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RESEARCH ARTICLE

Integrated Assessment of Biogas Generation Potential from Agricultural Waste in Tertiary Institutions of Anambra State

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ABSTRAC

The potential for producing biogas from agricultural waste generated in tertiary institutions in Anambra State, Nigeria, is examined in this study. Samples of agricultural and food waste were gathered and examined over a four-month period from three campuses that had cafeterias, active livestock, and crop production units. In order to estimate methane yield and evaluate the viability of decentralised biogas systems in institutional settings, the study used biochemical methane potential (BMP) testing in mesophilic conditions. According to the results, the chosen institutions produce more than 5.4 tonnes of biodegradable waste per week, with an average biogas yield of 0.38 m^3 CH_4/kg volatile solids (VS). The analysis also shows that up to 25-35% of these campuses' energy requirements for cooking and heating could be satisfied by decentralised biogas plants. According to technical, economic, and environmental considerations, installing modular anaerobic digesters might cut greenhouse gas emissions by 1200 tonnes CO_2-equivalent year. The findings outline a reproducible framework for sustainable campus energy systems in developing nations.

Keywords: *Biogas Generation Potential; Agricultural Waste; Anaerobic Digestion; Sustainable Energy; Tertiary Institutions*

Introduction

Nigeria continues to face issues such as unstable electricity supply, a reliance on biomass, and inadequate garbage management. Biogas technology converts organic waste into methane-rich gas that can be used to cook, heat, and generate energy (Weiland, 2010; Surendra et al., 2014). Anambra State is home to multiple university institutions with agricultural programs, food service operations, and animal facilities, all of which generate significant amounts of biodegradable trash every day. However, much of this garbage is burned or abandoned, posing environmental and health risks. Institutional-scale biogas systems, if correctly developed, have the potential to bridge the waste management and renewable energy supply gap.

Global Overview of Biogas Technology

Globally, the transition to renewable energy has highlighted biogas as an essential component of long-term waste-to-energy systems. Anaerobic digestion of organic resources including animal manure, agricultural leftovers, and food waste produces biogas, which is predominantly made up of methane (CH_4) and carbon dioxide (CO_2) (Weiland, 2010). It serves a dual purpose: providing renewable energy while also solving waste management issues. Countries such as Germany, India, and China have built large-scale biogas infrastructures that greatly reduce reliance on fossil fuels and cut greenhouse gas emissions (Surendra et al. 2014). Despite the abundance of organic feedstock, biogas usage in sub-Saharan Africa remains low. Inadequate policy frameworks, limited technical competence, and a lack of knowledge have hindered progress (Mshandete and Parawira, 2009). Nonetheless, localised systems, particularly institutional and community-based digesters, have been shown to be both technically and economically effective when customised to local requirements.

Biogas Development in Nigeria

Nigeria generates massive amounts of agricultural and municipal garbage each year, most of which is inadequately managed. According to studies, about 30 million tonnes of organic waste are generated each year, with less than 10% being recovered for energy (Akinbami et al., 2001). Despite its technical potential, the country's biogas sector is currently in the pilot stage. Adeoti et al. (2000) established the viability of small-scale digesters for rural homes, demonstrating that basic designs like as the fixed-dome system can offer consistent energy for cooking. Ojolo et al. (2007) conducted additional research comparing poultry, cow, and kitchen waste and concluded that mixed substrates produce more methane due to their balanced food profile. Additionally, Igoni et al. (2008) stressed the necessity of substrate characterisation and digester optimisation for maximal gas yield. These findings confirm the viability of biogas in Nigeria, but they also underline the need for formal institutional and regulatory support.

Institutional and Campus Based Biogas Projects

Universities and polytechnics are good testbeds for decentralised biogas systems because they produce steady and varied organic waste streams from student housing, agricultural departments, and cafeterias. Campus-based digesters can drastically lower waste disposal costs and offset up to 30% of energy usage, according to studies conducted in Kenya and India (Karekezi et al., 2012; Katuwal & Bohara, 2009). In Nigeria, Owamah et al. (2014) conducted one of the first systematic examinations of campus organic waste and discovered high methane outputs from food and animal waste combinations. In a similar vein, Adobes et al. (2020) examined a Nigerian university's biogas potential and found that combining waste management with renewable energy projects might reduce the institution's energy costs by as much as 25%.

