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Faculty of Tropical AgriSciences

Potential of Sugarcane Bagasse as Feedstock for Biogas Production in Nigeria

MASTER’S THESIS

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Declaration

I hereby declare that I have done this thesis entitled Potential of Sugarcane Bagasse as Feedstock for Biogas Production in Nigeria independently, all texts in this thesis are original, and all the sources have been quoted and acknowledged by means of complete references and according to Citation rules of the FTA.

In Prague, 2023

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Shobajo AbdulAzeez, BSc.

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Abstract

Sugarcane (*Saccharum officinarum*) was planted predominantly in Nigeria for the production of juice and animal feed. Nigeria is currently the second largest importer of sugar in Africa. The increase in sugarcane production has not been sufficient to meet the local demand for sugarcane products. Recent government interest in increasing the sugar sector and developing biofuels from indigenous feedstocks has prompted the growth of sugarcane production in Nigeria. Despite intentions to increase sugarcane production in Nigeria, there are no mechanisms in place to manage by-products such as bagasse. 1 tonne of sugarcane yields approximately 270 kilograms of bagasse. This suggests that if 50% of the demand for sugarcane production in Nigeria is met, the sugarcane bagasse would be a huge waste if no attempt is made to enrich it. The aim of this study was to determine the challenges faced by sugarcane farmers in Nigeria, identify the barriers to the adoption of biogas technology in Nigeria, and determine the optimal conditions for the anaerobic digestion of sugarcane. Questionnaires were used as a data collection method to provide valuable information on the experiences, perspectives and practices of 120 sugarcane farmers with respect to sugarcane production and biogas adoption. Two parallel batch anaerobic digestion (AD) experiments were conducted to determine the effect of different digestion strategies on the yield of biogas from sugarcane bagasse. Probit analysis was used to determine the factors that affect the willingness of a farmer to adopt a biogas system. The study findings indicate that age has a negative coefficient of -0.043, $p = 0.034$, indicating that older farmers are less willing to adopt biogas technology than younger farmers. As well, educational level has a positive coefficient of 1.150, $p < .001$, indicating that farmers with higher education levels are more willing to adopt biogas technology. The bagasse-cow manure assay produced a total of 6,360 ml of gas compared to only 5,542 ml produced by the bagasse-only assay. The study recommends that the government invests in the development of sugar processing infrastructures to improve the production of biogas. Public and private investments in the biogas sector should be encouraged and promoted to accelerate the adoption and utilisation of sugarcane bagasse as a feedstock for biogas.

Key words: Sugarcane, Bagasse, Biogas, Probit analysis, Nigeria.

Table of Contents

List of tables

List of figures

List of the abbreviations used in the thesis.

ABP	Anchor Borrowers Program
AD	Anaerobic Digestion
ANOVA	Analysis of Variance
BIP	Backward Integration Policy
CAES	Country Analysis Executive Summary
CBN	Central Bank of Nigeria
CM	Cow Manure
COP	Conference of Parties 21
CREN	Council for Renewable Energy, Nigeria
ECN	Energy Commission of Nigeria
EESI	Environmental and Energy Study Institute
FAO	Food and Agriculture Organization of the United Nations
FAOSTAT	Food and Agriculture Organization of the United Nations Statistics
GW	Gigawatts
IEA	International Energy Agency
JICA	Japan International Cooperation Agency
LNG	Liquefied Natural Gas
ML	Maximum Likelihood
MS	Mean Square
MTOE	Million Tons of Oil Equivalent.
MW	Megawatts
NSDC	National Sugar development Council
ORP	Oxidation Reduction Potential
RNG	Renewable Natural Gas
SB	Sugarcane Bagasse

SPSS	Statistical Package for the Social Sciences
SS	Sum of Squares
TS	Total Solid
TV	Television
UN	United Nations
UNFPA	United Nations Population Fund
US	United States
USA	United States of America
VS	Volatile Solid
WBA	World Bioenergy Association

1. Introduction

Sustainable development is currently one of the main catchphrases in contemporary development discourse between developed and developing countries. During the industrial revolution, most developed countries focused more on their economic growth, neglecting the imperatives of environmental protection. The term: Sustainable development means using the available resources without jeopardising the well-being of future generations.

At the United Nations Climate Change Conference (COP 21) 2015, held in Paris, member countries of the United Nations set their objective to reduce their carbon emissions by 30% by 2030 compared to those of 1990, and to reach carbon neutrality in 2100 (United Nations 2015).

Energy plays a very important role in economic growth, development, and alleviation of poverty in a nation. The inadequacy of energy supply limits economic growth, restricts socioeconomic activities, and adversely affects quality of life. The standard of living of a given country can be directly related to the per capita energy consumption (Meisen and Akin, 2008) Sources of energy take different forms, including energy from electricity, nuclear energy, water, wind energy and the Sun, in the form of fuelwood, coal, and petroleum, to mention a few.

As the effects of climate change, global warming, and other environmental phenomena are becoming more alarming, there is a paradigm shift toward the use of low carbon (Li et al. 2020) and renewable forms of energy. According to Statista, 2022, China tops the list of countries that use the most renewable energy, followed by the USA, Brazil, and India with 1,020 GW, 325 GW, 160 GW, and 147 GW installed renewable energy capacity, respectively in the year 2021.

Access to modern clean energy sources is an enormous challenge facing the African continent (Muhirwa F. et al, 2023). Like other African countries, where only about 36% of the population has access to electricity (Knee, A. 2007), electricity deficit is one of the greatest challenges facing Nigeria as a nation. Nigeria is the largest oil producer in Africa and has the largest natural gas reserves on the continent (CAES, 2020). It was the world's fourth leading exporter of liquefied natural gas (LNG) in 2012. In the present predicament as a nation, it is obvious that relying mainly on fossil fuel (petroleum) is not enough to meet the energy needs of the country (Oyedepo, S, 2012).

Nigeria is blessed with abundant renewable energy resources such as hydroelectric, solar, wind, tidal, and biomass. However, it seems that Nigeria has not taken advantage of her endowed renewable energy resources to generate electricity to solve the problem of an ongoing power outage in the country (Oke 2016). This stable electricity deficit in Nigeria has impeded the economic growth of the nation (Aderoju et al. 2017). Nigeria generates approximately 4000 MW of electricity, which is not adequate for its population of more than 206.14 million energy demands. The Council for Renewable Energy of Nigeria estimates that power outages caused a loss of 126 billion naira (US$ 984.38 million) annually (CREN 2009).

In addition to the huge income loss, it has also resulted in health hazards due to exposure to carbon emissions caused by the constant use of 'backyard generators' in different households and business enterprises, unemployment, and a high cost of living that leads to deterioration of living conditions (Oyedepo, 2012). Thus, the need to meet these rising demands justifies the adoption of other renewable energy alternatives, among which is biogas production.

Biogas is a non-toxic, colorless, combustible gas that is produced by the anaerobic decomposition of organic waste. It is mostly made up of methane (CH_4) and carbon dioxide (CO_2), with 1–5% of other gases, such as hydrogen, also being present.

The composition of biogas is heavily influenced by the substrate utilized in its production. Biogas is approximately 20% lighter than air. It produces no smoke and is nontoxic. Similarly to liquefied petroleum gas (LPG), it is an odorless, colorless gas that burns with a bright blue flame (Karki et al., 2005). This gas can either be used for cooking or transformed into energy. It can also be used in automobiles by operating the engine in dual-fuel mode with biogas as the primary fuel and gasoline and diesel as the secondary fuels. Using generators, biogas can be transformed into power. Gas is converted to electricity by generators, which can then be provided accordingly (Akhil et al., 2017). The biogas is derived from organic elements, including human waste, biomass, animal manure, green waste, and agricultural residues such as sugar cane bagasse.

2. Literature Review

2.1. Geographical Description of Nigeria

Nigeria is in West Africa between the latitudes of 3°15' and 13°30' North and the longitudes of 2'59' and 15'00' East. Because of its location in the tropics, the weather there is typically quite humid and features wet and dry seasons. In the west, Nigeria has a land border with the Republic of Benin; in the east, it has land borders with Cameroon and Chad; and in the north, it has a land border with Niger. The Gulf of Guinea forms its southernmost border and encircles the country. Figure 1 illustrates the location as well as the borders of the area.

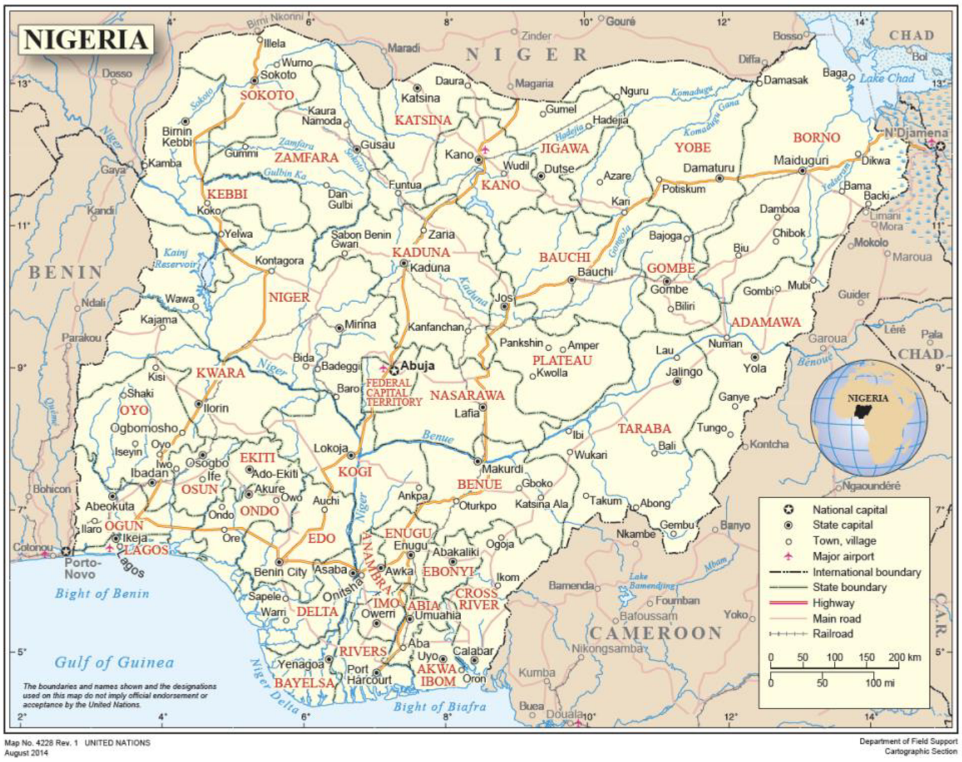


Figure 1. Map of Nigeria showing boundaries and location based on the UN map (UN, 2019).

Nigeria has a population of over 200 million people and a land area of approximately 920,000 km2. It is the seventh-largest population in the world and the largest in Africa. According to Sambo, 2011, Nigeria's population will reach 352,67 million by 2030, with a 4% growth rate. Table 1 displays the predicted population growth rate, the proportion of urban residents, and the number of individuals per family.

Nigeria has an abundance of natural resources. Despite these riches, the lack of access to electrical power has impeded the country's development. There is a strong association between socioeconomic growth and access to electricity (Piebalgs, 2007). Incorporating renewable energy into the national energy mix allows for the electrification of rural communities and islands. This will lower domestic consumption and preserve petroleum resources for continued export to generate foreign currency earnings.

2.2. Nigeria Sugarcane Bagasse index and Farms

Sugarcane is a major cash crop in Nigeria, having a long history of production dating back to the colonial era (Adamu, 2002). The crop is primarily used for sugar manufacture and ethanol fuel. Sugarcane production is largely concentrated in the country's north and south, with Kebbi, Katsina, Jigawa, and Sokoto states producing the most in the north and Lagos, Ogun, and Oyo states producing the most in the south.

Despite Nigeria's tremendous sugarcane production potential, the country has failed to reach the crop's full potential due to a variety of problems. Inadequate infrastructure, poor farming techniques, and lack of capita are among the issues (Wada et al, 2007). The absence of suitable infrastructure is a key factor impacting sugarcane production in Nigeria. Sugarcane production, harvesting, and transportation need specific infrastructure. Unfortunately, many sugarcane farmers in Nigeria lack access to sophisticated cultivation and harvesting equipment and facilities (Wada et al, 2007). This makes increasing yields and improving production difficult for them.

As well, many Nigerian sugarcane farmers still use traditional farming practices such as hand tilling and harvesting. These methods are inefficient and time-consuming, and they limit farmers' ability to produce sugarcane. Farmers in some areas may face challenges in accessing modern agricultural inputs, credit, and markets, which can limit their ability to improve their sugarcane output and earn a livelihood from their harvests.

Notwithstanding these obstacles, there have been some encouraging advancements in Nigeria's sugarcane business in recent years. The Nigerian Sugar Master Plan and the Backward Integration Policy (BIP) (NSDC, 2012) in the sugar sector are two efforts initiated by the federal government to increase sugarcane output in the country. Furthermore, private corporations such as Dangote Sugar Refinery and BUA Group have engaged in Nigeria's sugarcane industry. These corporations have constructed large-scale sugarcane fields and advanced processing facilities, resulting in employment creation and a market for local farmers.

In addition, the government has put in place several laws and initiatives to assist sugarcane producers in the North. The Central Bank of Nigeria (CBN), for example, has launched the Anchor Borrowers' Program (ABP) (CBN, 2015), which offers financial assistance to small-scale sugarcane producers in the region. The initiative offers farmers discounted loans, fertilizers, and other supplies, making it simpler for them to invest in their crops.

There is a huge potential for the cultivation of sugarcane on a large scale in the country, particularly along the entire length and breadth of the Niger and Benue rivers. On an area of around 89,000 hectares, almost 1.5 million tons of sugarcane are harvested (FAOSTAT, 2019). Thus, over 800,000 ha of land could support high yield sugar cane production in Nigeria. The creation of or the construction of partnerships with local businesses to stop negative impacts on good markets and building local supports for the long-term development of the sugar cane industry is being pursued to increase sugar cane productivity.

2.3. The Situation of Energy in Nigeria

Traditional and alternative forms of energy are abundant in Nigeria. It is estimated that there are 166 trillion standard cubic feet (scf) of natural gas and up to 36.2 billion barrels of crude oil in the world's reserves now (Akuru et al., 2011, PwC, 2019). There are up to 2.7 billion tons of coal and lignite deposits and roughly 31 billion barrels of oil equivalent in tar sands (Oyedepo, 2012). Nigeria has a lot of fossil resources, but getting your hands on them may be difficult and unpredictable (Naibbi, 2013). Because of the scarcity and insufficiency of fossil fuels, the demand for energy has been artificially lowered, and switching to renewable sources of power might be a key part of the solution.

