

Effect of Chemical Pre-treatment and Co-digestion on Biogas Yield from Animal Manures for Energy Production in Nigeria

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DOI: <https://doi.org/10.62154/ajesre.2025.019.01022>

Abstract

In recent times, biogas is fast becoming one of the most important fuels for electricity and heat energy production. In this work, three different animal manures from cow dung, goat excreta and chicken droppings were used for biogas production in different experiments based on raw feedstock and chemical pre-treatment, furthermore, an additional investigation of the biogas production potential was carried out based on co-digestion of the mixture of the same amount of the three feedstock manures in raw and pre-treated form. The result of the biogas generated indicated that the chicken manure produced the highest quantity of biogas in all three categories of experiments performed. Overall, the largest quantity of biogas was generated by the chicken manure in all three different categories of the experiments. For instance, in the first category, 0.528 m³, 0.484 m³ and 0.364 m³ were produced respectively for raw chicken manure, raw goat manure and raw cow dung manure. For the chemically pre-treated experimental sample feedstock used in the second category, 0.601 m³ was produced by the chicken manure showing a better result while the third category of the co-digestion revealed 0.697 m³ and 0.743 m³ in 20 days of the experimental period respectively for the mixed of the three raw manures and mixture of the three pre-treated manures. The gas chromatography experiment conducted in all the categories also revealed that the highest methane yield was obtained from the mixture of the three pre-treated manures such that the methane (73.24%), ammonia (0.74%), carbon (II) oxide (1.23%), hydrogen sulphide (0.82%) and carbon (IV) oxide (23.97%). Thus, the results obtained showed that the chemically pre-treated co-digestion biomass feedstock performs better than others concerning the quantity of biogas and methane production.

Keywords: Biogas, Biomass, Chemical, Pre-treatment, Renewable Energy, Wastes.

Introduction

The treatment of biomass for energy production involves multiple processes utilizing various biomass-degradable materials such as organic residues from domestic homes and industrial operations. In recent times, the treatment of biomass for biogas production has been used as an approach to reducing the quantity of municipal solid waste production in human communities for environmental sustainability (Atelge et al., 2020). The treatment of biomass for biogas production can be accomplished through a traditional route or the use of integrated chemical and traditional procedures for better yield of methane gas and reduction of gaseous impurities. The goal of chemical pre-treatment of different wastes combined is to increase the production of biogas by using chemicals that break down the

waste materials easily to enable the accessibility of organic materials to the biodegradable activities of microorganisms during anaerobic digestion. As a result, the yield and quality of biogas rise to a reasonable level. Furthermore, the rising carbon emissions and global atmospheric pollution, orchestrated by excessive utilization of fossil fuels, have brought some tremendous concerns to energy and environmental stakeholders. Therefore, the application of clean and sustainable energy technologies has become necessary (Efome et al., 2019; Rajendran et al., 2020). Biodegradable wastes from the agricultural and industrial sectors must be managed appropriately for the protection of our modern environment.

Anaerobic digestion technology has become an extensively accepted system for the environmentally friendly treatment of organic waste for the production of biogas and agriculturally based organic fertilizer for soil nutrient enrichment. Globally, there are millions of micro-digesters operating in different locations for the production of biogas for electricity, heating and cooking. In a modern context, the accumulation of waste materials must be reduced to reduce spontaneous methane emission into the atmosphere as a result of the natural anaerobic digestion process in landfill sites, which can cause air pollution and increase the global warming potential (Salameh et al., 2020). In different parts of the world, there are great variations in the quantities of waste production, and they are to be treated properly to avoid environmental pollution. The system where various waste materials are combined to be treated in a single unit of a biogas production facility is called co-digestion. The concept of co-digestion of biomass feedstock for biogas production is illustrated in Fig. 1. Co-digestion of waste materials allows for the use of integrated waste materials from different sources to be used (Cesaro et al., 2012; González et al., 2022; Potdukhe et al., 2021). Therefore, this study uses the three different feedstocks of cow manure, chicken manure and goat manure. The combination of these residues for the production of biogas in a single biodigester gives rise to the intended co-digestion of the waste materials. In consequence, this study is based on the feasibility of the anaerobic digestion process through the application of pre-chemical treatment for the enhancement of biogas production for energy application.