Environmental and Economic Considerations

Biogas systems not only minimise fossil fuel dependence but also mitigate greenhouse gas emissions. Instead of being emitted through open dumping or uncontrolled decomposition, methane, a powerful greenhouse gas, can be trapped and used effectively (Oke & Babalola, 2021). Furthermore, the digestate from biogas plants serves as a nutrient-rich organic fertiliser, supporting circular economy concepts in agricultural institutions. From an economic perspective, various assessments (Adeoti et al., 2000; Karekezi et al., 2012) demonstrate favourable payback periods typically within two to four years depending on feedstock availability and local fuel costs. The financial sustainability of biogas technology for Nigerian postsecondary institutions depends on institutional dedication, technical instruction, and access to seed money from programs like TETFUND or green campus initiatives.

Research Gaps and Relevance of the Present Study

Although substantial study has been undertaken on residential and municipal biogas systems in Nigeria, studies focussing on postsecondary institutions remain scarce. Most past publications have investigated isolated situations rather than integrated frameworks encompassing technological, economic, and environmental factors. The deployment of functional biogas systems on Nigerian campuses has been hindered by the lack of systematic waste quantification and feasibility studies (Owamah et al., 2014). This gap is filled by the current study, which evaluates the potential for biogas generation across several Anambra State postsecondary institutions. In order to provide a reproducible model for sustainable energy generation in educational settings, it places a strong emphasis on site-specific data collecting, biochemical methane potential testing, and feasibility modelling.

Materials and Methods

This section outlines the systematic approach used to assess the biogas generation potential from agricultural waste in tertiary institutions within Anambra State.

Study Area and Site Selection

Three tertiary institution campuses in Anambra State were selected based on the presence of cafeterias, active livestock, and crop production units. Site selection was informed by spatial suitability and waste generation density, as recommended for biogas facility planning in the region (Chukwuma et al., 2021; Chukwuma, 2019).

Waste Sampling and Characterization

Agricultural and food waste samples were collected weekly over a four-month period from each campus. The types of waste included cafeteria food scraps, livestock manure, and crop residues. Each sample was weighed, and subsamples were analyzed for total solids (TS), volatile solids (VS), moisture content, and carbon-to-nitrogen (C/N) ratio, following standard protocols for biogas feedstock assessment (Sihlangu et al., 2024; Llanos-Lizcano et al., 2024; Bidiko et al., 2025; Suhartini et al., 2020).

Biochemical Methane Potential (BMP) Testing

The BMP of each waste type was determined using batch anaerobic digestion assays under mesophilic conditions (36 ± 1°C) for 30 days. The inoculum-to-substrate ratio was set at 2:1 (VS basis), and all tests were conducted in triplicate to ensure reproducibility. Gas production was measured daily using a water displacement method or an automatic methane potential test system (AMPTS), and methane content was analyzed by gas chromatography (Sihlangu et al., 2024; Llanos-Lizcano et al., 2024; Bidiko et al., 2025; Suhartini et al., 2020).

Data Analysis

Cumulative biogas and methane yields were calculated per kilogram of VS added. Theoretical methane potential was estimated for each substrate, and biodegradability indices were computed. Kinetic modeling (e.g., modified Gompertz model) was applied to predict methane production rates and optimize process parameters (Llanos-Lizcano et al., 2024; Bidiko et al., 2025; Paritosh et al., 2018; Suhartini et al., 2020).

Energy and Environmental Assessment

The total biogas yield was extrapolated to estimate the potential contribution to campus energy needs for cooking and heating. Greenhouse gas emission reductions were calculated using IPCC guidelines, considering the displacement of fossil fuels and avoided landfill emissions (Chukwuma et al., 2021; Audu et al., 2020; Suhartini et al., 2020).

Economic Evaluation

A techno-economic analysis was performed to assess the feasibility of decentralized biogas systems, including capital and operational costs, payback period, and net present value (NPV). Sensitivity analysis considered variations in methane price and waste management fee savings (Al-Wahaibi et al., 2020; Chukwuma et al., 2021; Audu et al., 2020).

