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BIOGAS PRODUCTION FROM FREE NUTRITIOUS MEAL PROGRAM KITCHEN WASTE THROUGH ANAEROBIC DIGESTION

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ABSTRACT

The Indonesian Government's Free Nutritious Meals (Makan Bergizi Gratis; MBG) Program generates kitchen waste that may cause environmental problems if not properly managed. This study aimed to analyze the utilization of MBG kitchen waste for biogas production and evaluate its operational performance. The study was conducted using a 2,000-L biogas digester fed with kitchen waste from the Tamanagung Community Nutrition Service Unit (Satuan Pelayanan Pemenuhan Gizi; SPPG), Cluring, Banyuwangi, Indonesia. The waste was fed at 10 kg/day at a waste-to-water ratio of 1:1, with an inoculum consisting of 20 kg of cattle manure and 20 L of water. The start-up period lasted seven days, followed by 12 days of biogas production and utilization monitoring. The volume of utilized biogas was determined based on the average flow rate recorded every 10 min during stove operation. The results showed an average utilized biogas volume of 500 L/day, with an average flow rate of 5.90 L/min and an average stove operating time of approximately 85 min/day. The average operating pressure reached 80 mbar. These results indicate that MBG kitchen waste can be converted into biogas in quantities sufficient for direct use as an energy source. This utilization demonstrates the potential of MBG waste management for energy recovery and the implementation of a circular economy.

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INTRODUCTION

The Indonesian Government's Free Nutritious Meals (Makan Bergizi Gratis; MBG) Program generates organic kitchen waste from food preparation and meal service activities. Food and kitchen waste generally contain readily biodegradable organic matter, making them potentially suitable feedstocks for energy production through anaerobic digestion (Mirmohamadsadeghi et al., 2019; Bong et al., 2018; Braguglia et al., 2018). If not properly managed, organic waste can increase the waste management burden and cause environmental problems. One approach that can be applied is anaerobic digestion, a biological process carried out in the absence of oxygen that decomposes organic matter into biogas, which can be used as a renewable energy source (Xu et al., 2018; Kougias & Angelidaki, 2018; Chew et al., 2021). This approach is consistent with the principles of the circular economy, which promote the recovery of resources from waste streams to produce energy or other useful products (Santagata et al., 2021; Xu et al., 2018).

The use of kitchen waste as a substrate for anaerobic digestion has been widely studied because its organic matter content supports biogas and methane production (Mirmohamadsadeghi et al., 2019; Bong et al., 2018; Ren et al., 2018). Process performance is influenced by substrate characteristics, including solids content, organic matter fraction, pH, and biodegradability (Mirmohamadsadeghi et al., 2019; Xu et al., 2018; Meegoda et al., 2018). The use of an inoculum is also an important factor in anaerobic digestion because the presence of suitable microorganisms can support organic matter degradation and methane production. Animal manure, including cattle manure, has been used as an inoculum for food waste treatment because it contains microbial communities that support anaerobic processes (Xing et al., 2020; Dhamodharan et al., 2015).

The treatment of kitchen waste at the institutional scale may differ from laboratory-scale conditions, particularly in terms of feedstock variability, supply continuity, and operating conditions. Variations in substrate characteristics can affect process stability and biogas production performance (Xu et al., 2018; Li et al., 2018; Chiu & Lo, 2016). Therefore, studies under actual operating conditions are needed to assess the ability of the system to produce biogas from kitchen waste generated by food service activities. In addition to production, the success of biogas utilization should also be assessed based on the ability of the generated gas to be used directly as an energy source. The use of biogas as a fuel represents a form of energy recovery from organic waste that can increase the value of the treatment output (Kougias & Angelidaki, 2018; Mertins & Wawer, 2022; Sher et al., 2024).

In the context of the MBG Program, kitchen waste has the potential to be developed as a feedstock for biogas production because it is generated routinely from food service activities. However, studies linking the characteristics of MBG kitchen waste with biogas production and its direct utilization in end-use equipment remain limited. Assessment based on pressure, flow rate, operating duration, and utilized biogas volume can provide a more practical understanding of system performance under actual operating conditions. This direct utilization approach is relevant to the development of institutional-scale biogas systems that consider not only the ability to produce gas but also the ability to provide energy for operational needs (Sher et al., 2024; Mertins & Wawer, 2022; Nsair et al., 2020).