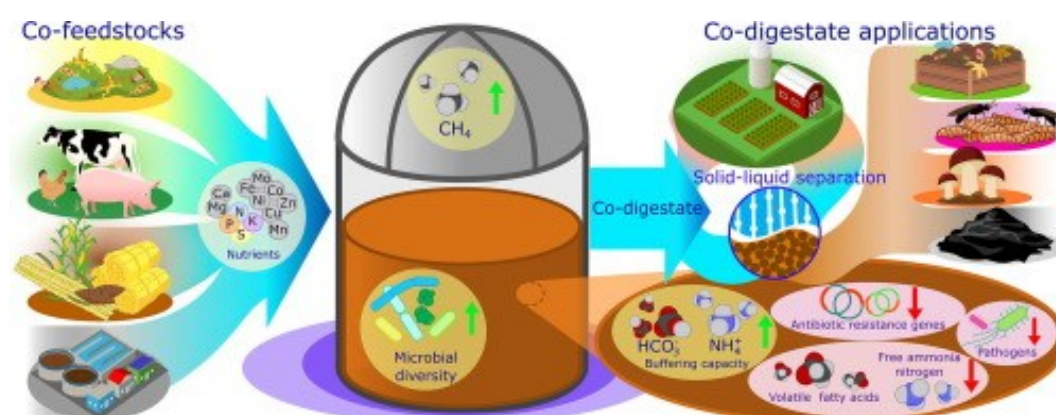


Fig. 1: Conceptual representation of biogas co-digestion system (Karki et al., 2021)

Objectives of the Study

This research aims to investigate the quantity and quality of biogas production from the co-digestion of biodegradable waste, animal manure from cow dung, poultry droppings and goat manure through anaerobic digestion systems. Therefore, the key research objectives are:

1. To determine the quantity and quality of biogas production from a mixture of animal manures.
2. To develop a biogas recovery strategy from the co-digestion of waste materials for energy generation.

Literature Review

Biowaste materials generated are commonly disposed of indiscriminately, such as burning in open space dump sites. Open dump sites create landfills that could be a source of uncontrolled methane emissions into the atmosphere (Chungsangunsit et al., 2004). Uncontrolled emissions of methane into the atmosphere have a potential negative impact on environmental pollution with a consequential threat to human health. The application of anaerobic digestion technology for the treatment of biodegradable waste materials is a strategic approach toward sustainable utilization of waste for energy production and mitigation of environmental pollution. Animal dungs can be used for the production of biogas through anaerobic digestion, but they must be in a better condition for effective yield of biogas in the context of enzymatic biochemical reactions (Mtui, 2009). From this perspective, the biodegradability of animal dung is necessary for the suitable production of biogas from an anaerobic digestion process. One way to enhance the overall digestion processes and increase the amount of biogas produced is to use chemical pre-treatment for biomass waste materials (González et al., 2022). Chemical pre-treatment is easier, faster, and more effective than other pre-treatment techniques (Ariunbaatar et al., 2014). The four pre-treatment techniques that are frequently employed in anaerobic digestion are chemical, biological, physico-chemical, and physical pre-treatment. The utilization of chemical pre-treatment for the enhancement of biogas production from waste materials can be improved, thereby making the biodegradation process easier to accomplish with increasing digestion efficiency. Organic wastes for the implementation of the co-digestion process should guarantee a significant production of biogas for improving energy recovery, depending on the digester capacity.

