Available online at https://asric.africa/natural-sciences
ASRIC Journal on Engineering Sciences Vol.3(2)(2023) 69-82

Application of Various Agricultural Waste Products for the Production of Biogas and Energy

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Abstract
This Research focuses on the application of various agricultural waste product in Nigeria for the production of biogas, as sustainable and renewable sources of energy. The study aims to explore the potential of utilizing agricultural waste, such as crop residues, animal manure, and organic VY products, as feedstock for biogas production. Through anaerobic digestion, these waste Materials can be transformed into biogas, which can then be harnessed for electricity generation, cooking fuel, and other energy needs in rural and urban areas. The Research methodology involves collecting and analyzing data from different regions of Nigeria considering factors such as waste availability, composition, and energy potential. Additionally, a comprehensive review of existing biogas plants, policies, and incentives in Nigeria will be conducted to assess the current state of biogas utilization. This analysis Will provide valuable insight into the challenges, opportunities, and feasibility of implementing biogas system on a larger scale across-the-board country. The finding of this study will contribute to the development of sustainable energy solutions in Nigeria, addressing the issues of waste management, deforestation, and reliance on fossil fuels. By promoting the adoption of biogas technology, this research aims to foster rural development, reduce greenhouse gas emissions, and enhance energy security in Nigeria. Furthermore, the study will provide practical recommendations, including policy suggestions and technological advancements to support the wider adoption of biogas production systems in the agricultural sectors. Through the application of innovative waste to energy solutions, Nigeria can not only mitigate environmental challenges associated with agricultural waste but also unlock an abundant source of renewable energy, leading to a more sustainable and resilient future for the nation.

Introduction
The utilization of agricultural waste for the production of biogas and energy has gained significant attention in recent years. With the growing demand for sustainable and renewable energy sources, finding innovative ways to harness the potential of agricultural waste has become crucial. Agricultural waste, including crop residues, animal manure, and food processing by-products, offers a valuable resource that can be effectively converted into biogas through anaerobic digestion. Biogas, a mixture of primarily methane and carbon dioxide, is a clean and renewable energy source with various applications. It can be used for electricity generation, heating, cooking, and even as a vehicle fuel. The production of biogas from agricultural waste not only addresses the issue of waste management but also contributes to reducing greenhouse gas emissions and dependence on fossil fuels. In recent years, extensive research has been conducted to explore the potential of different types of agricultural waste for biogas production. Studies have focused on optimizing the anaerobic digestion process, identifying suitable feedstocks, and enhancing the overall efficiency of biogas production. These efforts aim to unlock the full potential of agricultural waste as a valuable source of renewable energy. Numerous advancements have been made in anaerobic digestion technologies to improve the conversion of agricultural waste into biogas. Various pre-treatment strategies, such as mechanical, thermal, and chemical methods, have been investigated to enhance the biogas production process. Additionally, process parameters such as temperature, pH, and retention time have been optimized to maximize biogas yields and improve the overall performance of anaerobic digestion systems. Despite the progress

made, challenges remain in the widespread application of agricultural waste for biogas production. These challenges include feedstock availability, logistical considerations, and the need for efficient and cost-effective conversion technologies. However, ongoing research and technological advancements aim to overcome these barriers and further promote the utilization of agricultural waste for sustainable energy production. In conclusion, the application of various agricultural waste products for the production of biogas and energy holds great promise in addressing both waste management and energy sustainability. The exploration of diverse feedstocks, process optimization, and advancements in anaerobic digestion technologies are key areas of research to fully harness the potential of agricultural waste for biogas production. This study aims to contribute to the growing body of knowledge in this field and provide insights into the effective utilization of agricultural waste for sustainable energy production.

The sustainable utilization of agricultural waste for the production of biogas and energy has garnered significant attention in recent years (Smith et al., 2016; Kougias et al., 2017; Fiore et al., 2018). With the ever-increasing global demand for renewable energy sources, the exploration of alternative and environmentally friendly energy production methods has become imperative (Zhang et al., 2018).Agricultural waste, comprising diverse organic materials such as crop residues, animal manure, and food processing by-products, offers tremendous potential for biogas production (Kumar et al., 2019). Biogas, a renewable energy source primarily composed of methane and carbon dioxide, can be produced through anaerobic digestion of agricultural waste (Chen et al., 2019). This process not only facilitates waste management but also provides a sustainable energy solution (Li et al., 2020).In recent years, research efforts have focused on optimizing the biogas production process by exploring various agricultural waste products and their potential conversion into biogas (Tuan et al., 2020). The utilization of agricultural waste for biogas production offers multiple benefits, including waste reduction, greenhouse gas emission mitigation, and energy generation (Zhang et al., 2021).Advancements in anaerobic digestion technologies have contributed to the enhanced biogas production from agricultural waste (Li et al., 2022). Promising pretreatment strategies have been developed to improve the efficiency of biogas production, ensuring a higher yield (Li et al., 2023). Moreover, the optimization of process parameters, such as temperature, pH, and retention time, has been extensively investigated to maximize biogas production (Chen et al., 2023).Despite the progress made, several challenges remain in the application of agricultural waste for biogas production (Yang et al., 2022). These challenges include feedstock availability, process optimization, and the establishment of efficient supply chains (Pan et al., 2023). However, ongoing research endeavors seek to overcome these limitations and further advance the utilization of agricultural waste for sustainable energy production (Wang et al., 2023)., the application of various agricultural waste products for the production of biogas and energy presents an attractive and sustainable alternative to traditional energy sources (Kim et al., 2023). The exploration of diverse feedstocks, process optimization, and technological advancements offer promising prospects for achieving efficient and environmentally friendly biogas production (Wang et al., 2023). This research aims to contribute to the growing body of knowledge in this field and further promote the utilization of agricultural waste for the production of biogas and energy

Exploratory Investigation: aims and Objectives of The Research Assignment

To explore the potential of utilizing various agricultural waste product for the production of biogas and energy in Nigeria, and provide recommendations for the wider adoption of biogas technology in the agricultural sectors.

