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Review of Factors Affecting the Acceptance of Biogas Technology in Nigeria

BACHELOR'S THESIS

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Declaration

I hereby declare that I have done this thesis entitled Review of factors affecting acceptance of biogas technology 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. I declare that I have used AI tools in accordance with the university's internal regulations and principles of academic integrity and ethics. Appropriate references to the use of those tools have been made in the thesis.

In Prague, 17th April 2025.

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Jerry Efosa Osawaru

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Abstract

The vast amount of waste generated daily in Nigeria holds significant potential to serve as a sustainable energy source through the application of biogas technology. This technology offers a balance between waste generation and energy consumption by converting organic waste materials into biogas, a renewable energy source. Nigeria records extremely high volumes of annual waste, much of which is improperly disposed of, highlighting the country's potential to become a commercial biogas-producing nation. However, this potential remains largely untapped and biogas has not yet been effectively integrated into the national energy mix. This thesis presents a review based on the literature that analyses data on biogas development in Nigeria, with a focus on the factors that influence the acceptance of biogas technology. The findings indicate that the limited uptake and development of biogas in Nigeria is attributable to a combination of factors. These include the country's heavy reliance on fossil fuels, poor economic structure, inadequate and unregulated waste management systems, lack of supportive government policies, weak implementation of existing policies, discontinued research efforts, insufficient funding, infrastructural limitations, and other technical, market, institutional, and socio-cultural barriers. The literature used in this review consists primarily of peer-reviewed scientific journals, international reports, and data obtained from reputable scientific databases. A critical observation was the evident lack of continuity in research efforts regarding biogas technology in Nigeria, particularly in the areas of acceptance and development.

Key words: Biogas technology, Nigeria, Energy, Waste management, Anaerobic digestion.

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List of the abbreviations used in the thesis

AD	Anaerobic Digestion
°C	Degree Celsius
BTU	British Thermal Unit
CH_4	Methane Gas
CO_2	Carbon Dioxide
ECN	Energy Commission of Nigeria
ESMAP	Energy Sector Management Assistance Program
IAEA	International Atomic Energy Agency
kg	Kilogram
ktoe	Kiloton of Oil Equivalent
kW	Kilowatt
kWh	Kilowatt-hour
LPG	Liquefied Petroleum Gas
m^3	Cubic Meter
MSW	Municipal Solid Waste
MW	Megawatt
PRISMA	Preferred Reporting Items for Systematic Reviews and MetaAnalyses
PV	Photovoltaics
TCN	Transmission Company of Nigeria
UNIDO	United Nations Industrial Development Organization
USD	United States Dollar
WB	World Bank

1. Introduction

Biogas is a crude form of natural gas; it is a type of biofuel naturally produced from the decomposition of organic matter (plant and animal products) by bacteria in an anaerobic (oxygen-free) environment. It is made primarily of methane and carbon dioxide (Ramirez et al. 2015). Biogas technology has been around for a long time and its use has been enforced in most parts of the world (Macharia 2015). According to Kouglas & Angelidaki (2018), anecdotal evidence suggests that biogas was used in Assyria during the 10th century BC to heat bath water and in Persia during the 16th century. Jan Baptita Van Helmont, in the 17th century, first discovered that flammable gases could evolve from decaying organic matter. Count Alessandro Volta in 1776 concluded that there was a direct relationship between the amount of decaying organic matter and the amount of flammable gas produced (Chasnyk 2015). However, Sir Humphry Davy in 1808 discovered that methane was present in the gases produced during the anaerobic digestion of cattle manure (Macharia 2015).

In 1859, the first biogas digestion plant was built in India at Leper Colony, Bombay, and in the 1950s the development of small biogas plants for use in rural households started (Macharia 2015). In China, prosperous families started to build biogas plants in the 1940s; however, biogas technology developed rapidly in the 1970s with much assistance from the Chinese government. In 2007, China was recorded as the world's largest biogas producer with about 3,500 medium to large-scale digester units and approximately 18 million farm households using biogas (Macharia 2015). In modern times, biogas has been extensively used in India and China, whereas Germany is currently the world's largest biogas-producing nation. Germany recorded the highest growth levels with over 4,000 biogas plants, most of which are built on farms for electricity and heat generation (Korbag et al. 2020).

The urban population of Nigeria in 2030 is estimated to be between 46 and 54% of the total population, which is also estimated to be about 250 million. This is an indication that a large proportion of citizens will still be living in rural areas. Already, the country is facing an energy crisis involving both commercial and traditional energy resources. Petroleum products have been in acute shortage in urban areas since the dawn of the 1990s, although less acute incidents have occurred since 1975. Water lettuce, cassava leaves, livestock manure, and agricultural wastes are among the organic waste items that have been identified as possible feedstocks for the production of biogas in Nigeria. These resources provide a feasible path toward the production of renewable energy, coupled with industrial and urban waste. (Akinbami et al. 2014).

Nigeria produces over 227,500 tons of animal waste every day, which has a substantial potential for the production of biogas, a resource that might be used to generate electricity (Akinbami et al. 2014). According to estimations, each kilogram of fresh animal manure in Nigeria can produce 0.03 m^3 of biogas, which might result in a daily production of roughly 6.8 million m^3. In addition, 20 kg of municipal solid waste (MSW) per capita has been estimated to be generated annually in the country. By the 1991 census figure of 88.5 million inhabitants, the total generated MSW will be at least 1.77 million tonnes every year. With increasing urbanisation and industrialisation, the annual MSW generated will continue to increase (Mwirigi et al. 2014).

Biogas production may therefore be a profitable means of reducing or even eliminating the menace and nuisance of urban waste in many cities by recycling them (Roubik et al. 2020). Presently, biogas is not included in the national energy equation. However, this is not to say that a few units of biogas digesters are not already used in both the urban and rural segments of the country for various activities. In a recently concluded study, a 6.0 m^3 family-sized biogas digester was shown to generate 2.7 m^3 of biogas per day to meet the cooking requirement of a household with an average size of 9.0 people. This project has been estimated to have an initial investment cost of N41,088 (about US$500), annual expenditure of N5,909 (about US$70) and an annual benefit of N13,347 (about US$160) (Mwirigi et al. 2014). Although the financial analysis of this project declares it to have good economic potential, its high initial cost may make it inaccessible to most of its intended users, the poor urban and rural households. Unless some measures are adopted to reduce its capital cost and economically aid its intended users, biogas use could turn out to be another fuel for high-income households, thus defeating the objective of penetrating low-income households (Mengistu et al. 2016).

With this background information, and in order to project biogas use into the future, a three-scenario analysis of its market penetration has been adopted. The assumptions underlying this scenario analysis are: population growth, household income, government intervention and substrate availability. Using the 1991 National Population Commission census and the annual growth rate of the population gives the population projections and the associated total number of households. Based on the fact that the projections of the population and associated number of households already give a cumulative growth trend, the three adopted scenarios are based on the following assumptions:

- Low Biogas Growth Scenario = 0.1% of the households per annum adopt biogas digesters

- Moderate Biogas Growth Scenario = 0.5% of the households per annum adopt biogas digesters

- High Biogas Growth Scenario = 1.5% of the households per annum adopt biogas digesters

As a result of population increase, both developed and developing countries are faced with issues concerning the security of future energy and more profitable use of natural resources. However, such problems related to present and future energy can be solved using renewable energy (Swayer et al. 2019). Among the different sources of energy that have been explored, biogas offers one of the best alternative options as it presents an available opportunity to improve sustainable development through energy security. While the combustion of biogas, like natural gas, produces carbon dioxide (CO_2)—a greenhouse gas—the carbon in biogas originates from atmospheric carbon dioxide fixed in plant matter. Therefore, biogas production is carbon-neutral and does not add to greenhouse gas emissions, thereby reducing them (Alhassan et al. 2019).

One of the main benefits of biogas is the reduction of waste, which results in a cleaner environment. Waste material is transformed into a useful resource by being used as a substrate for anaerobic digestion during biogas production (Paolini et al. 2018). Unlike fossil fuels, which consist of the remains of organisms preserved in rocks in the Earth's crust with high carbon and hydrogen content and decompose over time to form non-renewable crude oil, biogas is a permanently renewable energy source due to anaerobic digestion (Paolini et al. 2018). Anaerobic biogas digestion helps improve the energy balance of a country, protects the environment, and preserves its natural resources (Swayer et al. 2019). The use of biogas reduces greenhouse gas emissions and lessens the severity of global warming. In addition, the use of biogas in a country helps reduce its dependence on imported fossil fuels (Alhassan et al. 2019). Other benefits of biogas usage and the factors affecting its acceptance in Nigeria will be discussed in detail in this thesis.

2. Literature Review

2.1. Background

Nigeria is a 36-state federal constitutional republic that includes Abuja as its Federal Capital Territory (FCT). The nation, which is in the West African subregion, is bordered by Cameroon to the east, Benin to the west, Niger to the north, and the Gulf of Guinea in the Atlantic Ocean to the south. It has a surface area of around 1 million km² and an estimated population of over 200 million people, with an average annual growth rate of about 2.6%. It is currently the most populous country in Africa and the seventh most populated nation in the world (Ifegbesan et al. 2016; Akintade 2021; NHC 2022).

The economy expands at an average rate of 6% each year and is primarily dependent on the export of oil products. A total of 924,000 km² make up the country's land area, of which 33% is arable—sown once every harvest—and 3.1% is cultivated with perennial crops. The tropical climate of the country, marked by high humidity in the southern region and high temperatures with an annual average of 27°C, promotes extensive agriculture. The nation is endowed with a wealth of natural resources, including crude oil, natural gas, iron ore, limestone, coal, tin, lead, and zinc (Ifegbesan et al. 2016). It also has solar energy, especially in the north, hydropower (including 277 small hydropower sites with a cumulative potential of 3,500 MW), wind and other renewable energy sources, mostly in the northern region and along the coastline.