Chemical pre-treatment of anaerobic digestion involves the use of chemical substances for the induction of the biochemical reaction in the system (Almegbl et al., 2024). There are several documented pieces of evidence regarding research on energy recovery from biomass applications for biogas production from biowaste materials in developing countries. However, the technological systems of quality production of biogas are still confronted by some obstacles regarding improved treatment of the waste materials and operation of the sustainable biogas production system (Belibagli et al., 2024; Karthikeyan

et al., 2024). An effective chemical pre-treatment of biomass raw materials can help in the implementation of a reasonable energy recovery strategy from a techno-economic perspective. The anaerobic digestion system of biogas production can be a biochemical action such that microorganisms conduct some activities of biodegradation of the raw materials to split the organic contents of the raw materials in the absence of air (oxygen) to achieve methanogenesis for biogas methane production (Kau et al., 2024; Kumar et al., 2024). In the pre-treatment phase, the application of some essential chemicals to accelerate the biodegradation procedures in the biochemical reactions involved in biogas production can facilitate the breakdown of the molecules in the raw materials. The chemical actions react with the raw materials to effectively produce the required methane gas. Subsequently, this study examined how chemical pre-treatment application affected the yield and production rate of biogas from the co-digestion of different animal manures and their co-mixtures in different proportions.

Materials and Methods

Anaerobic Bio-digestion Materials

Different types of bio-digestion materials have been utilized in recent years for the production of biogas through the process of anaerobic digestion for biogas methane production. The global contraction in the ever-increasing energy demand has resulted in the overuse of energy resources, particularly in urban areas. Anaerobic bio-digestion materials can take the form of solid, semi-liquid, and liquid waste, among other waste products. Materials for anaerobic bio-digestion can be generated from industrial waste, animal waste, and agricultural plant materials from post-crop harvests and domestic food consumption. Anaerobic digestion of biodegradable waste generates methane through a threefold process that produces useful energy in the form of methane, conserves the environment by reducing the amount of waste and toxic materials, and yields valuable by-products such as animal manure (Vijin Prabhu, 2021). In this research work, the selected anaerobic bio-digestion waste materials are cow dung manure, goat manure, and chicken poultry manure.

Experimental Procedure of the Research Samples

The biological process of anaerobic digestion involves a sequential systematic procedure for the breakdown of the biogenic content of biogenic wastes for the production of biogas in the absence of air. The integrated biological processes are hydrolysis, acidogenesis, and methanogenesis. The experimental set, as shown in Fig. 1, involves the feeding of feedstock into the biodigester and application of the pre-treatment chemical for the induction of biochemical actions on the substrate. The samples used in this study were collected from a local commercial farm, Layuza farm in Nasarawa Local Government Area in Nasarawa state, Nigeria. The samples are stored in airtight plastic bottles before the chemical

procedural application and the anaerobic digestion experiments. A wet state chemical pre-treatment approach was applied using the NaOH, HCl and C_2H_5OH , representing alkaline, acid and ethanol chemical pre-treatment, respectively. The research samples were obtained and mixed thoroughly with 1000 mL of each of the chemical reagents in the context of solid-to-liquid mixing with water to give an adequate saturation required for the biochemical reaction.

The measurement of the research samples for the experimental activities in this study is such that 2 kg of cow dung manure, 2 kg of goat manure and 2 kg of chicken manure and each of the samples is mixed with 2 liters of water separately for the slurry formation. The slurries were stirred accordingly through a manual approach until all the lumps were dissolved in the mixtures. The mixtures are then transferred to the laboratory-scale biodigester for experimentation. In the course of the experiments, follow-up stirring of the samples was conducted occasionally and the temperature of the system was measured at every interval of an hour for 20 days. The coverage of the duration for the temperature measurements was from 8:00 – 18:00 hours and compared with the ambient temperatures. The first phase of the experiments was conducted for the selected raw research samples, while the second phase of the experiment was repeated consecutively for the chemically pre-treated samples of the three manures using the chemical reagents of NaOH, HCl and C_2H_5OH . The purpose of the application of the chemical pre-treatment is to disrupt the natural biomass structure of the organic compound to reduce the crystallinity of the cellulose, for increasing enzymatic action for digestion. It helps to break down lignin for improved digestibility to increase the yield of the biogas.



