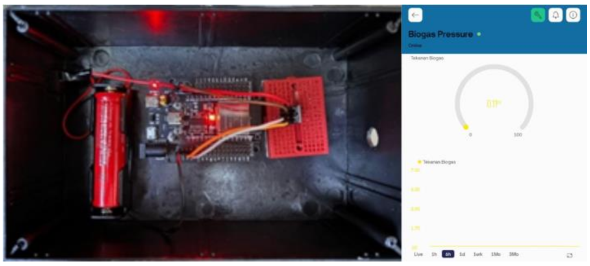

Figure 6. Box A and the Blynk display

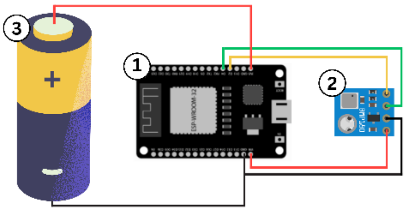

Figure 7. Box A Illustration

Table 6. Box A tools and purpose

No.	Tools	Purpose
1.	Esp32	Microcontroller
2.	BMP180	Pressure Sensor
3.	1865 Battery	Power Supply

This testing is conducted over five days according to the scheme in Figure 8.

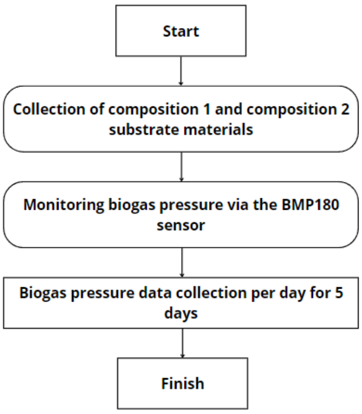

Figure 8. Testing scheme of the effectiveness of biogas production

2.2 Identification of Biogas Productivity and Quality

This study aims to investigate the relationship between temperature and substrate humidity and how they affect the activity of methanogenic bacteria. The variations in biogas production will serve as evidence for this correlation. The monitoring of temperature, humidity, and biogas volume will be carried out using DHT11, MQ-4, and MQ-135 sensors. These sensors will be seamlessly integrated with Internet of Things (IoT) technology through the Blynk application/web interface. The interface will then present the collected data to the user [20], [21], [22]. These sensors are installed inside Box B, as shown in the circuit Table 7, Figures 9 and 10.

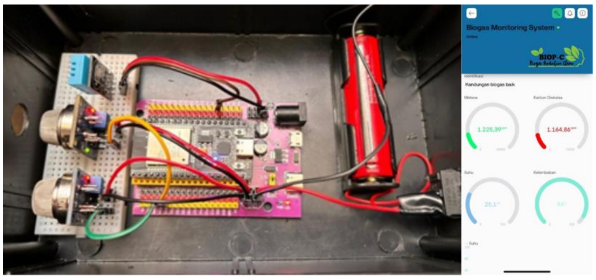

Figure 9. Box B and the Blynk display

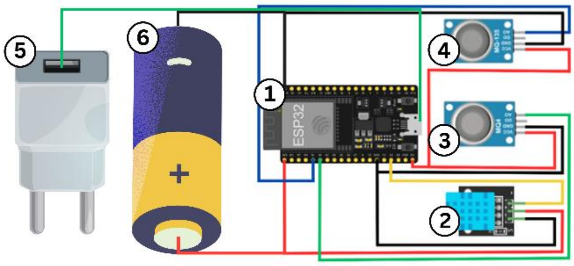

Figure 10. Box B Illustration

Table 7. Box A tools and purpose

No.	Tools	Purpose
1.	Esp32	Microcontroller
2.	DHT11	Humidity and Temperature Sensor
3.	MQ-4	Methane Sensor
4.	MQ-135	Carbon Dioxide Sensor
5.	10-watt Adaptor	Main Power Supply
6.	1865 Battery	2nd Power Supply

The testing is conducted by placing the digester tank outdoors to capture data under significant temperature and humidity variations. The duration of the testing is four days with monitoring conducted twice daily, in the morning from 05:00 to 07:00 and in the afternoon from 12:00 to 13:00. This setup facilitates the study of whether different weather conditions impact biogas productivity.

To provide a more comprehensive overview, the testing setup can be depicted using the schematic in Figure 11.