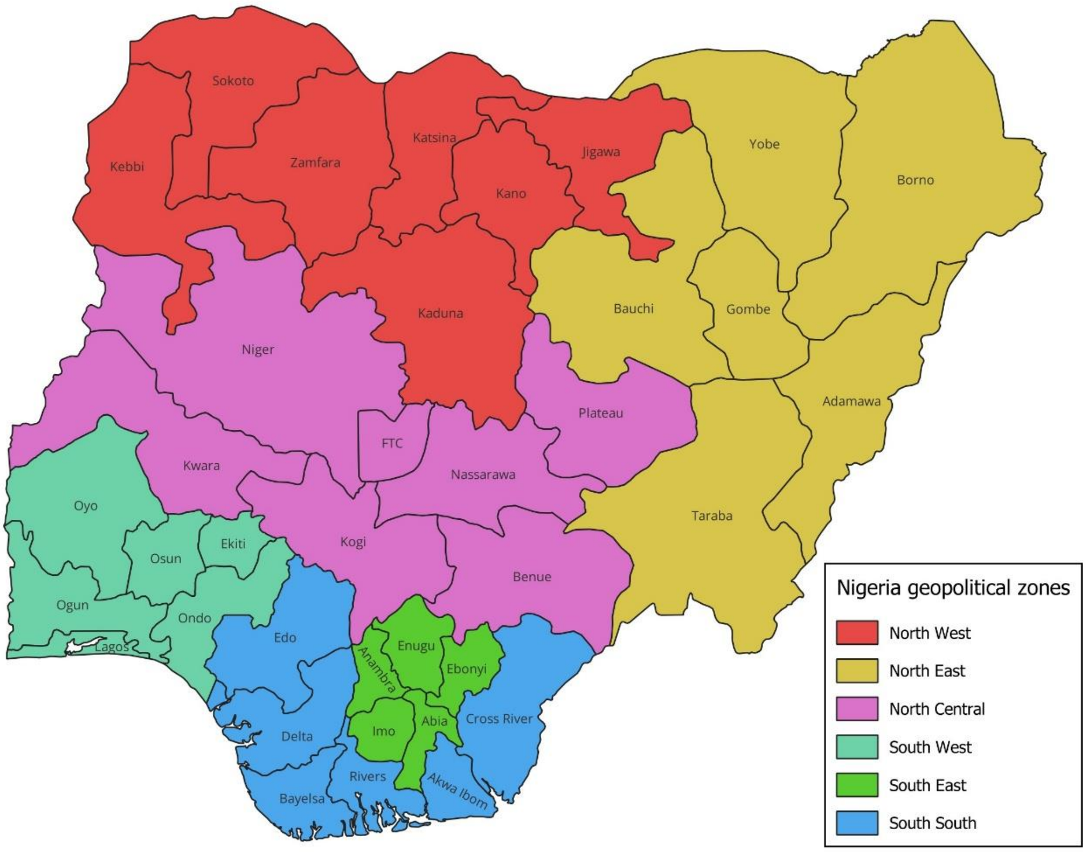
As a result of the high and growing population, enormous amounts of waste are inevitably produced every day, without an efficient waste management system in place for proper disposal. Additionally, more energy is needed to meet the rising demand (Akinbami et al. 2014). Meanwhile, the widespread waste produced daily can be used as an energy source to provide sufficient energy for the population through the use of biogas technology.

The nation requires a robust waste management system to handle the massive volumes of waste produced each day. The use of biogas technology has the potential to maintain equilibrium between waste generation and energy consumption, as the technology is based on the production of energy in the form of biogas from organic waste materials (Itodo et al. 2021). Nigeria's warm climate allows for the anaerobic digestion (AD) of organic waste without the need for additional heating. Therefore, the acceptance and use of biogas technology could be one of the most effective means of reducing waste, generating energy and protecting the environment in Nigeria.

Although biogas technology is a well-established solution in many parts of the world, including Germany, the United Kingdom, France, Switzerland, Norway, Denmark, Austria, Sweden, the Netherlands, the Republic of Korea, China, and India, its rate of development is still very low in Nigeria and most African nations. The adoption and rapid growth of biogas technology in most European countries can be attributed to several national initiatives, particularly the Renewable Energy Directives (RES) developed by the European Union.

The use of biogas for various purposes, including the generation of electricity, injection into natural gas pipelines, district heating, and as fuel for cars, buses, and trains, is common in Europe, the United States, and Latin America, where biogas technologies are frequently applied on a large scale. On the contrary, biogas technology is used on a small or household scale in Asia and several African nations, where the generated biogas is typically used for domestic tasks such as cooking and lighting. Clearly, to accelerate the development of biogas technology in Nigeria, proper preparation is required for the pre-design, design, operation, and post-design phases of biogas plants (Akinbami et al. 2014).

Figure 1. Map of Nigeria Showing its 36 States



Source: Akintade 2020; NHC 2022

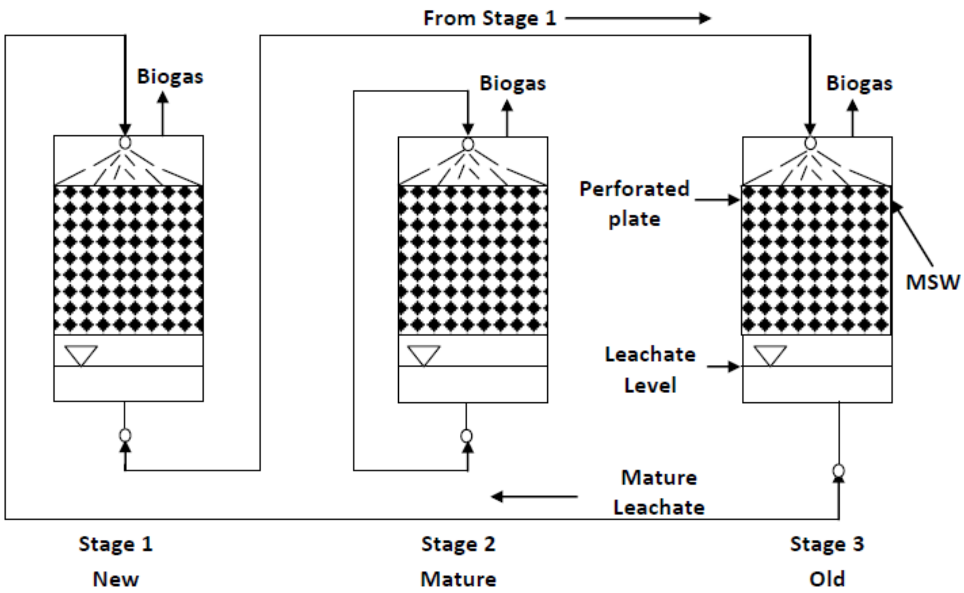
2.2. Biogas Technology

Biogas, often referred to as compost gas, swamp gas, or sewer gas, is a naturally clean and renewable source of energy derived from the decomposition of organic matter (Prakash et al. 2005; Swayer et al. 2019). Biogas, which consists of approximately 55% to 65% methane and 30% to 40% carbon dioxide, has a calorific value of 5000 to 5500 cal/kg and is suitable for cooking, lighting, drying, and as fuel for internal combustion engines (Prakash et al. 2005).

A biogas plant is a set-up of equipment that produces a methane-rich combustion gas from fermentable organic matter. It operates by subjecting the organic materials to decomposition by microorganisms in the absence of air, resulting in the production of methane, water, and carbon dioxide. This process occurs naturally and is termed anaerobic decomposition (Khoiyangbam et al. 2011). The anaerobic decomposition of organic matter takes place in a container called a digester. Animal waste, urban waste, and crop residues are commonly used materials as feedstock. Other materials used include fruit and vegetable waste, rice husk, leaves and branches of trees, sugarcane trash, cotton dust, and tobacco waste. Any easily biodegradable organic cellulose material from plant or animal sources serves as a potential raw material to produce biogas (Roubik & Mazancova 2020).

Biogas plants are classified as batch type and continuous type. The batch-type biogas plant requires feeding once every 50 to 60 days; 8 to 10 days after feeding is required to continuously supply gas for 40 to 50 days until the digestion of organic materials is completed. It is then emptied and refilled after some time. A consistent supply of gas through a conventional gas holder is maintained by charging and emptying the batteries of digesters one at a time. These types of biogas plants require a large amount of labour and capital to install and operate, and are only economical when operated on a large scale. These types of plants are mostly operated in European countries and are not suitable for operation in Nigerian rural areas (Prakash et al. 2005).

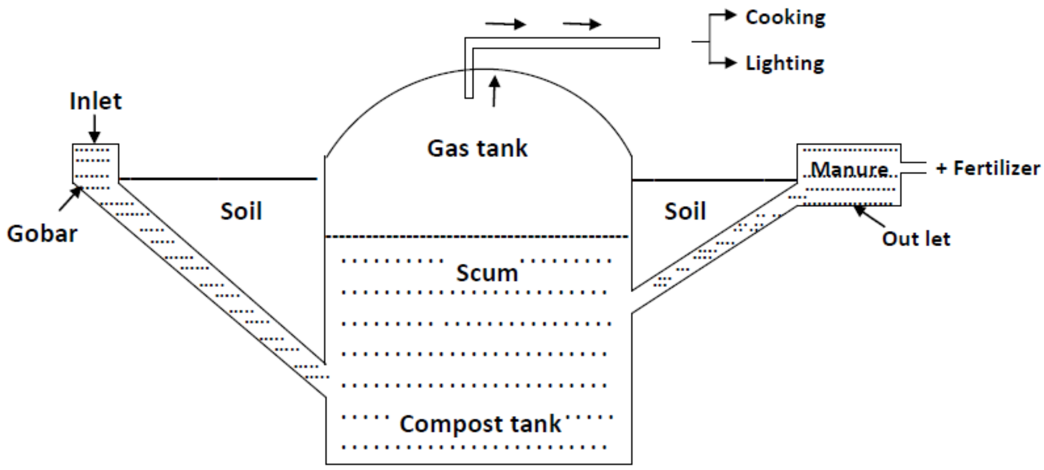
Figure 2. Batch Type Biogas Plant



Source: Prakash et al. 2005

The continuous plant demands a daily feed input with a specific amount of biomass. The biomass is completely digested as it slowly passes through the digester, and the slurry is discharged through an outlet. Retention time, the period during which biomass remains in the digester, depends on the type of material used as biomass and the operating temperature. This type of plant operates continuously and stops only to allow for the removal of sludge (undigested organic matter residue). The feeding method of these plants aligns with daily waste generation, does not require storage, and is best suited for small-scale biogas production and individual ownership. These types of plants are more common in Nigeria and its developing neighbours (Prakash et al. 2005; Raja & Wazir 2017).