Fig. 2: Laboratory scale experimental set-up for the research

Results and Discussion

Biogas is generated from the anaerobic digestion experiment conducted and the gases produced were analyzed using gas chromatography to determine their constituents by percentage composition. Fig. 3 shows the first set of experiments conducted for the raw manures without any chemical pre-treatment application after 20 days. The digester produced biogas from the different kinds of feedstock used for the experiment. The sample feedstocks used for the experiments are in different categories, as shown in Fig. 3. The feedstocks are raw cow dung manure, raw goat manure, and raw chicken manure in the first category. In the second category are pre-treated cow dung manure, pre-treated goat manure and pre-treated chicken manure. The third category has mixtures of the three raw manures and the pre-treated mixtures of the three manures. The quantities of the biogas produced by each of the sample feedstocks are shown in Fig. 3. It was observed that in the first category, the raw chicken manure produces 0.528m^3 of biogas with the period of 20 days of the experiment followed by 0.484m^3 from the raw goat manure feedstock and the least biogas production of 0.364m^3 from the cow dung manure. In the framework of the second category of the experiments conducted, the pre-treated samples of feedstocks from the three animals were used. In this case, the biogas production quantity is 0.413m^3 , 0.522m^3 and 0.601m^3 respectively for the pre-treated cow dung manure, pre-treated goat manure and pre-treated chicken manure. The third category is experimental co-digestion of three wastes mixed in raw form and then in a pre-treated form. In the raw mixture feedstock, the quantity of biogas production for the entire period of 20 days was 0.697m^3 while the result obtained for the anaerobic digestion of the pre-treated mixture of the animal wastes was 0.743 , as the highest value obtained in this work.

In general, chicken manure produced more yields than goat and cow excrement. Because chicken manure has a greater nitrogen content and a favourable pH value, which is ideal for forming biomethane in anaerobic digestion, it often yields more biogas than cow dung and goat manure. The carbon-to-nitrogen ratio of cow dung is also a favourable factor for the production of a reasonable quantity of biogas in the anaerobic digestion system. The high levels of volatile solids and COD in goat dung indicate that it contains a strong organic content for biodegradation, which is necessary for efficient biogas conversion. Additionally, it was commonly noted that, in comparison to the other two manures, the daily output of biogas from poultry-dropping manure is higher. This might be because the manure with higher biomass humidity has a larger nitrogen concentration than the others. On the other hand, cellulose elements are more prevalent in cow dung manure than in other wastes, which may be the reason why this task has the least potential to produce biogas. Additionally, it was noted in every trial that biogas generation began slowly at first but then increased in amounts with discernible improvement a week before the experiments ended. Even though chicken manure has been shown to produce a larger quantity of biogas, it

tends to produce more hydrogen sulphide and has a great affinity for corroding the metallic components of internal combustion engines used for the generation of electricity. In addition, the biogas produced by the tests was analyzed using gas chromatography. Overall, it was found that, out of all the animal wastes, chicken waste generates the most biogas methane, as seen in Figs. 4-6. Methane production from untreated chicken manure is 72.23% in Fig. 4, while the percentages for goat manure and cow dung manure are 67.06% and 69.34%, respectively. The percentage of biogas methane production for the processed wastes from the animal manures is also shown in Fig. 5 as 68.52%, 70.98%, and 74.01% for cow dung manure, goat manure, and chicken waste manure, respectively. As illustrated in Fig. 6, 72.88% and 73.24% are displayed for both mixed untreated and mixed treated manures in the co-digestion scenario, respectively. Co-digestion is a useful strategy for boosting the bio-digestion of organic waste products, according to the overall performance of the biogas production and methane quality results obtained. However, other factors may need to be taken into account and properly monitored to improve the processes involved. For example, to improve the elimination of volatile materials and speed up bio-digestion, the anaerobic digestion process necessitates that the biochemical flexibility of the system be closely observed and assessed.

