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# Evaluation of Different Feedstocks for Biogas Output and Bioslurry Quality in Household Digesters in Banyuwangi

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ABSTRACT

This study evaluates the effect of different feedstock types on biogas production and bioslurry quality at the household scale in Banyuwangi Regency. The assessment focused on biogas byproducts in the form of bioslurry derived from three types of feedstock household organic waste, goat manure, and cow manure. The research employed a completely randomized design (CRD) experimental method, in which each feedstock was fermented in a biodigester for one month, after which the resulting bioslurry was analyzed in the laboratory. The parameters measured included pressure (P), volume (V), daily gas production (ΔV), as well as the quality of bioslurry macronutrients pH, organic carbon, total nitrogen, $P_2O_5$, $K_2O$, C/N ratio and tests for pathogenic microbes. The results showed that all three feedstock types have potential as biogas substrates, indicated by positive gas production rates throughout the fermentation period. Cow manure yielded the highest cumulative biogas production potential (ΔV 146.81 liters), followed by household organic waste (ΔV 116.17 liters) and goat manure (ΔV 95.87 liters). In terms of bioslurry quality, cow manure provided relatively higher nutrient content ($N_{total}$ and $P_2O_5$) compared to goat manure and household organic waste. The household-scale biogas technology applied in Banyuwangi demonstrates significant potential as a renewable energy source. However, its liquid digestate byproduct tends to have low nutrient content and carries biological risks that warrant attention in its utilization. Therefore, post-treatment measures such as composting or further maturation are necessary to ensure bioslurry safety and improve its agronomic value.



## I. Introduction

Renewable energy serves as a fundamental pillar of sustainable development, particularly in addressing the energy crisis and the environmental impacts of fossil fuels. Biogas has emerged as one of the most promising solutions, especially for household-scale applications in rural areas, as it makes use of abundant organic waste that remains underutilized. The anaerobic digestion process not only produces methane-rich biogas for cooking and lighting but also generates bioslurry as a valuable byproduct that can serve as organic fertilizer. The adoption of biogas technology can significantly reduce dependence on firewood and kerosene, aligning with the Sustainable Development Goals (SDGs), specifically Goal 7 (affordable and clean energy) and Goal 13 (climate action). However, the effectiveness of such systems largely depends on the characteristics of the feedstock used[1]. Research conducted in various regions has shown considerable variation in outcomes depending on the type of substrate, highlighting the need for location-specific studies. Therefore, exploring diverse types of local feedstock is crucial to maximizing the potential of this renewable energy source[2].

Banyuwangi Regency has strong natural resource potential in the agricultural and livestock sectors, one of which is the utilization of biomass as a renewable energy source. Agricultural waste and livestock manure from cattle and goat farms scattered across the region are often not properly managed, posing risks of environmental pollution and direct methane emissions into the atmosphere. At the same time, household organic waste also represents an environmental issue that requires serious attention. Converting these wastes into biogas offers a dual solution: managing waste while

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simultaneously producing energy[3]. However, the implementation of household-scale biogas technology in Banyuwangi still faces challenges, such as low efficiency and suboptimal gas quality, which are strongly suspected to be linked to the selection of feedstock without sufficient scientific basis. Communities often choose feedstock solely based on availability, without considering its effects on gas yield and fertilizer quality. This has led to limited interest in adopting biogas technology, as it is often perceived as inefficient. Therefore, research examining the specific effects of different feedstock types on digester performance is urgently needed to provide appropriate technical guidance for local communities[4].

The fundamental problem lies in the absence of comprehensive comparative data on the performance of three potential feedstocks in Banyuwangi household organic waste, goat manure, and cow manure in producing biogas and high-quality bioslurry. Each feedstock has unique chemical characteristics, such as the carbon to nitrogen (C/N ratio), lignin content, and biodegradability rate, which directly affect the dynamics of the anaerobic digestion process. Cow manure, for instance, is known to have an ideal C/N ratio, but its gas production rate can be slower compared to goat manure, which contains higher nitrogen levels. Meanwhile, household organic waste is highly heterogeneous and may contain inhibitors that disrupt the metabolism of anaerobic microorganisms if not properly pretreated. A lack of understanding of these characteristics can lead to digester inefficiencies, such as acidification, low biogas yield, and prolonged retention time[5]. Therefore, identifying the most suitable feedstock under Banyuwangi's local conditions is essential for developing effective policies and technical recommendations[6].