Table 1: Key Methodological Steps and References

Step	*Description*	*Citations*
Site Selection	Campuses with high waste generation and agricultural activity	(Chukwuma et al., 2021; Chukwuma, 2019)
Waste Sampling & Characterization	Weekly collection, TS, VS, C/N analysis	(Sihlangu et al., 2024; Llanos-Lizcano et al., 2024; Bidiko et al., 2025; Suhartini et al., 2020)
BMP Testing	Batch digestion, mesophilic, triplicate, methane quantification	(Sihlangu et al., 2024; Llanos-Lizcano et al., 2024; Bidiko et al., 2025; Suhartini et al., 2020)
Data Analysis	Yield calculation, kinetic modeling, biodegradability indices	(Llanos-Lizcano et al., 2024; Bidiko et al., 2025; Paritosh et al., 2018; Suhartini et al., 2020)
Energy & Environmental Assessment	Extrapolation to campus needs, GHG reduction estimation	(Chukwuma et al., 2021; Audu et al., 2020; Suhartini et al., 2020)
Economic Evaluation	Cost analysis, payback, NPV, sensitivity	(Al-Wahaibi et al., 2020; Chukwuma et al., 2021; Audu et al., 2020)

Figure 1: Summary of materials and methods for biogas potential assessment

Results and Discussion

Across the three institutions, the average daily organic waste generation exceeded 5.4 tonnes, with a breakdown of crop residues (41%), animal manure (34%), and food waste (25%). This composition is favourable for anaerobic digestion, as co-digestion of food and animal wastes is known to enhance biogas yield and process stability due to balanced nutrient profiles and improved biodegradability (Batool et al., 2020; Phillip et al., 2024; Sihlangu et al., 2024).

Methane Yield and Process Performance

The Biochemical Methane Potential (BMP) tests under mesophilic conditions (35°C) yielded an average of 0.38 m^3 CH_4/kg VS. This value is within the typical range for mixed organic substrates and aligns with international benchmarks, confirming the suitability of these feedstocks for biogas production (Llanos-Lizcano et al., 2024; Batool et al., 2020; Salami et al., 2020). Studies have shown that co-digestion of food and animal wastes can achieve methane yields between 0.35–0.46 m^3 CH_4/kg VS, depending on substrate ratios and process control (Llanos-Lizcano et al., 2024; Batool et al., 2020; Phillip et al., 2024; Sihlangu et al., 2024).

Table 2: Methane Yields from Comparable Substrates

Substrate Type	*Methane Yield (m^3 CH_4/kg VS)*	*Citations*
Food Waste	0.39–0.46	(Llanos-Lizcano et al., 2024; Batool et al., 2020; Sihlangu et al., 2024)
Animal Manure	0.32–0.36	(Batool et al., 2020; Sihlangu et al., 2024)
Mixed/Crop Residues	0.35–0.38	(Llanos-Lizcano et al., 2024; Batool et al., 2020; Salami et al., 2020)
Institutional Mix	0.38 (this study)	(Llanos-Lizcano et al., 2024; Batool et al., 2020; Salami et al., 2020)

Figure 2: Methane yields for various organic waste streams in biogas systems

System Design and Feasibility

A fixed-dome digester is recommended due to its proven reliability, low maintenance, and suitability for institutional settings with variable waste input (Bortoloti et al., 2023; Esposito et al., 2012). Full-scale studies confirm that such systems can handle load variations without significant loss in methane yield, provided that operational parameters (pH, temperature, OLR) are closely monitored (Bortoloti et al., 2023; Esposito et al., 2012; Filer et al., 2019).

Environmental Impact

Diverting organic waste to biogas plants is projected to reduce CO_2 emissions by approximately 1,200 tonnes annually. This aligns with findings that biogas systems significantly lower greenhouse gas emissions compared to open dumping or landfilling, supporting institutional sustainability goals (Ukpong et al., 2025; Okeniyi et al., 2013; Oladejo et al., 2020; Salami et al., 2020).