Renewable energy sources in the country include solar radiation with insolation between 3.5 and 7 kWh/m2/day, wind with speeds up to 4 m/s at 10 meters, and biomass from many different sources (Naibbi, 2013). The energy needs of Nigeria may be met year-round by renewable sources (Ezema et al., 2016, Ojolo et al. 2012). Nigeria has the capacity to generate 600,000 MW of solar power from just 1% of its land mass, 14,750 MW of hydroelectric power, and 77.8% of its total land mass is suitable for biomass energy (Okeke, 2016).

The population growth in Nigeria is expected to continue steadily over time. As a result, there will be a higher need for accessible energy. Table 2 shows a forecast of Nigeria's energy demand in the next few years. Energy consumption might reach 250.84 MTOE by 2030, (Ojolo et al., 2012), with the industrial sector experiencing the greatest increase. By 2030, demand might be anywhere from 224.54 MTOE to 747.27 MTOE (Sambo, 2011), depending on the rate of expansion in the specified industries. According to (JICA, 2019), forecasts put 2030 energy consumption at 138.84 MTOE.

The country's energy needs are greater than what can be met by domestic production. It is estimated that Nigerians used roughly 27.91 TWh (2.4 MTOE) of energy (IEA, 2019). This only meets a tiny fraction of the required energy, 2.2%. It has been noted that a big chunk of the nation is currently without access to electricity. Between sixty and seventy percent of the Nigerian population does not have access to modern power (Oyedepo, 2013). Since many rural areas still lack access to reliable energy service, they are frequently hit the hardest. Power Resources supplied to energy-accessible regions is insufficient and unreliable, resulting in a significant demand-supply mismatch. As well, the electricity given to the industrial sector is insufficient, prompting businesses to look into other, privately arranged methods of power generation (Oyedepo, 2013). Some academics have proposed utilizing renewable energy to power homes and businesses independently from the grid (Ezema et al., 2016, Akhator, 2019, Maren, 2013). This will guarantee that people in the country's outlying regions have reliable access to power.

According to Maren et al., 2013, Nigeria as a country is wasting its renewable energy potential by relying too much on oil and gas. Although biomass is not widely employed for electricity production, it is thought to predominate in the primary energy mix due to a combination of causes including poverty, a lack of simple access to commercial energy sources, and cultural considerations (Sa’ad et al., 2016, Sokan-Adeaga et al., 2015).

Primary energy demand in Nigeria as of 2018 was biofuels and waste (114.02 MTOE) as the most abundant source of energy within the energy mix, followed by oil (26.31 MTOE), gas (14.92 MTOE), hydro (0.55 MTOE), and coal (0.02 MTOE) (IEA, 2018). The percentages of energy generated from solar photovoltaics and other low-carbon sources were negligible. According to Sa'ad and Bugaje, 2016, There is a negative relationship between Nigerians' use of biomass fuel and their actual earnings, even though poverty is positively connected with biomass use.

2.4. Biogas Technology

Biogas is produced by anaerobic digestion, a process that decomposes organic matter, using a set of microorganisms under anaerobic conditions, to produce biogas and digestate (Yang et al. 2015). According to Sosnowski, Wieczorek, and Ledakowicz (2003) and Schnürer and Jarvis (2010), anaerobic digestion is a set of biological processes in which microbes break down biodegradable material without the presence of oxygen.

Biogas, which is made primarily of methane and carbon dioxide, is the main output of AD (Nijaguna 2002; Sajeena, Jose, and Madhu, 2014; Tengku *et al.,* 2014). Anaerobic digestion technology is a biochemical process used for the biological treatment of waste that produces sustainable energy and reduces greenhouse gas emissions (Almomani and Bhosale 2020).

One of the most innovative methods of agricultural management is the production of biogas through the biomass anaerobic digestion process, as it can recycle nutrients and energy while also reducing pollution (Al Seadi et al. 2008; Agbor et al. 2011; Adekunle and Okolie 2015). Biomass is an organic material that has been photosynthesised to store energy. It is present in plants and can spread to animals through the food chain (Petrov, Bi, and Lau 2017). Given that energy crop farming is likely to compete with food production for land, water, and nutrients, the availability of biomass sources to produce biomass fuels on a commercial scale is of great concern without compromising food security (Ertem, Neubauer, and Junne 2017; Lijó et al. 2017; Petrov, Bi, and Lau 2017).

Thus, agricultural crop waste is frequently used as a source of biomass fuels to address food security (Cheng 2017).

Agriculture, forestry, and the organic part of municipal solid waste constituted 10, 87, and 3% of the biomass supplied, respectively (WBA, 2017) Biogas can be used to generate energy, heat, and power engines, fuel cells, and micro-turbines. It can also be converted into biomethane, which is known as Renewable Natural Gas (RNG) and used in the transportation sector or put into the gas system (EESI, 2021).

Various types of anaerobic digesters have been devised, built, and utilized for biogas production, but regardless of the digester type used, there is a need to thoroughly monitor the performance of the configuration in use to avoid any unexpected changes that may occur during the process. Temperature, hydraulic retention duration, pH, total solids, volatile fatty acids, volatile solids, organic loading rate, shear stress, and catalysts can all have a negative impact on the process if not properly regulated.

To have a good biogas production process and yield, a correct range of these parameters must be set during the biogas production process (Ghasemi et al. 2018). The optimal temperature ranges for anaerobic digestion are mesophilic (35–40 °C) and thermophilic (55–60 °C). Most anaerobic digestion plants throughout the world run in the mesophilic temperature range since the heat required to maintain that temperature is low and the process is very stable in this temperature range.

Thermophilic plants, on the other hand, need more heat and attention to operate, but they are required when digestion needs to be accelerated, resulting in improved biogas outputs and decreased pathogens in effluent slurry (WBA, 2021). The four biological and chemical processes of anaerobic digestion are hydrolysis, acidogenesis, acetogenesis, and methanogenesis (Fig. 3).

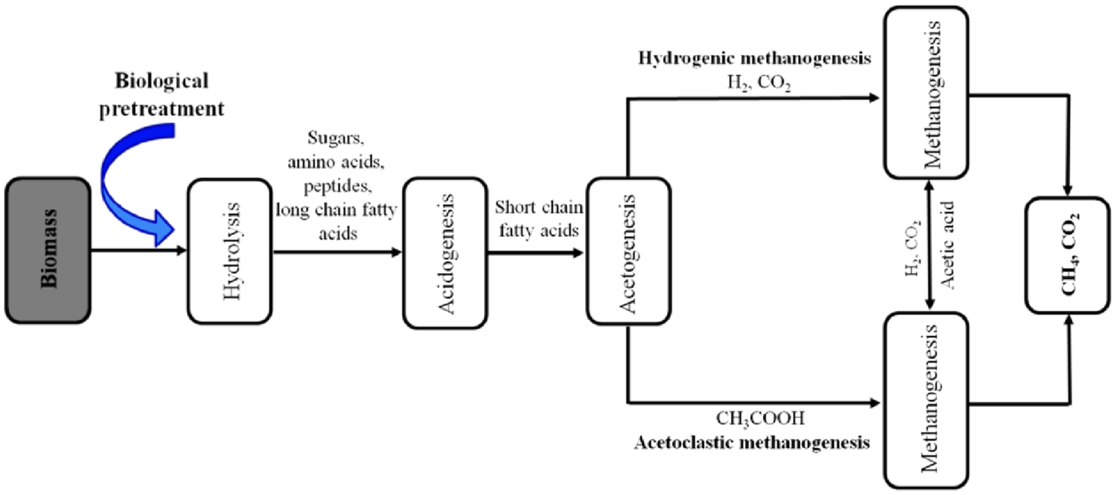


Figure 2. A flowchart showing the biological stages of anaerobic digestion (Olatunji et al., 2021)

Sugars, amino acids, and fatty acids are broken down from larger organic polymers like those found in biomass during the hydrolysis process. The hydrolysis of complex organic materials into soluble molecules by the catalytic action of fermentative bacteria is a rate-limiting phase that ultimately decides the biodigestion of the feedstock. The byproducts of hydrolysis include hydrogen and acetate, both of which are used by methanogens in the later step of the process, but some of the molecules may still be rather big and require additional breakdown during acidogenesis before they can be used in methane synthesis (Raja, 2017). Acidogenesis is the next step in anaerobic digestion, after hydrolysis. Acidogenic bacteria further decompose the feedstock. By breaking down organic matter, these fermentative bacteria create an acidic environment in the reactor and release NH3, CO2, H2, H2S, organic acids, and shorter volatile acids, as well as a small number of additional by-products. Butyric acid, acetic acid, propionic acid, etc. are some of the major acids produced at this step. During the process of anaerobic digestion, microorganisms known as acetogens convert carbon and energy sources into acetate, a derivative of acetic acid.

During the methane generation process, acetogens catabolize part of the acidogenesis stage products into acetic acid, CO2, and H2. Methanogenesis, the final stage of anaerobic digestion, involves the conversion of acetogenesis byproducts into methane. Methanogenesis has two broad routes that utilize acetic acid and carbon dioxide, the two principal products of the first three stages. With this process, carbon dioxide (CO2) can be converted into methane (CH_4) and water (H_2O), while acetic acid serves as the primary mechanism for methane release during methanogenesis, resulting in the release of methane and carbon dioxide (the two primary products of anaerobic digestion) (Raja, 2017).

2.5. Potential for Nigeria's biogas technology

Due to Nigeria's high population and 2.8% annual growth rate (Aliyu A. and Amadu L., 2017), huge amounts of waste are inevitably produced daily without an effective waste management system. Furthermore, due to the diverse livestock farming in Nigeria, the accumulated waste from the slaughter slabs contributes significantly to the possible hazards of foodborne diseases and has adverse effects on air quality, agriculture, potable water and aquatic life (Adeyemi et al., 2007). As these wastes are not properly maintained, the resulting emission of methane (CH_4) from manure, untreated organic waste and wastewater becomes toxic to the environment.

Meanwhile, this abundant waste generated daily can be utilised as energy resources for providing adequate energy to citizens through the adoption of biogas technology. Other feedstock substrates identified for an economically feasible biogas programme in Nigeria include sugarcane bagasse, water lettuce, water hyacinth, dung, cassava leaves, urban refuse, solid waste (including industrial) waste, agricultural residues and sewage.

2.6. Background of biogas technology in Nigeria

The status of biogas technology in Nigeria remains blemishes. At inception in the 1980s, the first record of a biogas plant was a 425 litres daily producing plant built at Usman Danfodiyo University, Sokoto. Since then, the adoption and operation of biogas technology in Nigeria is still in the developing stage. Some of the factors that hinder the development of the biogas system in Nigeria could be caused by unfavourable government policies, inadequate technology funding, and individual unwillingness.

Some biogas projects that have been executed in Nigeria include the construction of biogas plants at Zaria Prison in Kaduna, Ojokoro in Lagos, Mayflower School Ikene in Ogun State, and a biogas plant at Usman Danfodiyo University in Sokoto (Adeyanju

2008; Igoni et al. 2008) The digester capacity is between 10 and 20 m^3. A critical assessment of these plants has revealed that they are yet to be commercialized or non-operational.

2.7. Biogas as a sustainable alternative to fossil fuel

According to Bond and Templeton (2011), biomass consisting mostly of carbohydrates, proteins, lipids, cellulose, and hemicellulose can be used as feedstock for the production of biogas. However, certain factors, such as the chemical and physical form of biomass, affect the biodegradability of the feedstock (Lee, 2007). Depending on the organic content, the amount and quality of methane produced differ from one feedstock to another (Hagos et al., 2017). The methane content of biogas reflects its energy value; therefore, the quality of a selected feedstock is significant in terms of the biogas generated. Low biogas production can indicate a low methane concentration, indicating a low energy value (Nnfcc, 2016).

Before selecting a feedstock for biogas, there are certain factors that must be considered. These include:

1. The feedstock must be available in sufficient quantities for the biogas plant to be economically viable over a 10- to 20-year period (Nnfcc, 2016)
2. The feedstock must have satisfied the theoretical methane production potential test (Biswas et al., 2007).
3. The feed stock should be fresh and have a sufficient moisture content. Feedstock that has been exposed to the sun for an extended period can become useless due to moisture loss (Nnfcc, 2016, Dussadee, et al., 2016)
4. For optimal biogas generation, the carbohydrate percentage of the feedstock should be within the permissible range (Jørgensen, 2009), otherwise co-digestion should be explored. According to reports, if the feedstock is mostly composed of carbohydrates such as cellulose and hemicellulose, the methane production will be poor (Sridevi et al., 2012).
5. The feedstock must have satisfied the theoretical methane production potential test (Biswas et al., 2007).

2.8. Sugarcane Bagasse as a feedstock for Biogas

Sugarcane is a C4 plant with a high photosynthetic rate (Bezerra and Ragauskas, 2016). Sugarcane has a bio-conversion rate that is 150% to 200% higher than the typical plant (Gutiérrez et al., 2018). As a result, sugarcane leftovers have the potential to be transformed into biomass fuels (Souza et al. 2018). According to data from 2019, worldwide sugarcane cultivation was 1949.3 million tonnes, with Brazil accounting for 38.6% of total production, followed by India (20.8%), China (5.6%), Thailand (5.4%) and Pakistan 3.4% (FAO, 2021). Approximately 79% of sugarcane is used in the sugar industry for sugar production, with the remainder staying in the fields (Meghana and Shastri, 2020).

Bagasse is produced as a residue with a moisture percentage of 45-50% during the sugarcane juice extraction process. Bagasse is a lignocellulosic biomass with 42-46% cellulose, 23% hemicellulose, and 21-26% lignin. Bagasse had 44.0-49.2% carbon, 43.0-44.7% oxygen, 4.7-6.5% hydrogen, 0.2-0.4% nitrogen, 0.1-0.4% sulphur, and 2.7-3.1% ash, according to elemental analysis (Mohammadi et al., 2020; Sharma et al., 2018; Shukla and Kumar, 017). Pretreatment and hydrolysis can transform cellulose and hemicellulose, which have a lengthy chain of sugar monomers, into bioenergy [38]. The major ingredient in bagasse is xylose. Xylose (C5H10O5) is a monosaccharide produced by hydrolysis of hemicellulose in the form of xylan. Xylose is also known as wood sugar because it is found in hemicellulose, which is found in wood.