Figure 3. Continuous Type Biogas Plant



Source: Prakash et al. 2005

Saleh (2015) distinguished three main types of simple biogas plants: balloon plants, fixed dome plants, and floating drum plants. The fundamental architectural components of small-scale biogas reactors are the same for all three types: an airtight digesting chamber or vessel with input and exit, an airtight biogas collection unit (for example, the upper half), and an extension chamber (Raja & Wazir 2017).

The balloon plants consist of a digester bag made of rubber or plastic and are suitable for the digestion of difficult feed materials. Red mud plastic (RMP), butyl, and Trevor's have successfully been used as balloon materials. The low construction cost, ease of transportation, simplicity in emptying, cleaning, and maintenance, as well as high digester temperatures, make it highly recommended in areas with consistently high and stable temperatures, where the balloon skin would not be easily damaged. However, this type of biogas plant has a very short lifespan (Prakash et al. 2005).

The fixed dome plants consist of a fixed, static gas space in an enclosed digester in which gas is stored. The pressure of the gas increases with the volume stored; therefore, the digester's volume has a maximum limit of 20 m^3 (Saleh 2015). This type of plant has a lifespan of more than 20 years due to the absence of moving or rust-prone steel parts. They are constructed underground, which saves space and protects them from harsh weather conditions. A major disadvantage of this plant is the significant fluctuation in gas pressure. Fixed dome plants also require the supervision of highly experienced technicians for proper construction (Prakash et al. 2005).

The floating drum plants consist of a digester and a moving gas holder that floats in a water jacket or in fermentation slurry. The gas is stored in the gas drum (Mustaq et al. 2016). This type of plant produces a good yield of biogas (Saleh 2015). Although its operation is simple and easy to understand—leading to fewer construction errors and constant gas pressure—the high construction and maintenance costs due to frequent painting and the presence of many corrodible metal parts are notable disadvantages (Prakash et al. 2005; Saleh 2015). However, in situations of uncertainty, floating drum plants are generally recommended and are universally applicable.

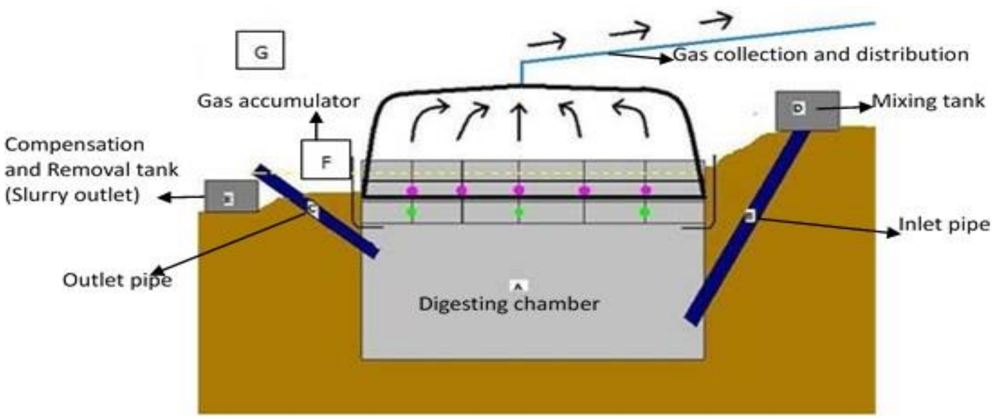
The digester volume (VD) is determined by the quantity of fermentable slurry (feed material, e.g., cow dung and mixing water) provided daily (Sd) and the retention time (RT). Factors affecting the biogas digestion process include temperature, pressure, `

solid-to-moisture ratio in biomass, pH value, feeding rate, and the carbon-to-nitrogen ratio (Prakash et al. 2005).

According to the schematic in Fig. 4, a typical biogas plant should include the following components: a digesting chamber, inlet pipe, outlet pipe, mixing tank, compensation and removal tank (slurry outlet), gas accumulator, and gas collection and distribution system. The digesting chamber, a deep circular well that is airtight, is where anaerobic decomposition or fermentation takes place. Organic solid waste and water are placed inside the chamber, and as a result, gas is formed and rises to the surface (Raja & Wazir 2017). Raw materials are introduced into the digester's base through the inlet pipe.

The slurry is discharged from the digester through the outlet pipe. The mixing tank is used to prepare a homogeneous mixture of raw materials usually equal parts biomass and water to feed into the digester. In the compensation and removal tank (slurry outlet), solid slurries and liquid waste are collected from the digestion chamber via a pipe and can be used as fertiliser due to their high nitrogen content. The gas generated is collected in the gas accumulator, which may be a concrete dome or a floating drum over the digestion chamber. The fixed gas collection and distribution system is located at the top of the gas accumulator and directs the gas to the consumption unit (Raja & Wazir 2017).

Figure 4. Basic Design Component of a Biogas Plant



Source: Raja & Wazir 2017

2.2.1. Biogas Production Technique and Use

An anaerobic digestion (AD) technique is used to produce biogas (Akintade 2021). The AD process is most frequently used to generate biogas from organic waste with high moisture content, such as agricultural residues, animal manure, and human waste. Animal waste is retained for an average of 20 to 40 days, while organic garbage is kept for an average of 60 to 90 days. Depending on the type of waste material, the resulting gas contains 55 to 80% methane (Raja & Wazir 2017).

Animal dung and other materials used as biogas feedstock are processed in enclosed spaces, where methane-producing and other anaerobic microorganisms act on the organic materials to break them down and produce methane gas (CH_4), carbon dioxide (CO_2), and trace amounts of other gases such as hydrogen sulphide (H_2S) (Akintade 2021). Anaerobic digestion occurs in two stages, facilitated by specific bacteria acting on different organic components. During the initial stage, acidogenic bacteria break down complex organic compounds into simpler sugars, glycerol, peptides, and alcohols. When these simpler compounds accumulate in sufficient quantity, methanogenic bacteria begin to transform them into methane. The atmospheric conditions in the chamber significantly influence these methane-producing microbes, and if conditions do not fall within a relatively narrow range, the process can either slow down or halt entirely (Raja & Wazir 2017).

The organic material is mixed with waste and manure in the receiving tank and heated to a temperature of 38 to 52 °C (100 to 125.6 °F)—a process applicable primarily to large-scale biogas plants—before being introduced into the digester where biogas is generated. The digested biomass slurry remains in the digester for two to three weeks before it can be used as crop fertiliser (Akintade 2021). Gas production can be accelerated and made more reliable by continuously feeding the digester with modest volumes of waste each day. Moreover, this approach helps maintain the nitrogen content of the slurry for use as fertiliser (Roubik et al. 2020).

The gas generated can be combusted to produce heat or used as fuel in gas engines connected to a generator to produce both heat and electricity—once trace contaminants such as water, hydrogen sulphide, and siloxanes have been removed. If CO_2 is also removed from biogas, the resulting gas, commonly referred to as biomethane, has the same properties as purified natural gas and can be used in all applications of natural gas, including transportation fuel, fuel cells that efficiently convert it to electricity, or as a raw material in the chemical industry. Biogas can be processed to remove CO_2 and other gases and used similarly to natural gas, either directly as a fuel or in place of kerosene in Nigeria, potentially preventing between 375 and 60,952 tons of CO_2 emissions (Akintade 2021; Jelinek et al. 2021).

Some fundamental information on production and domestic biogas usage is provided in Table 1.

Table 1. Some Basic Parameters on Biogas Production and Use

Parameters	**Details**
Digesting temperature	20ºC to 35ºC
Retention time	Depending on material, 3 – 40 days
Biogas generation	0.3 – 0.5m^3 gas/m^3 digester volume/day
Biogas energy contents	6KWh/m^3 = 0.61L diesel fuel
Food wastes	80 litre/kg; Retention time: 3 - 4 days
Food grain	500 litre/kg; Retention time: 5 days
Cow yields	0.4 m^3/kg dung; Retention time: 40 days
Human yields	0.02 m^3/person per day
Gas requirement (lighting)	0.1 to 0.15 m^3/h-one lamp
Gas requirement (cooking)	0.3 to 0.9 m^3/person per day

Source: Raja & Wazir 2017

2.2.2 Biogas Composition

The composition of biogas depends on the feed material, as shown in Table 2, and this influences the production of additional gases (Akintade 2021). Herout et al. (2011) stated that grass biomass produced nearly the largest amount of biogas after anaerobic digestion in batch fermenters at a temperature of 32 °C. Compared to municipal biowaste, abattoir waste, and animal faeces, only sewage sludge generated a higher yield. From the beginning of fermentation to the 20th day, grass biomass exhibited the highest biogas generation dynamics among all substrata, with 97% of total production completed within this timeframe.

Table 2. Percentage Composition of Methane in Some Typical Biomass Material

Material	Methane Percentage
Cattle Manure	65
Poultry Manure	60
Farmyard Manure	55
Kitchen Waste	60
Straw	59
Grass	70
Leaves	50
Water Hyacinths	67
Algae	63

Source: (Raja & Wazir 2017; Akintade 2021)

Methane and carbon dioxide are the main gases generated. The ignition temperature of biogas ranges around 500 °C, making it about 20% lighter than air. It is an odourless, colourless gas that burns with a clear blue flame, resembling that of LPG (liquefied petroleum gas) (Raja & Wazir 2017). In addition to methane and carbon dioxide, other gases produced include hydrogen sulphide, nitrogen, hydrogen, and oxygen, as shown in Table 3. Compared to methane, these gases are produced in modest quantities (Bharathiraja et al. 2018; Akintade 2021).