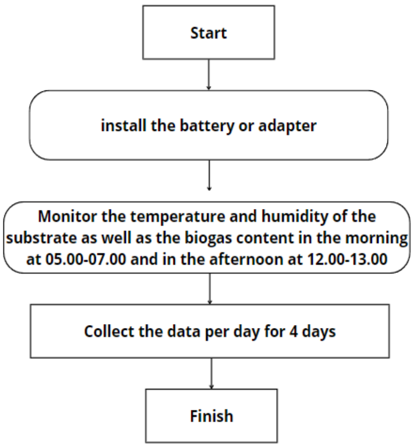

Figure 11. Testing scheme of identification of biogas productivity and quality

3. Results and Discussions

3.1 Effectiveness of Biogas Production Result

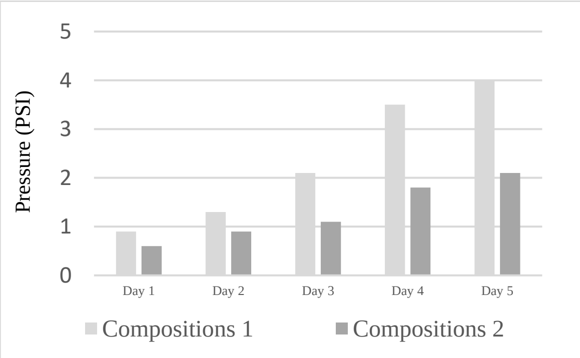

Figure 12. Data of biogas pressure in 5 days

After analyzing the biogas pressure under two different substrate compositions, the data from the aforementioned diagram can be compared in Table 8.

Table 8. Data of biogas pressure in 5 days

Times	Biogas Pressure (PSI)	
	Compositions 1	Compositions 2
Day 1	0,9	0,6
Day 2	1,3	0,9
Day 3	2,1	1,1
Day 4	3,5	1,8
Day 5	4	2,1

Based on the data mentioned in Table 8, it can be inferred that substrate composition 1, which used molasses, produced biogas with a pressure that was twice as high compared to substrate composition 2, which used coconut water, during the entire 5-day testing period.

The difference can be explained by the fact that molasses contains a high amount of sugar, which acts as a significant carbon source for anaerobic microorganisms during fermentation. Sugar serves as the main energy source for these microorganisms, so the addition of molasses accelerates their growth and activity, resulting in higher biogas production [23].

3.2 Identification of Biogas Productivity and Quality Result

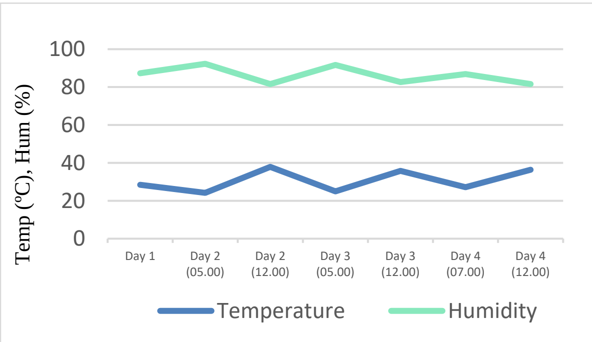

Figure 13. Result of temperature and humidity measurement

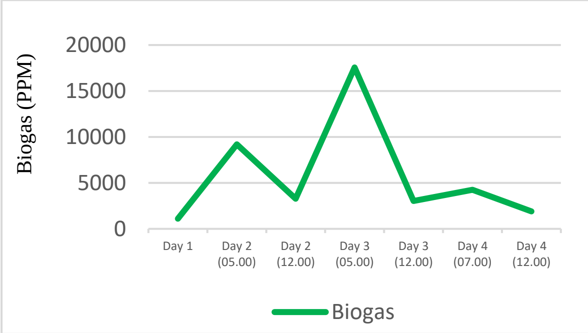

Figure 14. Result of biogas measurement

The data mentioned in Tables 13 and 14 was obtained after a four-day testing period. Therefore, the quality can be determined by analyzing Table 9.

Based on the presented data, it is clear that temperature and humidity significantly affect the performance of methanogenic bacteria. In addition, the conducted tests suggest that the methanogenic bacteria responsible for biogas production are mesophilic, meaning they thrive in temperatures ranging from 25-31°C and under high humidity conditions [24]. This is due to the placement of the digester tank outdoors, where temperature and humidity vary based on the weather in Indonesia, the country where the testing took place. Conversely, the activity of thermophilic methanogenic bacteria, which thrive in high-temperature conditions, was not observed in this experimental setup due to the unsuitability of Indonesia's temperature conditions for their function.