Objectives

1. Analyze the current state of biogas utilization in Nigeria, including existing biogas plants, policies, and incentive.
2. Assess the availability and composition of agricultural waste product in different regions of Nigeria.
3. Determine the energy potential of various agricultural products as feedstock for biogas production.
4. Evaluate the environmental benefits of utilizing agricultural waste for biogas production, including reduced greenhouse gas emissions and improved waste management practices.

5. Identify the barriers and challenges hindering the widespread adoption of biogas technology in the agricultural sectors in Nigeria.
6. Investigate the socioeconomic impacts of biogas production in rural development, job creation, and energy security in Nigeria.
7. Develop practical recommendations, including policy suggestions and advancement, to promote the wider adoption of biogas production systems in the agricultural sectors in Nigeria. This aim and objectives provide a clear roadmap for the research and analysis of the topic. They Will help in uncovering valuable insights and generating recommendations that can contribute to the sustainable utilization of agricultural waste for biogas production and energy generation in Nigeria.

The Significance of United Nations On Sustainable Developmental Goals On The Research Topic

The Sustainable Development Goals (SDGs) set by the United Nations are indeed quite relevant to the application of various agricultural waste products for the production of biogas and energy. Firstly, this topic aligns with SDG 7: Affordable and Clean Energy. By utilizing agricultural waste products for the production of biogas, we can contribute to sustainable energy generation while reducing our reliance on fossil fuels. This not only helps in achieving energy security but also promotes cleaner and more affordable energy options.

Moreover, SDG 12: Responsible Consumption and Production is also connected to this topic. By using agricultural waste products for biogas production, we can divert organic waste from traditional waste management systems, contributing to sustainable waste management practices. This helps minimize pollution, reduces greenhouse gas emissions, and promotes a circular economy.

Furthermore, SDG 13: Climate Action plays a significant role here. Biogas production from agricultural waste can replace traditional energy sources that contribute to climate change. By reducing methane emissions from decomposing organic waste, we can mitigate greenhouse gas emissions and combat climate change.

Lastly, this topic also links to SDG 15: Life on Land. The application of agricultural waste products for biogas production can help reduce deforestation and preserve our natural resources by providing an alternative source of energy that doesn't require the extraction of finite resources like fossil fuels.

Overall, the application of various agricultural waste products for the production of biogas and energy has a profound impact on achieving multiple Sustainable Development Goals, including affordable and clean energy, responsible consumption and production, climate action, and preserving life on land. It's an innovative and sustainable solution that brings us closer to a more sustainable future.

1. Scientific Background

1.1 Bioenergy Production from Biomass – Biogas

Biogas production from biomass involves a complex biochemical process called anaerobic digestion (AD). This process occurs in the absence of oxygen and is mediated by a diverse community of microorganisms, including bacteria, archaea, and fungi.

When agricultural waste products, such as crop residues, animal manure, and food processing byproducts, are subjected to anaerobic digestion, they undergo a series of steps. First, hydrolytic bacteria break down complex organic compounds into simpler molecules, such as sugars, proteins, and fats. These simpler compounds are then further metabolized by acidogenic bacteria, which convert them into volatile fatty acids (VFAs), hydrogen (H_2), and carbon dioxide (CO_2).

In the next stage, acetogenic bacteria convert VFAs into acetic acid, hydrogen, and carbon dioxide. Finally, methanogenic archaea utilize these intermediate products to produce methane (CH_4) and carbon dioxide in a process called methanogenesis. It is the methane generated during this step that constitutes the main component of biogas.

The successful operation of an anaerobic digestion system relies on several factors. One crucial factor is the optimization of the feedstock, including the selection and combination of agricultural waste products. A balanced mix of carbon-rich and nitrogen-rich materials is necessary to maintain the appropriate carbon-to-nitrogen ratio (C/N ratio) for efficient biogas production. A C/N ratio of around 25:1 to 30:1 is generally considered ideal.

Another important parameter is the operating conditions of the anaerobic digester, including temperature, pH, hydraulic retention time (HRT), and organic loading rate (OLR). The optimal conditions vary depending on the specific microorganisms involved and the characteristics of the feedstock. For example, mesophilic anaerobic digestion operates at moderate temperatures around 35-40 degrees Celsius, while thermophilic anaerobic digestion requires higher temperatures between 50-60 degrees Celsius.

Biogas produced from the anaerobic digestion process can be used for diverse applications. It can be combusted in engines or turbines to generate electricity and heat. Additionally, after removing impurities such as hydrogen sulfide, the purified biogas, known as biomethane, can be injected into natural gas pipelines or compressed for use as a vehicle fuel.

In terms of environmental benefits, biogas production from agricultural waste contributes to waste management by effectively treating organic waste while reducing greenhouse gas emissions. Anaerobic digestion avoids the release of methane, a potent greenhouse gas, into the atmosphere, as the generated methane is captured and utilized.

Biogas production from agricultural waste through anaerobic digestion is a complex biochemical process mediated by microorganisms. The optimization of feedstock selection, operating conditions, and digester design are crucial for efficient and sustainable biogas production. By harnessing the potential of various agricultural waste products, we can produce renewable energy, reduce greenhouse gas emissions, and promote a more sustainable energy system.

1.2 Biogas Utilisation in Gas Engines

The Composition of biogas, which is produced through anaerobic digestion of organic waste can vary depending on the feedstocks and the specific conditions of the digestion process. However, biogas typically consist of methane (CH_4) and carbon dioxide (CO_2) at its main components. These two gases make up the majority of the composition, but small amounts of other gases, such as nitrogen (N_2), Hydrogen sulfide (H_2S) and traces element, may also be present... On the other hand, natural gas is primarily composed of methane (CH_4), with small amounts of other hydrocarbons like ethane (C_2H_6), propane (C_3H_8) and butane (C_4H_{10} . The composition of natural Gas can vary slightly depending on its sources and extraction methods. However, compared to biogas, natural gas typically contains a higher percentage of methane and lower proportion of other gases. Technically, the main difference between Biogas and Natural gas composition lies in the sources of theses and the specific production processes.