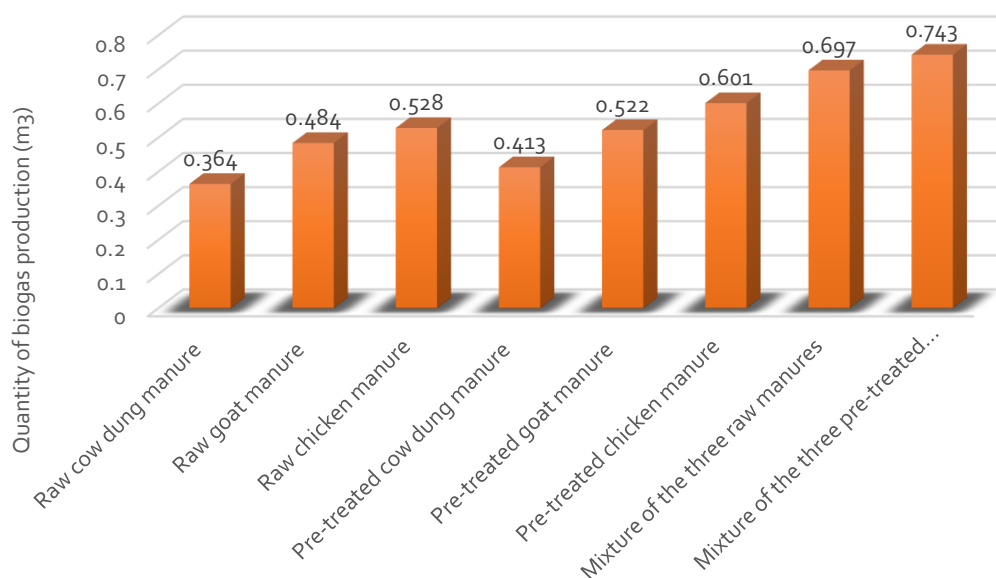


Fig. 3: Quantity of biogas production

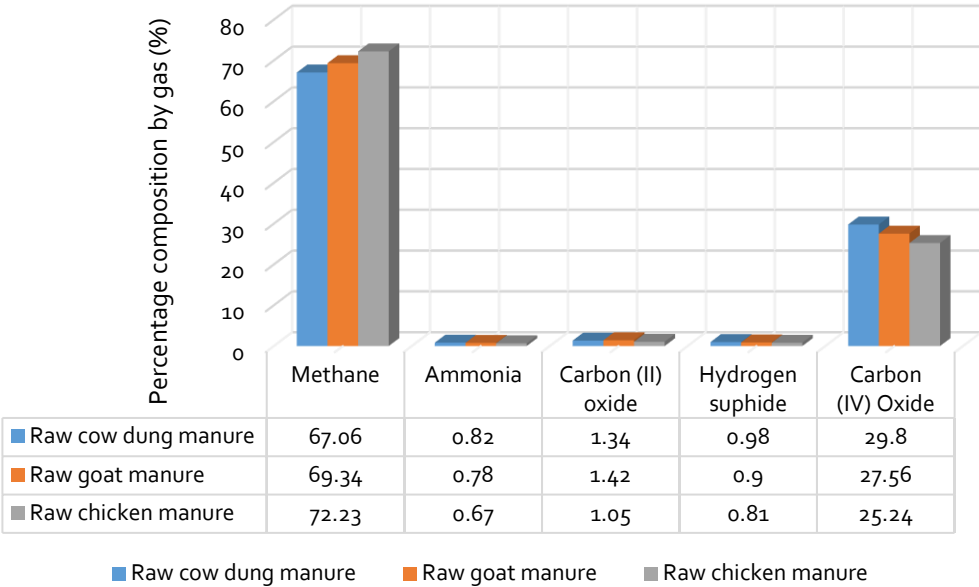


Fig. 4: Results of the gas chromatography analysis of the biogas from the untreated feedstock