The literature review indicates that cow manure is the most extensively studied feedstock and is often used as a reference substrate. Previous studies have shown that cow manure produces biogas with a methane concentration of around 55–65%, with an optimal retention time of 30–40 days[2]. Its main advantage lies in the stability of the digestion process, as its C/N ratio falls within the ideal range of 20–30 for anaerobic microbes. However, other studies highlight that goat manure, with a narrower C/N ratio and finer particle size, has a higher specific methane yield per gram of volatile solids. Research findings reveal that goat manure can produce 25% more biogas than cow manure in digesters of the same volume, with a comparable methane content[1]. This suggests that goat manure may be a promising yet often overlooked feedstock. In contrast, the utilization of household organic waste poses greater complexity due to its variable composition and high moisture content, requiring pretreatments such as shredding and co-digestion adjustments to achieve optimal conditions[7][8].

Equally important is the evaluation of bioslurry quality as a co-product with significant economic value. Bioslurry is a liquid organic fertilizer rich in macro- and micronutrients, as well as beneficial microorganisms that enhance soil fertility. Its quality is strongly influenced by the type of feedstock, which determines the final nutrient content such as nitrogen, phosphorus, potassium (NPK), and organic matter after the digestion process. Studies have shown that bioslurry derived from cow manure contains higher levels of total nitrogen and phosphorus compared to that from household organic waste[3]. Conversely, other research reveals that bioslurry from lignocellulose-rich feedstock, such as organic waste, may contain higher levels of humic and fulvic acids, which are beneficial for improving soil structure. Understanding the nutrient profiles of bioslurry from different feedstocks provides added economic value for biogas users, as it can reduce the need for chemical fertilizers and support organic farming. Therefore, the feasibility of a feedstock should be assessed not only in terms of its gas yield but also in relation to the agronomic value of the bioslurry it produces[9][10].

In line with the identified research gap, this article evaluates the effects of different feedstock types namely household organic waste, goat manure, and cow manure on biogas production and bioslurry quality at the household scale in Banyuwangi Regency. The study was designed to measure parameters including pressure (P), volume (V), daily gas production (ΔV), and the macronutrient quality of bioslurry pH, organic carbon, total nitrogen, $P_2O_5$, $K_2O$, C/N ratio, as well as the presence of pathogenic microbes. The findings of this research are expected to provide empirical data and scientific recommendations for communities, particularly those utilizing bioslurry as liquid organic fertilizer. These recommendations aim to encourage wider adoption of biogas technology, contributing to energy security, sustainable waste management, and the advancement of organic agricultural productivity in Banyuwangi Regency.

## II. Method

This study is an experimental research with a quantitative approach. The design employed was a Completely Randomized Design (CRD) with a single factor, namely the type of feedstock. This factor consisted of three treatments P1 (household organic waste), P2 (goat manure), and P3 (cow manure). The research was conducted in a batch system, in which the digester was fully loaded at the beginning of the experiment and left until the anaerobic digestion process was completed. The dependent variables measured were the biochemical characteristics of the bioslurry. The flowchart of the experiment is presented in Figure 1.

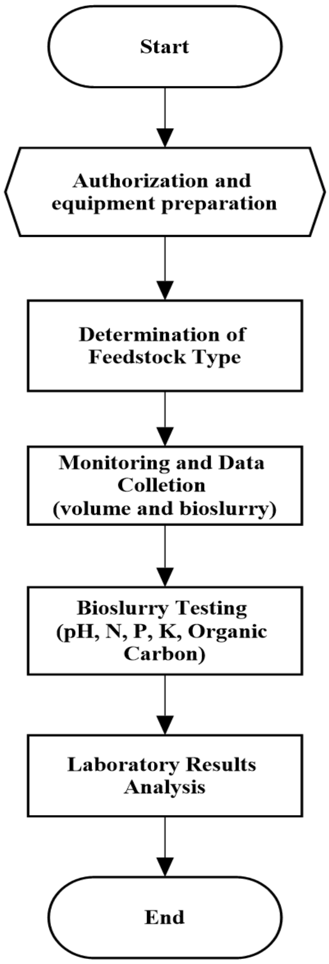


Fig. 1. Research Flowchart

Bioslurry samples from the 30-day anaerobic fermentation process were analyzed to measure nutrient content, covering both chemical and biological parameters. The research subjects were located in Banyuwangi Regency, representing real household-scale users. Each treatment had the following subject composition:

a. Household Organic Waste (P1)