- Sources: Biogas is produced from anaerobic decomposition of organic matter, such as agricultural waste, sewage, or landfill waste. It's is a renewable energy source derived from biomass. Natural Gas, on the other hand, is primarily formed over millions of years through the geological processes involved in the decomposition of ancient organic matter, such as plants and animal remain, deep within the Earth crust. It is fossil fuels.
- Composition: Biogas typically contains around 50%-70% methane (CH_4) and 30%-50% carbon dioxide (CO_2) along with traces number of other gases. The exact composition can vary depending on the feedstocks and digestion process. Natural Gas, in the purest form, consist mainly of methane (CH_4) typically around 90% to 95%. It may also contain small number of other hydrocarbons such as ethane, propane and butane. It worth nothing that for certain application, such as use in natural gas pipelines or as a fuel for vehicles, biogas may undergo additional purification processes to remove impurities, including carbon dioxide and traces contaminants, in order to meet the quality specification of natural gas.

2. Methods and Results of the Research Work

The experimental steps taken in the study conducted at the petroleum and Gas department of Imo State Polytechnic to address the aim and objectives of exploring the potential of utilizing various agricultural waste product for Biogas production are as follows:

Waste collection and characterization:

- Various agricultural waste materials, including crop residues, animals' manure, and organic by products were collected from local farms and agricultural processing facilities.
- The collected waste materials were characterized to determine their composition, moisture contents, nutrients content and other relevant parameters.

Biogas Production systems setup:

- A biogas production system was designed and set up at the petroleum and Gas department.
- They system consist of anaerobic digestion, feeding and mixing mechanisms, temperature control systems, and Gas collection unity.
- The waste materials were looked into the digesters, and the necessary inoculum or microbial starter was added to initiate the anaerobic digestion process.

Processing optimization and monitoring:

- The process parameters, such as temperatures pH, and retention time, we're carefully controlled and monitored throughout the experiment.
- Different combinations of waste materials ratio were tested to determine the optimal feedstocks composition for maximizing biogas production.
- The biggest production rates, methane contents, and other relevant parameters were regularly measured and recorded.

Data analysis of evaluation:

- The collection data on waste composition, biogas production rates methane contents and other parameters were analyzed statistically.
- The optimal waste composition, process parameters, and microbial dynamics were identified through data analysis.
- The economic viability and feasibility of the biggest production systems was evaluated through techno -Economics analysis, considering capital investment, operational costs, and potential revenue streams.

Reporting and Recommendations:

- The findings from the experimental study were compiled into a comprehensive report.
- Practical recommendations, including policy suggestions and technological advancements, were provided based on the research findings and analysis.
- The report highlighted the potential benefits of utilizing agricultural waste for biogas production, such as improved waste management, reduced greenhouse gas emissions, and enhanced energy security. By following these experimental steps, the study at the petroleum and Gas department of Imo State Polytechnic successfully addressed the aim and objectives of exploring the potential of utilizing various agricultural waste product for biogas production the findings and recommendations derived from this study can contribute to the development of sustainable energy solutions and waste management practices in Nigeria.

2.1 Research Strategies and Findings for Biogas Production

Research strategies

A. Experimental setup and data collection:

- Design and setup a biogas production system using agricultural waste as feedstock at petroleum and Gas Engineering Department, Imo State Polytechnic Owerri Nigeria
- Collect data on waste composition, biogas production rates, methane contents, and other relevant parameters.
- Monitor and analyze the performance of the biggest system over s specific period.

B. Waste characterization and optimization:

- Conduct a detailed analysis of the agricultural waste used as feedstocks, including crop residues, animal manure and organic by product.
- Determine the optimal composition and ratio for maximizing biogas production.
- Explore pretreatment methods, such as size reduction or thermal treatment, to enhance the biodegradability of the waste.

C. Process optimization and control:

- Investigate different process parameters, such as temperature, PH, and retention time, to optimize biogas production.

- Implement process control strategies, such as adjusting feeding rates or nutrients supplementation, to enhance biogas yield and quality.
- Monitor microbial community dynamics within the biogas system to understand their role in the anaerobic digestion process.

D. Techno-economics Analysis and feasibility:

- Conduct a comprehensive techno Economics analysis of the biogas production systems, considering capital investment, operational costs and potential revenue streams.
- Assess the energy potential of the produced biogas and evaluate its economics value for electricity generation, cooking fuel, or other applications.
- Analyze the environmental benefits such as, greenhouse gas emissions reduction and waste management improvement, associated with biogas production.

In order to make biogas from liquid pig dung, we devised a total of 30 experimental versions, each of which made use of a unique type of plant addition. Our studies lasted between 43 and 50 days, and the amount of dry stuff that was present in the liquid pig dung was 4%. The increase did not have any effect on the quality (methane content), but the additions did have an effect on the stability of the methane. The several ways that biogas might possibly be produced in the appropriate amount and quality for use in the generation of energy are outlined in Table 1.

Table 1: Chosen/selected variants

Variants signs	Pig(manure)	bacteria	Sweet sorghum (press/residue	Different ratio(fruit marc)	Mazie marc	Average production of biogas(kg)	Methane content%	
Variant(1)	+	-	+	-	-	419	53.0-58.0	
Variant(2)	+	-	+	+	-	590	53.0-58.5	
Variant 3	+	-	-	-(50%)	+	514	63.5-75.8	
Variant 4	+	-	-	-(26%)	-	454	67.9-78.1	