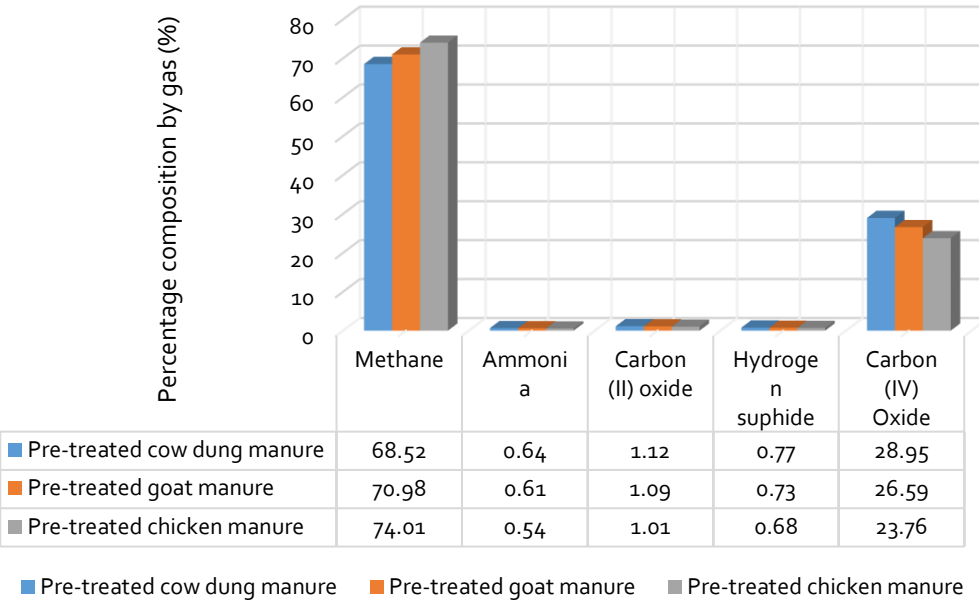


Fig. 5: Results of the gas chromatography analysis of the biogas for pre-treated feedstock

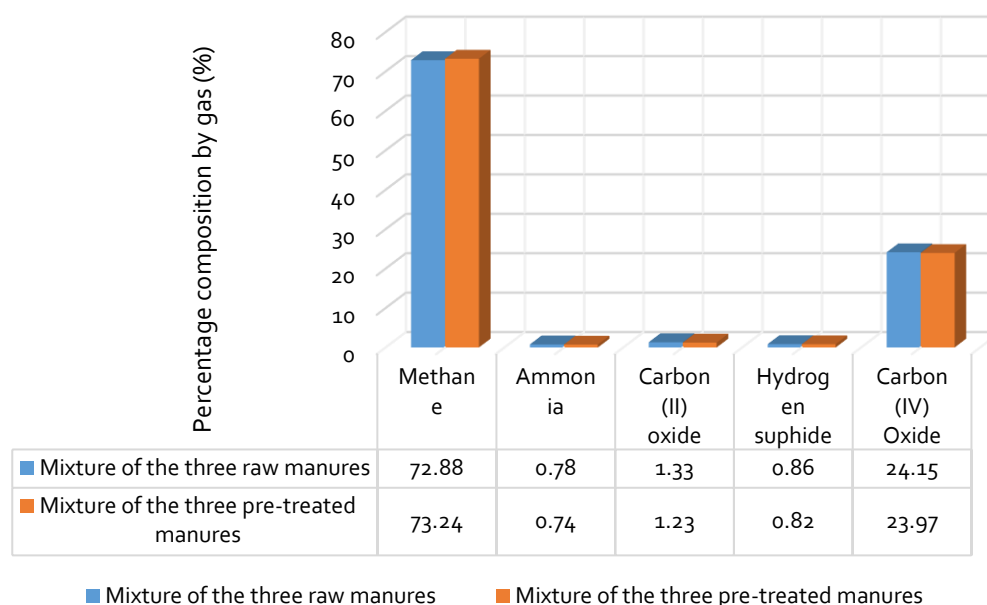


Fig. 6: Results of the gas chromatography analysis of the biogas for the mixture of untreated and pre-treated feedstock