Household organic waste (rice leftovers, vegetables, fruit peels) was separated from inorganic materials, chopped into pieces of approximately 1–2 cm, and mixed with water at a 1:1 (w/v) ratio to achieve a Total Solid (TS) content of around 10–15%. The mixture was then pre-fermented separately for 4 days before being used as feedstock, with the aim of facilitating decomposition by anaerobic bacteria in the biodigester or reactor.

b. Goat Manure (P2)

Fresh goat manure collected from smallholder farms in Kalibaru District was mixed with water at a 1:1 (w/v) ratio to form a slurry.

c. Cow Manure (P3)

Fresh dairy cow manure collected from smallholder farms in Muncar District was mixed with water at a 1:2 (w/v) ratio, following common local practices to achieve a consistency suitable for digestion.

## III. Results and Discussion

Based on gas consumption measurements over a 30-day period using three different types of feedstock household organic waste (HOW), cow manure (CM), and goat manure (GM) the results showed clear variations in daily gas production as well as a gradual upward trend for each feedstock. The collected data revealed differences in the average gas production among the three materials, with cow manure consistently yielding the highest values, followed by household organic waste and goat manure. A linear regression analysis was applied to assess the trend of gas production over time, identifying the relationship between the observation days (independent variable) and gas production volume (dependent variable). The regression results produced three linear equations, each representing the daily rate of gas production increase. Accordingly, cow manure showed the highest gas production rate at 1.22 liters per day, followed by goat manure at 1.02 liters per day, and household organic waste at 0.97 liters per day. These differences in slope values indicate that cow manure has relatively greater biogas production potential compared to the other two substrates.

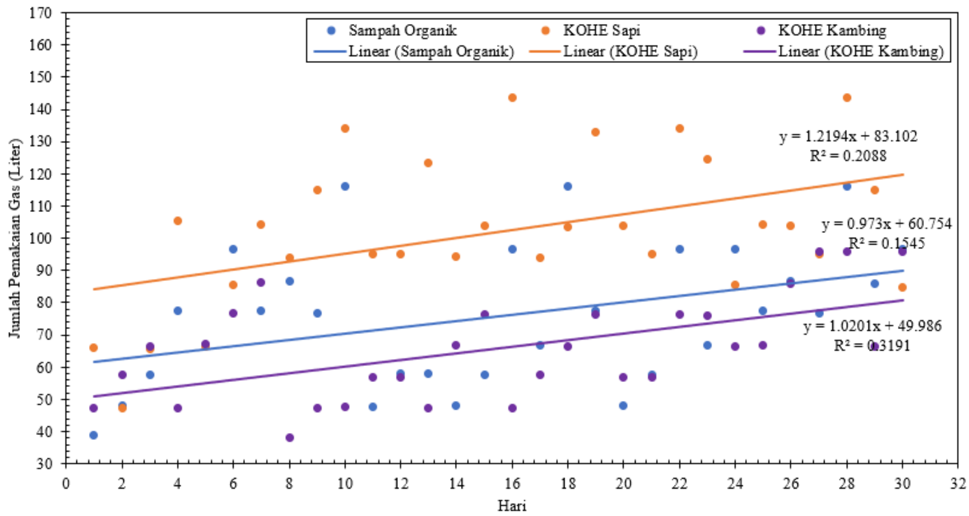


Fig. 2. Graph of Gas Consumption Comparison for the Three Types of Feedstock

Nevertheless, the coefficients of determination ($R^2$) obtained were relatively low: 0.1545 for household organic waste, 0.2088 for cow manure, and 0.3191 for goat manure. These low $R^2$ values indicate that the variation in gas consumption is not fully explained by time alone. In other words, although there is a general upward trend in gas production over time, daily fluctuations remain considerable and are likely influenced by other factors such as changes in substrate composition, pH fluctuations, microbial activity, and possible environmental disturbances such as temperature or humidity variations during the fermentation process. This is illustrated in Figure 2.