Engineering Recommendations

i. **Feedstock Management:** Maintain a balanced mix of food waste and manure to optimize methane yield and process stability (Batool et al., 2020; Phillip et al., 2024; Sihlangu et al., 2024).
ii. **Process Monitoring:** Regularly monitor TS, VS, pH, and OLR to prevent inhibition and maximize biogas output (Llanos-Lizcano et al., 2024; Cabrita & Santos, 2023; Filer et al., 2019).
iii. **System Choice:** Fixed-dome digesters are robust and cost-effective for institutional applications (Bortoloti et al., 2023; Esposito et al., 2012).
iv. **Environmental Compliance:** Implement gas scrubbing for hydrogen sulfide removal, especially with high-manure content, to protect equipment and meet emission standards (Sihlangu et al., 2024).

Conclusion

Biogas production from organic waste streams in tertiary institutions has a very high potential to be both technically and environmentally viable, as well as commercially viable, when sound engineering and scientific principles are applied. This study has demonstrated that methane gas yields (0.38 m^3 CH_4/kg VS) from the anaerobic co-digestion of animal manure, food waste, and crop residues at mesophilic temperature conditions can be comparable to those reported by similar studies conducted globally (Llanos-Lizcano et al., 2024; Rattanapan et al., 2019; Idrissa et al., 2023).The adoption of robust digester designs, such as fixed-dome systems, ensures operational reliability and cost-effectiveness, especially in institutional settings where waste generation is continuous but variable (Pilarska et al., 2023; Rattanapan et al., 2019).

From an engineering perspective, process optimization including careful monitoring of pH, organic loading rate, and substrate composition is essential to maximize methane yield and maintain system stability (Llanos-Lizcano et al., 2024; Rattanapan et al., 2019; Idrissa et al., 2023). The integration of biogas technology not only provides a renewable energy source but also contributes to substantial reductions in greenhouse gas emissions, aligning with global sustainability and circular economy goals (Pilarska et al., 2023; Atelge et al., 2020; Meena et al., 2022). Furthermore, the valorization of digestate as a biofertilizer enhances the overall resource efficiency of the system (Atelge et al., 2020; Meena et al., 2022).

For successful implementation, it is crucial to address logistical and operational barriers, such as consistent feedstock supply and effective waste segregation, while also considering economic feasibility and community engagement (Pilarska et al., 2023; Glivin & Sekhar, 2019; Yadav et al., 2022). Continuous research and the application of advanced monitoring and modeling tools will further enhance process efficiency and scalability (Llanos-Lizcano et al., 2024; Jeong et al., 2021; Bensegueni et al., 2025).

In summary, with proper design, management, and stakeholder involvement, biogas systems in academic and institutional environments can deliver reliable energy, environmental benefits, and educational value, serving as a model for sustainable waste management and renewable energy integration (Pilarska et al., 2023; Atelge et al., 2020; Meena et al., 2022; Rattanapan et al., 2019; Idrissa et al., 2023).

References

Adeoti, O., Idowu, O. A., & Falegan, T. (2000). Engineering design and economic evaluation of a family-sized biogas plant. *Nigerian Journal of Renewable Energy*, 8(1&2), 1–6.

Akinbami, J. F. K., Ilori, M. O., Oyebisi, T. O., Akinwumi, I. O., & Adeoti, O. (2001). Biogas energy use in Nigeria: Current status, future prospects and policy implications. *Renewable and Sustainable Energy Reviews*, 5(1), 97–112. https://doi.org/10.1016/S1364-0321(00)00008-9

Al-Wahaibi, A., Osman, A., Al-Muhtaseb, A., Alqaisi, O., Baawain, M., Fawzy, S., & Rooney, D. (2020). Techno-economic evaluation of biogas production from food waste via anaerobic digestion. *Scientific Reports*, 10. https://doi.org/10.1038/s41598-020-72897-5

Atelge, M., Atelge, M., Krisa, D., Kumar, G., Eskicioglu, C., Nguyen, D., Chang, S., Atabani, A., Al-Muhtaseb, A., & Ünalan, S. (2020). Biogas Production from Organic Waste: Recent Progress and Perspectives. *Waste and Biomass Valorization*, 11, 1019-1040. https://doi.org/10.1007/s12649-018-00546-0

Audu, I., Barde, A., Yila, O., Onwualu, P., & Lawal, B. (2020). Exploring Biogas and Biofertilizer Production from Abattoir Wastes in Nigeria Using a Multi-Criteria Assessment Approach. *Recycling*. https://doi.org/10.3390/recycling5030018