Table 3. Typical Composition of Biogas

Element	Percentage Composition
Methane (CH_4)	50 – 75
Carbon dioxide (CO_2)	25 – 50
Hydrogen sulphide (H_2S)	Traces
Nitrogen (N_2)	0 – 10
Hydrogen (H)	0 – 1
Water vapour (H_2O)	Traces
Oxygen (O_2)	0 – 2

Source: Bharathiraja et al. 2018; Swayerr et al. 2019; Itodo et al.

In a study by Calbry-Muzyka et al. (2022), a variety of factors were identified that affect the composition of trace biogas, using manure biogas as a case study. These include manure conditions, co-substrate conditions, digester type, digester conditions, and biogas contaminant type. As indicated in Table 3, several trace compounds present in raw biogas generated from anaerobic digestion can negatively impact its usefulness. However, these compounds can be eliminated through pretreatment or conditioning (Akintade 2021).

2.2.3 Benefits of Biogas Production

Small-scale biogas plants have been reviewed and found to have great potential and multiple benefits, especially in rural areas of developing nations such as Nigeria. The anaerobic digestion technology used for biogas production is cheaper and simpler than other biofuel technologies, making it ideal for domestic farming and small-scale applications. This technology can make a significant contribution to sustainable energy recovery from organic waste, particularly municipal and agricultural waste (Raja & Wazir 2017).

Organic waste from municipalities and farms is currently abundant and can be used for electricity generation (Oyedepo 2012). In addition to being a sustainable energy source, it is essential to fully utilise biomass, agricultural, forestry, animal husbandry, and fishery waste to reduce pollution and protect the environment from excessive greenhouse gas emissions. Waste management, particularly in Nigeria and her developing neighbours, remains one of the most serious environmental challenges. Two critical benefits of biogas technology are environmentally friendly waste handling and the production of clean, renewable energy.

Promotion and growth of agriculture and animal husbandry in rural regions can be further enhanced by integrating waste management, organic fertiliser production, and biogas utilisation. This combination can also improve rural living standards—one of the key strategies that could gradually reduce dependence on fossil fuels (Raja & Wazir 2017).

Other benefits of biogas production include cost-effectiveness, long service life (up to 20 years), the production of high quality organic fertiliser and the prevention of deforestation due to reduced pressure on fuelwood (Bharathiraja et al. 2018). Additionally, it supports job creation, agricultural development, reduced workload for women, and mitigation of air pollution (Akinbomi et al. 2014).

2.2.4 Limitations to Biogas Development

Despite technological advancements, the inefficiencies of current biogas production techniques remain a significant drawback. At present, there are limited innovative solutions to optimise the process and make biogas production abundant and affordable. This suggests that large-scale production is still not feasible. Although existing biogas plants can meet some energy needs, many governments remain hesitant to invest in the sector (Kemausour et al. 2018).

Methane concentrations in the atmosphere are estimated to have doubled to 1.7 ppm due to human activities such as cattle rearing, rice cultivation, and waste accumulation in large disposal sites. While this presents no direct health risk to humans, methane is a potent greenhouse gas—approximately 22 times more powerful than carbon dioxide (CO_2). Since methane is naturally produced in the atmosphere, it significantly contributes to the greenhouse effect. In fact, methane accounts for approximately 20% of the total increase in the greenhouse effect linked to human activity. Furthermore, global warming could lead to acidification of major oceans (Paolini et al. 2018).

Another drawback to biogas development is that even after compression and refinement, impurities can remain in the gas. If this biofuel is used to power automobiles, it may corrode engine components, leading to increased maintenance costs. Therefore, the gas is more suitable for water boilers, lamps, and stovetops (Khayal 2019).

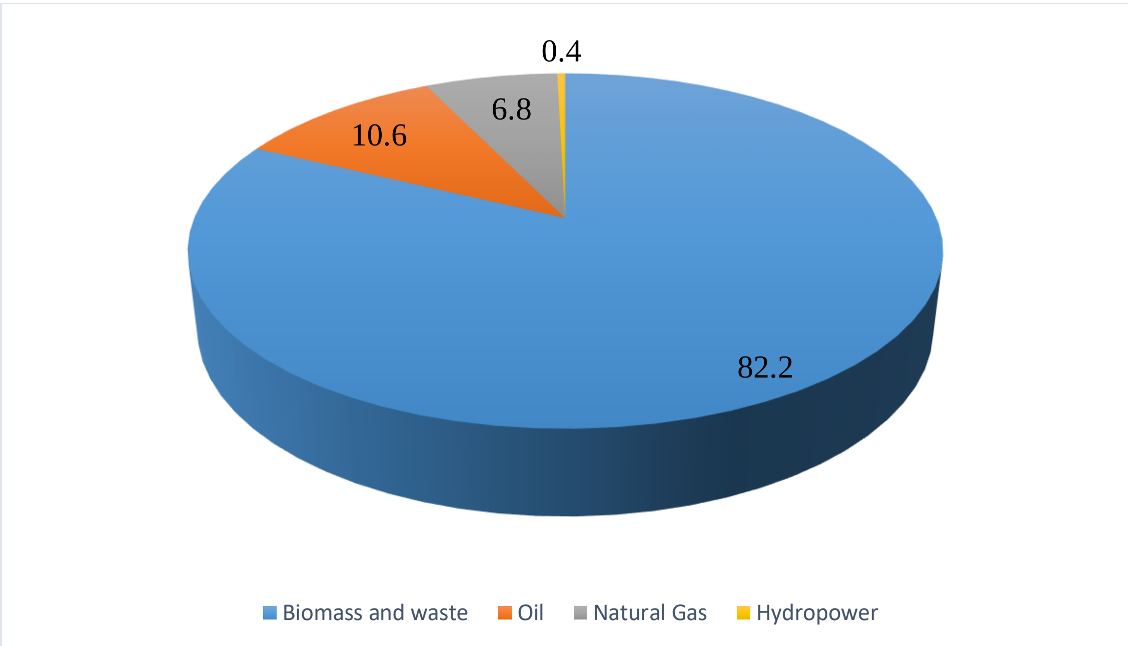
As with other renewable energy sources such as solar and wind, biogas production is affected by weather. The ideal temperature for bacteria to break down waste is approximately 37 °C. In colder climates, digesters require thermal energy to maintain a steady supply of biogas (Olugasa et al. 2018; Khayal 2019). Another limitation is that commercial biogas facilities are only viable in areas with abundant raw materials, such as food waste and manure. This makes biogas generation more practical for suburban and rural locations (Khayal 2019).

2.3. The Nigeria Energy Situation

2.3.1. Energy Supply in Nigeria

Nigeria's total primary energy production in 2020 was roughly 158,750 kilotonnes of oil equivalent (ktoe), according to the International Energy Agency (IEA 2020). The country's persistent reliance on conventional energy sources is demonstrated by the fact that the majority of this supply—82.2%—came from trash and biomass. In contrast, renewable energy sources continued to make up a small portion of the total. For example, only 0.4% of the energy supply came from hydropower. Despite their restricted use, wind and solar energy technologies still have a very little overall impact on the country's energy mix (IEA 2020).

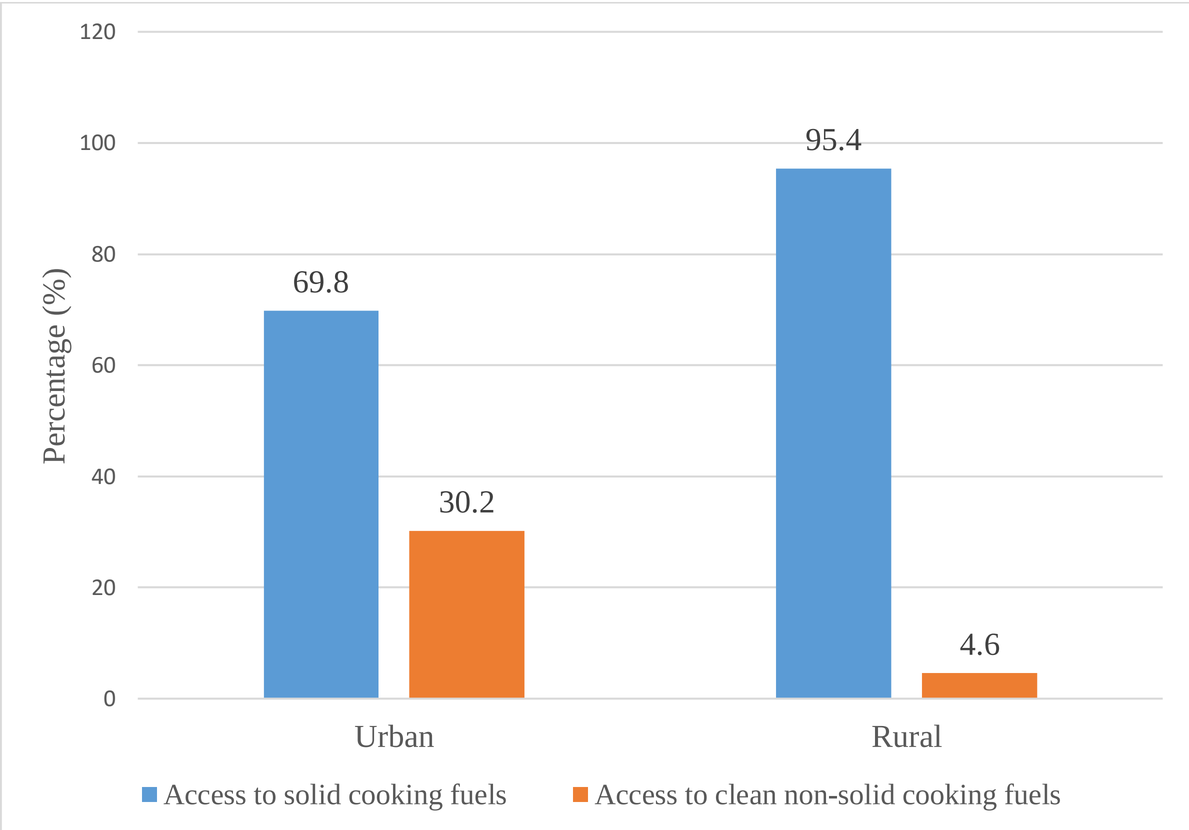
Figure 5. Percentage Primary Energy Supply in Nigeria by Source



Source: IEA 2020

The majority of Nigerians continue to rely on biomass as their main energy source, especially for cooking and heating, making it the nation's principal energy source (Akinbomi et al. 2014; Osunkwo et al. 2020). According to the Sustainable Energy for All (SE4ALL) project, Nigeria has made very little headway in expanding access to non-solid cooking fuels since 1990, despite continuous international efforts to promote clean energy. According to World Bank data from 2021, as of 2020, just 4.6% of people in rural areas and 30.2% of people in urban areas had access to clean, non-solid cooking fuels. This demonstrates a huge difference between urban and rural families in terms of access to cleaner energy options.