Around 60% of bagasse is estimated to be used in the boilers of sugar mills and related distilleries, while the rest is used in paper mills, animal feed, soil amendment, and other applications that can be improved (Sharma et al., 2018). Although burning bagasse in boilers is one of the best options, the production of ash in boilers and the incomplete combustion of biomass emit pollutants such as carbon monoxide, methane, nitrogen oxides, benzene, formaldehyde, aromatics, and respirable particulate matter, which causes fouling/scaling/corrosion of heat transfer surfaces and has a negative impact on human health and the environment (Prasara et al., 2019). The conversion of bagasse to biogas using anaerobic processes will eliminate the primary issues related to its combustion.

2.9. Characteristics of Bagasse as a suitable biogas feedstock

The complex and resistant nature of bagasse restricts access to microbes and their enzymes. As a result, pretreatment is required to relax the structure and partially remove hemicelluloses and lignin, improving the accessibility of microorganisms and their enzymes for cellulose hydrolysis (Zheng et al., 2014). For bagasse pretreatment, there are numerous physical, chemical, and biological methods available, each with its own set of advantages and disadvantages (Ghosh et al., 2020; Vats et al., 2019a).

2.10. Pretreatment of Sugarcane Bagasse for Biogas Production

The biodegradability of a lignocellulose feedstock depends on a number of characteristics, including its lignin content, crystallinity, polymerization grade, surface area, solubility and their own active enzymes (Yang et al, 2011; Cheah et al, 2020). Researchers have examined a variety of pretreatment methods to improve biodigestion of lignocellulosic feedstock and boost methane output. Pretreatment techniques are chosen based on the physicochemical qualities and structural arrangement of the feedstock, with the goal of enhancing the creation of organic feedstock while still preserving the matter in the process. In general, the objectives of pretreatments are:

1. to increase the approachability of the enzymes to the cellulose and hemicelluloses and lead to degradation of the feedstock.
2. avoid degradation or carbohydrates loss.
3. eliminate the release of possible inhibitors.
4. be economical, and
5. reduce the possible impact on the environment (Taherzadeh et al., 2008)

The pretreatment of bagasse using physical, chemical, or biological approaches to increase digestibility for biogas generation has been thoroughly explored (Abraham et al., 2020). Researchers worldwide are developing bagasse pretreatment techniques to improve biomethanation (Kataria et al., 2017; Nitsos et al., 2018). Some of the pretreatment techniques for Bagasse to improve biogas generation are acid, alkali, steam explosion, and hydrothermal.

Acid treatment breaks biomass bonding (hydrogen bond, covalent bond, and van der Waals forces) and releases hemicellulose-rich fractions. This process solubilises hemicelluloses and precipitates soluble lignin, making cellulose more degradable (Abraham et al., 2020). This creates enzyme inhibitors. In various loading circumstances, biomass reacts with alkali (NaOH, KOH, Na_2CO_3, $Ca(OH)_2$).

Alkali pretreatment weakens hydrogen bonding between cellulose and hemicelluloses and ester bonding between lignin and saponified hemicelluloses by hydroxyl ions. Depolymerisation and lignin modification produce a dense cellulosic fibre. The porosity of the material increases the enzymatic surface area (Bolado-Rodríguez et al., 2016; Nosratpour et al., 2018; Talha et al., 2016).

The steam explosion removes hemicelluloses and modifies the lignin for the generation of biofuels. Saturated high-pressure steam pretreats biomass. Then, abrupt depressurised cooling explodes biomass water, depolymerising lignin, and exploding cellulose fibrils. Acetic acid and other organic acid derivatives hydrolyse hemicelluloses and autohydrolyse biomass components (Kumar et al., 2020).

Hydrothermal pretreatment involves the incubation of biomass with high-pressure water. Acetate and its derivatives are formed when subcritical water dissolves the acetyl group of hemicellulose. These catalysts speed up the process. Reduced sugar unit polymerisation makes it more suitable for bacterial action (Costa et al., 2014; Mustafa et al., 2018; Nosratpour et al., 2018).

3. Aims of the Thesis

The aims and objectives of this research are to:

1. Determine the challenges faced by Sugarcane farmers in Nigeria.
2. Determine the proximate composition of the Sugarcane Bagasse
3. Produce biogas by anaerobic co-digestion of sugarcane bagasse with cow dung.
4. Determine the cumulative volume of biogas produced.
5. Identify the impediments to the adoption of biogas technology in Nigeria.

3.1. Research Questions

1. What is the potential of sugarcane bagasse as a feedstock for biogas production in Nigeria?
2. What are the optimal conditions for enzymatic hydrolysis of sugarcane bagasse?
3. What is the effect of different digestion strategies on the yield of biogas from sugarcane bagasse?
4. What are the perception, challenges, and factors influencing the use of Sugarcane bagasse as a feedstock for biogas production in Nigeria?

3.2. Research Hypothesis

Null Hypothesis (H0), Alternative Hypothesis (Ha):

H0: The fermentation strategy does not affect the yield of biogas from sugarcane bagasse.

Ha: The fermentation strategy affects the yield of biogas from sugarcane bagasse.

H0: Demographic variables, perception, challenges, and factors influencing the use of Sugarcane do not have predictive relationship with willingness to adopt biogas among Farmers in Nigeria.

Ha: Demographic variables, perception, challenges, and factors influencing the use of Sugarcane have predictive relationship with willingness to adopt biogas among Farmers in Nigeria.

4. Methods

4.1. Study Area

The sugarcane bagasse for this study was obtained from sugarcane farms in Oyo State, Nigeria. Nigeria has a population of 216,735,601 in 2022 based on projections of the latest United Nations data. The number of households in Nigeria reached 43.0 million in 2020 in Nigeria, according to the National Statistical Office. This is 2.52% higher than in the previous year. Nigeria ranks seventh on the list of countries (and dependencies) by population. The population density in Nigeria is 226 per km^2 (586 people per mi^2). The total land area is 910,770 km^2 (351,650 sq. miles). 52.0 % of the population is urban (107,112,526 people in 2020) (UNFPA – Nigeria 2022).

Oyo state is predominantly an agricultural area whose main cash crops are cocoa, timber, oil palm, and kolanuts. The food crops grown are cassava, yam, cocoyam, and grain crops such as maize and rice. The state has two main seasons, i.e., the rainy season and the dry season. Tree crops cultivated include cocoa, mango, cashew, citrus, oil palm, and arable crops cultivated include maize, yam, cassava, cocoyam, tomatoes, and vegetables, among others. The state has 33 Local Government Areas and three Agro Ecological Zones (AEZs) namely rain forest, derived savannah, and savannah zones.

The patterns of energy use in Nigeria's economy can be divided into industrial, transport, commercial, agricultural, and household sectors (ECN 2005) and it is the same as in Oyo state.

The household sector represents the largest share of energy use in the country, approximately 65%. This is largely due to the low level of development in all other sectors. The main energy-consuming activities in Nigerian households are cooking, lighting and the use of electrical appliances. Cooking accounts for a staggering 91% of household energy consumption, lighting uses up to 6%, and the remaining 3% can be attributed to the use of basic electrical appliances such as televisions and press irons (ECN, 2003).

The digestion and production of biogas production was carried out in the biogas research laboratory at the Czech University of Life Sciences, Prague, Czechia.

4.2. Study Population:

In this research, a total of 120 sugarcane farmers were selected as the sample population for the study. 120 questionnaires were distributed to these farmers, who are in Ibadan, Oyo State, to gather relevant data and information.

The use of questionnaires as a data collection method can provide valuable insights into the experiences, perspectives, and practices of these farmers regarding sugarcane production. This information will then be used to identify common issues, trends, and challenges faced by sugarcane farmers in the region and to propose recommendations to address these issues.

4.3. Sample Size:

In this research, a simple random sampling technique was utilized to select the study participants. The research aims to administer questionnaires to a total of 120 sugarcane farmers in Akufo Ibadan, which constitutes the study population. The total number of sugarcane farmers in the study population is estimated to be approximately 200 farmers.

By employing the simple random sampling technique, every sugarcane farmer in the study population has an equal chance of being selected for participation in the study. This technique ensures that the selected sample is representative of the study population and can provide reliable data for the research. With a sample size of 120 participants, the study aims to gather comprehensive data on the factors affecting sugarcane production and biogas adoption among farmers in the study area.

The sample for the study is calculated thus;

$$\mathrm{n} = \frac{N}{(1 + \mathrm{N}(\mathrm{e})^2)}$$

In the above equation, "N" represents the population size. It refers to the total number of individuals in the population from which you want to draw a sample. The population size is an important factor to consider when determining the sample size, as larger populations may require larger sample sizes to achieve the same level of precision.

"n" represents the required sample size. It refers to the number of individuals that is needed to include in your sample to estimate a population parameter with a desired level of precision and confidence. The sample size is determined based on factors such as the level of precision required, the level of confidence desired, the variability of the population, and the size of the population.

The variable "e" represents the margin of error. Margin of error is the amount of error that is acceptable in the sample size estimation for the desired level of confidence. It is expressed as a proportion or a percentage and indicates the degree of precision or accuracy required in the estimation.

The larger the value of "e", the larger the required sample size, and the smaller the value of "e", the smaller the required sample size.

Thus;

$$\mathrm{n} = \frac{N}{(1 + \mathrm{N}(\mathrm{e})^2)}$$

$$= \frac{200}{(1 + 200(0.05)^2)}$$

$$= \frac{200}{(1 + 200(0.0025)}$$

$$= \frac{200}{(1 + 0.675)}$$

$$= \frac{200}{(1.675)}$$

$$= 119.4$$

$$\sim 120$$

Therefore, the required sample size for the study is 120.

4.4. Data collection:

This study was based on a cross-sectional survey that considered both primary and secondary data sources. The primary data were gathered from sample sugarcane farmers through a semi-structured questionnaire.

A first draft of the questionnaire was designed according to the research objective and the required data as reported in the literature on factors affecting sugarcane production, technology adoption in general, and biogas adoption in particular. Then, this questionnaire was pre-tested during an exploratory survey organized in the study zone. A focus group discussion with the head of farmers in Akufo Ibadan was also organized along with the exploratory survey to get insights on the main driving forces determining the challenges the farmers face as well as adoption of biogas in the area. From the preliminary results of this survey, the questionnaire was updated and later on, used for primary data collection

Semi-structured interview questionnaires were chosen because they could include quantitative and qualitative questions. The questionnaire was pretested before the collection of actual data to improve wording and avoid ambiguity. The secondary data were collected from different published and unpublished sources, including books, journal articles, office reports and records, and internet sources. The secondary data were used as a background information to triangulate statistical results and to support arguments. The data collected consisted of demographic, socioeconomic, biophysical, and institutional factors. The observation units were factors affecting sugarcane production and wiliness to use biogas technology.

In addition to the primary and secondary data sources, this research involved the collection of sugarcane bagasse from the study area. The purpose of these samples collection was to test the impact of various digestion strategies on the biogas yield from sugarcane bagasse.

Furthermore, inoculum and cow manure, which served as co-substrate, were collected from the Biogas Research Laboratory and Laboratory of Animal Science, respectively. Both laboratories are located at the Faculty of Tropical AgriSciences, Czech University of Life Sciences, Prague, Czechia.

The inclusion of these additional materials in the study was to provide insights into the effects of various digestion strategies on biogas yield and will also help to compare the performance of sugarcane bagasse as a feedstock to that of other substrates. The use of inoculum and cow manure as co-substrate will also help to determine the optimal feedstock combination for maximum biogas production. By utilizing a diverse range of materials and substrates, this study aims to provide comprehensive and applicable information on biogas production from sugarcane bagasse.

4.5. Pretreatment of bagasse and co-digestion

In the study, two parallel batch anaerobic digestion (AD) experiments were conducted to determine the effect of different digestion strategies on the yield of biogas from sugarcane bagasse.

Particulate matter (>1 mm) was removed from the inoculum by passing through a 1 mm pore size sieve. The inoculum was stored at room temperature for more than 7 days under anaerobic conditions to decrease endogenous methane production. The pH of the inoculum, and two batch assays was measured.

The substrates and inoculum were mixed in a ratio of 1:2 in terms of grammes to avoid potential substrate inhibition and low microbial density.

All reactors were sealed with rubber stoppers and connected to a mechanical agitator to provide complete mixing. During the test, pH, CO_2, Oxidation Reduction Potential (ORP) and amount biogas produced were measured.

In the test, a blank and a control was included. In the blank experiment, the indigenous biogas production from the inoculum was measured using only the inoculum, which was subtracted from the total biogas produced from all test samples.

After 26 to 30 days of incubation, when the daily methane production is less than 1% of the overall methane production, all experiments was stopped.

4.6. Analytical approach

The content of the total solid based on wet weight (TS) and volatile solid on the basis of wet weight (VS) of all samples, including those of the CM and innoculum, were determined according to standard methods as reported by Drosg et al 2013.

The pH was measured using the automatic pH meter. The daily amount of Biogas was measured using the water displacement method.

4.7. The Empirical Model Specification

Different econometric strategies may be used to evaluate the adoption behavior of a household to biogas technology; whatever method is used is determined on the nature of the outcome and the variables being used to explain it. The dependent variable in this study will be a dichotomous endogenous variable, while the explanatory factors included both categorical and numeric measures.

People's propensity to switching to a biogas system will be measured with a probit analysis. The probit model, which employs a probit link function, is most often estimated using the standard Maximum Likelihood (ML) procedure (Greene, 2003). Probit models have been used in a number of studies on adoption behavior (Luo B. et al., 2021, Jan and Akram, 2017)

Mathematically, the general linear regression model is expressed as follow:

$$Y_i = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_p X_p + \varepsilon_i = X\beta + \varepsilon$$

Where, Y is the dependent variable, βs are the regression coefficients, Xs are a vector of explanatory variables, and ε is the error term.

4.8. Statistical analysis

Dixon's test ($P \leq 0.05$) was used to check for outliers in the Sugarcane Bagasse digestion assays. One-way analysis of variance (ANOVA) was performed with the

Statistical Package for the Social Sciences (SPSS), to assess statistical differences in biogas yield between the various co-digestion at a 95 % confidence level to accept or reject the null hypothesis. Probit analysis with the Maximum Likelihood (ML) procedure was used to assess the effect of different variables on the willingness-to-adopt a biogas system by the farmers.

4.9. Variables that may explain the adoption of Biogas technology:

Frequently, the explanatory variables that influence the adoption of biogas technology lack a firm theoretical basis. This may be due to the fact that households consider factors beyond socioeconomic incentives, such as noneconomic factors. In this study, demographic, socioeconomic, and institutional factors were identified as the most influential determinants of biogas adoption. Socioeconomic, demographic, biophysical, and institutional factors have been identified as crucial determinants of biogas technology adoption in prior research.