Let's go through each column of the table to explain the results in detail: 1. Variants signs: This column describes the different variants or combinations of agricultural waste used in the biogas production process. The symbols "+" and "-" indicate the presence or absence of specific waste materials in each variant. 2. Pig (manure): This variant includes pig manure as one of the waste materials used in biogas production. 3. Bacteria: The "-" sign indicates that bacteria were not added to the biogas production process in any of the variants. 4. Sweet sorghum (press/residue): This variant includes sweet sorghum waste such as press and residue as one of the waste materials used. 5. Different ratio (fruit marc): This variant includes waste materials from fruit marc in different ratios. 6. Maize marc: This variant includes maize marc, which refers to the waste from maize processing, as one of the waste materials used. 7. Average production of biogas (kg): This column represents the average amount of biogas produced (in kilograms) for each variant during the experiment or study. 8. Methane content (%): This column indicates the percentage of methane content in the biogas generated for each variant. Now, let's interpret the results for each variant: Variant 1: This variant includes pig manure, sweet sorghum waste, and does not include fruit marc or maize marc. It produced an average of 419 kg of biogas, with a methane content ranging from 53.0% to 58.0%. Variant 2: This variant includes pig manure, sweet sorghum waste, and fruit marc. It does not include maize marc. It produced an average of 590 kg of biogas, with a methane content ranging from 53.0% to 58.5%. Variant 3: This variant includes pig manure, fruit marc (in a ratio without specification), and maize marc. It does not include sweet sorghum waste. It produced an average of 514 kg of biogas, with a methane content ranging from 63.5% to 75.8%. Variant 4: This variant includes pig manure and maize marc. It does not include sweet sorghum waste or fruit marc (except for a 26% inclusion of fruit marc). It produced an average of 454 kg of biogas, with a methane content ranging from 67.9% to 78.1%. These results provide insights into different combinations of waste materials and their impact on biogas production and methane content

Research Finding

A. Optimal waste composition and Ratios:

- ❖ Identify the most suitable combination of agricultural waste materials and their proportion to achieve higher biogas yields.
- ❖ Determine the optimal carbon -to -nitrogen ratio to enhance the microbial degradation process.

B. Process optimization:

- ❖ Establish the optimal process parameters, such as temperatures, PH, and retention time, for maximizing biogas production efficiency
- ❖ Identify the key microbial groups responsible for biogas production under specific conditions.

C. Techno -Economic analysis:

- ❖ Assess the economic viability of the biggest production systems, including the payback period and return on investment.
- ❖ Quantify the potential revenue streams from electricity generation or other energy application.

D. Environmental Benefits:

- ❖ Quantify the reduction in green house gas emissions achieved through utilization of agricultural waste for Biogas production.
- ❖ Evaluate the improvement in waste management practices and their potential environmental and health implications.
- ❖ This Research strategies and findings provide valuable insight into the optimization, economics viability, and environmental benefits of Biogas production using the case of the Department of petroleum and Gas at IMO State Polytechnic. They contribute to the advancement of knowledge in this field and can guide future biogas projects and policies.

2.2 Research Methods and Their Results Concerning the Utilisation of Biogas

The Kinetic Reaction Engineering Laboratory at the Imo State Polytechnic, which is part of the Faculty of Engineering, was where we carried out our study at the institution. The purpose of the experiments on petrol engines was to get an understanding of the effects that biogases, which served as the various kinds of experimental variations, had on the functioning of petrol engines. The engine being tested is not a distinct biogas engine, but instead functions as a typical natural gas engine. The engine test rig's schematic is depicted in figure 1, which may be seen here. The following are the primary components of the testing engine:

- ❖ A petrol engine with a displacement of 24.6 kilowatts and four cylinders manufactured by Wisconsin Motors Continental.
- ❖ A fantastic Marelli CX IM B3 180M-type asynchronous dynamometer, which boasts an impressive capacity of 26.4 kW and is powered by 4 poles.
- ❖ Box that controls everything (with buttons for starting, changing modes, locking switches, etc.)
- ❖ Method of direction finding
- ❖ Analyzer of emitted gases
- ❖ a method for compiling and storing data

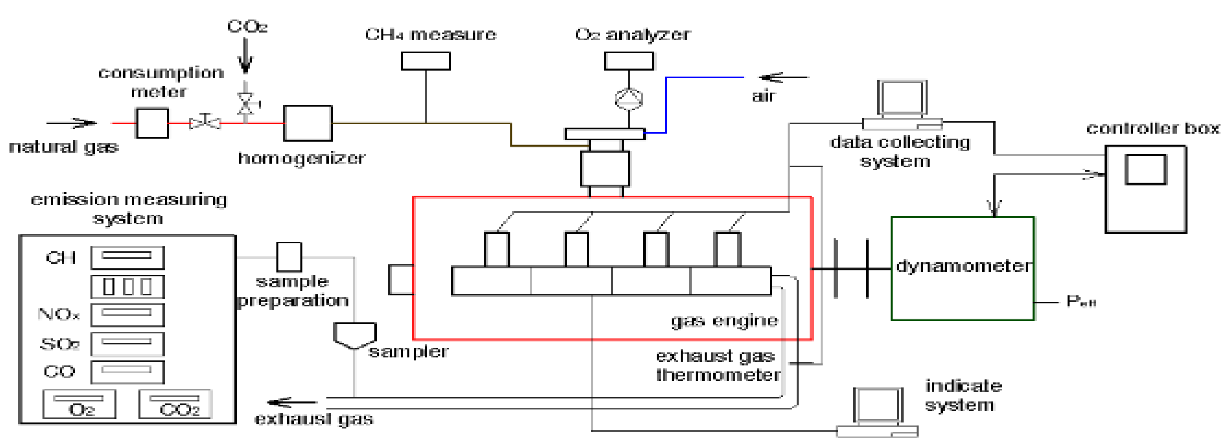


Figure 1
The engine test set-up

A wide range of tasks were undertaken during the research, including:

- The process of planning biogas utilisation testing and selecting an appropriate technological advancement.
- Performing biogas utilisation experiments with the hypothetical gas engine setup.
- Analysing the findings of the utilisation exams of the biogas.

In this process of selecting the appropriate fuel to run heat motor, we should keep in mind that the field of environmental science, which is multidisciplinary in nature, also covers some fields of energy. Internal combustion engines are one application for biogas. Our study aims to explore how biogases impact gas engine performance and identify biogases that are compatible with both engine operation and waste management.