Table 9. Data on the correlation of temperature and humidity with biogas productivity

Times	Temperature	Humidity	Biogas (ppm)
Day 1	28,4˚C	87,27 %	1.102
Day 2 (05.00)	24,18˚C	92,29 %	9.197
Day 2 (12.00)	37,9˚C	81,59 %	3.267
Day 3 (05.00)	24,96˚C	91,66 %	17.562
Day 3 (12.00)	35,81˚C	82,62 %	3.025
Day 4 (07.00)	27,16˚C	86,83 %	4.252
Day 4 (12.00)	36,34˚C	81,59 %	1.902

4. Conclusions

Overall, this research provides new insights into the combination of biogas formation and the Internet of Things. The testing focuses on two main points: biogas productivity and evaluating the tools created. Generally, the formation of biogas through the utilization of organic waste in portable digester tubes integrated with IoT presents significant opportunities for developing renewable energy in developing countries, particularly Indonesia. However, several aspects require consideration. The sustainability aspect became the primary focus following the success of this research. Based on the tests conducted, it can be concluded that the tools developed can still be further optimized. For instance, the amount of biogas produced does not correspond to the quantity of organic waste being processed. A digester tube with a capacity of 250 litres can accommodate substrate from five houses per month, but the resulting biogas output will not be proportional. This discrepancy reduces both the effectiveness of biogas productivity and cost efficiency, which are critical considerations for the sustainability of this tool. Increasing the size of the digester tube is a prudent option; this adjustment would enable a shift in biogas production from a household scale to a village scale. Digester tubes can be implemented using a large-scale planting system, allowing the biogas produced to be stored in 3 kg LPG cylinders and distributed directly to the community, thus facilitating the use of biogas as an alternative to LPG. In this context, collaboration between the government and the community is essential to foster a strong relationship through positive initiatives in environmental empowerment and renewable energy development.

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References

[1] Ernawati, S. Nurjanah, N. P. Adriana, E. N. Pratiwi, and A. Apriani, "The Effect of Counseling on Family Planning Acceptors in Decision Making on Contraceptive Devices during the Postpartum Period," *Formosa J. Sci. Technol.*, vol. 1, no. 5, pp. 593–602, 2022, doi: 10.55927/fjst.v1i5.1277.

[2] I. F. U. Muzayanah, H. H. Lean, D. Hartono, K. D. Indraswari, and R. Partama, "Population density and energy consumption: A study in Indonesian provinces," *Heliyon*, vol. 8, no. 9, p. e10634, 2022, doi: 10.1016/j.heliyon.2022.e10634.

[3] M. B. Latif, M. A. Islam, M. S. Hossain, and S. S. Aurpa, "Effect of Sludge Content on the Decomposition of Different Types of Food Waste," *Sustain.*, vol. 15, no. 3, 2023, doi: 10.3390/su15032782.

[4] M. M. Adrian, E. P. Purnomo, A. Enrici, and T. Khairunnisa, "Energy transition towards renewable energy in Indonesia," *Herit. Sustain. Dev.*, vol. 5, no. 1, pp. 107–118, 2023, doi: 10.37868/hsd.v5i1.108.

[5] F. Ríos, F. Caparrós-Salvador, M. Lechuga, and M. Fernández-Serrano, "Complete biodegradability assessment of polyoxyethylene glycerol ester non-ionic surfactant: Aerobic, anaerobic, combined biodegradation and inhibitory effects," *Water Res.*, vol. 248, no. October 2023, 2024, doi: 10.1016/j.watres.2023.120857.

[6] J. Joshi *et al.*, "Integrating microbial electrochemical cell in anaerobic digestion of vegetable wastes to enhance biogas production," *Bioresour. Technol. Reports*, vol. 27, no. August, p. 101940, 2024, doi: 10.1016/j.biteb.2024.101940.

[7] K. H. Phan *et al.*, "Anaerobic biodegradation of mixed azo dyes in thermophilic and mesophilic conditions," *Case Stud. Chem. Environ. Eng.*, vol. 9, no. February, p. 100667, 2024, doi: 10.1016/j.cscee.2024.100667.

[8] L. R. Machado, A. H. Ferrarez, J. L. Junior, and F. C. Alves, "Biogas production and composition optimization in an anaerobic digestor using cheese whey and swine manure as substrate," *Acta Sci. - Technol.*, vol. 44, 2022, doi: 10.4025/actascitechnol.v44i1.56923.

[9] N. D. Susetyo, F. Rhohman, and M. M. Ilham, "Perbandingan Zat Penyusun Dalam Pemanfaatan Limbah Cair Tahu Sebagai Energi Alternatif Biogas," *J. Mesin Nusant.*, vol. 2, no. 2, pp. 109–118, 2020, doi: 10.29407/jmn.v2i2.14185.

[10] S. Theuerl *et al., The future agricultural biogas plant in Germany: A vision*, vol. 12, no. 3. 2019. doi: 10.3390/en12030396.