Figure 6. Percentage Access to Cooking Fuels in Urban and Rural Areas of Nigeria

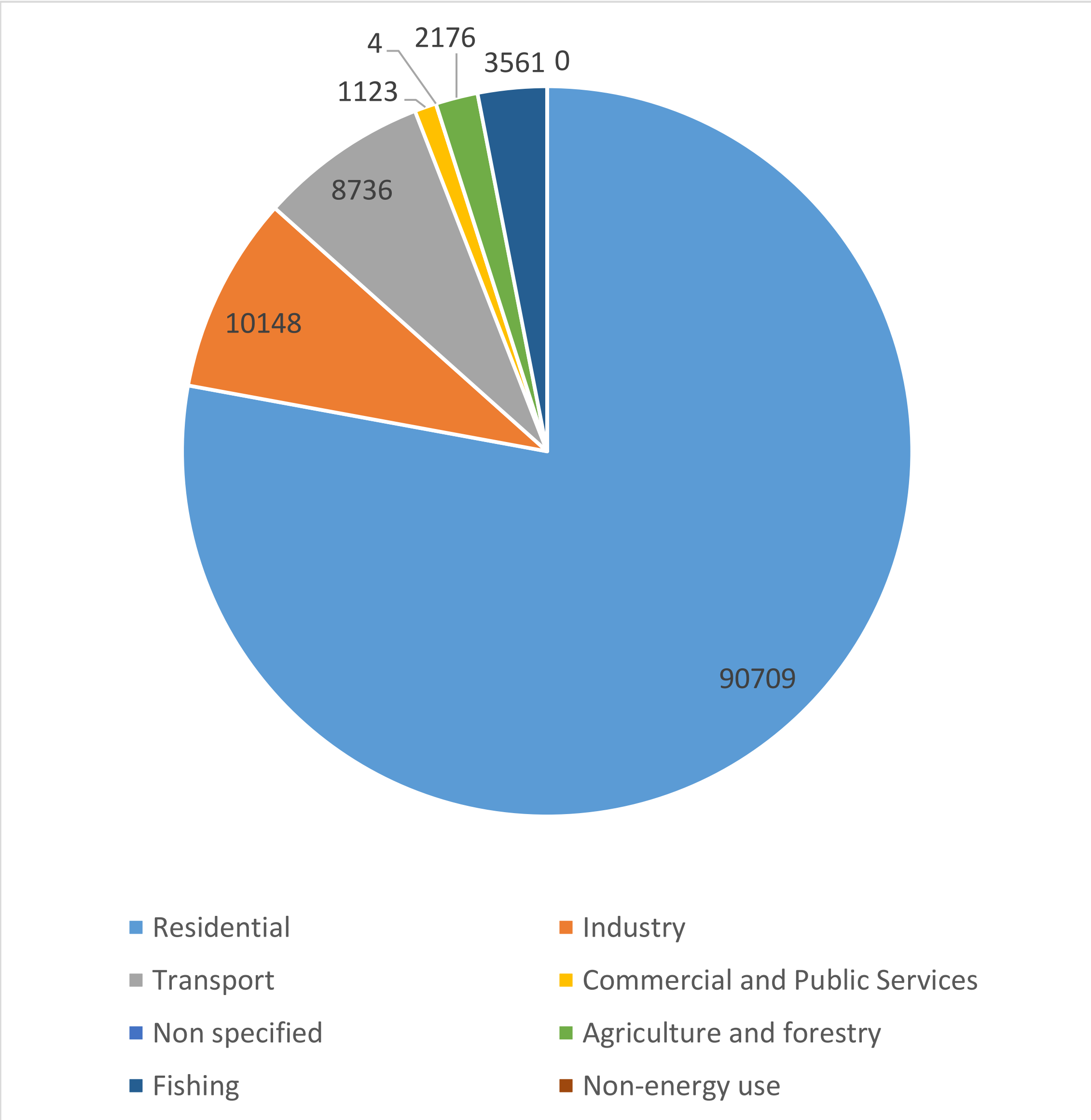


Source: WB 2020; IRENA 2021.

2.3.2. Energy Consumption in Nigeria

The residential sector accounted for the largest portion of Nigeria's overall final energy consumption in 2012, which was 116,457 kilotonnes of oil equivalent (ktoe), as seen in the figure below.

Figure 7. Energy Consumption in Nigeria by Economic Sector in ktoe



Total Energy Consumption – 116,457ktoe.

Source: Akande et al. 2015

The total amount of energy used by all sectors and users is referred to as primary energy consumption. In addition to additional inputs including biomass waste, biodiesel, ethanol, firewood, and wood-based fuels, it comprises energy obtained from natural sources (Osunkwo et al. 2020). Overall consumption is still low, as seen in Table 4, with significant variations in growth rates over time. According to research, home energy use is still dominated by solid fuels including firewood, charcoal, and animal or agricultural waste. On the other hand, only a small portion of the population, mostly those in the middle and upper income ranges, have access to contemporary energy sources.

Table 4. Primary Energy Consumption in Nigeria 2010 – 2020

Year	Value (Quadrillion Btu)	% Change
2010	0.83	24.47
2011	1.18	42.47
2012	1.18	-0.22
2013	1.52	28.60
2014	1.66	9.19
2015	1.57	-5.48
2016	1.58	0.77
2017	1.54	-2.45

Source: Osunkwo et al. 2020

2.3.3. Energy Balances

Table 5. Nigeria's Energy Balances in 2012, Measured in Kilotonnes of Oil Equivalent (ktoe).

	Crude Oil	Oil Products	Natural Gas	Biofuels and Waste	Hydro	Coal and Peat	Total
Production	129,409	0	33,645	108,142	487	30	271,712
Exports	-126,413	-755	-21,032	0	0	0	-148,201
Imports	0	8,440	0	0	0	0	8,440
International aviation bunkers	0	-186	0	0	0	0	-186
International marine bunkers	0	-397	0	0	0	0	-397
Changes in stock	1,830	538	0	0	0	0	2,368
Total primary energy supply (TPES)	4,825	7,640	12,613	108,142	487	30	133,736
TPES (%)	3.61%	5.71%	9.43%	80.86%	0.36%	0.02%	100.00%

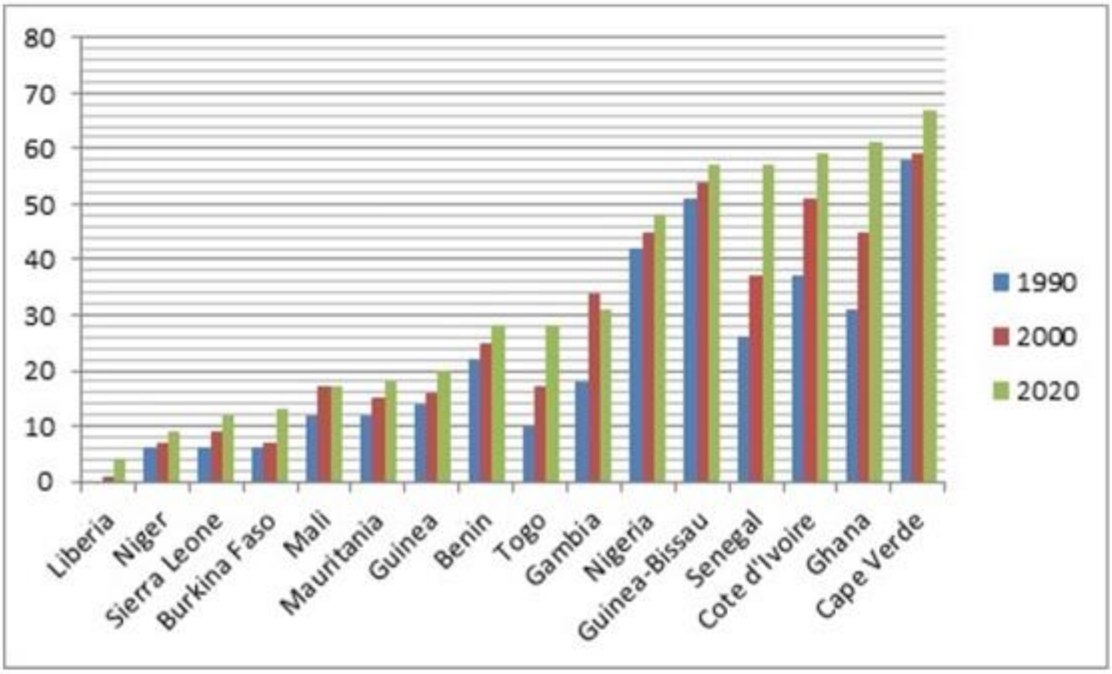
Source: IEA 2012

2.3.4. Electricity

In Nigeria, electricity still only makes about 2% of the ultimate energy consumed, making it a secondary energy source. Electricity accounts for only 9% of residential energy consumption. Interestingly, about 80% of the country's power demand comes from the commercial and residential sectors, with the remainder going to the industrial, special tariff, and street lighting sectors. Just 1% of all power is consumed by large users, such as corporations and large enterprises (Chanchangi et al. 2022).