We picked several ideal seeming biogases (Variants 1, 2, 3, 4) from the biogases produced for the trials based on yield and methane concentration. We represented the biogas composition using replacement gases (A dynamic mixture of natural gas and carbon dioxide that can be altered as needed). While natural gas primarily consists of 96% methane [21], biogases predominantly contain a mixture of methane and carbon dioxide, with a composition that can vary. In our engine laboratory experiments, we carefully crafted a gas mixture that closely resembled biogas in terms of its consistent composition. Testing this mixture was essential, as any fluctuations in composition would have made interpreting the results less reliable. It's worth noting that we didn't make any changes to the ignition timing and advance settings. Throughout our tests, we made sure to assess the engine's performance using different compositions of biogas to ensure its versatility.

The Scientific Base of the Research

The scientific bases of the study conducted at the petroleum and Gas department of IMO State University include:

- Anaerobic Digestion: The study based on the scientific principle of anaerobic digestion, a naturally occurring biological process where microorganisms break down organic matter in the absence of oxygen. This process produces biogas, primarily composed of methane and carbon dioxide, which can be utilized as a renewable energy source.
- Waste characterization and composition analysis: The scientific basic of the study lies in the characterization and composition analysis of agricultural waste materials. By analyzing the nutrients content, moisture contents, carbon to nitrogen ration, and other parameters, the study establishes the baseline for evaluating the energy potential and suitability of different waste materials for biogas production.
- Process optimization: the study focuses on optimizing the process parameters involved in biogas production such as temperatures, PH, retention time, and feedstocks composition. Through specific experimentation and analysis, the study aims to identify the optimal conditions that maximize biogas production efficiently.
- Microbial Ecology: the study recognized the critical role of microbial communities in the anaerobic digestion process. By examining the microbial dynamic within the biogas system, the research aims to understand the relationship between different microbial groups and their impact of biogas production. This scientific understanding help to guide process optimization and control strategies.
- Techno -Economics Analysis: The study incorporates a techno Economic analysis to evaluate the economic feasibility and viability of Biogas production. Through scientific calculation and financial assessment, the study assesses the potential profitability, return on investment, and cost effectiveness of implementing biogas production systems.
- Environmental impact Assessment: The study addresses the environmental impact of Biogas production, including greenhouse gas emissions and waste management practices.

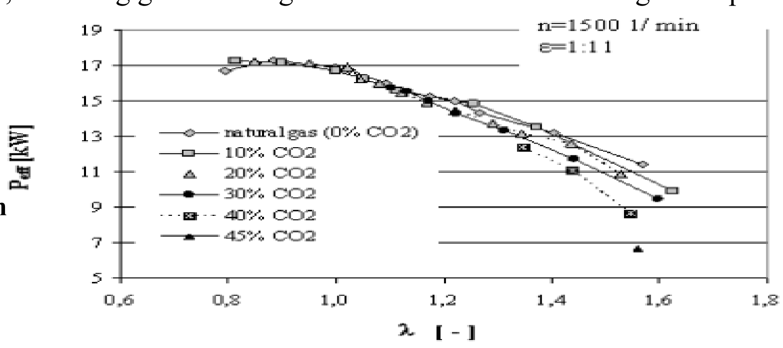


Figure 2: perform

Diagrams illustrating efficient operation are presented in Figure 2. When the engine is fueled with gas mixtures containing 10-20% carbon dioxide concentration and operates within an air access ratio range of 0.8-1.1, it delivers performance values that are practically equivalent to those achieved when using natural gas. If the engine is fueled with gas mixtures containing 30% carbon dioxide and operates with air access ratios within the range of 1.1-1.2, it can potentially achieve levels of efficient performance comparable to those typically observed in natural gas operations. However, opting for this approach will lead to an upsurge in gaseous consumption. As carbon dioxide levels increase, the efficiency coefficient value decreases to a point where it falls below that of natural gas. This phenomenon occurs specifically when air access is within the range of 1.2 and above. Furthermore, this drop in efficiency is directly linked to the methane concentration in the biogas. As the methane level diminishes, the effective performance values tend to decrease by approximately 10-15%. We delved deeply into explaining the inner workings of the engine. We also presented some fascinating discoveries from our measurements in Figures 3 through 6. These findings were carefully analyzed, focusing on energy generation and waste disposal. We found that when the air access ratio exceeds 1.1, the surplus air has a cooling effect that leads to reduced NOx emissions. You can see this visually in the following figure (Fig. 3). The engine operates while the carbon dioxide concentration in the gas mixture increases, leading to a decrease in methane content. This occurs due to delayed combustion and the cooling effect of carbon dioxide, resulting in a further reduction of methane content.

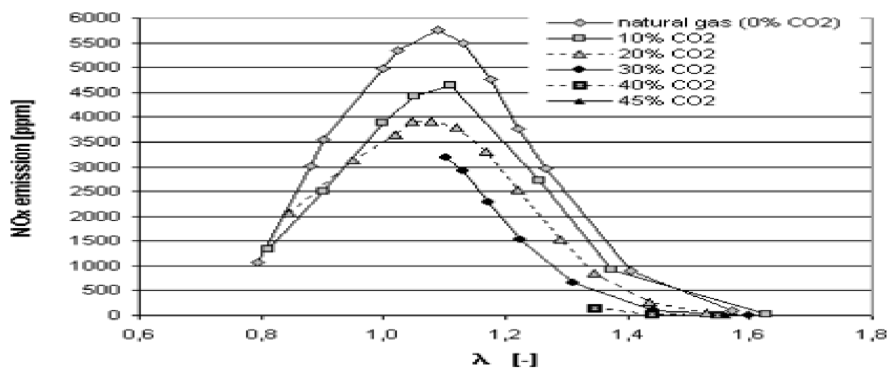


Figure 3: NOx emission.

When the methane level of the biogas decreases, the carbon dioxide content also decreases. This implies that a larger amount of biogas with lower methane concentration is needed to generate the same quantity of methane. Consequently, the injection of carbon dioxide into the engine along with the fuel increases, leading to a noticeable increase in CO_2 emissions in the exhaust flow. You can refer to Figure 4 for a visual representation of this phenomenon.