This study aimed to analyze the utilization of MBG kitchen waste for biogas production and evaluate its operational performance. The study was conducted using a 2,000-L anaerobic digester, while biogas performance was evaluated based on pressure, flow rate, operating duration, and utilized biogas volume. The results are expected to provide empirical information on the utilization of MBG kitchen waste as a renewable energy source and serve as a basis for developing a more practical and sustainable MBG kitchen waste management system.

MATERIAL AND METHOD

This experimental study employed a descriptive quantitative approach to evaluate the utilization of kitchen waste from the Indonesian Government's Free Nutritious Meals (Makan Bergizi Gratis; MBG) Program as a feedstock for biogas production. The waste was obtained from the Tamanagung Community Nutrition Service Unit (Satuan Pelayanan Pemenuhan Gizi; SPPG), Cluring, Banyuwangi, Indonesia, which serves approximately 3,000 meal portions per day and generates an average of 30 kg of kitchen waste per day. A total of 10 kg of waste per day was used as digester feedstock. Biogas production and utilization were monitored for 12 days following a 7-day start-up period.

1. Materials

The materials used in this study included MBG kitchen waste, cattle manure as an inoculum, and water. The equipment included a 2,000-L biogas digester configured according to the design of the BIRU Program (BIRU Program, n.d.), a manometer, a flow meter, and a biogas stove. Characterization of the waste and inoculum included moisture content, total solids (TS), volatile solids (VS), fixed solids (FS), and pH. Moisture content, TS, VS, and FS were determined using gravimetric methods, while pH was measured using a pH meter. The layout of the digester system and biogas utilization line is shown in Figure 1, including the inlet, digester, outlet, main biogas line, water drain, measurement instruments, and biogas stove.

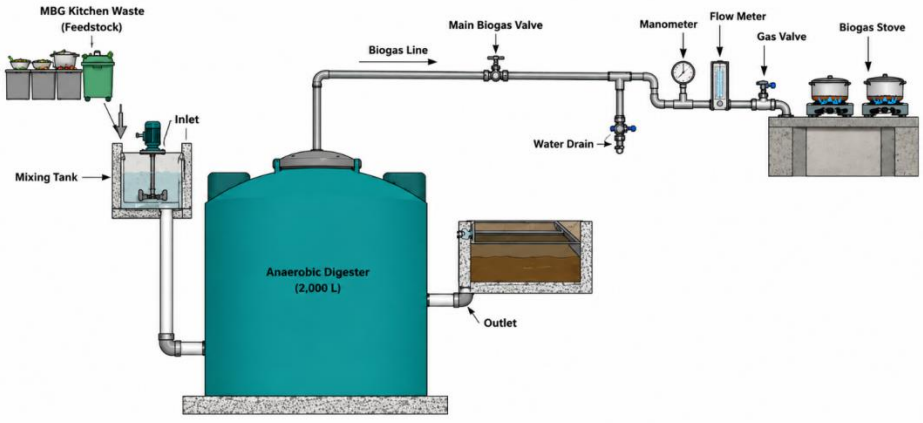


Figure 1. Biogas System for MBG Waste Treatment, including the inlet, anaerobic

digester, outlet, main biogas line, water drain, measurement instruments, and biogas stove.

B. METHOD

The inoculum was prepared by mixing 20 kg of cattle manure with 20 L of water at a 1:1 ratio and then introduced into the anaerobic digester. The start-up period was conducted for 7 days at approximately 32 °C to establish anaerobic conditions. The gas produced during this period was not included in the observation data. After the start-up period, 10 kg/day of MBG kitchen waste was mixed with water at a 1:1 ratio and then introduced into the anaerobic digester. The operating temperature was maintained at approximately 32 °C.

The biogas was directed through the main biogas line and utilized using a biogas stove. The pressure was recorded using a manometer, while the biogas flow rate was recorded using a flow meter every 10 min during stove operation until the pressure reached 15 mbar. The average flow rate was calculated from all flow rate measurements recorded during the utilization period, while the utilized biogas volume was calculated as the product of the average flow rate and operating duration. The procedures for digester operation and biogas utilization followed the technical guidelines of the BIRU Program (BIRU Program, n.d.) and the anaerobic digestion guide by Vögeli et al. (2014).