Although cow manure exhibited the highest rate of increase, its $R^2$ value was not greater than that of goat manure. This suggests that cow manure data were more variable from day to day. Such high variability may be attributed to differences in material homogeneity or instability in fermentation conditions. In contrast, goat manure displayed the highest $R^2$ value (0.3191), indicating a relatively more consistent linear trend even though its average production was not as high as cow manure. This finding suggests that the fermentation process for goat manure was more stable, albeit with a slightly lower rate of increase.

Meanwhile, laboratory testing of macronutrient content revealed significant variations across all parameters examined. The results showed that the nutrient levels in bioslurry from all three feedstocks were too low to be directly applied as liquid organic fertilizer. Similar studies have emphasized that anaerobic digestion does not always eliminate all pathogens, meaning that the quality of the initial feedstock is a critical factor[11]. The bioslurry analysis results are presented in Table 1.

Table 1. Bioslurry Nutrient Parameters

| Parameters | Organic waste | Cow Manure | Goat Manure | Permentan Standart |
|---|---|---|---|---|
| C-Organic | 0,03 | 0,04 | <1,08 | 10 % |
| pH | 8,05 | 7,59 | 8,78 | 4,0 – 8,5 |
| N-Total | 0,016 | 0,021 | 0,015 | Min. 0,50 % |
| $P_2O_5$ | 0,0013 | 0,0035 | 0,0016 | Min. 0,30 % |
| $K_2O$ | 0,03 | 0,04 | 0,04 | Min. 0,30 % |
| Ratio C/N | 1,88 | 1,90 | <72 | - |

Based on the laboratory analysis, the macronutrients total nitrogen (N-total), $P_2O_5$, and $K_2O$ in all three feedstocks were found to be below the minimum threshold required by ministerial regulations. This indicates that the bioslurry from these three feedstocks, in its current state, does not meet the criteria for commercial sale as liquid organic fertilizer. Cow manure (CM) tended to show slightly higher values for nitrogen and phosphorus, but the differences were not significant.

Total nitrogen (N-total) is a key parameter that determines the nutrient value of bioslurry as a fertilizer, as it plays a direct role in plant vegetative growth. Based on the test results, cow manure (CM) recorded the highest N-total value at 0.021%, followed by household organic waste (HOW) at 0.016%, and goat manure (GM) at 0.015%. These differences can be attributed to variations in the initial C/N ratios of each feedstock as well as the efficiency of microbial decomposition during anaerobic digestion. CM, with its more balanced C/N ratio, tends to facilitate nitrogen mineralization more effectively compared to HOW, which may contain higher carbon content, or GM. Nevertheless, all of these N-total values are extremely low when compared with the quality standards for liquid organic fertilizer set by the Ministry of Agriculture Regulation No. 261 of 2019, which requires a minimum N-total content of 2.0%. This indicates that bioslurry produced from household-scale digestion is more appropriately categorized as a soil amendment or a highly diluted liquid organic fertilizer, rather than a primary nitrogen source. This finding aligns with previous research, which reported that liquid digestate generally contains lower nutrient concentrations than solid digestate[12]. Similarly, the phosphorus (expressed as $P_2O_5$) and potassium (expressed as $K_2O$) contents in all three bioslurry samples were also found to be very low. For phosphorus, CM again showed the highest value ($3.50 \times 10^{-3}$%), while GM and HOW recorded $1.60 \times 10^{-3}$% and $1.30 \times 10^{-3}$%, respectively. A similar pattern was observed for potassium, where CM and GM had the same $K_2O$ content (0.04%), while HOW was slightly lower (0.03%). The low levels of P and K further confirm the dilute nature of bioslurry as a fertilizer. Previous studies have shown that digestate nutrient content is highly dependent on the type of feedstock and the digestion process, with livestock manure feedstocks generally containing higher levels of P and K than municipal organic waste, as reflected in the CM results of this study[13].