Batool, N., Qazi, J., Aziz, N., Hussain, A., & Shah, S. (2020). Bio-Methane Production Potential Assays of Organic Waste by Anaerobic Digestion and Co-Digestion. *Pakistan Journal of Zoology*, 52. https://doi.org/10.17582/journal.pjz/20190322170334

Bensegueni, C., Kheireddine, B., Khalfaoui, A., Amrouci, Z., Bouznada, M., & Derbal, K. (2025). Optimization of Biogas and Biomethane Yield from Anaerobic Conversion of Pepper Waste Using Response Surface Methodology. *Sustainability*. https://doi.org/10.3390/su17062688

Bidiko, G., Sangib, E., & Gnaro, M. (2025). Optimization of biogas production through co-digestion of cafeteria food waste and cow dung using the response surface methodology. *Frontiers in Energy Research*. https://doi.org/10.3389/fenrg.2025.1568478

Bortoloti, M., Challiol, A., Navarro, B., Sicchieri, I., Kuroda, E., & Fernandes, F. (2023). Challenges of Load Variation on Anaerobic Digestion of Organic Waste on a Full Scale: An Applied Study. *Waste and Biomass Valorization*, 14, 4141-4154. https://doi.org/10.1007/s12649-023-02120-9

Cabrita, T., & Santos, M. (2023). Biochemical Methane Potential Assays for Organic Wastes as an Anaerobic Digestion Feedstock. *Sustainability*. https://doi.org/10.3390/su151511573

Chukwuma, E. (2019). Facility location allocation modelling for bio-energy system in Anambra State of Nigeria: Integration of GIS and location model. *Renewable Energy*. https://doi.org/10.1016/j.renene.2019.04.022

Chukwuma, E., Okey-Onyesolu, F., Ani, K., & Nwanna, E. (2021). GIS bio-waste assessment and suitability analysis for biogas power plant: A case study of Anambra state of Nigeria. *Renewable Energy*, 163, 1182-1194. https://doi.org/10.1016/j.renene.2020.09.046

Esposito, G., Frunzo, L., Liotta, F., Panico, A., & Pirozzi, F. (2012). Bio-methane potential tests to measure the biogas production from the digestion and co-digestion of complex organic substrates. *The Open Environmental Engineering Journal*, 5, 1-8. https://doi.org/10.2174/1874829501205010001

Filer, J., Ding, H., & Chang, S. (2019). Biochemical Methane Potential (BMP) Assay Method for Anaerobic Digestion Research. *Water*. https://doi.org/10.3390/w11050921

Food and Agriculture Organization. (2020). The State of Food and Agriculture 2020: Overcoming water challenges in agriculture. Food and Agriculture Organization of the United Nations. https://doi.org/10.4060/cb1447en

Glivin, G., & Sekhar, S. (2019). Waste Potential, Barriers and Economic Benefits of Implementing Different Models of Biogas Plants in a Few Indian Educational Institutions. *BioEnergy Research*, 13, 668-682. https://doi.org/10.1007/s12155-019-10073-y

Idrissa, O., Tsuanyo, D., Kouakou, R., Konaté, Y., Sawadogo, B., & Yao, K. (2023). Analysis of the criteria for improving biogas production: focus on anaerobic digestion. *Environment, Development and Sustainability*, 1-28. https://doi.org/10.1007/s10668-023-03788-8

Jeong, K., Abbas, A., Shin, J., Son, M., Kim, Y., & Cho, K. (2021). Prediction of biogas production in anaerobic co-digestion of organic wastes using deep learning models. *Water Research*, 205, 117697. https://doi.org/10.1016/j.watres.2021.117697

Llanos-Lizcano, R., Senila, L., & Modoi, O. (2024). Evaluation of Biochemical Methane Potential and Kinetics of Organic Waste Streams for Enhanced Biogas Production. *Agronomy*. https://doi.org/10.3390/agronomy14112546

Meena, P., Pal, A., & , S. (2022). Characterization, utility, and interrelationship of household organic waste generation in academic campus for the production of biogas and compost: a case study. *Environment, Development and Sustainability*. https://doi.org/10.1007/s10668-022-02747-z

Mshandete, A. M., & Parawira, W. (2009). Biogas technology research in selected sub-Saharan African countries – A review. *African Journal of Biotechnology,* 8(2), 116–125.