RESULTS

The results included the initial characteristics of MBG kitchen waste and the inoculum, the utilized biogas volume during the 12-day observation period, and the relationship between biogas pressure, utilized volume, and utilization duration. The characterization results of the inoculum and MBG kitchen waste, as well as the composition of the MBG kitchen waste, are presented in the following tables:

Table 1. Characteristics of the Inoculum and MBG Kitchen Waste. Water content, TS, VS, and FS were determined using the gravimetric method, while pH was measured using a pH meter

No	Parameter	Results	
		Inoculum (%)	MBG Kitchen Waste (%)
1	Moisture content	22	34
2	Total Solids (TS)	78	66
3	Volatile Solids (VS)	18	14
4	Fixed Solids (FS)	4	6
5	pH	6	4

Table 2. Average Composition of MBG Organic Waste from the Tamanagung Community Nutrition Service Unit (SPPG), Cluring, Banyuwangi

No	Component	Percentage (%)
1	Rice/staple food	40
2	Vegetables	40
3	Fruit peels	30
4	Side dishes/protein	10
5	Other food waste	-
	Total	100

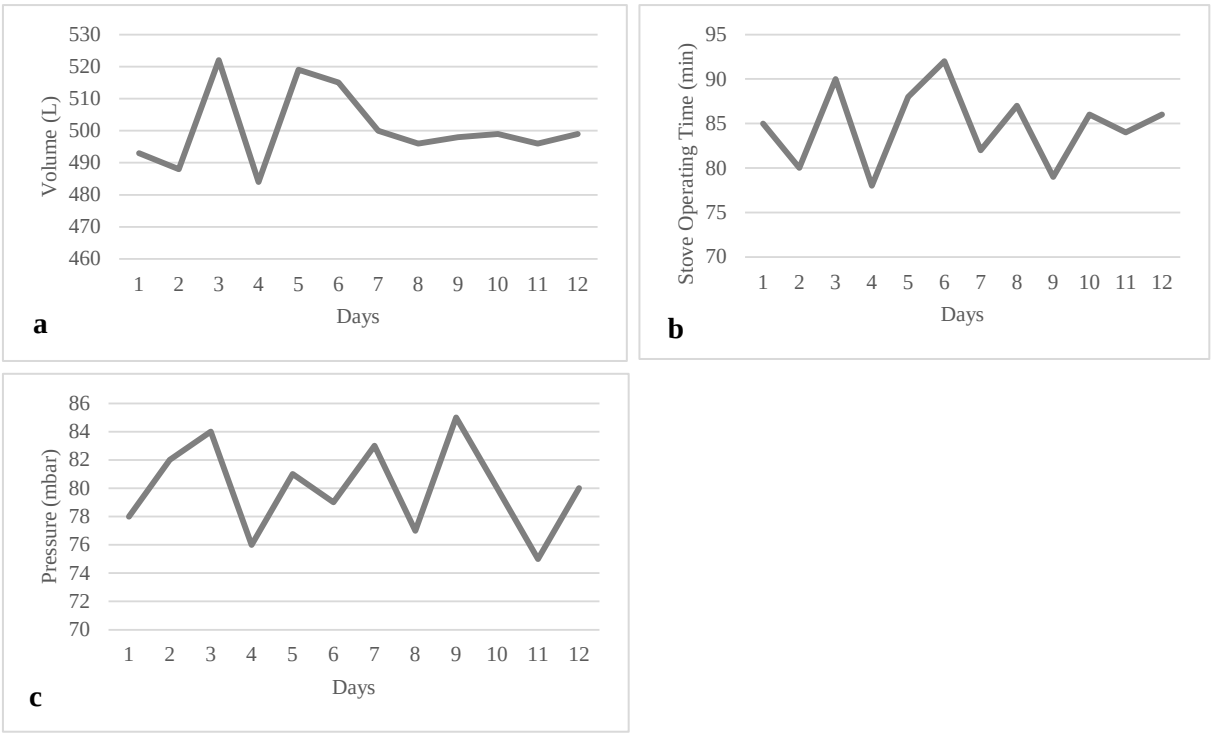
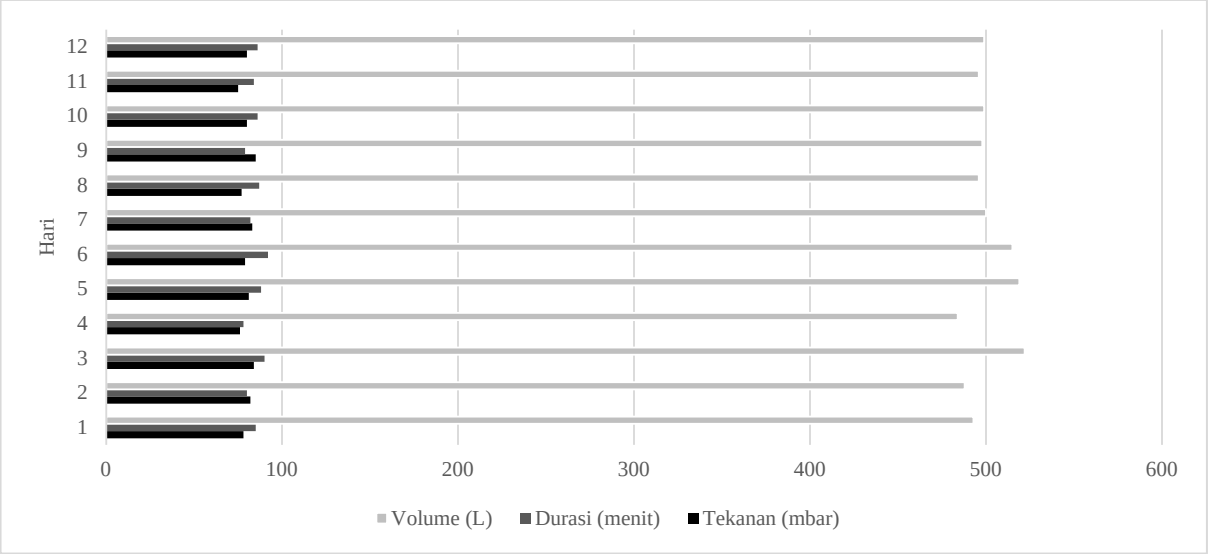