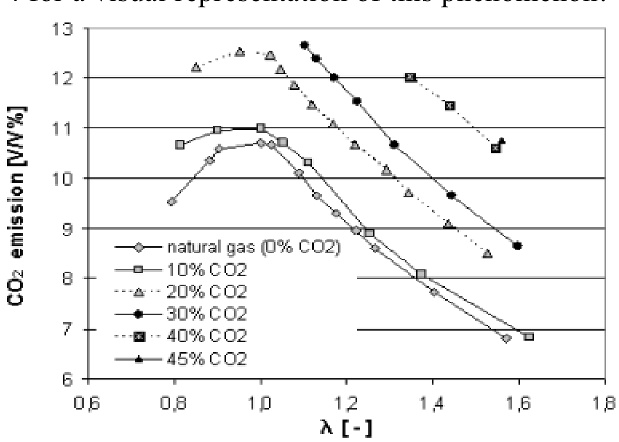


Figure 4:carbon dioxide emission

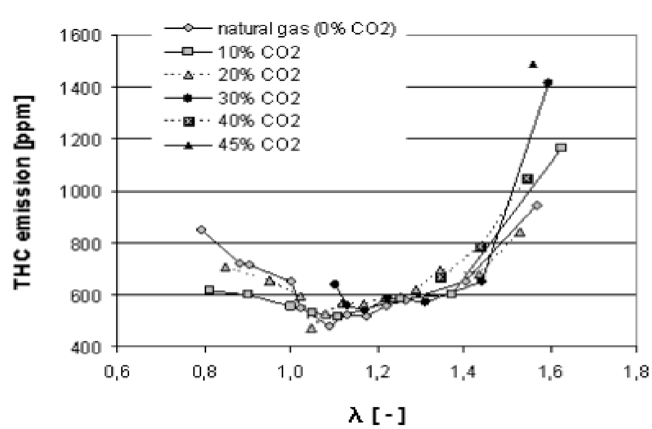


Figure 5:THC(Emission)

As the carbon dioxide component in the energy carrier increases, the conditions for combustion deteriorate, leading to a higher concentration of unburned hydrocarbons in the exhaust gas. Interestingly, when the air access ratio is within the range of 1.2-1.5, gas engines fueled by natural gas and gas mixtures with higher carbon monoxide content (and lower methane content) operate similarly, as shown in Figure 5.

The following figure (Fig. 6) illustrates a significant increase in CO emissions at an air access ratio of 1.0. This can be attributed to the generation of a richer mixture. However, CO emissions stabilize at considerably lower levels within the range of 1.1-1.4(1.5) air access ratios, regardless of the carbon-dioxide composition of the gas mixture. When the air access factor exceeds 1.4(1.5), the combustion process experiences increased drag, resulting in higher CO emission. Based on the findings, it is clear that when a typical gas engine operates using a gas mixture with low methane concentration, the CO emissions remain unaffected as long as the engine maintains a continuous air availability coefficient within the range of 1.1 to 1.4.

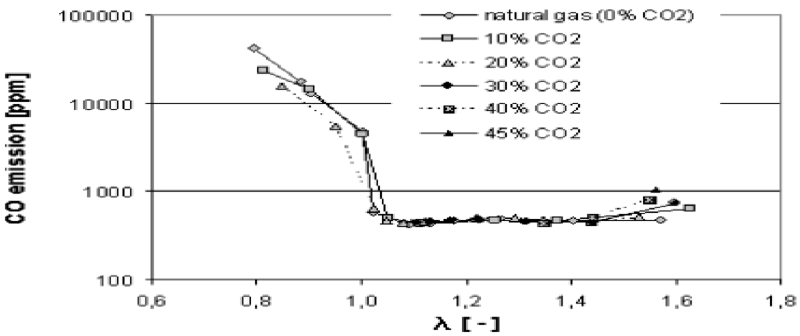


Figure 6:carbon dioxide emission.

After conducting extensive testing on biogases with different levels of methane, the research findings indicate that biogas containing 60-72% methane can be effectively used as fuel in a standard petrol engine due to notable improvements made. When the methane concentration in biogas decreases, it causes the operating temperature range of petrol engines to become narrower and shift towards a higher air access ratio (1.2-1.6). Consequently, the performance values decrease by around 10-15%, and there is a slight decrease in efficiency by approximately 2-4%. Emission studies have shown that when using the biogases produced from our versions, lower emissions are observed within the operating range of petrol engines, specifically between 1.2 and 1.6. Notably, there is a significant reduction of up to 20% in NOx emissions. However, it is worth mentioning that the levels of CO and THC emissions remain relatively unchanged. The increased CO_2 emissions can be attributed to the higher concentration of CO_2 in the biogas used, which is derived from biological sources.

After conducting extensive biogas utilization experiments, we have observed some remarkable and tangible outcomes. Here are the concrete results:

- By utilizing biogas with a methane content of 70% and maintaining an air access ratio within the range of 1.1-1.2, the engine can achieve performance levels comparable to natural gas operation, albeit with slightly higher gas consumption.
- Because of the effects of growing carbon-dioxide, the effective production and efficiency would fall dramatically at greater air access ratios.
- During the operation of petrol engines, when lean burn occurs, the higher concentration of CO_2 in different biogases leads to an increase in NOx emissions.
- The increased CO_2 emissions are due to the biogas's CO_2 concentration. CO and THC emissions, on the other hand, increase abruptly when there is little air access or when there is a substantial air surplus.
- By continuously operating within the range of air access ratios between 1.2 and 1.6, we observed a reduction in overall emissions.

3. Complex Waste Disposal And Energy Production

Here's a carefully fine-tuned version of your sentences: "In addition to energy, political, environmental, and competitive factors, rural development factors play a significant role in supporting the production and utilization of renewable energy sources. Therefore, our article presents research findings that can greatly assist in these domains, ensuring the efficient and effective operation of existing energy production facilities, as well as facilities dedicated to biogas production from waste. Our research's strength stems from successfully showcasing the significance of intricate ecological factors through rigorous biogas production trials and comprehensive testing. We even conducted experiments involving the use of biogas in petrol engines. Based on our study's findings, we can draw the following conclusions:

- By utilizing anaerobic fermentation of biomass derived from raw materials and plant-based additives, it is possible to produce a suitable quantity and high-quality biogas for powering petrol engines.
- By incorporating the mentioned modifications, it becomes feasible to create the perfect conditions for generating biogas, an exciting renewable energy source, right at the workshop level.