[11] I. K. A. Atmika, K. Sebayuana, T. G. T. Nindhia, I. W. Surata, I. Putu Ari Astawa, and A. A. I. A. S. Komaladewi, "The effect of loading rate to biogas production rate of the 500 liter anaerobic digester operated with continuous system," *E3S Web Conf.*, vol. 120, no. 201 9, pp. 10–13, 2019, doi: 10.1051/e3sconf/201912002004.

[12] S. Thiruketheeswaranathan and A. Dharshayini, "Design of Small-scale Biogas Plant for Household Need," *Middle East J. Appl. Sci. Technol.*, vol. 04, no. 03, pp. 40–43, 2021, doi: 10.46431/mejast.2021.4305.

[13] K. Maurus, N. Kremmeter, S. Ahmed, and M. Kazda, "High-resolution monitoring of VFA dynamics reveals process failure and exponential decrease of biogas production," *Biomass Convers. Biorefinery*, vol. 13, no. 12, pp. 10653–10663, 2023, doi: 10.1007/s13399-021-02043-2.

[14] A. Mukasine, L. Sibomana, K. Jayavel, K. Nkurikiyeyezu, and E. Hitimana, "Correlation Analysis Model of Environment Parameters Using IoT Framework in a Biogas Energy Generation Context," *Futur. Internet*, vol. 15, no. 8, 2023, doi: 10.3390/fi15080265.

[15] S. P. Wijaya, S. Ainun, and D. A. Permadi, "Methane Emission Estimation and Dispersion Modeling for a Landfill in West Java, Indonesia," *J. Civ. Eng. Forum*, vol. 7, no. 3, p. 239, 2021, doi: 10.22146/jcef.62824.

[16] S. He, L. Su, H. Fan, and R. Ren, "Methane explosion accidents of tunnels in SW China," *Geomatics, Nat. Hazards Risk*, vol. 10, no. 1, pp. 667–677, 2019, doi: 10.1080/19475705.2018.1541826.

[17] E. Gul, G. Baldinelli, A. Farooqui, P. Bartocci, and T. Shamim, "AEM-electrolyzer based hydrogen integrated renewable energy system optimisation model for distributed communities," *Energy Convers. Manag.*, vol. 285, no. April, p. 117025, 2023, doi: 10.1016/j.enconman.2023.117025.

[18] S. Wang, F. Ma, W. Ma, P. Wang, G. Zhao, and X. Lu, "Influence of temperature on biogas production efficiency and microbial community in a two-phase anaerobic digestion system," *Water (Switzerland)*, vol. 11, no. 1, 2019, doi: 10.3390/w11010133.

[19] S. Villamil, C. Hernández, and G. Tarazona, "An overview of internet of things," *Telkomnika (Telecommunication Comput. Electron. Control.*, vol. 18, no. 5, pp. 2320–2327, 2020, doi: 10.12928/TELKOMNIKA.v18i5.15911.

[20] M. Mina and K. Kartika, "Monitoring System for Levels of Voltage, Current, Temperature, Methane, and Hydrogen in IoT-Based Distribution Transformers," *Int. J. Eng. Sci. Inf. Technol.*, vol. 3, no. 1, pp. 22–27, 2023, doi: 10.52088/ijesty.v3i1.414.

[21] F. N. Abbas, I. M. Saadoon, Z. K. Abdalrdha, and E. N. Abud, "Capable of gas sensor MQ-135 to monitor the air quality with arduino uno," *Int. J. Eng. Res. Technol.*, vol. 13, no. 10, pp. 2955–2959, 2020, doi: 10.37624/IJERT/13.10.2020.2955-2959.

[22] M. A. Hailan, B. M. Albaker, and M. S. Alwan, "Transformation to a smart factory using NodeMCU with Blynk platform," *Indones. J. Electr. Eng. Comput. Sci.*, vol. 30, no. 1, pp. 237–245, 2023, doi: 10.11591/ijeecs.v30.i1.pp237-245.

[23] W. Romaniuk *et al.*, "Study of Technological Process of Fermentation of Molasses Vinasse in Biogas Plants," *Processes*, vol. 10, no. 10, 2022, doi: 10.3390/pr10102011.

[24] G. M. Salkhozhayeva, K. M. Abdiyeva, S. Y. Arystanova, and G. D. Ultanbekova, "Technological Process of Anaerobic Digestion of Cattle Manure in a Bioenergy Plant," *J. Ecol. Eng.*, vol. 23, no. 7, pp. 131–142, 2022, doi: 10.12911/22998993/149516.