The ideal C/N ratio for organic fertilizer is <20. Both household organic waste (HOW) and cow manure (CM) showed extremely low C/N ratios (<2), indicating that the organic matter had undergone advanced decomposition and had lost much of its carbon content. In contrast, goat manure (GM) exhibited a very high C/N ratio, suggesting incomplete decomposition or the presence of recalcitrant material that is difficult to break down. The organic carbon (C-organic) content in all three bioslurry samples was consistently very low, recorded at <1.08 mg/L for GM, 0.04% for CM, and 0.03% for HOW. These very low values indicate that most of the easily degradable organic matter (volatile solids) had already been consumed by anaerobic microbes during digestion to produce biogas. As a result, the remaining organic matter in the bioslurry was dominated by more stable, recalcitrant fractions. The C/N ratio of the bioslurry is therefore expected to be very narrow (calculated from the very low C-organic and N-total values). Bioslurry with a narrow C/N ratio and stable organic matter of this kind is highly beneficial for soil application, as it can release nutrients directly without immobilizing nitrogen from the soil, thereby avoiding competition with plants. Household organic waste (HOW) and goat manure (GM) produced alkaline pH values, while cow manure (CM) was neutral. These values remain within the tolerance range for most plants, although alkaline pH can affect the availability of certain micronutrients. The pH values of bioslurry from the three feedstocks ranged from alkaline to strongly alkaline. GM recorded the highest pH at 8.78, followed by HOW at 8.05, and CM at 7.59. This alkaline condition is a typical characteristic of bioslurry produced from well-functioning anaerobic digestion, during which ammonia ($NH_3$) is generated from nitrogen mineralization. High pH values carry both advantages and drawbacks. On the positive side, bioslurry can be used to neutralize acidic soils. On the negative side, when pH exceeds 8.5, ammonia volatilization may occur, leading to nitrogen loss into the atmosphere and potentially causing unpleasant odors. Therefore, bioslurry with high pH should preferably be applied by incorporating it into the soil or by diluting it beforehand to minimize nitrogen loss. The results of laboratory testing of bioslurry samples compared with liquid organic fertilizer standards are presented in Figure 3.

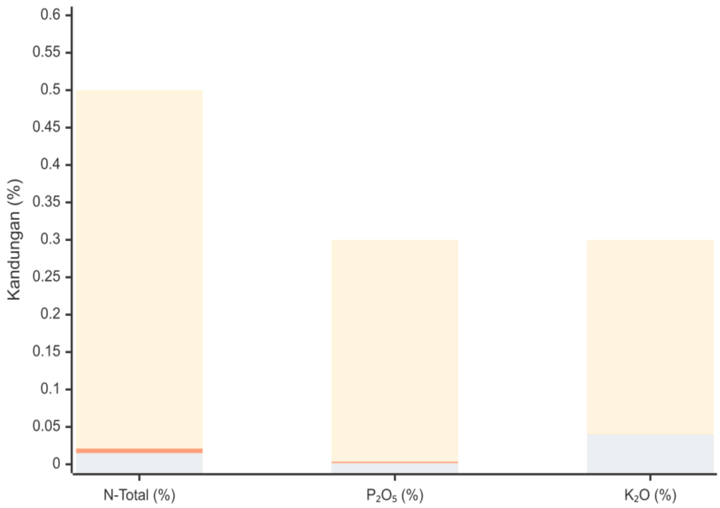


Fig. 3. Macronutrient Content of Bioslurry Compared with Liquid Fertilizer Standards

The contents of other macronutrients such as calcium (Ca), magnesium (Mg), and sulfur (S) were also found to be very low. Micronutrients such as Zn, Mn, Cu, and Fe were below the detection limit of the instruments, indicating that their concentrations were nearly negligible. The levels of Mg, Ca, Na, and S in all three bioslurry samples were consistently very low, ranging from the order of $10^{-2}$ to $10^{-3}$%. CM again tended to show slightly higher values for some elements, such as Ca ($9.40 \times 10^{-3}$%) and Na ($1.07 \times 10^{-2}$%), compared to the other two feedstocks. Meanwhile, micronutrients such as iron (Fe), zinc (Zn), manganese (Mn), copper (Cu), and boron (B) were either below the detection limit (<BDL) or present only in trace amounts. This further supports the conclusion that the bioslurry produced is not a significant source of micronutrients. Its application is more suitable for enriching soil with trace element diversity rather than serving as a primary nutrient supply.