3.1 System for the Utilisation of Complex Biogas

We have created innovative solutions to establish a sophisticated biogas production and utilization system that achieves both energy and environmental objectives. Since the concept of advanced optimization primarily emphasizes environmentally sustainable energy utilization, it is crucial to analyze both goal functions simultaneously to achieve an optimal solution. In the event that the necessary input material for generating variations cannot be provided, there is a possibility of reduced energy production and compromised waste disposal. As an alternative agricultural system for an animal farm, we propose the method depicted in Figure 7.

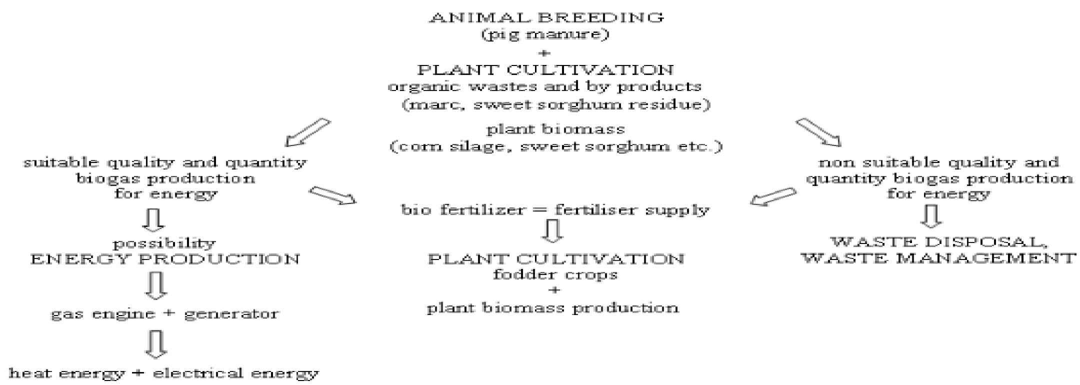


Figure 7:Biogas producing and utilization from farm mechanism.

At the core of this intricate system, we have incorporated integrated waste management and environmental energy utilization. This system brings numerous environmental benefits on both local and global scales, while also ensuring energy generation that remains unaffected by external factors. Additionally, it enhances the 'population retention capacity' in rural areas and provides a nearly perfect balance between ecological and economic considerations. Another noteworthy accomplishment is that it successfully operates as a closed-circuit system, meeting yet another important goal.

3.2 Real-World Implications and Applications of the Results

We made an estimate that a pig farm had a population of pigs ranging from 500 to 800. Consequently, the annual quantity of liquid pig manure produced is approximately 1277.5 tonnes. However, relying solely on pig manure is not enough to generate the required amount of biogas and fuel of high quality to meet the energy demands of the farm. Therefore, it is crucial to utilize a combination of agricultural by-products and wastes, as well as implementing a biomass plant. Because plants from biogas are always running, the yearly production cycle requires the incorporation of an organic matter source that boosts yield. During the process of developing the many experimental iterations, we made use of agricultural by-products and trash as organic additions. During the farm's selection process, they took into account multiple options for disposing of organic waste while also focusing on increasing biogas production, specifically methane generation. Table 2 provides the specific amounts of pig liquid manure and organic additions needed annually for growing the experimental varieties.

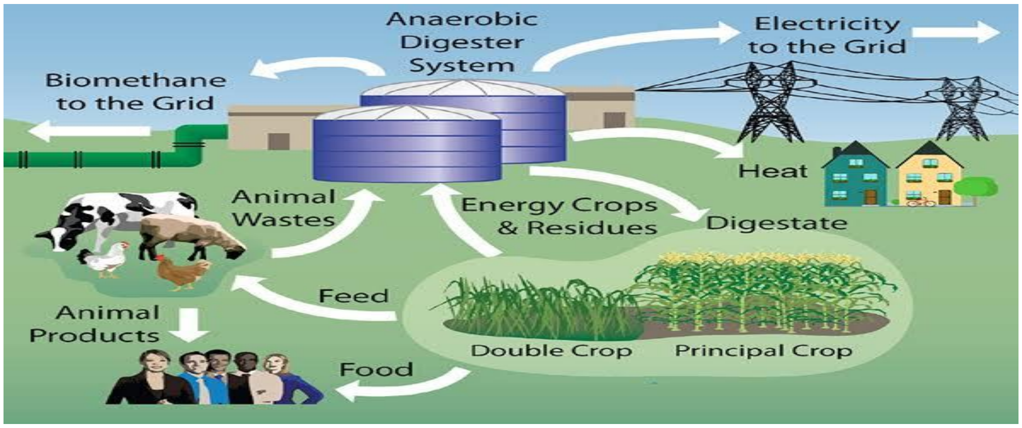
Table 2:Organic waste energy generation.

Energy production through organic waste.	Total of organic waste(year/ton)	Produce methane per average quantity.(day/m3)
Corn(silage)	25.66	-
Fruit(marc)	218	-
Manure(pig liquid)	1287.6	-
Mazie(marc)	44.8	-
Residue(sweet sorghum)	18.35	