Biogas Recovery Strategy for Power Generation

Anaerobic digestion of organic waste is one method for recovering biogas for energy generation. As shown in Fig. 7, there are different phases of biochemical processes in anaerobic digestion. The breakdown of biomass feedstock involves some complex processes for the disintegration and solubilization of the complex organic matter in the organic materials and the subsequent transformation of the waste materials into gas (Masebinu et al., 2019; Negri et al., 2020; Wu et al., 2021). Municipal solid waste (MSW), animal manure, food waste and agricultural residues are examples of easily accessible organic waste sources that are used as feedstock for biogas production. To improve the production of biogas, an anaerobic co-digestion process can be used. In the second step, anaerobic digestion is used in a digester, a controlled environment where microorganisms break down organic matter to produce biogas, which is mainly carbon (IV) dioxide and methane gas. To maximize the production of biogas, the biogas digestion design must be carried out in a way that takes into account variables like temperature, pH, mixing, and retention time. To increase the digestibility of some feedstocks, pre-treatment application is required. Following the pre-treatment procedure, the engine runs on fuel to generate electricity. Bio-methanation in commercial power generation entails purifying the gas to eliminate contaminants for electric power generation. The steps involved in the biogas recovery strategy for power generation are shown in Fig. 8. The application of enriched biogas (biomethane) instead of raw biogas significantly advances the performance of the biogas electric power generation system.

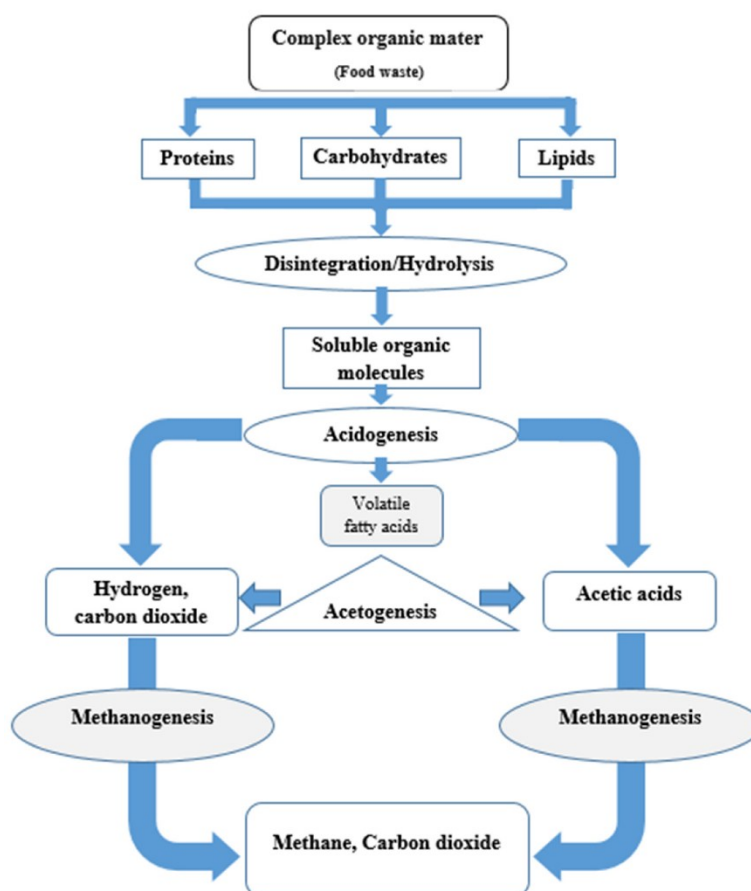


Fig. 7: Biochemical phases of anaerobic digestion process (Benyahya et al., 2021)