4.9.1. Age:

Age is an important factor that may impact the decision to adopt biogas technology. Older heads of household may be better able to afford investments in adopting biogas technology. However, they may be less adaptable and more resistant to adopting new technologies. Because older household heads may be more risk-averse than younger ones and have a lower propensity to adopt novel technology (Adesina et al., 1995), it was predicted that age would either have a positive or negative impact on the decision to adopt biogas technology.

4.9.2. Education:

The level of education may positively affect the adoption of biogas technology. Due to the use of sustainable energy sources, heads of households with a higher education level may be more informed, knowledgeable, and conscious of environmental health.

Thus, it was anticipated that a household head's level of education would have a positive effect on the adoption of biogas technology (Walekhwa, 2009, Uhunamure, 2019).

4.9.3. Size of the household:

Additional factor that may impact the adoption of biogas technology. Greater household size may necessitate a greater number of workers, and consequently, more laborers for daily biogas operation tasks. Therefore, it was hypothesized that household size would either positively or negatively influence the adoption of biogas technology. Y. Kebede et al. (1990) found that farmers who regard their family members as valuable sources of support are more prone to experiment with novel agricultural practices. In contrast, those who view their family as dependents may be less likely to engage in risky behavior.

4.9.4. Total Income:

Total income is an additional factor that may impact the adoption of biogas technology. Higher-income households are more likely to adopt biogas technology than lower-income households (Mengistu et al. 2016). Thus, it was hypothesized that household income would positively influence the adoption of biogas technology.

4.9.5. Farm Size:

The farm size may also influence the adoption of biogas technology. Also indicative of socioeconomic status is the extent of the landholdings. Medium-sized farms are more likely to have biogas digesters installed than smaller farms (Katuwal H. 2022).

4.9.6. Primary Energy Source:

The use of renewable energy as a principal energy source can be a significant factor in determining the adoption of biogas technology. It indicates a household's openness to renewable and pure energy sources and may contribute to a more sustainable and eco-friendly lifestyle.

4.9.7. Perception of the use of Biogas and Bioslurries:

The perception of the use and management of biogas and bio-slurries may also impact the adoption of biogas technology. In some African communities, the installation of biogas technologies is socially unacceptable because they require the accumulation of bovine manure and human excreta, which are viewed as disgusting refuse. Thus, households' reluctance to use restrooms for biogas energy generation and management and to use bio-slurries as fertilizer was expected to have a negative impact on the adoption of biogas technology (Amigun, 2012).

4.9.8. Access to Electricity

It was anticipated that access to electricity would hinder the adoption of biogas technology. Once installed, a power connection requires no additional labor nor expenses. Spare components are also more affordable and accessible than those of biodigesters. Farmland provides feedstock to operate biogas digesters (Munir and Yiyun, 2022). Therefore, it was hypothesized that access to electricity would hinder the adoption of biogas technology.

5. Results and Discussion

5.1. Demographical Data of Respondents

Table 1: Respondents by Gender

	Gender	Frequency	Percent
Valid	Male	78	65
	Female	42	35
	Total	120	100

Table 1 shows that 65% of the respondents were males while 35% of them were females. This shows that about 2/3 of the farmers in the area are men. These findings align with the research conducted by Onah et al. (2023), indicating that men typically assume the role of primary income earners in households, in accordance with the cultural and traditional norms of the region. As well, Bello et al. (2021) highlights that gender differences have varying effects on agricultural productivity, which can be attributed to culturally defined roles and labor divisions in Nigeria. This is a good indicator for the adoption of biogas technology considering the fact that the main decision-makers in Nigeria households are men. Another potential explanation is that females have multiple responsibilities, including household duties in addition to agricultural production, which limits their time and ability to learn and adapt to new technologies. Alternatively, it could be attributed to a higher risk-taking propensity among males, as suggested by He et al (2002), which makes them more open to implementing novel technologies such as biogas technology that could result in increased profitability.

Table 2: Respondents by Age

Ages	Frequency	Percent
<35	28	23.33
35-45	33	27.5
46-55	32	26.67
56-65	20	16.67
>66	7	5.83

Table 2 shows that the largest proportion of respondents (54.17%) are within the age of 35 – 55 years, suggesting that they were mostly within the active working age group. As well 23.33% were less than 35 years and 16.67% were between the ages of 56 and 65 years.

The age distribution of the respondents in this study is important in understanding the potential of sugarcane bagasse as a feedstock for biogas production. According to Table 2, the majority of the respondents (54.17%) were mostly within the active working age group. This result is consistent with the findings of a study by Salam et al. (2020), which reported that most of the respondents involved in the biogas industry in Bangladesh were aged between 30 and 50 years. Similarly, a study by Hamad et al. (2019) found that the majority of the respondents involved in the biogas industry in Sudan were aged between 31 and 50 years.

The implication of this result is that the potential of sugarcane bagasse as a feedstock for biogas production is likely to be influenced by the level of awareness and interest among the active working population. This is because the active working population is more likely to have the necessary knowledge, skills, and resources to engage in biogas production. Therefore, efforts to promote the use of sugarcane bagasse as a feedstock for biogas production should be targeted towards this age group. This could be achieved through awareness campaigns, training programs, and financial incentives.

Table 3: Respondents by Level of Education

Education	Frequency	Percent
No Education	29	24.2
Primary	33	27.5
Secondary	43	35.8
Tertiary	15	12.5
Total	120	100

Table 4 shows that the highest level of education of most of the farmers was Secondary school education at 35.8% of the respondents. 27.% of them had primary education as the highest level, 24.2% had no formal education, while 12.5% of the farmers had a Tertiary education. The low level of education among the farmers in the current study may also have implications for the adoption of biogas technology. Biogas technology requires a certain level of technical knowledge and skills for its successful implementation and operation. Therefore, the lack of education among the farmers may pose a challenge in the implementation and adoption of biogas technology.

For instance, Sime et al. (2021) conducted a study in Ethopia and found a statistically significant difference in the average education level attained by household heads who adopted biogas technology and those who did not ($p < 0.01$). The study found that for every additional year of education completed by a household head, there is a 24.16% increase in the likelihood of the household adopting biogas technology. This suggests that as the education level of household heads increases, their ability to gather information, understand their perception, and make informed decisions regarding biogas technology also increases. This finding is consistent with previous research by Riddell and Song (2019), which showed that households with higher levels of education tend to adopt new technologies more quickly than those with lower levels of education.

Table 4: Respondents by Farm Experience

Farm Experience	Frequency	Percent
<6	18	15.0
06 -10	38	31.7
11-15	17	14.2
16-20	12	10.0
21-25	14	11.7
>26	21	17.5

Table 4 presents the distribution of respondents by their farm experience. The mean farm experience of the respondents was 14.81, with approximately 50% of the farmers having less than 10 years of experience. The results indicate that there is a diverse range of farm experiences among the respondents, which may have implications for the adoption of biogas technology.

Table 5: Respondents by Monthly Income

Monthly Income (N)	Frequency	Percentage
< 20000	2	1.7
20000 - 39999	19	15.8
40000 - 59999	21	17.5
60000 - 79999	25	20.8
80000 - 99999	28	23.3
>100000	25	20.8

Table 6 shows that 1.7% of the farmers earn below ₦20,000 ($43.48), 15.8% earn within ₦20,000 ($43.48) to ₦39,999 ($86.95), 17.5% earn within ₦40,000 ($87.00) to ₦59,999 ($130.43), 20.8% earn within ₦60,000 ($130.87) to ₦79,999 ($173.91), 23.3%

earn within ₦80,000 ($173.91) to ₦99,999 ($217.39), and 20.8% of the farmers earn above ₦100,000 ($217.39). However, the mean monthly income of the farmers in the survey was ₦75,866 ($165.05).. This indicates that the majority of the farmers are within the middle-income range. These findings are consistent with the results of previous studies on the relationship between income and biogas adoption.

A study by Rahman et al. (2021) found ot that households that have adopted biogas tend to have a per capita income that is 13-27% higher than those who have not adopted biogas. This is attributed this to the fact that biogas technology requires a significant upfront investment, which may be more feasible for households with higher incomes. Similarly, a study by Kutawal (2022) in Nepal found that households with higher incomes were more likely to adopt biogas technology, as they were better able to afford the initial investment and ongoing maintenance costs.

The mean monthly income of the farmers in the survey was ₦75,866 Naira, which is slightly higher than the median income level in Nigeria. This suggests that the farmers who participated in the study are relatively well-off compared to the general population. However, it is important to note that income levels alone may not be sufficient to determine the potential for biogas adoption, as there are other factors such as access to finance, awareness, and availability of technical support that can also influence adoption.

It is thus imperative that efforts to promote the use of sugarcane bagasse as a feedstock for biogas production should consider the income levels of the target population. Given that biogas production requires a significant upfront investment, it may be more feasible to target households with higher incomes or provide financing options to lower-income households to enable them to access the technology.

Table 6: Respondents by Major customers

Customers	Frequency	Percent
Self	20	16.7
Consumers	7	5.8
Retailers	93	77.5
Total	120	100

Table 6 shows that Majority of the Sugarcane farmers (77.5%) sell to retailers who later sell the cane in small bits in the market. 16.7% of the farmers do not plant sugarcane for market but are rather their consumers. And finally, 5.8% of the farmers sell to consumers of in markets.

The majority of the sugarcane farmers in the study area sell to retailers who later sell the cane in small bits in the market is consistent with other studies that have reported the prevalence of small-scale sugarcane farming in Nigeria (Issa & Sanusi, 2020)). This has a negative impact on the production of Sugarcane in the country. In Nigeria, sugarcane is primarily grown for sugar production rather than consumption. While the country has a growing sugar industry that produces sugar from sugarcane, the industry is largely concentrated in the northern part of Nigeria, where sugarcane cultivation is most prevalent. There are invariably no fully functional sugar industries in the southern part of Nigeria. According to FAS Lagos, Nigeria's sugar consumption in May 2021/22 was projected to be approximately 1.6 million metric tons, which is slightly lower than the 1.61 MMT consumed in the previous marketing year, despite the country's population growing by 3% annually.

This can be attributed to a recent trend of decreasing sugar consumption, with the per capita sugar consumption in 2020 being approximately eight kilograms, significantly lower than the global average of approximately 36 kilograms per person. Health concerns are prompting many individuals, especially those in the middle-income bracket, to seek alternative sweeteners like honey (Ebenezer 2021).

Table 7: Details of on-going sugar projects under the National Sugar Master Plan (Ebenezer 2021) highlighting only one project in the south.

S/No	Company	Region	Estimated Milling Capacity/Annum	Land Size (Ha)
1	Savanah Sugar Company Numan, Adamawa State - Dangote	North	Phase 1: 85,000MT Phase 2: 120,000MT	32,000
2.	Sunti Golden Sugar Estate Limited, Sunti Niger State - Flour Mills	North	50,000MT	7,000
3.	BUA Sugar Company Limited, Lafiagi, Kwara State	North-Central	120,000MT	6,500
4.	Oyo Sugar Processors Limited, Iseyin, Oyo State	South	N/A	N/A
5.	Goronyo Sugar Company, Gorony, Sokoto State	North	N/A	N/A
6.	Dangote Nasarawa Sugar Project, Tunga, Nasarawa State	North	180,000MT	40,000
7.	Great Northern Agribusiness Limited, Gagarawa, Jigawa State	North	75,000MT	12,900

The utilization of sugarcane bagasse for biogas production can provide an additional source of income for the farmers, as well as promote sustainable agriculture through the utilization of agricultural waste.

Table 8: Respondents by Primary Source of Energy

Primary Source	Frequency	Percent
Charcoal	43	35.8
Gas (LPG)	15	12.5
Kerosine	23	19.2
Solar	1	0.8
Wood	38	31.7
Total	120	100

The major primary sources of fuel used by the farmers are Charcoal (35%) and Wood (31.7%). Other primary sources of energy used are Kerosine and Gas (LPG) at 19.2% and 12.5 respectively. Only 0.8% of the farmers use Solar power as a source of energy which shows the level the farmers are in the adoption and usage of renewable energy sources. The primary sources of fuel used by the farmers are charcoal and wood, which are non-renewable energy sources. This is consistent with other studies that have reported the prevalence of non-renewable energy sources in rural areas of developing countries (Mohammadi et al., 2023). This highlights the need to promote the adoption and usage of renewable energy sources, such as biogas, which can be produced from sugarcane bagasse, to mitigate the adverse effects of non-renewable energy sources on the environment and human health.

Regarding the primary source of energy used by the farmers, the study reveals that charcoal and wood are the major sources of fuel, followed by kerosene and gas, with only a few using solar power. This finding is in line with previous studies conducted in Nigeria, which have shown that charcoal and firewood are still the most widely used sources of energy, despite the availability of renewable energy sources. This is also in line with the findings of World Health Organization's report (2016), which discovered that approximately 181.3 million people, which is equivalent to 94%, predominantly use wood, charcoal, coal, and kerosene as cooking fuels. The impact of this on the willingness to adopt biogas technology in Nigeria may be mixed. On the one hand, it highlights the fact that traditional cooking fuels like wood, charcoal, and kerosene are still widely used, indicating a potential need for alternative and more sustainable energy sources. Biogas technology, which uses organic waste to produce gas for cooking, could be a viable alternative to these traditional fuels. On the other hand, the fact that previous studies have shown a continued preference for traditional fuels despite the availability of renewable energy sources suggests that there may be resistance to adopting new technologies. Additionally, the widespread use of traditional fuels may indicate a lack of infrastructure and resources necessary to implement and maintain biogas systems, which could also hinder willingness to adopt this technology.