Figure 2. (a) Daily utilized biogas volume (L/day). (b) Daily stove operating time (min/day). (c) Daily measured gas pressure (mbar).

The characterization results (Table 1) showed that MBG kitchen waste had a moisture content of 34%, TS of 66%, VS of 14%, FS of 6%, and pH of 4, while the inoculum had a moisture content of 22%, TS of 78%, VS of 18%, FS of 4%, and pH of 6. The waste composition (Table 2) was dominated by rice and vegetables, each accounting for 40%, followed by fruit peels at 15% and side dishes at 5%. Thus, rice and vegetables were the main substrate components, accounting for 80% of the total waste used.

During the 12-day observation period, the utilized biogas volume ranged from 484–522 L/day, with an average of 500 L/day (Figure 2a), while the average stove operating time was

84.75 min/day (Figure 2b). The initial operating pressure also fluctuated, with an average of 80 mbar (Figure 2c). Fluctuations in these three parameters indicate that changes in biogas availability from day to day were accompanied by variations in operating duration and



pressure conditions during stove operation. In general, a larger biogas volume resulted in a longer operating time, while a decrease in pressure indicated reduced biogas availability during utilization (Figure 3)

Figure 3. Comparison of fluctuations in utilized biogas volume (L), biogas operating time for stove operation (min), and gas pressure (mbar)

DISCUSSION

MBG kitchen waste has characteristics that support its use as a substrate for anaerobic digestion. Based on its composition, the waste was dominated by rice and vegetables, each accounting for 40% (Table 2). This composition is consistent with the characteristics of food waste, which generally contains high levels of organic matter and is considered a potential substrate for biogas production (Zhang et al., 2014; Mirmohamadsadeghi et al., 2019; Bong et al., 2018; Braguglia et al., 2018). Several studies have also shown that rice- and vegetable-based food waste can be used as feedstock for anaerobic digestion because its organic fraction is relatively readily converted by anaerobic microorganisms (Zhang et al., 2007; Ren et al., 2018; Xu et al., 2018; Bong et al., 2018).