Nigeria's progress has fallen short of that of several other West African countries, even though the country's electricity rates are quite high. The graph below illustrates how the electrification rate has increased by just 5% during the early 1990s, reaching 55.4% by 2020.

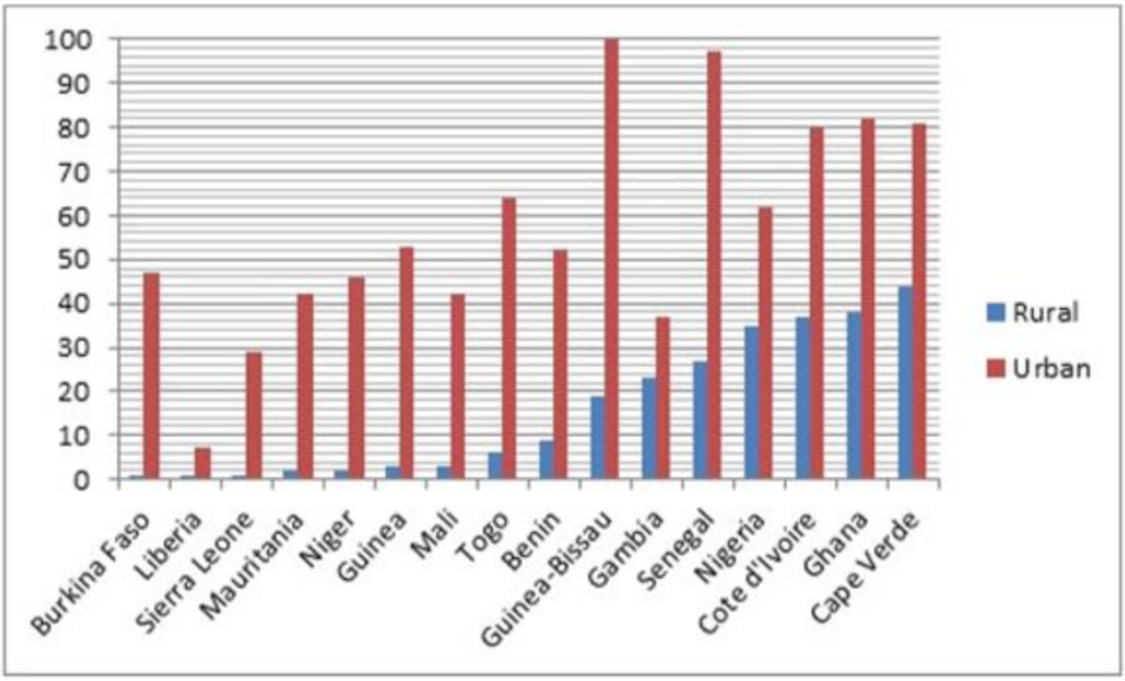
Figure 8. Trends in Electrification Rates in West Africa from 1990 – 2020



Source: WB 2020

Even while Nigeria's rural electrification rate (35%) and urban electrification rate (62%) differ less than in certain other West African nations, Figure 9 shows that the difference is still significant.

Figure 9. Disparity Between Rural and Urban Electrification Rates in West Africa



Source: WB 2020

In 2008, the International Atomic Energy Agency (IAEA) and the Nigerian Energy Commission (ECN) predicted that, under a reference scenario that assumed 7% annual economic growth, the demand for electricity would increase to 15,730 MW by 2010 and 119,200 MW by 2030. These forecasts were predicated on growing demographic pressure and expected economic growth (Oladipo et al. 2018). The former Power Holding Company of Nigeria (PHCN) and the World Alliance for Decentralized Energy (WADE) were among the other players who created further forecasts. They came at the same conclusion, despite differences in methodology and scope: if business as usual continues, there will likely be a significant increase in the gap between supply and demand for electricity (Chanchangi et al. 2022).

2.3.5. On-grid and Off-grid Electrification Scenarios in Nigeria

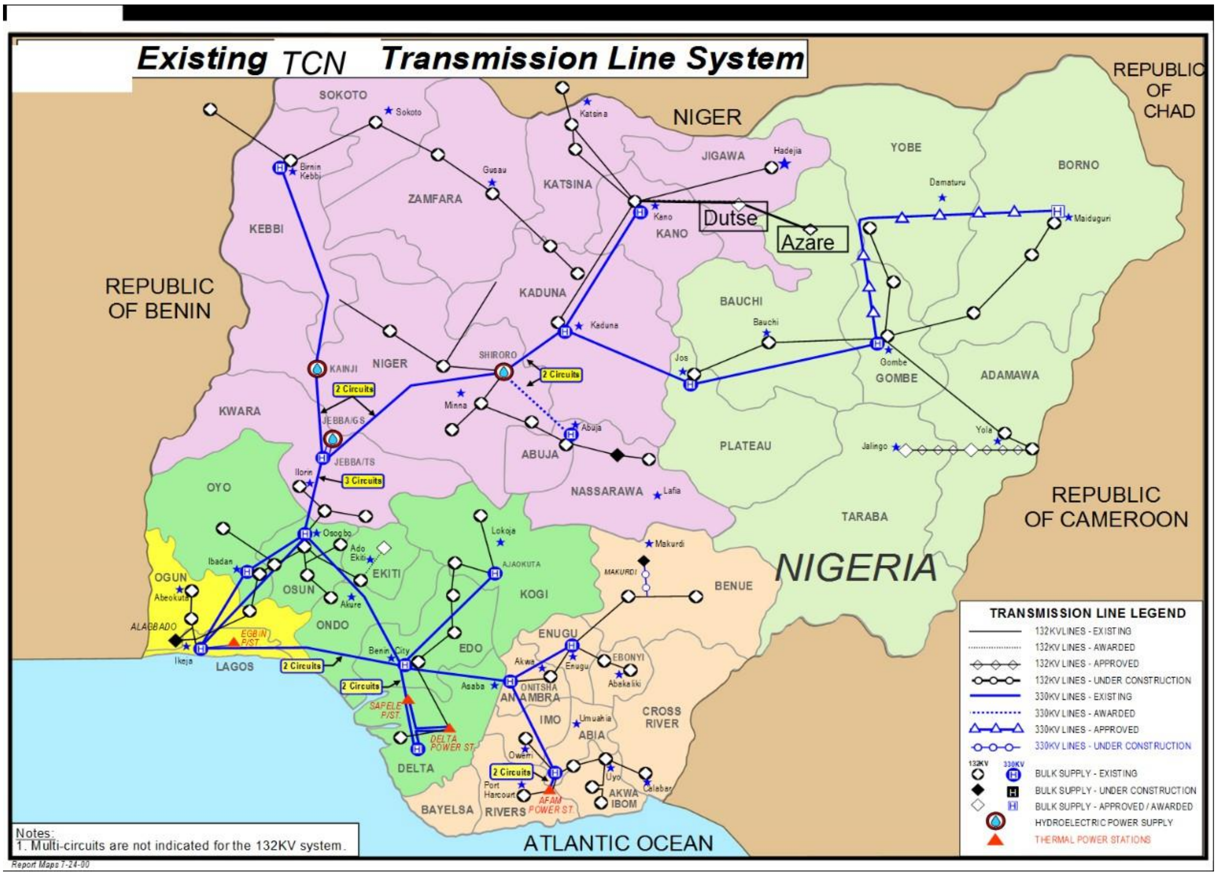
To support universal electricity access in Nigeria, Zambia, and Tanzania, the World Bank, ESMAP, and the KTH Division of Energy System Analysis introduced the

National High Resolution Dynamic Least Cost Options Plan in 2018. This open-access, web-based tool enables users to model electrification scenarios by adjusting variables such as fuel costs and electricity demand in relation to existing infrastructure. For Nigeria, approximately 60% of the unelectrified population is expected to gain access through standalone photovoltaic (PV) systems, given that the cost of grid extension is significantly higher—estimated at 5.8 billion USD, which constitutes nearly 80% of the total projected investment of 7 billion USD (World Bank 2021).

By mid-2015, a total of 58 permits had been granted for on-grid electricity generation, representing an aggregate capacity of 26,423.21 MW. Most of this capacity was designated for thermal power plants located in Nigeria's southern region, where oil and gas resources are concentrated. However, only 11,774 MW of this licensed capacity had been developed, and just 3,801.19 MW was operational by June 2015, primarily due to insufficient maintenance (Oladipo et al. 2018). At that time, the electricity distribution infrastructure encompassed 224,838 km of overhead and underground low-voltage (LV), 11 kV, and 33 kV lines—excluding the area covered by the Kaduna Electricity Distribution Company, which was yet to be included. Under the ongoing power sector reforms, the national distribution system was divided into 11 zones, each managed by a separate Electricity Distribution Company (DISCO) (Oyedepo 2012).

Although the national transmission grid has an installed capacity of around 5,800 MW, its effective wheeling capacity is closer to 4,600 MW. The grid is operated by the Transmission Company of Nigeria (TCN), which is owned by the federal government (Oladipo et al. 2018).

Figure 10. The TCN Transmission Line System



Source: Oladipo et al. 2018

2.3.6. Nigeria Energy and Electricity Challenges

The large gap between the supply and demand of electricity is the reason for frequent power outages, as was previously mentioned. As a result, the sector is confronted with a number of difficulties, such as its heavy reliance on gas, inadequate technical and technological know-how, failure to maintain infrastructure and implement energy-efficient practices, a lack of regulation, and frequent attacks on energy infrastructure (Chanchangi et al. 2022).

Due to inadequate maintenance and vandalism, the transmission network is currently crowded and suffers losses of up to 25%, especially in the northern region. Frequent system breakdowns are a result of its radial nature. Conflicts in the community and security, non-performing engineering procurement, construction, and commissioning

(EPCC), severe manpower shortages, expensive grid extension, and excessive bureaucracy are some of the other difficulties. High technical and non-technical losses, a lack of skilled substation operators and personnel, distribution equipment vandalism, electricity theft, a poor maintenance culture made worse by the lack of automated and centralized control systems, insufficient funding, issues with the transmission and distribution interfaces, and ineffective revenue collection are other issues facing the distribution grid (Oladipo et al. 2018).