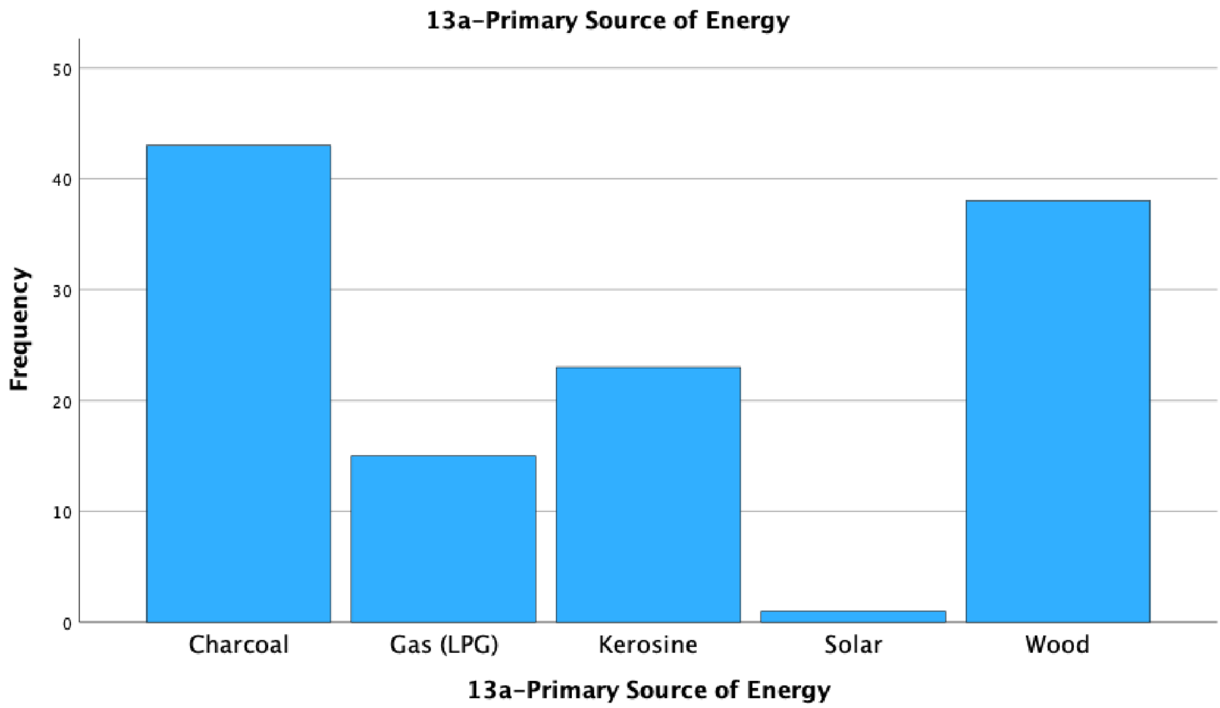


Figure 3. A bar chart showing the primary sources of energy of the respondents.

5.2. Descriptive analysis for awareness of biogas technology

One of the factors that can hinder the adoption of biogas systems is limited awareness of the potential advantages and disadvantages of biogas. To investigate this issue, a section of the questionnaire was dedicated to assessing the respondents' awareness of biogas technology and its pros and cons.

In Table 8, the level of awareness of farmers about biogas and its impact on biogas production was evaluated. The results of the study indicate that the majority of farmers, about 83.3% (n=100), have knowledge about biogas, while only 16.7% (n=20) were not aware of it. This shows a relatively high level of awareness among the farmers about biogas as a potential source of energy. Among those who were aware of biogas, the most common source of information was schools (55.0%), followed by books (9.2%), and radio (8.3%). The low percentage of those who obtained information about biogas from online sources (3.3%) and social interaction (2.5%) indicate the need for more awareness campaigns using digital platforms and community outreach programs.

The study also assessed the farmers' knowledge about the use of farm waste as a feedstock for biogas production. The results showed that 50% of the farmers were aware of the potential of farm waste for biogas production, while the other half were not aware of this fact. This suggests that more awareness campaigns and education on the use of farm waste as a feedstock for biogas production are needed to increase adoption rates.

Table 9: Awareness of the Farmers about Biogas

	Frequency	Percentage
Do you know Biogas		
Yes	100	83.3
No	20	16.7
Total	**120**	**100.0**
Information Source		
School	66	55.0
TV	6	5.0
Online	4	3.3

Radio	10	8.3
Books	11	9.2
Social Interaction	3	2.5
Nil	20	16.7
Total	**120**	**100.0**
Know that Farm Waste can be used for Biogas		
Yes	60	
No	60	
Total	**120**	
Know any Biogas Plant in the Community		
Yes	30	25
No	90	75
Total	**120**	**100.0**

Finally, the study also assessed the availability of biogas plants in the community. Only 25% of the farmers reported the presence of a biogas plant in their community, while the majority, 75%, reported the absence of one. This indicates a need for more investment in biogas plant installation and awareness campaigns to encourage the adoption of biogas as a source of energy.

The results from this study indicate that sugarcane bagasse has high potential for biogas production. This makes sugarcane bagasse makes it a valuable feedstock for biogas production, which can provide a renewable source of energy for cooking and electricity generation. The potential of sugarcane bagasse as a feedstock for biogas production has been demonstrated in several studies (Agrawal et al. 2022; Eshore et al. 2017; O'Hara et al. 2020; Armah et al. 2020; Janke et al. 2015). Biogas production from sugarcane bagasse has been reported to have a high yield of methane, which is a valuable source of renewable energy (Eshore et al. 2017). Furthermore, biogas production from sugarcane bagasse can also reduce greenhouse gas emissions (Armah et al. 2020), as well as enhance soil fertility through the application of biogas residue as a fertilizer (Janke et al. 2015).

In Nigeria, the utilization of biogas as a source of energy is still relatively low, and there is a need to promote its adoption and usage. Several studies have identified the challenges hindering the adoption of biogas in Nigeria, including the high cost of installation and maintenance, lack of awareness, and inadequate government support (Ogunsanmi et al., 2019; Adebayo et al., 2018). Addressing these challenges can promote the adoption and usage of biogas in Nigeria, which can contribute to the attainment of the Sustainable Development Goals (SDGs) on renewable energy, climate change, and sustainable agriculture.

The study found a relatively high level of awareness among farmers about biogas as a potential source of energy. However, more awareness campaigns and education on the use of farm waste as a feedstock for biogas production are needed to increase adoption rates. A study by Yaradua & Bello (2020) also found that farmers in Nigeria have limited knowledge about biogas technology and its potential as a source of renewable energy. Therefore, there is a need for continuous education and sensitization campaigns to increase awareness and promote the adoption of biogas technology.

Furthermore, the study found that only 25% of farmers reported the presence of a biogas plant in their community, indicating a need for more investment in biogas plant installation and awareness campaigns. In a study by Akinbami et al. (2001), it was found that the major barriers to the adoption of biogas technology in Nigeria are inadequate financing, lack of government support, and limited access to technical knowledge. Therefore, to promote the adoption of biogas technology in Nigeria, there is a need for increased government support and investment, as well as access to financing and technical knowledge. The study also found that there is a growing awareness of low-cost biogas systems among farmers in Nigeria, which can make this alternative energy source accessible to a wider range of households.

The study also highlights the potential of biogas as a sustainable waste management solution, which can efficiently process organic waste materials, reducing the amount of waste that needs to be disposed of and minimizing the associated environmental impacts. This finding is supported by a study by (Athira and Subha 2017), which found that biogas technology can significantly reduce the amount of organic waste generated and contribute to sustainable waste management.

The study identified several factors that influence the adoption and use of sugarcane bagasse as a feedstock for biogas production, including technical, financial, and institutional factors. Technical factors, such as the availability of suitable technology and knowledge, were found to be crucial in promoting the adoption and use of sugarcane bagasse as a feedstock for biogas production.

To promote the adoption and utilization of sugarcane bagasse as a feedstock for biogas production in Nigeria, several actions could be taken. Providing government support through subsidies, tax incentives, or technical assistance to farmers and biogas producers could reduce the cost of production and increase the profitability of biogas production from sugarcane bagasse. This is also supported by the findings of Jekayinfa et al. (2020) who stated that the implementation of energy from biomass and its sustainability largely depends on adequate support from the government.

Creating a market for biogas and promoting its use could be crucial in promoting the adoption and utilization of sugarcane bagasse as a feedstock for biogas. Providing access to affordable credit and loan opportunities and promoting cost-saving technologies are also critical in promoting the adoption and utilization of sugarcane bagasse as a feedstock for biogas. Building sugar processing infrastructures to extract juice from sugarcane and produce sugar could reduce the amount of bagasse unused and increase the attractiveness of sugarcane as a cash crop. Finally, implementing government policies and regulations that promote the adoption and utilization of sugarcane bagasse as a feedstock for biogas could also be crucial in promoting the development of the biogas sector in Nigeria. Daniel-Gromke et al 2018 and Chen 2017 found out that in most developed countries, the advancement of technology adoption has been attributed to the presence of regulations and supportive government policies as the cornerstone.

Finally, the study highlights the need for increased education and outreach efforts to inform farmers about the various applications of biogas, such as its use as an energy source for generating electricity. This finding is supported by a study by Odekunle et al. (2020), which found that biogas technology has the potential to significantly contribute to Nigeria's electricity generation and reduce dependence on fossil fuels. According to the findings of Odekunle et al. (2020), there is potential to produce 1040 MWh and 1664.6 MWh of electricity from biogas, assuming a low-end conversion efficiency of 25% and high-end conversion efficiency, respectively. The study's ultimate conclusion is that waste-to-wealth technology could be a practical solution to Nigeria's energy crisis if it is adequately researched and utilized. Therefore, there is a need for increased investment in biogas technology and awareness campaigns to promote its use as a source of renewable energy in Nigeria.

5.3. Perception of the Farmers on the use and awareness of Biogas

The findings presented in the table 9, highlight the perceptions of farmers regarding the use and awareness of biogas as an alternative energy source. The mean scores for each variable provide an overall perception of farmers towards the given statement. A mean score of 3 indicates a neutral response, while scores closer to 1 represent agreement and scores closer to 5 represent disagreement.

The variable with the lowest mean score of 2.19 is "Biogas can cause offensive odor in the vicinity." The high level of agreement among farmers (80%) shows that it is important to sensitize the farmers about biogas production. According to Luo et al. (2022) if set up properly, there are several available to reduce odor emission from anaerobic digesters.

The second variable, "Biogas can solve waste disposal problem," received a mean score of 2.79. The high level of agreement among farmers (60%) towards this statement indicates that biogas systems can efficiently process organic waste materials, reducing the amount of waste that needs to be disposed of and minimizing the associated environmental impacts. This finding supports the potential of biogas as a sustainable waste management solution.

Table 10: Perception of the farmers on the use and awareness of biogas (N=120)

Description of Variables	Agree (%)	Neutral (%)	Disagree (%)	Mean
Biogas can cause offensive odor in the vicinity	80	15	5	2.19
Biogas is only for the rich	34	8	58	3.32
Biogas can be used for cooking and other activities	23	1	76	3.81
Biogas can be a source to generate electricity	9	9	82	4.08
Biogas can solve waste disposal problem	60	8	32	2.79
Using biogas can create job opportunities	24	3	73	3.78
Biogas is expensive to install	25	20	55	3.55
Biogas is cheaper compared to other energy sources	19	14	67	3.81

The mean score of 3.32 for the variable "Biogas is only for the rich" indicates a disagreement among farmers regarding this statement. The high percentage of farmers who disagree with this statement (58%) suggests that there is a growing awareness of low-cost biogas systems that can make this alternative energy source accessible to a wider range of households. This finding highlights the importance of increasing awareness and education among farmers regarding the availability and affordability of biogas systems.

The variable with the highest mean score of 4.08 is "Biogas can be a source to generate electricity." However, the low level of agreement among farmers (9%) towards this statement highlights a lack of awareness of the potential of biogas as an energy source for generating electricity. Biogas can be used to generate electricity in small-scale and large-scale systems (Joale et al. 2020), and this finding emphasizes the need for increased education and outreach efforts to inform farmers about the various applications of biogas.

The mean score of 3.55 for the variable "Biogas is expensive to install" suggests a neutral perception among farmers towards this statement. The variable "Biogas is cheaper compared to other energy sources" received a mean score of 3.81, indicating a neutral perception among farmers towards the affordability of biogas systems. Several studies have reported that biogas systems can provide economic benefits such as reduced energy costs and increased income generation (Ali et al. 2011; Walekhwa et al. 2018). In addition, incentives and subsidies can increase the affordability of these systems, as reported by previous studies (Kivaisi 2001; Amigun et al. 2011). These findings highlight the need for further research and analysis to determine the actual costs and economic benefits of biogas systems, as well as the potential for incentives and subsidies to increase the affordability of these systems.

The variable "Using biogas can create job opportunities" received a mean score of 3.78, indicating a neutral perception among farmers towards this statement. However, the percentage of farmers who agree with this statement (24%) suggests that biogas systems have the potential to create employment opportunities in rural areas. Previous studies have reported that biogas systems can create employment opportunities in rural areas (Amigun et al. 2011; Walekhwa et al. 2018). Therefore, it is important to promote the social and economic benefits of biogas production and utilization to increase its adoption as a viable energy source. This finding highlights the need for further research and analysis to determine the potential for biogas systems to contribute to rural development and poverty reduction.

It is important to note that some of the responses, such as "Biogas is only for the rich," had a mean value of 3.32, which suggests that there is a perception among some farmers that biogas is not accessible to them. This perception may be linked to the perception that biogas is expensive to install, which had a mean value of 3.55. While it is true that biogas systems do require an initial investment, it is important to emphasize the potential long-term economic and environmental benefits of biogas production, such as reduced energy costs, increased income generation, and improved waste management.

Generally, while there is some level of awareness among farmers regarding the potential uses of biogas, there are also several misconceptions and negative perceptions that need to be addressed in order to increase its adoption as a viable energy source. The findings highlight the need for increased education and outreach efforts to inform farmers about the potential of biogas as an alternative energy source and its various applications, as well as the need for further research to determine the economic, social, and environmental benefits of biogas production and utilization.

5.4. Major challenges of sugarcane production in the Study Area.

In table 10, the results show that the major challenges of sugarcane production in the study area are the lack of sugar processing infrastructures, followed by the lack of government support, lack of market potential, and high cost of starting capital and production inputs. The mean values of these challenges are 1.07, 1.59, 2.38, and 2.61, respectively. These challenges could potentially hinder the adoption and utilization of sugarcane bagasse as a feedstock for biogas in the study area.

The finding that the lack of sugar processing infrastructures is a significant challenge in the study area is supported by the research of Wada et al. (2007). Wada et al. (2007) conducted a study in Nigeria, which found that the lack of sugar processing infrastructures was a major challenge for sugarcane production. This challenge could limit the potential of sugarcane bagasse as a feedstock for biogas, as the lack of processing facilities makes it difficult to extract the juice from sugarcane and produce sugar, leaving a significant amount of bagasse unused. Moreover, the lack of sugar processing infrastructures could lead to low prices for sugarcane, making it less attractive for farmers to grow it as a cash crop (Wada et al. 2007).

This finding has significant implications for the potential use of sugarcane bagasse as a feedstock for biogas. If there are not enough sugar processing infrastructures in the study area, then it may not be feasible to produce enough sugarcane juice to meet the demand for biogas production. This could limit the overall potential for biogas production from sugarcane bagasse in the study area. Additionally, low prices for sugarcane could discourage farmers from growing it as a cash crop, further limiting the potential for biogas production from sugarcane bagasse.