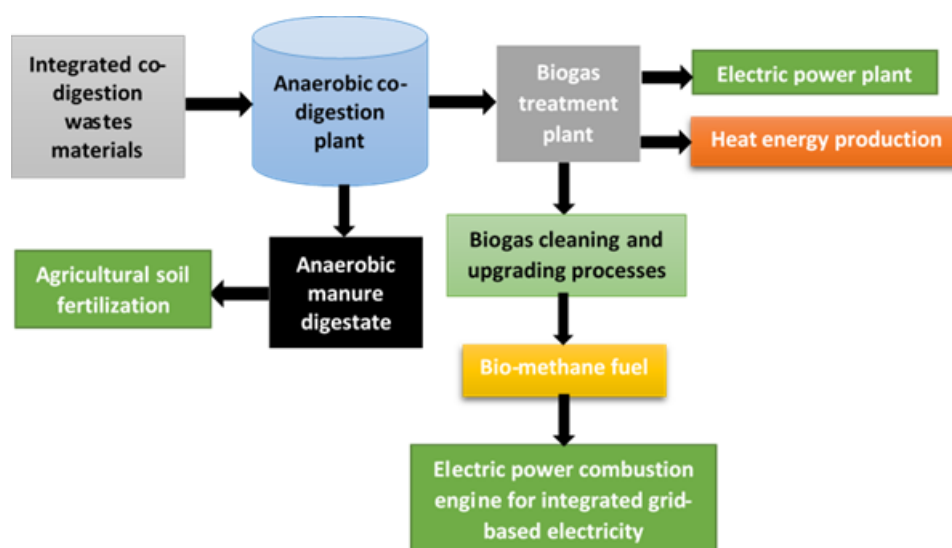


Fig. 8: Pathways to biogas recovery for energy production and sustainability

An efficient method of recycling bio-waste that may be used as fuel for heat and power cogeneration is biogas. The anaerobic digestion of organic matter produces biogas, which can be transformed into power in a number of ways. The most popular approach uses biogas as fuel for turbines to generate electricity for the off-grid or grid-connected communities. An alternative is to clean biogas and utilise it in fuel cells or convert it to hydrogen for energy production. Resources derived from agriculture and livestock have a lot of potential for producing biopower, primarily because they are relatively inexpensive. However, in this setting, Nigeria has overlooked the role of agricultural leftovers for biopower production.

Conclusion and Recommendation for Future Research

Using a bio-digestion system to process and treat organic wastes to recover energy and produce other organically beneficial by-products is known as anaerobic digestion technology. Anaerobic digestion can reduce environmental pollution by eliminating offensive odours and converting organic nitrogen to ammonia. This work has investigated the potential of biogas production from different animal manures based on their raw feedstock condition and in their pre-treated condition. The co-digestion experimental investigation for the biogas production capability was also carried out to enable higher rates of biodegradation and improve biogas production quantity from the anaerobic digestion system used in this work. A wide-ranging experimental study has been conducted under laboratory conditions on small-scale experimental processes for the viability of biogas production from different animal manures. The results obtained have proven that biogas production quantity can be increased based on chemically pre-treated co-digestion feedstock of the three waste materials used as feedstock.

However, it is anticipated that future research will focus on the processes to enhance biogas production efficiency and make digestion facilities more financially viable. Given the notable improvement in methane yields, there is also some hope that the addition of biogenic waste materials to the manures can enhance a better production quantity of biogas. The possibility of deducing that the condition of biogas production in the small-scale investigated in this work can also be applicable when applied on a bigger scale requires more investigation. This consequently indicated that further study is required with regard to improved biogas yields from the set of waste materials used in this study. From an economic perspective, the benefits of using the wastes for small-scale electricity generation in rural communities in Nigeria can also be investigated to ascertain their contribution to the circular economy. Establishing a biopower plant in Nigeria is essential, given the exceptional value of producing biopower from animal and agricultural waste. With reliable support from the government, the nation can motivate farmers to handle these wastes properly. As a result, waste management across the nation requires the implementation of plans and targeted initiatives. In order to bring this industry closer to

commercial success, a number of issues pertaining to automated garbage collection and administrative challenges must be resolved.

Acknowledgement

The authors strongly acknowledge the financial support from the Tertiary Education Trust Fund (TETFund) based on Institution-Based Research (IBR) grant provided to the Federal Polytechnic Nasarawa (FPN).

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