At about 150 kWh, Nigeria has one of the lowest per capita electricity usage rates in the world. In 2011, there were an average of 28 outages per day for users connected to the grid. In order to safeguard electrical appliances from frequent blackouts, stabilizers must be used, which puts an additional cost strain on end users. In addition to having an impact on living standards, this circumstance represents a significant barrier to economic expansion (Oyedepo 2012). In the 1990s, textile mills in towns like Kaduna, Kano, and Lagos closed, a sign of deindustrialization brought on by an unstable power supply. According to the Council for Renewable Energy of Nigeria (CREN), the yearly economic impact of power outages in Nigeria is projected to be around 126 billion naira (USD 984 million). Furthermore, it takes an estimated 260 days and costs 960% of per capita income to get an energy connection in Nigeria, making it one of the hardest countries to do so (Oladipo et al. 2018; Chanchangi et al. 2022).

Power Africa claims that the absence of a robust and open regulatory framework, a lack of reputable and trustworthy utilities, and macroeconomic volatility are the main issues facing Nigeria's energy sector.

2.3.7. Current Status of Decentralized Power Generation in Nigeria

About 30 MW of production capacity is covered by off-grid licenses, whereas 49 MW is covered by embedded generating licenses. Nigerian electrification has advanced more slowly than anticipated, particularly in rural and isolated locations (Oyedepo 2012). The concentration of federal and state electrification programs on grid extension is one of the main reasons given, as it dramatically raises costs for rural low-density areas with poor payment capacity and minimal demand. Efforts to electrify places have been further delayed by political meddling in the process and disputes within and between communities (Oladipo et al. 2018).

Businesses and individuals have been forced to self-generate electricity due to frequent, unforeseen blackouts. According to estimates, private, independent generators—mostly tiny gasoline or diesel units—provide the remaining 50% of the electricity used, with just 50% coming from the national grid. These generators were expected to have a combined capacity of 6,000 MW in 2009. The South-South and South-East regions, especially the Niger Delta states, and the capital city of Lagos have the biggest numbers of generators. The majority of investments in self-generation come from businesses. There are 20 off-grid generating licenses totaling 305.5 MW, mostly for industrial use. In a region in western Nigeria that is not served by the national grid, there is only one license for off-grid distribution (Chanchangi et al. 2022).

When the federal government started the Rural Electrification Programme in the 1970s to use diesel generators to power local government buildings, off-grid electrification using conventional sources got underway. Renewable energy has become more prevalent in off-grid electrification in recent years. In the 1990s, off-grid photovoltaic (PV) systems (mini-grids and freestanding systems) were installed by the Energy Commission of Nigeria (ECN) and the previous Federal Ministry of Power and Steel for applications such as cooling, irrigation, and residential electrification. The Rural Electrification Agency (REA) and the Federal Ministry of Environment (FME) have lately joined these initiatives (Oyedepo 2012).

In order to electrify rural areas in all 36 states and the Federal Capital Territory (FCT) using renewable energy, the Federal Ministry of Power started Operation Light Up Rural Nigeria in 2014 (Ofualagba & Ejofodomi 2020). Some electrification projects incorporate off-grid photovoltaic-powered street lighting and water pumping equipment, but the majority still concentrate on grid growth. Several states have undertaken small-scale off-grid village electrification projects in partnership with the business sector (Ofualagba & Ejofodomi 2020).

A 2015 survey conducted by the Nigerian Energy Support Programme (NESP) found that 55 companies had installed a total of 2,033.75 kW of off-grid PV systems—

both mini-grids and standalone systems. Most of these systems serve as backup in grid-connected areas, but some were installed in unelectrified rural communities for residential and commercial use. Small wind turbines for water pumping have also been piloted across various regions. For instance, Sayya Gidan Gada village in Sokoto benefits from a turbine provided by the Sokoto Energy Research Centre (SERC). In Danjawa village, Sokoto, SERC developed a hybrid mini-grid combining 10 kW solar and 2 kW wind power in collaboration with the World Bank, ECN, and local authorities. Danjawa also hosted pilot installations of off-grid PV-powered street lighting (Oladipo et al. 2018).

Small-scale hydropower projects have also been investigated. The United Nations Development Programme (UNDP) and the United Nations Industrial Development Organization (UNIDO) have been involved in this area through their regional small hydro center. For instance, the National Agency for Science and Engineering Infrastructure (NASENI) created locally produced turbines for the 400kW mini-hydro plant in Taraba State and the 70kW micro-hydro plant in Osun State. ECN has also set up a pico-hydro power plant in Nasarawa State that uses kinetic turbine technology. In terms of biomass, it is said that UNIDO is working on a 5 MW mini-grid project, though it is unknown how far along it is at this time. However, in the Middle Belt and South-West regions of Nigeria, private investors are pushing biomass-based rural electrification more and more (ECN 2019).

3. Aims of the Thesis

The purpose of this study was to identify and discuss the various factors influencing the acceptance and use of biogas technology in Nigeria. It also aimed to present the current state and challenges of the Nigerian energy and electricity sector, and to subsequently explore the potential of biogas, including its benefits and the limitations hindering its development as an alternative source of renewable energy, despite the collapse of the nation's energy sector.

Furthermore, the study aimed to examine the impact of institutional factors—such as government funding and policies, private sector participation, and cultural and economic constraints—on the acceptance and development of biogas technology in Nigeria.

4. Methods

This thesis was written as a literature review. To effectively address the topic of factors affecting the acceptance and use of biogas technology in Nigeria, a review of the current state and challenges within the country's energy and electricity sector, alongside the development of biogas adoption, was conducted using a modified PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) approach, formerly known as QUORUM (Quality of Reporting of Meta-Analyses). This approach enabled the use of a minimal yet evidence-based set of sources.

The literature review involved gathering previously published articles from peer-reviewed scientific databases, as well as officially published reports and datasets from international organisations such as the World Bank, the International Energy Agency (IEA), ScienceDirect, Web of Science, Elsevier, and Google Scholar. These sources were specifically selected for their relevance to Nigeria's energy sector and the adoption and development of biogas technology.

The search for relevant data was guided by the thesis keywords—biogas technology, Nigeria, anaerobic digestion, energy, waste management, among others—combined using logical conjunctions. All sources retrieved from the scientific databases were examined for alignment with the objectives of the thesis. These were then complemented with data from international organisations and synthesised into four key chapters: Biogas Technology, Biogas in Nigeria, Nigeria's Energy Challenges, and Acceptance of Biogas Technology in Nigeria.

The process of classifying, summarising, and comparing the obtained data facilitated a critical and constructive analysis of the topic.

Chat-GPT was used as an auxiliary tool for simplifying and paraphrasing academic texts, improving text structure and coherence, clarifying concepts, and proofreading, in accordance with the university's regulations and academic integrity principles.

Results and Discussion

4.1. Biogas in Nigeria

In Nigeria, biomass energy is primarily used for cooking and heating rather than for electricity generation. The estimated livestock population of 289.7 million produces approximately 61 million tonnes of waste annually. If half of this waste were biologically gasified, it could generate approximately 40 MW of electricity per year—equivalent to 0.2% of Nigeria's total electricity demand (Kemausuor et al. 2018). Despite the absence of any functional biomass-based energy generation facilities in the country, the Nigerian Energy Commission projects that biomass could contribute an additional 3,345 MW to power production by 2025. With the exception of a few biogas plants, Nigeria currently neither produces nor consumes biofuels (Itodo et al. 2021). Past governmental efforts to promote biofuel integration into the national energy mix—primarily through public awareness campaigns—have failed to yield the desired results due to a lack of sustained commitment and implementation (Akinbomi et al. 2014).

The development of biogas technology in Nigeria has received limited attention, with only a handful of pilot plants established by research institutions. The progress of biogas development has been hindered by numerous challenges, including difficulties in biomass storage, technical limitations, inadequate governmental financial support, and low public awareness regarding the benefits of biogas as an energy source (Khayal 2019). Considering that Nigeria's current energy mix is dominated by fuelwood, petroleum products, and hydroelectric power, biogas has yet to be meaningfully incorporated into the country's energy portfolio (Akinbomi et al. 2014).

4.2. Development of Biogas in Nigeria

Biogas technology was first introduced in Africa between 1930 and 1940. During this period, simple biogas digesters were constructed in Algeria to supply energy to farmhouses. Despite this early introduction, the use and implementation of biogas in

Nigeria—as in many other African countries—remains in its infancy (Ngumah et al. 2013; Akintade 2021).

The first biogas plant in Nigeria was established in the 1980s at Usman Danfodiyo University, Sokoto. It featured a basic design and could produce approximately 425 litres of biogas per day. Since then, around 21 pilot demonstration plants with capacities ranging from 10 to 20 m^3 have been set up in various regions of the country (Ngumah et al. 2013). The slow pace of biogas development in Nigeria is attributed to several factors, including unfavourable government policies, limited technological investment, public disinterest, and a general lack of awareness (Akintade 2021).

Unless the government takes steps to diversify Nigeria's energy sources—especially in the residential, industrial, and commercial sectors—and adopts modern waste-to-energy technologies, the current energy situation is unlikely to improve (Oyedepo et al. 2012).

According to Akinbami et al. (2014), viable feedstock substrates for a cost-effective biogas programme in Nigeria include manure, cassava leaves, sewage, water hyacinth, water lettuce, industrial waste, municipal solid waste, and urban refuse. Approximately 227,500 tonnes of fresh animal waste are produced daily in Nigeria. Given that one kilogram of livestock waste can yield around 0.03 m^3 of biogas, this translates to an estimated 6.8 million m^3 of biogas per day. Furthermore, the annual generation of municipal solid waste in each state capital is estimated at 20 kg per capita (Akinbomi et al. 2014). Thus, Nigeria possesses abundant and economically viable biomass resources suitable for biogas production. In addition, ongoing research continues to explore the potential of other organic materials for biogas generation (Akintade 2021).