The finding that the lack of government support is a significant challenge in promoting the adoption and utilization of sugarcane bagasse as a feedstock for biogas is supported by previous studies. A study by Adeyanju et al. (2020) on the development of renewable energy in Nigeria identified the lack of government support as a significant challenge to the growth of renewable energy. Similarly, a study by Dulal et al. (2013) on the development of biogas in Asia highlighted the importance of government support in the form of policies, regulations, and incentives to promote the development of biogas.

In Brazil, where sugarcane bagasse is a widely available feedstock for biogas, the government has implemented various policies to support the development of biogas. For instance, the National Biofuels Policy (RenovaBio) provides incentives for the production and consumption of biofuels, including biogas (Grangeai et al., 2021). The Brazilian government has also provided financial support for research and development of biogas technologies, such as the PROBIOGÁS program (Brazilian Biogas Program) (PROBIOGÁS 2010).

The lack of government support in the study area implies that there is a need for the government to take a more active role in promoting the development of biogas from sugarcane bagasse. The government could provide subsidies, tax incentives, or technical assistance to farmers and biogas producers to reduce the cost of production and increase the profitability of biogas production.

Table 11: Major challenges of sugarcane production in the Study Area.

Challenges	Agree	Neutral	Disagree	Mean
High cost of starting capital and production inputs	65	9	26	2.61
Lack of knowledge on planting techniques	8	0	93	4.15
Inadequate Credit and Loan opportunities	66	22	13	2.47
Lack of sugar processing infrastructures	100	0	0	1.07
Lack of market potential	71	21	8	2.38
Lack of government support	83	17	0	1.59
Problem of pest and diseases	57	20	23	2.65

The results of the study highlight the major challenges of sugarcane production in the study area, with a specific focus on the potential of sugarcane bagasse as a feedstock for biogas production. One of the significant challenges identified is the lack of market potential, with a mean value of 2.38. This implies that despite the availability of sugarcane bagasse as a feedstock for biogas production, there is low demand and a lack of a well-established market for biogas, making it difficult for farmers and biogas producers to sell their products.

Previous studies have also identified market-related challenges in the biogas industry. For instance, a study by Nevzorova & Kutcherov (2019) identified the lack of a well-developed market as one of the significant barriers to the adoption of biogas technology. Similarly, a study by Kumaran et al. (2016) reported that the lack of a reliable and stable market for biogas is a significant challenge facing the biogas sector.

The implication of the lack of market potential identified in this study is that there is a need to create a market for biogas and promote its use to increase the adoption and utilization of sugarcane bagasse as a feedstock for biogas production. To achieve this, policymakers and stakeholders need to focus on promoting the benefits of biogas and increasing awareness among potential users.

The study highlights the challenge of high starting capital and production input costs, which could potentially hinder the adoption and utilization of sugarcane bagasse as a feedstock for biogas production. The mean value of 2.61 suggests that farmers and biogas producers in the study area face significant challenges in terms of capital investment and production inputs. This is consistent with the findings of previous studies that have identified high costs as a major barrier to the adoption of biogas technology.

A study by Situmeang et al. (2022) found that the high cost of capital investment was the most significant barrier to the adoption of biogas technology in rural areas. Similarly, a study by Mukisa et al. (2022) reported that despite its potential benefits, biogas technology development is hindered by various barriers, among which the lack of investment capital is one of the most significant.. These studies suggest that the high cost of production is a common challenge facing biogas producers in different regions.

The implication of the high cost of starting capital and production inputs is that there is a need to provide access to affordable credit and loan opportunities and promote cost-saving technologies to enable small-scale farmers and biogas producers to invest in biogas production from sugarcane bagasse. To achieve this, policymakers and stakeholders need to develop policies and strategies that support the adoption of cost-saving technologies and provide financial incentives to farmers and biogas producers. A study by Baena-Moreno et al. (2020) suggested that the implementation of policies such as feed-in tariffs and subsidies could help promote the development of the biogas sector.

Sugarcane is an important crop for bioenergy production, especially for the production of biogas, which is a renewable and sustainable source of energy. However, the production of sugarcane is not without its challenges, especially in certain areas. The current study found that lack of knowledge on planting techniques is not a significant challenge in the study area, with a mean value of 4.15.

Access to credit and loan opportunities is a crucial factor in the adoption and utilization of sustainable agriculture and bioenergy practices, including the use of sugarcane bagasse as a feedstock for biogas production. The current study found that inadequate credit and loan opportunities were a major challenge in the study area, with a mean value of 2.47.

This finding is consistent with previous research, which has shown that limited access to credit and finance can significantly affect the adoption and implementation of sustainable agriculture and bioenergy practices. For example, a study by Bekchanov et al. (2019) found that inadequate access to credit and finance was a major barrier to the adoption of renewable energy technologies, including biogas production, in Sri Lanka. Similarly, a study by Mohamed and Temu (2008) found that access to credit was a crucial factor in the adoption of sustainable agricultural practices, such as conservation agriculture, in Tanzania.

The implication of this result is that providing access to affordable credit and loan opportunities could be crucial in promoting the adoption and utilization of sugarcane bagasse as a feedstock for biogas. This could be done through collaboration with financial institutions or by providing incentives for private investment in biogas production. Improved access to credit and finance could lead to increased investment in biogas production from sugarcane bagasse, which could in turn promote sustainable agriculture and contribute to the development of the bioenergy sector.

The challenge of pest and disease problems in sugarcane production is a well-documented issue in literature. Studies have shown that several factors contribute to the incidence and severity of pests and diseases, including environmental conditions, plant variety, and management practices (Gonçalves et al. 2012; Goebel et al. 2018).

For example, Gonçalves et al. (2012) reported that sugarcane yellow leaf virus (SCYLV) and sugarcane mosaic virus (SCMV) were among the most prevalent diseases affecting sugarcane production in Brazil. In South Africa, Goebel et al. (2018) found that sugarcane stem borer (Diatraea spp.) and leafhopper (Perkinsiella saccharicida) were major pests that affected sugarcane growth and yield.

The mean value of 2.65 obtained in this study suggests that pest and disease problems are moderately significant in the study area. This finding has important implications for sugarcane production in the region, as it highlights the need for effective pest and disease management strategies.

One such strategy is the use of resistant varieties that are less susceptible to pests and diseases. Several studies have shown that planting resistant can significantly reduce the incidence and severity of pests and diseases in sugarcane (Rajput et al., 2021; Bhatt et al., 2022). Other strategies include cultural practices such as sanitation, crop rotation, and timely harvesting, as well as the use of biological control agents and chemical pesticides (Gonçalves et al., 2019; Goebel et al. 2018).

5.5. Factors Influencing the Use of Sugarcane bagasse for Biogas Production

Table 12: Factors Influencing the Use of Sugarcane bagasse for Biogas Production

Factors	Agree	Neutral	Disagree	Mean
Awareness of sugarcane	0	0	100	5
Awareness about Biogas	70	19	11	3.83
Awareness of Sugarcane bagasse as biogas	63	24	13	3.73
Availability of Sugarcane Bagasse	97	3	20	2.06
Government Support	74	15	11	3.83
Capital	3	20	78	4.05

Technical Know how	36	14	50	3.12
Access to credit and loans	68	3	29	2.54
Availability of technology near markets and farms	63	15	23	2.23

The utilization of sugarcane bagasse for biogas production has received significant attention in recent years due to its potential as an alternative energy source. This study aimed to investigate the factors that influence the adoption and use of sugarcane bagasse as a feedstock for biogas production. The results of the survey are presented in Table 11.

The high level of awareness about sugarcane among the respondents is not surprising, given that sugarcane is a major cash crop in many regions of the world, including Brazil, Thailand, and India (OECD-FAO, 2021). However, the relatively lower levels of awareness about biogas and sugarcane bagasse as a potential feedstock for biogas production highlights the need for increased education and outreach efforts to promote the use of this renewable energy source.

Several studies have shown the potential of sugarcane bagasse as a feedstock for biogas production. For example, a study by Arelli et al. (2021) found that sugarcane bagasse could be effectively used as a substrate for biogas production, with a maximum methane yield of 440 ml CH_4/g volatile solid from bioaugmented bagasse at a TS of 40% and 340 ml CH_4/g volatile solid for non-bioaugmented bagasse. Similarly, a study by Alsebiey et al. (2023) showed that the co-digestion of sugarcane bagasse and cattle manure resulted in higher biogas yields and methane content than either substrate alone.

The low mean values obtained for awareness about biogas and sugarcane bagasse as a potential feedstock for biogas production suggest that there is a need for increased education and outreach efforts to promote the use of this renewable energy source. This is particularly important given the increasing demand for renewable energy sources and the potential of sugarcane bagasse as a sustainable and cost-effective feedstock for biogas production.

The importance of feedstock availability for biogas production has been highlighted in several studies. For example, a study by Taherzadeh et al. (2008) found that the availability of feedstock was a key factor influencing the feasibility of biogas production, particularly in developing countries where feedstock supply chains can be less reliable. Similarly, a study by Ammenberg & Feiz (2017) found that the availability and quality of feedstock were the most important factors influencing the performance of a biogas plant.

The high mean value obtained for the availability of sugarcane bagasse as the most important factor influencing the use of sugarcane bagasse for biogas production is consistent with these findings. Sugarcane bagasse is a byproduct of the sugarcane industry, and its availability can be influenced by a range of factors, including harvesting and processing methods, storage and transport, and competition from other uses such as animal feed and fuel.

Government support and awareness of biogas were also found to be important factors influencing the use of sugarcane bagasse for biogas production, with a mean value of 3.83. This finding is consistent with the role of government policies and initiatives in promoting renewable energy sources, including biogas, in many countries. For example, the Brazilian government has implemented a range of policies and incentives to support the development of the biogas sector, including tax incentives, grants, and low-interest loans (gov.br, 2022).

The results of this study suggest that policies and initiatives to promote the use of renewable energy sources, including biogas, may be beneficial in encouraging the adoption and use of sugarcane bagasse for biogas production. This is particularly important given the increasing demand for renewable energy sources and the potential of sugarcane bagasse as a sustainable and cost-effective feedstock for biogas production.

The result that technical know-how is a more important factor than capital is also supported by previous research. For example, a study by Gafoor et al. (2016) on the status of renewable energy in Pakistan found that the lack of technical knowledge during the installation and operation phases resulted in the failure of biogas plants, which were plagued with durability issues. Similarly, a study by Muvhiiwa et al. (2016) on the impact and challenges of sustainable biogas implementation in South africa, identified the lack of technical expertise as a major challenge.

The finding that access to credit and loans is also an important factor is consistent with previous studies on the financing of renewable energy projects. For example, the study by Nevzorova & Kutcherov (2019)on the barriers to the wider implementation of biogas as a source of energy also found that the lack of access to finance was one of the major barriers. This was also supported by Patinvoh and Taherzadeh (2019) on the challenges of biogas implementation in developing countries, identifying the lack of access to affordable finance as a key challenge.

The implication of these findings is that policymakers and project developers should focus on providing technical assistance and access to financing options to promote the adoption and use of sugarcane bagasse for biogas production. In addition, efforts should be made to increase awareness about the biogas production process to overcome the lack of technical expertise. Overall, these findings suggest that sugarcane bagasse has great potential as a feedstock for biogas production, and that financial constraints are not a significant barrier to its adoption and use.

The finding that proximity to markets and farms is a significant factor in the efficient utilization of sugarcane bagasse for biogas production is supported by previous studies. For example, a study by Kumar et al. (2021) while exploring the impact of constraints to suitable biogas plant locations in Sweden found that the location of the biogas plant was a crucial factor in determining the cost-effectiveness of the process.

The implication of this result is that the development of biogas production facilities near sugarcane mills and market demand may contribute to the efficient utilization of sugarcane bagasse for biogas production. This could help to reduce transportation costs, which are a significant component of the total costs of biogas production. In addition, it could create opportunities for rural development by providing a new source of income for farmers and creating jobs in the biogas production industry.In conclusion, the adoption and use of sugarcane bagasse as a feedstock for biogas production in the study area is influenced by various factors. The findings of this study indicate that the availability and accessibility of the feedstock, as well as policies and initiatives to promote the use of renewable energy sources, are crucial factors. The provision of technical assistance and access to financing options may also facilitate the adoption and use of sugarcane bagasse for biogas production.

5.6. Probit Analysis on the willingness to adopt biogas technology.

Table 13: Willingness to use Biogas if available:

	Frequency	Percentage
Are you willing to use biogas if it is available		
Yes (1)	89	74.2
No (0)	29	24.2
Undecided	2	1.7
Total	**120**	**100**

The finding that a high percentage of farmers are willing to use biogas if it is available is consistent with previous studies on the acceptance and adoption of biogas technology in rural areas. For example, a study by Zemo and Termansen (2017) on farmers' willingness to participate in collective biogas investment in denmark found that how that the majority of farmers, including farmers who never considered investing in biogas before and farmers that already participate in conventional biogas plants, are interested in a partnership-based biogas investment (PBI). Similarly, According to Nayum and Klöckner (2014) and Balundė et al. (2020), individuals' attitudes towards a particular issue can shape their behavior in accordance with it, particularly if the attitude is positive.

The implication of this result is that there is a significant potential for the adoption of biogas technology as a source of energy in the farming community. This could have several benefits, including reducing the dependence on fossil fuels, improving energy security, and reducing greenhouse gas emissions. In addition, the use of biogas technology could provide a source of income for farmers by generating electricity or producing biogas for cooking and heating.

However, it is important to note that willingness to use biogas does not necessarily translate into actual adoption of the technology. Several barriers, such as lack of technical knowledge, limited access to financing, and inadequate infrastructure, can hinder the adoption and implementation of biogas technology. Therefore, efforts should be made to address these barriers and promote the adoption of biogas technology in a sustainable and inclusive manner.

Table 14: provides information about the study's dependent variable and its distribution among the study participants. The dependent variable is the willingness of farmers to adopt biogas technology, and the table shows that out of the 118 farmers, 89 (75.4%) were willing to use biogas, while 29 (24.6%) were not willing to use it. It is important to note here that 2 famers were undecided about this and were excluded from the model.

Table 14: Probit Analysis on the willingness to adopt biogas technology by farmers:

Model Information

Dependent Variable	20-Willingness to use Biogas[a]
Probability Distribution	Binomial
Link Function	Probit

a. The procedure models 1 as the response, treating 0 as the reference category.