Table 2. Results of Bioslurry Microbiological Analysis

| Parameters | Organic waste | Cow Manure | Goat Manure | Permentan Standart |
|---|---|---|---|---|
| E. Coli | 1500 | 930 | 3,6 | <1000 MPN/ml |
| Salmonella sp. | >110.000 | 4300 | >110.000 | Negative/0 MPN/ml |

The analysis of E. coli levels showed that the GM sample was within a relatively safe limit (3.6 MPN/ml), while the HOW and CM samples exceeded the commonly accepted safety threshold. The test for Salmonella sp., however, proved to be the most critical. The HOW and GM samples contained Salmonella at extremely high levels (>110,000 MPN/ml), exceeding the maximum detection limit. The CM sample also tested positive for Salmonella, with a concentration of 4,300 MPN/ml. The presence of Salmonella makes this bioslurry unsafe for direct application on food crops, particularly vegetables consumed raw, due to the high risk of contamination and disease transmission.

The biological safety tests revealed highly critical findings. All three bioslurry samples were found to contain pathogenic bacteria indicative of fecal contamination, namely E. coli and Salmonella sp., at very high and hazardous levels. In fact, the HOW and GM samples showed Salmonella concentrations exceeding 110,000 MPN/ml, an alarmingly high figure. This level drastically surpasses the safety limits set by any standard, including the Indonesian National Standard (SNI) for organic fertilizers. The high pathogen populations indicate that the household-scale anaerobic digestion process did not reach sufficient temperature or retention time to ensure proper sanitation and effectively eliminate pathogens. This condition poses a serious public health risk if the bioslurry is applied to food crops, especially vegetables that are consumed raw.

The main finding of this study is that despite the clear differences in nutrient content, the three bioslurries derived from different feedstocks share one critical similarity: very low nutrient levels and very high pathogen contamination. The implication is that bioslurry produced under household-scale systems with such operating conditions does not qualify as liquid organic fertilizer according to fertility and biological safety standards. Rather, it is more accurately described as liquid digestate, rich in microorganisms (both beneficial and pathogenic) but poor in nutrients. Its application to soil must therefore be carried out with great caution, given the associated health risks.

To improve the quality and safety of bioslurry, several process enhancements are required. First, the sludge retention time in the digester should be significantly extended (to >60 days) to ensure adequate pathogen reduction. Second, applying pretreatments to the feedstock, such as chopping or pre-composting, can enhance the digestion rate. Third, and most importantly, the bioslurry should undergo further post-treatment, for instance through aerobic composting, before it can be safely applied. The aerobic process helps raise the temperature and drastically reduce pathogen populations, as recommended by many researchers.

## IV. Conclusion

Based on the results and discussion regarding the evaluation of different feedstocks on biogas production and bioslurry quality at the household scale in Banyuwangi Regency, it was found that the three types of feedstock produced varying amounts of gas. Biogas derived from household organic waste showed the lowest gas production compared to goat manure and cow manure. The highest production was obtained from cow manure, reaching 146.81 liters. Meanwhile, the nutrient quality tests revealed that feedstock type influenced the bioslurry characteristics. Bioslurry from cow manure showed slightly higher values of total nitrogen (N-total) and phosphorus ($P_2O_5$) compared to goat manure and organic waste. However, overall, the nutrient contents (N, P, K) of all bioslurry samples were very low and did not meet the standards for liquid organic fertilizer set by the Ministry of Agriculture Regulation No. 261/2019. Moreover, contamination by E. coli and Salmonella sp. was found in concentrations far exceeding safe limits. A retention time of one month in the digester was insufficient to stabilize organic matter or reduce pathogens, making the product more accurately classified as liquid digestate—low in nutrients and posing high risks. Its utilization therefore requires further treatment, such as aerobic composting or longer storage. Extending the retention period beyond 30 days is recommended. Future research should explore post-treatment methods such as filtration, pasteurization, microbial inoculants, as well as economic analysis, impacts on plant growth and soil health, and optimization strategies to improve nutrient availability while reducing pathogens.

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