This suitability is also reflected in the physicochemical characteristics of MBG kitchen waste. The waste had TS of 66% and VS of 14% (Table 1), indicating the presence of an organic solids fraction that can serve as a substrate during anaerobic digestion. Solids characteristics and organic matter content are important parameters associated with the biodegradability and biogas production potential of organic waste (Labatut et al., 2011; Meegoda et al., 2018; Mirmohamadsadeghi et al., 2019). In anaerobic digestion, complex organic matter is gradually degraded through hydrolysis, acidogenesis, acetogenesis, and methanogenesis to produce biogas

(Zhang et al., 2014; Kougias & Angelidaki, 2018; Xu et al., 2018). However, this process is strongly influenced by the environmental conditions required by microorganisms, including pH. In this study, the waste had an initial pH of 4, while the inoculum had a pH of 6. These conditions indicate that the substrate was relatively acidic, making the inoculum important for providing an anaerobic microbial community and supporting the degradation of organic matter through to the biogas formation stage (Li et al., 2018; Meegoda et al., 2018; Xing et al., 2020).

The use of cattle manure as an inoculum for food waste treatment has been reported to support organic matter degradation and biogas production (Dhamodharan et al., 2015; Xing et al., 2020). The effectiveness of an inoculum is associated with the presence of microbial communities that can accelerate the establishment of suitable biological conditions for anaerobic digestion (Labatut et al., 2011; Hosseini Koupaie et al., 2019). Compared with various types of organic waste, food waste generally has relatively high biogas production potential because of its organic matter content, although actual yields are strongly influenced by substrate characteristics and operating conditions (Bong et al., 2018; Chiu & Lo, 2016; Mirmohamadsadeghi et al., 2019). With its predominance of food materials, measured VS content, and the use of an inoculum containing an anaerobic microbial community, MBG kitchen waste exhibited characteristics suitable for conversion into biogas. Pasted markdown

The results showed that 10 kg/day of MBG kitchen waste produced biogas that could be delivered and utilized during the 12-day observation period. The reported volume represents the utilized biogas volume, namely the volume of gas discharged from the anaerobic digester and delivered to the stove; therefore, it does not represent the total gas produced and stored in the gas space. The volume was determined based on flow meter readings recorded every 10 min during utilization. The daily volume was calculated using the following equation:

$$V = Q \times t$$

Description:
V = gas volume (L)
Q = average flow rate (L/min)
t = stove operating time (min) (Nsair et al., 2020)

Based on the measurements, the average flow rate was 5.90 L/min and the average stove operating time was 84.75 min/day. The volume was measured daily, resulting in an average utilized biogas volume of 500 L/day. The use of flow rate, pressure, and operating duration as operational indicators is consistent with approaches for evaluating biogas system performance that consider process conditions and gas flow characteristics (Nsair et al., 2020; Meegoda et al., 2018).

This volume indicates that the organic fraction of MBG kitchen waste can be converted into biogas through anaerobic digestion. Food waste is generally recognized as a potential substrate because of its organic matter content, although biogas production is influenced by substrate composition, material characteristics, inoculum, and operating conditions (Zhang et al., 2014; Bong et al., 2018; Mirmohamadsadeghi et al., 2019; Braguglia et al., 2018). Factors such as temperature, pH, organic loading rate, retention time, moisture content, and inoculum

characteristics can also affect anaerobic digestion performance (Meegoda et al., 2018; Srisowmeya et al., 2020; Ajayi-Banji & Rahman, 2022). Compared with previous studies, the results of this study should be interpreted based on the substrate loading of 10 kg/day and the specific characteristics of MBG kitchen waste. Therefore, direct comparison of absolute gas volumes cannot be made without standardizing the substrate basis and process conditions. Nevertheless, obtaining approximately 500 L/day indicates that MBG kitchen waste has a practical potential for biogas production under the operating conditions of this study.

Daily fluctuations in biogas volume (Figure 2a) are common in food waste treatment because waste composition is not always uniform. Changes in the proportion of organic materials can affect substrate availability and microbial activity during anaerobic digestion (Zhang et al., 2007; Xu et al., 2018; Ren et al., 2018). In addition, pH, temperature, organic loading, and microbial community dynamics can cause changes in the rate of biogas formation (Li et al., 2018; Nsair et al., 2020; Peng et al., 2018). Operating conditions and process stability are also important factors because changes in process parameters can affect microbial activity and the continuity of biogas formation (Srisowmeya et al., 2020; Zhang et al., 2016). Thus, the volume fluctuations observed during the 12-day period reflect the dynamics of the biological process, while the average volume of 500 L/day indicates that the system remained capable of supplying biogas for utilization.