Table 15. Categorical Variable Information

			N	Percent
Dependent Variable	Willingness to use Biogas	0	29	24.6%
		1	89	75.4%
		Total	118	100.0%

Table 15 presents the descriptive statistics of the continuous variables that were included in the Probit analysis. The variables include challenges, perception, factors, age, marital status, household size, educational level, farm experience, farm size, and monthly income. The mean values of these variables range from 2.4092 to 76025.42, with standard deviations ranging from 0.27382 to 35504.926. The minimum and maximum values of the variables are also reported.

Table 16 presents the result of the omnibus test, which compares the fitted model against the intercept-only model. The likelihood ratio chi-square value is 51.281, with 10 degrees of freedom and a significance level of less than 0.001. This result shows that the fitted model is statistically significant compared to the intercept-only model, χ^2(10) = 51.281, p < .001.

Table 16: Continuous Variable Information

		N	Minimum	Maximum	Mean	Std. Deviation
Covariate	Challenges	118	1.71	3.14	2.4092	.27382
	Perception	118	1.75	4.38	3.4195	.49125
	Factors	118	2.78	4.33	3.6648	.33126
	age	118	24	73	45.74	12.131
	Marital Status	118	1	3	1.81	.452
	Household Size	118	2	9	4.82	1.344
	Educational Level	118	1	4	2.36	.992
	Farm Experience	118	2	35	14.86	9.075
	Farm Size	118	1	22	5.68	3.632
	Monthly Income	118	15000	170000	76025.42	35504.926

Table17: Omnibus Test[a]

Likelihood Ratio Chi-Square	df	Sig.
51.281	10	<.001

Dependent Variable: 20-Willingness to use Biogas

Model: (Intercept), Challenges, Perception, Factors, 1-age, 3-Marital Status, 4-Household Size, 5-Educational Level, 6-Farm Experience, 7-Farm Size, 8-Monthly Income[a]

a. Compares the fitted model against the intercept-only model.

Table 18: Parameter Estimates

Parameter	B	Std. Error	Hypothesis Test	
			Wald Chi-Square	Sig.
(Intercept)	2.805	3.0179	.864	.353
Challenges	.807	.6438	1.573	.210
Perception	-.719	.3817	3.552	.059
Factors	-.851	.5453	2.437	.118
age	-.043	.0202	4.471	.034
Marital Status	-.095	.4751	.040	.841
Household Size	.018	.1426	.016	.900
Educational Level	1.150	.2306	24.883	<.001
Farm Experience	.043	.0251	2.929	.087
Farm Size	.136	.0715	3.632	.057
Monthly Income	-8.861E-7	6.2351E-6	.020	.887
(Scale)	1[a]			

Dependent Variable: 20-Willingness to use Biogas

Model: (Intercept), Challenges, Perception, Factors, 1-age, 3-Marital Status, 4-Household Size, 5-Educational Level, 6-Farm Experience, 7-Farm Size, 8-Monthly Income

a. Fixed at the displayed value.

Table 18 presents the results of the Probit analysis, which examines the relationship between the dependent variable (willingness to adopt biogas technology) and the independent variables (challenges, perception, factors, age, marital status, household size, educational level, farm experience, farm size, and monthly income). The table reports the estimated coefficients, standard errors, and the results of the hypothesis tests (Wald chi-square and significance level) for each variable.

The intercept has a coefficient of 2.805, which indicates the baseline probability of farmers' willingness to adopt biogas technology. The variable of age has a negative coefficient of -0.043, $p = 0.034$, indicating that older farmers are less willing to adopt biogas technology than younger farmers. Educational level has a positive coefficient of 1.150, $p < .001$, indicating that farmers with higher education levels are more willing to adopt biogas technology. The other variables, challenges, perception, factors, marital status, household size, farm experience, farm size, and monthly income, do not have significant effects on farmers' willingness to adopt biogas technology.

The parameter estimates for the probit analysis provide valuable insights into the factors that influence farmers' willingness to adopt biogas technology. The significant coefficient of age suggests that older farmers are less willing to adopt biogas technology than younger ones. This result is consistent with previous studies that have found a positive relationship between age and technology adoption (Paxton et al., 2011). Paxton et al. (2011) discovered that there was a significant correlation between the usage of precision agriculture technologies and younger, higher-educated producers. It is possible that older farmers may have lower levels of education and may be more resistant to change compared to younger farmers. Therefore, targeted efforts to educate and raise awareness among older farmers may be necessary to increase their willingness to adopt biogas technology.

On the other hand, the positive coefficient of educational level is consistent with previous research that found a positive relationship between education and technology adoption (Uematsu 2010; Singh 2000; Morris & Venkatesh 2000). According to the research by Uematsu, there is a positive correlation between education and the adoption of technology. In the agricultural sector, farmers with higher levels of education have better access to information and knowledge that can enhance their farming operations. Education may provide farmers with the necessary skills and knowledge to understand the benefits of biogas technology, and to operate and maintain the biogas systems. Therefore, educational programs and extension services can be developed to enhance farmers' understanding of the technology and promote its adoption.

The non-significant coefficients of challenges, perception, factors, marital status, household size, farm experience, farm size, and monthly income suggest that these factors do not significantly influence farmers' willingness to adopt biogas technology. However, these findings may be context-specific and may vary depending on the socio-economic and cultural contexts of the study area. Therefore, it is important to conduct further research in different contexts to validate these findings.

Overall, the parameter estimates for the probit analysis suggest that age and education are the most significant factors that influence farmers' willingness to adopt biogas technology. These findings have important implications for policymakers and practitioners working in the renewable energy sector, as they highlight the need to target educational programs and awareness campaigns towards older and less educated farmers to increase the adoption of biogas technology

Specifically, the parameter estimate for Educational Level indicates that for every one-unit increase in educational level, the odds of willingness to use biogas increase by a factor of e^1.150 = 3.15. Additionally, the parameter estimate for age suggests that for every one-year increase in age, the odds of willingness to use biogas decrease by a factor of e^-.043 = 0.958.

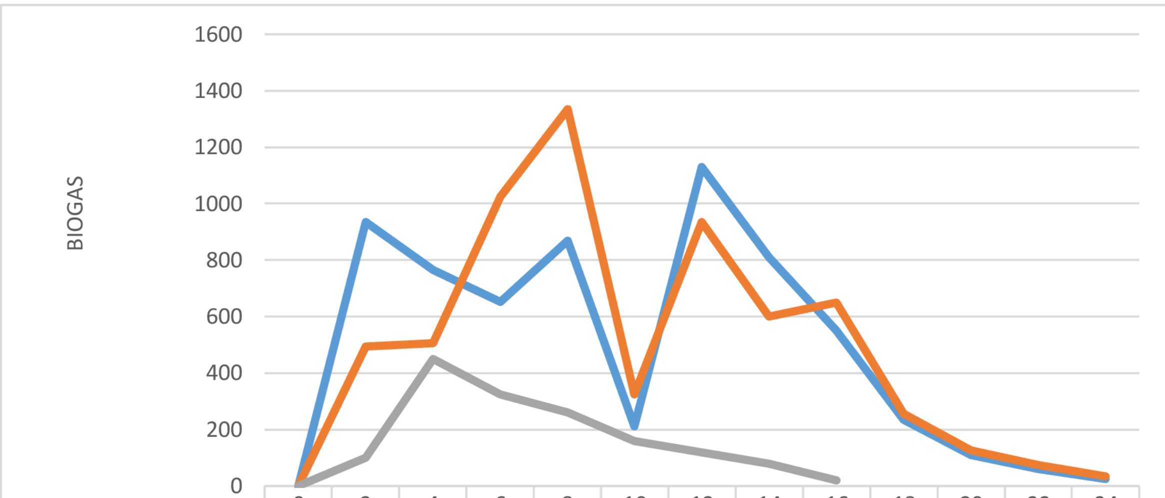
The results of the probit analysis show that both educational level and age are significant predictors of willingness to use biogas as a source of energy. The parameter estimate for educational level indicates that higher levels of education are positively associated with an increased willingness to use biogas. This finding is consistent with previous studies as discussed above.

The implications of these results for the study are that educational campaigns promoting the benefits of biogas as a renewable energy source should be targeted towards younger individuals with higher levels of education. This could increase the adoption of biogas as an alternative source of energy, which would have positive environmental and economic implications. Additionally, policymakers should consider offering incentives to individuals who adopt biogas as a source of energy, particularly those who are older and may be less likely to use it voluntarily.

In conclusion, the results of the probit analysis indicate that both educational level and age are significant predictors of willingness to use biogas. These findings are consistent with previous studies and suggest that educational campaigns and policy incentives could be effective in promoting the adoption of biogas as a renewable energy source.

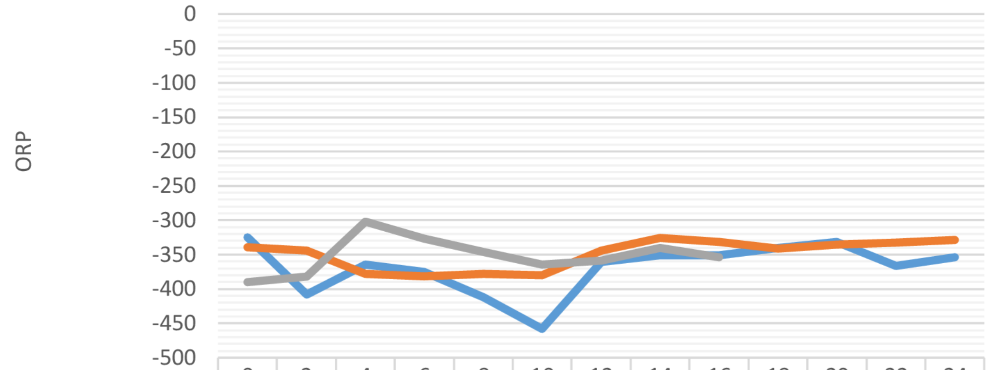
5.7. Results of the two batch anaerobic digestion (AD) experiments.

Figures 4, 5 and 6 shows the results of the biogas production, Oxidation Reduction Potential and pH from sugarcane bagasse using different fermentation strategies. The results of the assays were measured in terms of pH, oxidation-reduction potential (ORP) in millivolts (mV), and gas volume in milliliters (ml) produced over a period of 24 days.



	0	2	4	6	8	10	12	14	16	18	20	22	24
Batch- SC	0	935	765	652	870	210	1130	810	550	235	110	60	25
Batch- SC+Cow	0	495	505	1025	1335	325	935	600	650	255	125	75	35
Inoculum	0	100	450	325	260	160	120	80	20				

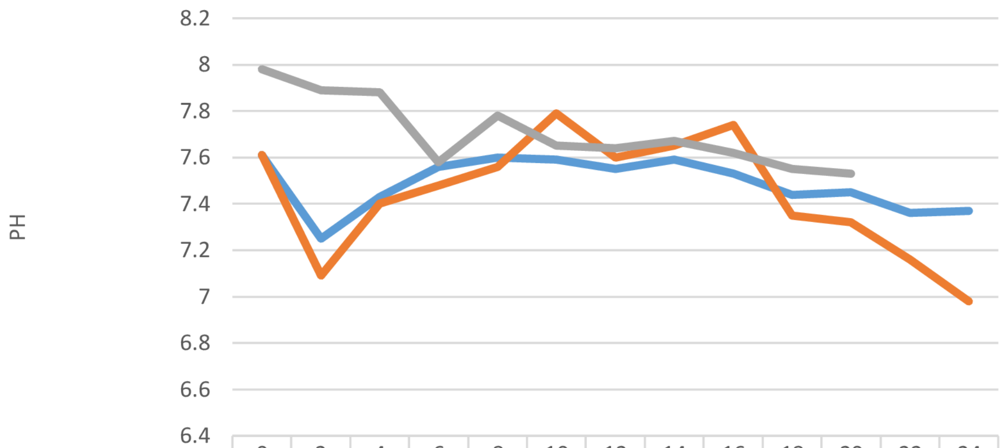
Figure 4. Variation in Biogas production (ml) of Sugarcane bagasse (SB) and co digestion of Sugarcane bagasse and Cow manure, over a period of 24 days.



DAY	0	2	4	6	8	10	12	14	16	18	20	22	24
Batch- SC	-325	-408	-365	-375	-412	-458	-361	-351	-351	-340	-332	-366	-354
Batch- SC+Cow	-339	-344	-379	-382	-378	-380	-345	-326	-332	-342	-336	-332	-329
Inoculum	-390	-382	-302	-327	-346	-364	-358	-340	-354				

DAY

Figure 5. Variation in Oxidation Reduction Potential (mV) of the batch tests over a period of 24 days.



Day	0	2	4	6	8	10	12	14	16	18	20	22	24
Batch- SC	7.61	7.25	7.43	7.56	7.6	7.59	7.55	7.59	7.53	7.44	7.45	7.36	7.37
Batch- SC+Cow	7.61	7.09	7.4	7.48	7.56	7.79	7.6	7.65	7.74	7.35	7.32	7.16	6.98
Inoculum	7.98	7.89	7.88	7.58	7.78	7.65	7.64	7.67	7.62	7.55	7.53		

Figure 6. Variation in pH of the batch tests over a period of 24 days.

The biogas volume produced was measured every two days. In figure 4, The bagasse-cow manure assay consistently produced higher gas volumes compared to the bagasse-only assay. For example, on day 2, the bagasse-cow manure assay produced 935 ml of gas, while the bagasse-only assay produced only 495 ml of gas. This trend continued throughout the entire duration of the assay, with the bagasse-cow manure assay producing a total of 6,360 ml of gas compared to only 5,542 ml produced by the bagasse-only assay.

These results are consistent with findings from previous studies that have also investigated the impact of co-digestion of agricultural residues with livestock manure on the biogas production process. For example, Tian et al. (2023) reported that the addition of pig manure to rice straw during anaerobic co-digestion resulted in increased biogas production compared to corn straw alone. Similarly, according to studies by Chen et al. (2020) and Wang et al. (2018), incorporating a co-substrate in anaerobic digestion often leads to an increase in biogas yields ranging from 1.27 to 3.46 times more than that obtained from mono-digestion. This is attributed to the positive synergistic effects established in the digestion medium, as well as the supply of essential nutrients.

The implications of the results of this study suggest that the addition of cow manure as a co-substrate to sugarcane bagasse may enhance the anaerobic digestion process and biogas production. This finding is important as it may contribute to the development of more sustainable and efficient biogas production processes, which can help reduce reliance on fossil fuels and promote a more sustainable energy mix.