Oke, A., & Babalola, M. (2021). Municipal solid waste management practices and challenges in Nigeria: A review. *Journal of Material Cycles and Waste Management*, 23, 230–240. https://doi.org/10.1007/s10163-020-01104-8

Okeniyi, J., Obiajulu, U., Ogunsanwo, A., Odiase, N., & Okeniyi, E. (2013). CH4 emission model from the waste of Sus Domesticus and Gallus Domesticus in Nigerian local farms: environmental implications and prospects. *Mitigation and Adaptation Strategies for Global Change*, 18, 325-335. https://doi.org/10.1007/s11027-012-9365-7

Oladejo, O., Elemile, O., Abiola, A., & Olanipekun, A. (2020). Estimation of Methane Emission Potentials in Landmark University Open Dump Site, Omu-Aran, Kwara State Nigeria. **, 5, 53-59. https://doi.org/10.36108/laujoces/0202/50(0160)

Paritosh, K., Mathur, S., Pareek, N., & Vivekanand, V. (2018). Feasibility study of waste (d) potential: co-digestion of organic wastes, synergistic effect and kinetics of biogas production. *International Journal of Environmental Science and Technology*, 15, 1009-1018. https://doi.org/10.1007/s13762-017-1453-5

Phillip, A., Bhatt, S., Sharma, N., & Poudel, B. (2024). Enhanced Biogas Production Using Anaerobic Co-digestion of Animal Waste and Food Waste: A Review. *Journal of Scientific Research and Reports*. https://doi.org/10.9734/jsrr/2024/v30i82297

Pilarska, A., Kulupa, T., Kubiak, A., Wolna-Maruwka, A., Pilarski, K., & Niewiadomska, A. (2023). Anaerobic Digestion of Food Waste—A Short Review. *Energies*. https://doi.org/10.3390/en16155742

Rattanapan, C., Sinchai, L., Suksaroj, T., Kantachote, D., & Ounsaneha, W. (2019). Biogas Production by Co-Digestion of Canteen Food Waste and Domestic Wastewater under Organic Loading Rate and Temperature Optimization. *Environments*. https://doi.org/10.3390/environments6020016

Salami, L., Patinvoh, R., Folami, N., & Salami, K. (2020). Theoretical Prediction of Biogas from Solid Waste Generated In University Of Lagos, Nigeria. **, 35, 26-26.

Sihlangu, E., Luseba, D., Regnier, T., Magama, P., Chiyanzu, I., & Nephawe, K. (2024). Investigating Methane, Carbon Dioxide, Ammonia, and Hydrogen Sulphide Content in Agricultural Waste during Biogas Production. *Sustainability*. https://doi.org/10.3390/su16125145

Suhartini, S., Nurika, I., Paul, R., & Melville, L. (2020). Estimation of Biogas Production and the Emission Savings from Anaerobic Digestion of Fruit-based Agro-industrial Waste and Agricultural crops residues. *BioEnergy Research*, 14, 844 - 859. https://doi.org/10.1007/s12155-020-10209-5

Surendra, K. C., Takara, D., Hashimoto, A. G., & Khanal, S. K. (2014). Biogas as a sustainable energy source for developing countries: Opportunities and challenges. *Renewable and Sustainable Energy Reviews*, 31, 846–859. https://doi.org/10.1016/j.rser.2013.12.015

Ukpong, E., Ofunama, P., & Daniel, E. (2025). Agricultural Waste Materials and Air Pollution: A Survey on The Effects of Farm Animal Wastes on Air Quality. *International Journal of Research and Scientific Innovation*. https://doi.org/10.51244/ijrsi.2025.120600122

Weiland, P. (2010). Biogas production: Current state and perspectives. *Applied Microbiology and Biotechnology*, 85(4), 849–860. https://doi.org/10.1007/s00253-009-2246-7

Yadav, P., Yadav, S., Singh, D., Giri, B., & Mishra, P. (2022). Barriers in biogas production from the organic fraction of municipal solid waste: A circular bioeconomy perspective.. *Bioresource technology*, 127671. https://doi.org/10.1016/j.biortech.2022.127671