The biogas produced was not only accumulated in the anaerobic digester but was also successfully delivered and directly utilized as an energy source through a biogas stove. Utilization performance was indicated by the operating duration, defined as the period during which biogas was delivered and used to operate the stove until the gas pressure reached the final utilization limit. During the 12-day observation period, the biogas was utilized for an average of approximately 85 min/day (Figure 2b). Operating duration provides more practical information than gas volume alone because it indicates the ability of the produced biogas to directly meet energy needs. The use of biogas for cooking is a form of energy recovery commonly developed in organic waste treatment through anaerobic digestion (Kougias & Angelidaki, 2018; Deublein & Steinhauser, 2011; Mertins & Wawer, 2022). Direct use of biogas for cooking has also been implemented in small-scale and institutional biogas systems (Vögeli et al., 2014; Ratanatamskul et al., 2015).

The relationship between biogas volume, pressure, and operating duration shows that these three parameters represent different but interrelated aspects of biogas utilization (Figure 3). Volume indicates the amount of gas available for utilization, pressure indicates the gas driving force within the system, while operating duration indicates how long the gas can be used. During utilization, gas flows from the storage space to the stove, causing the pressure to gradually decrease. When a larger volume of gas is available, utilization tends to last longer, whereas a decrease in pressure indicates a reduction in the gas available for delivery. This relationship shows that operating duration is determined not only by the amount of biogas but also by pressure conditions and flow characteristics within the system. Monitoring pressure and flow is an important part of evaluating biogas utilization performance under operating conditions (Nsair et al., 2020; Mertins & Wawer, 2022; Deublein & Steinhauser, 2011).

The pressure recorded in this study was the gas pressure in the main biogas line before the gas was delivered to the stove, representing the relative biogas pressure within the distribution system. The average pressure during the observation period was 80 mbar, and utilization was stopped

when the pressure reached 15 mbar. This value falls within the low-pressure range suitable for biogas utilization for cooking in household or small-scale installations. The BIRU technical guidelines also identify gas pressure as an important operational parameter in biogas systems and their utilization (Program BIRU, n.d.). The operation of small-scale biogas systems also requires flow and pressure control to ensure stable gas delivery to the utilization device (Vögeli et al., 2014; Ratanatamskul et al., 2015). Previous studies have shown that successful utilization of biogas for cooking depends not only on the available gas volume but also on the pressure required to maintain gas flow to the utilization device (Mertins & Wawer, 2022; Nsair et al., 2020). Thus, the success of this study was demonstrated not only by biogas formation but also by its ability to provide gas at a pressure and volume sufficient for direct stove operation for an average of approximately 85 min/day.

The utilization of MBG kitchen waste for biogas production demonstrates the potential application of the circular economy concept, as waste that would otherwise become a residue can be converted into an energy source to support operational activities. This approach not only has the potential to reduce the waste disposal burden but also provides value in the form of renewable energy from locally available resources (Girotto et al., 2015; Santagata et al., 2021; Kougias & Angelidaki, 2018). Resource recovery through anaerobic digestion also enables organic waste to be converted into biogas and digestate with further potential value (Bong et al., 2018; Chew et al., 2021; Dutta et al., 2021). Further utilization of digestate through digestate recycling may serve as a subsequent development stage to retain nutrients and improve the sustainability of anaerobic digestion (Dutta et al., 2021; Mirmohamadsadeghi et al., 2019). Thus, MBG waste treatment has the potential to be developed beyond waste management into a resource recovery system that generates energy while supporting sustainable residue management.

CONCLUSION

The results showed that MBG kitchen waste has the potential to be used as a substrate for biogas production, as indicated by its characteristics and the predominance of organic materials, particularly rice and vegetables. At a waste loading of 10 kg/day, the system produced an average utilized biogas volume of 500 L/day during the 12-day observation period. The biogas was not only successfully produced but also directly utilized through a biogas stove for an average of approximately 85 min/day at an average operating pressure of 80 mbar. These results indicate that biogas production from MBG kitchen waste has the potential to be implemented as an energy recovery approach and a circular economy-based waste management strategy.

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