The higher biogas yields from the bagasse-cow manure assay have significant implications for the potential use of sugarcane bagasse as a feedstock for biogas production. The addition of cow manure as a co-substrate not only increased the biogas yield, but also provided a source of nitrogen and other essential nutrients for microbial growth, which may have led to improved substrate degradation and biogas production (Wang et al., 2017). This suggests that using sugarcane bagasse in combination with cow manure could be a viable option for biogas production and waste management in sugarcane-producing regions.

The ORP values for the two systems as shown in figure 5m were also within the acceptable range for anaerobic digestion, i.e., -200 to -400 mV. The oxidation-reduction potential (ORP) of the biogas only strategy started at -339.4 mV and decreased over time to -328.8 mV, indicating a reduction in the oxidation potential of the system. On the other hand, the ORP of the cow manure strategy started at -324.8 mV and increased to -353.6 mV, indicating an increase in the oxidation potential of the system. The negative ORP values indicated that the fermentation was taking place under anaerobic conditions. The bagasse-cow manure assay exhibited a lower ORP compared to the bagasse-only assay at most time points, indicating a higher microbial activity and electron transfer in the presence of cow manure as a co-substrate.

The ORP values obtained in this study are consistent with the findings of other studies. For instance, Chotinatch et al. (2017), while researching on the effect of pH and ORP on biogas production at different organic loading rate tested discovered that the optimum of ORP during the acidogenesis and methanogenesis phase were -284 ‡ 32.71 mV and -335.63 ‡ 28.97 respectively. Similarly, Nghiem et al (2014) discovered that the ORP values increased to between -320 and -270 mV, from the natural baseline value of -485 mV, while studying oxidation reduction potential as a parameter to regulate micro-oxygen injection into anaerobic digester for reducing hydrogen sulphide concentration in biogas.

The higher microbial activity and electron transfer observed in the bagasse-cow manure assay could be attributed to the synergistic effect of the co-digestion of bagasse and cow manure. This is consistent with the findings of other studies that have shown that co-digestion of different substrates can enhance the performance of anaerobic digestion. For instance, a study by Esposito et al. (2012) showed that co-digestion of food waste and cattle manure resulted in higher biogas yields compared to mono-digestion of either substrate.

In Figure 6, after two days of fermentation, the pH of the biogas only strategy decreased to 7.09, while the pH of the cow manure strategy increased to 7.25. This suggests that the addition of cow manure had a buffering effect on the pH of the fermentation. However, this effect was not consistent throughout the entire duration of the assay, with the pH values fluctuating in both assays.

The pH is a critical parameter in anaerobic digestion, as it affects the microbial activity and performance of the digester. The observed fluctuation in pH values in both assays is consistent with findings from previous studies. For example, research by Zhou et al. (2016) on the mesophilic methane fermentation at different pH of 6.0, 7.0 and 8.0

revealed that biogas production could be enhanced by maintaining cultures at pH 7.0, indicating noteworthy implications for the expansion of biogas technology.

The buffering effect of cow manure on the pH observed in the bagasse-cow manure assay is consistent with the results of previous studies. For instance, research by Dongxue et al. (2021) on the co-digestion of corn straw and cow manure reported that the addition of cow manure increased the buffering capacity of the digester, resulting in a more stable pH during the fermentation process. The buffering effect of cow manure can be attributed to its high content of alkaline substances such as ammonia and bicarbonate ions, which help to neutralize acidic compounds produced during the fermentation process.

The implications of the observed pH fluctuations and buffering effect on the overall performance of the digester in this study are significant. The fluctuations in pH values can lead to reduced microbial activity and biogas production, as well as the accumulation of volatile fatty acids and other organic acids, which can inhibit the fermentation process. The buffering effect of cow manure observed in the bagasse-cow manure assay suggests that the addition of cow manure can help to stabilize the pH and improve the overall performance of the digester. However, further research is needed to optimize the co-digestion process and identify the optimal ratio of bagasse to cow manure for maximum biogas production.

To assess the statistical significance of the difference in biogas yield between the various co-digestion strategies, we performed a one-way analysis of variance (ANOVA) using the Statistical Package for the Social Sciences (SPSS). The null hypothesis was that the fermentation strategy does not affect the yield of biogas from sugarcane bagasse.

Table 19 presents the sum of squares (SS), degrees of freedom (df), mean square (MS), F-value, and significance level (Sig.) for the between groups and within groups factors, as well as for the total variation.

Table 19: ANOVA

Biogas					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	2.462	1	2.462	.000	.997

Within Groups	3960161.385	24	165006.724		
Total	3960163.846	25			

The results of the ANOVA show that the F-value for the between groups factor is 0.000, and the significance level (Sig.) is 0.997. This indicates that there is no significant difference between the mean biogas yield of the two digestion strategies. As the significance level is much higher than the alpha level of 0.05. Thus we fail to reject the null hypothesis, which states that the fermentation strategy does not affect the yield of biogas from sugarcane bagasse. This is also in line with the findings of Chao et al. 2016 which found out that there was no significant difference in methane yield of co digestion of banana peels and cow manure.

The non-significant result of the ANOVA test could be due to several reasons. One possible explanation is that the cow manure used as co-substrate did not have a significant impact on the overall biogas yield, as the amount used might have been too small to make a significant difference. Another explanation could be that the inoculum used was not strong enough to make a significant difference in biogas yield.

6. Conclusions

The study shows that the main challenges of sugarcane production in the study area are the lack of sugar processing infrastructures, the lack of government support, the lack of market potential and the high cost of starting capital and production inputs. These challenges could potentially hinder the adoption and utilization of sugarcane bagasse as a feedstock for biogas production.

The awareness about biogas is another significant factor, with a mean value of 3.83. This suggests that increasing awareness about biogas could be crucial in promoting the adoption and utilization of sugarcane bagasse as a feedstock for biogas. This could involve educating farmers and biogas producers about the benefits of biogas production and its potential as a source of renewable energy.

The awareness of sugarcane bagasse as a feedstock for biogas has a mean value of 3.73, indicating that this factor is also significant. This suggests that there is a need to increase awareness about the potential of sugarcane bagasse as a feedstock for biogas. Educating farmers and biogas producers about the potential of sugarcane bagasse as a feedstock for biogas could be crucial in promoting its adoption and utilization.

The awareness of sugarcane has a mean value of 5, indicating that this factor is not significant. This suggests that farmers and biogas producers are already aware of sugarcane as a crop and its potential as a cash crop. Therefore, increasing awareness of sugarcane may not be necessary to promote its adoption and utilization as a feedstock for biogas.

The anaerobic biogas production from sugarcane bagasse, the addition of cow manure as a co-substrate can have an impact on the initial microbial activity and electron transfer in the digester, resulting in a lower ORP. The use of cow manure as a co-substrate may have a buffering effect on the medium, resulting in a slightly higher pH in some cases. The bagasse-cow manure assay consistently produced higher gas volumes compared to the bagasse-only assay. The bagasse-cow manure assay produced a total of 6,360 ml of gas compared to only 5,542 ml produced by the bagasse-only assaybased on ANOVA results, we cannot conclude that there is a significant difference in biogas yield between the two digestion strategies (i.e., with or without cow manure as a co-substrate).

Therefore, both digestion strategies appear to be equally effective in producing biogas from sugarcane bagasse.

As well. The results of this study indicate that sugarcane bagasse has potential as a feedstock for biogas production and should be further explored as a renewable energy source. However, further research may be required to confirm this conclusion and investigate other factors that can affect biogas production from sugarcane bagasse

6.1. Impact of the thesis

The study identifies the availability of sugarcane bagasse as a critical factor for the production of biogas from sugarcane bagasse. The study also indicates that increasing awareness of biogas and sugarcane bagasse as a feedstock for biogas could be crucial to promoting its adoption and utilisation. These findings could inform policy makers, researchers and stakeholders about the factors that influence the use of sugarcane bagasse for biogas production and the strategies that could be used to promote its adoption and use.

The findings of this thesis could have important implications for the bioenergy industry. The results suggest that this waste material could be used to produce renewable energy in the form of biogas, which could help to reduce reliance on non-renewable sources of energy such as fossil fuels.

Overall, the results of this thesis provide valuable insights into the potential of sugarcane bagasse as a feedstock for biogas production. Further research could focus on optimizing the digestion process by testing different ratios of sugarcane bagasse and cow manure, as well as exploring the potential of other co-substrates.

6.2. Recommendations

1. The government should invest in the development of sugar processing infrastructures to enhance the utilization of sugarcane bagasse as a feedstock for biogas production.
2. The government should provide support to farmers and biogas producers in the study area to mitigate the high cost of starting capital and production inputs for sugarcane production and biogas generation.
3. Stakeholders should explore and create new markets for biogas production from sugarcane bagasse to increase its potential as a source of renewable energy.
4. Awareness campaigns should be developed to educate farmers and biogas producers about the benefits of biogas production and its potential as a source of renewable energy.
5. Educational programs should be designed to inform farmers and biogas producers about the potential of sugarcane bagasse as a feedstock for biogas to promote its adoption and utilization.
6. The government should encourage and promote public and private investments in the biogas sector to accelerate the adoption and utilization of sugarcane bagasse as a feedstock for biogas.
7. Further studies should be conducted to optimize the use of cow manure as a co-substrate with sugarcane bagasse and to determine the optimal ratio of cow manure to sugarcane bagasse.

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Appendices

List of the Appendices:

Appendix 1: Schedule of Master Thesis

Activity	Time Frame
Writing and Approval of Proposal	
Further Literature Review	
Design of Methodology and Approval	1 week
Questionnaire Design and Approval	2 weeks
Data Collection and Collation	August 1st – December 3rd
Data entry and Analysis	December 19th – January 30th
Interpretation of Results	February 3rd – March 20th
Conclusion and Recommendation	April 11th – 18th
Review of Thesis	April
Final Submission	

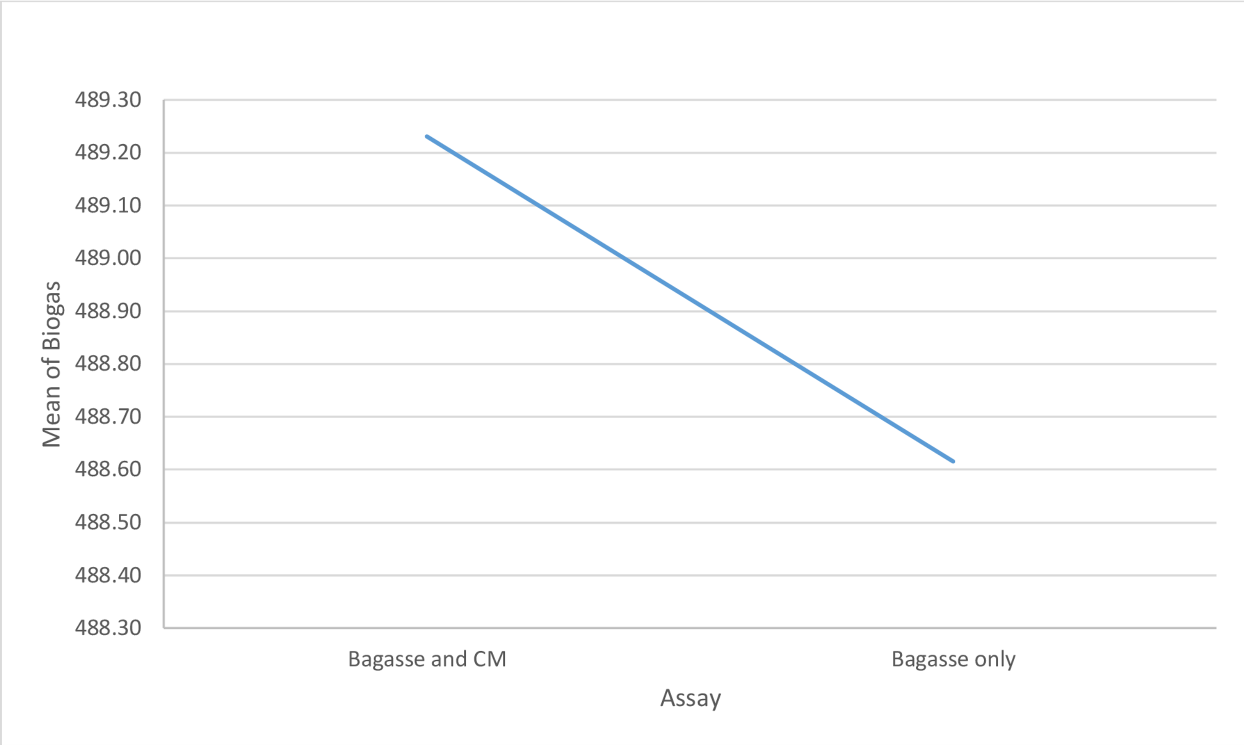
Appendix 2: Daily readings of pH, ORP and Biogas Production from the Sugarcane bagasse and cow manure batch assay.

Day	Date / time	ph	ORP [mV]	Gas volume [ml]
0	3/25/23 17:00	7.61	-339.4	0
2	3/27/23 17:00	7.09	-344.1	495
4	3/29/23 17:00	7.4	-378.5	505
6	3/31/23 17:00	7.48	-381.6	1025
8	4/2/23 17:00	7.56	-377.8	1335
10	4/4/23 17:00	7.79	-379.8	325
12	4/6/23 17:00	7.6	-344.6	935
14	4/8/23 17:00	7.65	-325.7	600
16	4/10/23 17:00	7.74	-332	650
18	4/12/23 17:00	7.35	-341.5	255
20	4/14/23 17:00	7.32	-335.6	125
22	4/16/23 17:00	7.16	-332.4	75
24	4/18/23 17:00	6.98	-328.8	35

Appendix 3: Daily readings of pH, ORP and Biogas Production from the Sugarcane bagasse batch assay.

Day	Date / time	Ph	ORP [mV]	Gas volume [ml]
0	3/25/23 17:00	7.61	-324.8	0
2	3/27/23 17:00	7.25	-408.2	935
4	3/29/23 17:00	7.43	-364.8	765
6	3/31/23 17:00	7.56	-375	652
8	4/2/23 17:00	7.6	-412.2	870
10	4/4/23 17:00	7.59	-458	210
12	4/6/23 17:00	7.55	-360.8	1130
14	4/8/23 17:00	7.59	-351.3	810
16	4/10/23 17:00	7.53	-351.3	550
18	4/12/23 17:00	7.44	-340	235
20	4/14/23 17:00	7.45	-332	110
22	4/16/23 17:00	7.36	-366.1	60
24	4/18/23 17:00	7.37	-353.6	25

Appendix 4: Means Plot of the two batch tests.



Appendix 5: Taking samples for pH and ORP test.

Appendix 6: A picture with some of the farmers in the study area

Appendix 7: A picture with the head of farmers in study area on his sugarcane farm.