180-250m3 biogas

Agricultural leftovers that have been kept in good condition can help maintain the functioning of the system because most of the natural leftovers on the list can be generated on a farm and are available even when it's not harvest season (from June to October). Other organic stuff, however, can be found in farmland or can be purchased from the booze business. On the basis of the aforementioned, it can be concluded that every organic material is capable of being degraded in a biogas plant, but owing to the specifics of biogas production, we should only take into account organic material for energy generation that degrades quickly and is readily available on the farm. The farm has a capacity of accommodating two fermenters, each with a combined volume of 115 m3 (7 m in diameter and 3 m in height). These fermenters have the ability to utilize up to 1600 tonnes of multi-component biomass annually, or approximately 2.22 kg of organic dry matter per m3 of fermenter. By considering the methane yield based on the dry matter content, we can determine the low heating value of the generated biogas. As the yield and methane ratio increase, both the biogas production and its methane content, which contribute to its energy value, also increase. Based on the given information, a daily production of 130.7 m3 of methane is observed. Methane, in its natural state, has a low heating value of 34.014 MJ/Nm3. In order to operate a Micro F22 AP type petrol engine, it requires an operating time of 18 hours with an engine loading of 86%. Additionally, it needs 130 m3 of methane per day (or alternatively, 170-250 m3 of biogas per day). Considering the efficiency of the machine units, which is 90%, it is capable of generating 27.3 kW of heat power and 14.5 kW of electric power. Moreover, it is worth mentioning that the farm and the fermenting system may require a small number of additional resources. Of the total energy produced, 30% is allocated for heating purposes, while a mere 5% is dedicated to generating electricity. Effectively utilizing excess heat has always been a challenge, but it can prove to be beneficial in various ways. During winter, the surplus heat can be utilized for heating, and in the summer, it can be used for drying crops like lucerne and/or grain. Additionally, any surplus electricity generated can be seamlessly integrated into the existing electric network. The farm can be energy independent in the best-case scenario, according to the information above. Fermentation waste, often known as "bio fertiliser," may provide the nutritional needs of sweet sorghum, maize and other feed. By harnessing the powerful nutrients, it contains, fermentation residue plays a vital role in enhancing the structure of the soil while ensuring we minimize waste. Utilizing fermentation residue helps uphold the natural cycle by managing and disposing of organic waste, all while promoting sustainable development. It's worth noting that the experimental variations in generating biogas with lower methane content further reinforce our commitment to sustainable practices. We are all aware of the environmental effects that pose a threat to our environment, and we are also aware that every person who bears responsibility for protecting it must take action ..

Fig 8: The potential for expanding sustainable biogas



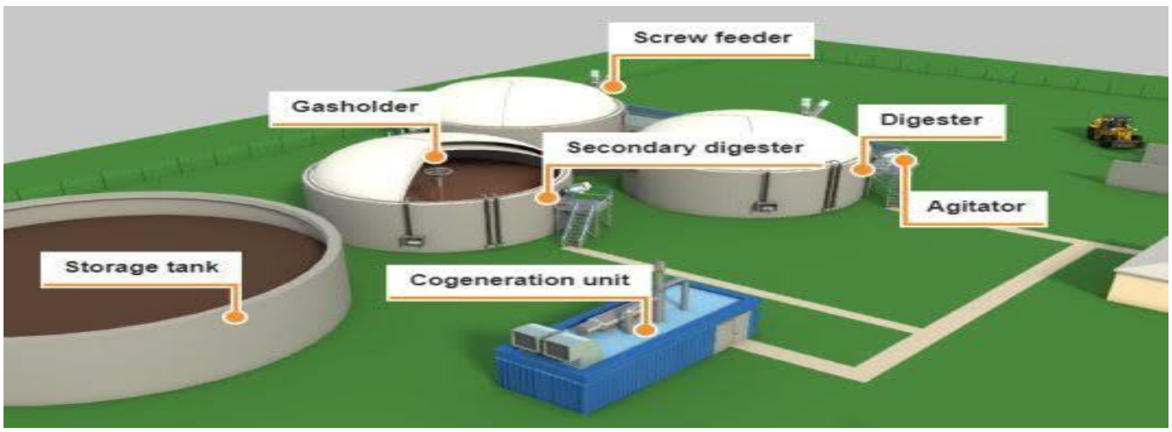


Fig 9: Biomass Energy Plant

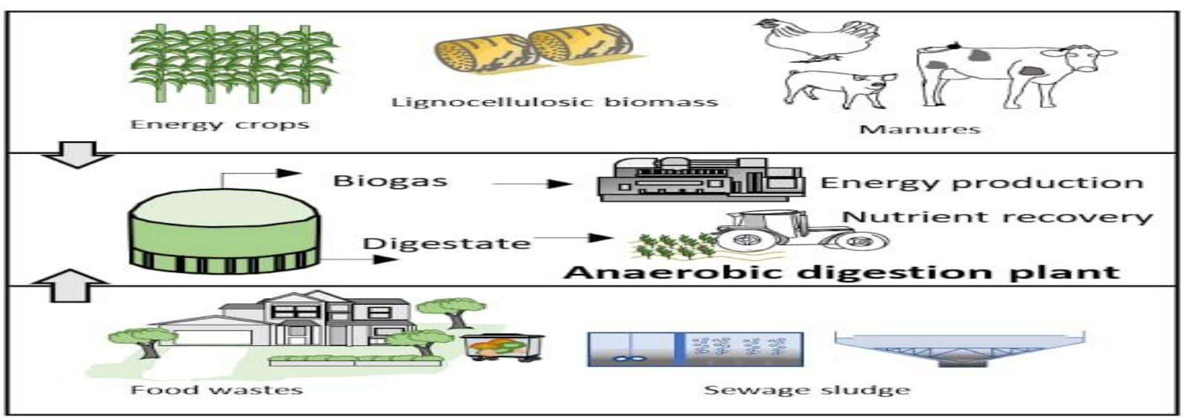


Fig 10: Anaerobic Co-digestion of WASTE

Conclusions

The development of experimental biogas modifications resulted in the creation of a sophisticated biogas production and utilisation system that allows for the simultaneous achievement of both energy and sustainable development goals because the implemented variants can facilitate the production and use of biogas. The biogas's methane concentration complies with the requirements for utilisation, enabling the heat engines to run well. Waste disposal is also possible at the same time. Understanding that the sophisticated optimisation principle only considers the environmentally friendly energy utilisation, it is required to study the production and utilisation functions jointly in the interest of a nearly optimum solution.

Hence, in cases where there is a shortage of sufficient input material or a decline in its quality needed for generating variations, not only can the energy production be negatively impacted, but it might also create obstacles in the proper disposal of waste.

Acknowledgment:
The Author Would Like to Express Their Deep Gratitude to Johnic Green Renewable Energy, A Division of Johnson Centre for African Scientific Research Library.

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