As shown in **Table 6**, the available feedstock supports the feasibility of developing large-scale biogas plants in various parts of the country. Moreover, the enforcement of ranching policies would further facilitate livestock waste collection, enhancing biogas production potential.

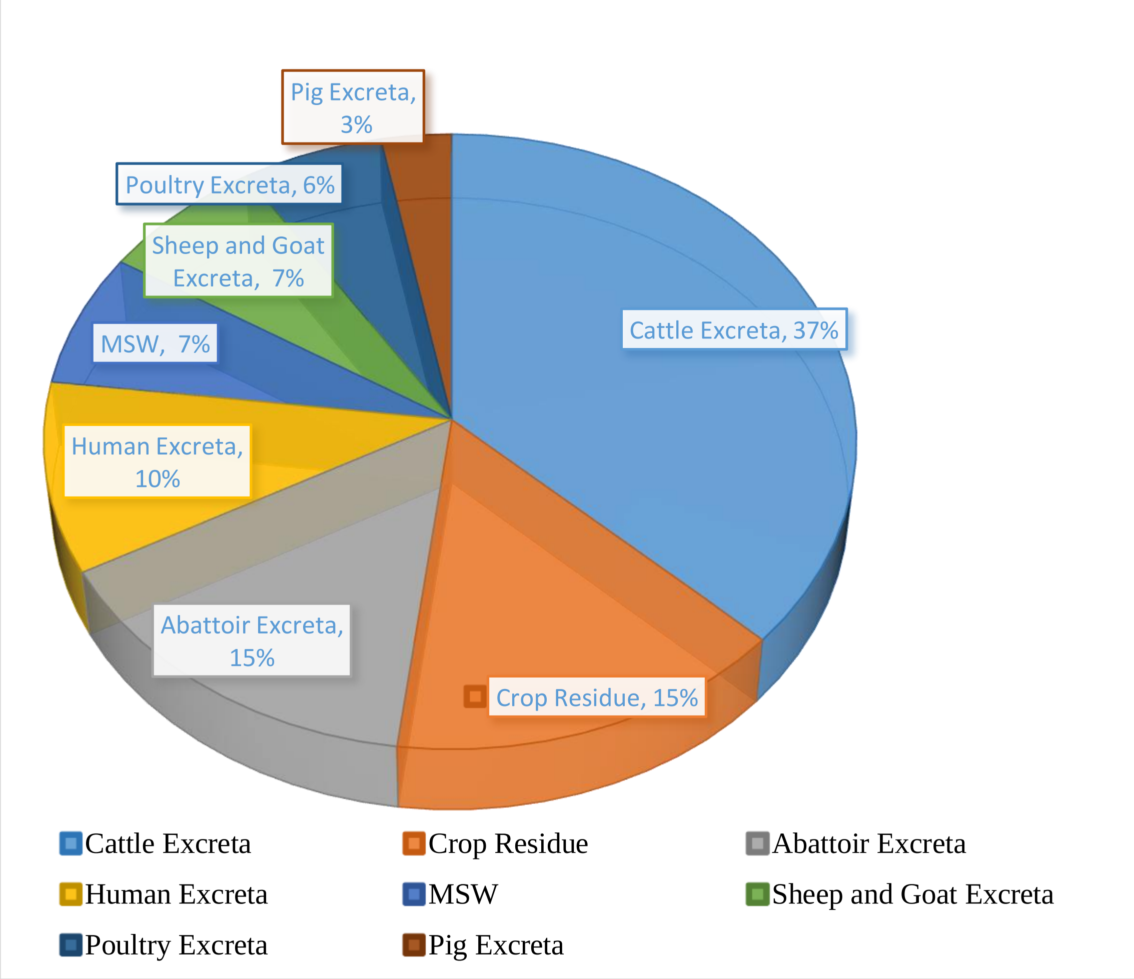
Table 6. Potential Biogas Obtainable from Biomass Generated in Nigeria.

Biomass (Organic Waste)	Total Biomass Generated (million tons/year)	Total Biomass Generated (million tons/year)
Crop residue	83	4.98
Municipal solid waste (MSW)	39.1	1.29
Abattoir waste	83.3	4.42
Poultry excreta	32.6	2.5
Sheep and goat excreta	39.6	2.3
Pig excreta	15.3	0.92
Cattle excreta	197.6	6.52
Human excreta	52	2.6
Total	542.5	25.53

Source: Ngumah et al. 2013

Findings from Ngumah et al. (2013) on the biogas potential of organic waste in Nigeria indicate that 68% of solid biowaste originates from animal waste (abattoir and excreta). In comparison, municipal solid waste (MSW), human excreta, and agricultural waste contribute approximately 7%, 10%, and 15% respectively, as illustrated in Figure 5.

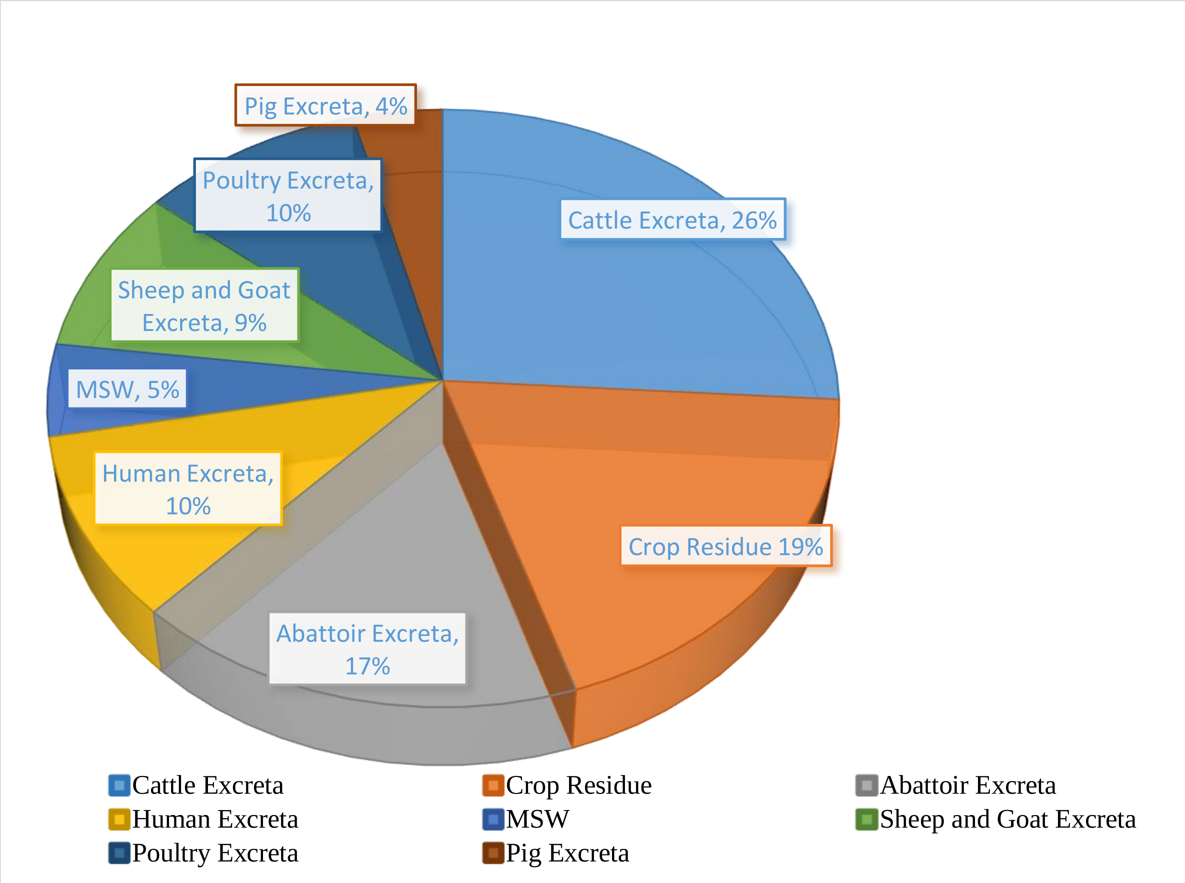
Figure 11. Distribution of Biomass Generated in Nigeria



Source: Ngumah et al. 2013

An estimated 542.5 million tonnes of biowaste are produced annually in Nigeria. Based solely on livestock waste, this biowaste has the potential to generate approximately 66% (16.66 billion m^3) of the total biogas output (see Table 6), with the remaining contributions coming from crop residues (19%), human excreta (10%), and municipal solid waste (MSW) (5%).

Figure 12. Volume Distribution of Potential Biogas Obtainable from Biomass Generated in Nigeria.



Source: Ngumah et al. 2013

A few biogas projects have been implemented in Nigeria, including the installation of biogas plants at Zaria Prison in Kaduna, Ojokoro in Lagos, Mayflower School in Ikene (Ogun State), and Usman Danfodio University in Sokoto, with digester capacities ranging from 10 to 20 m³. However, most of these projects are either non-operational or remain in the research phase and have not yet reached commercialization (Akinbomi et al. 2014; Akintade 2021).

According to Akinbomi et al. (2014), several reasons have been cited for the failure of past pilot biogas initiatives in Nigeria. These include the absence of appropriate policy frameworks, poor implementation of existing biofuels regulations, lack of government commitment, technical limitations (such as difficulty in sourcing spare parts and skilled labour), inefficient waste management systems, lack of continuity by successive administrations, poor storage and transportation infrastructure, inadequate structural facilities, and low public awareness of the benefits of biogas technology.

4.3. Availability of Biogas Feed Materials in Nigeria

Biogas can be generated in controlled, contained, and usable quantities from readily available local materials (Kabir et al. 2013). Unlike fossil fuels, biogas can be produced from a wide range of biogenic waste sources, including animal and plant waste, human waste, biomass, cow dung, green waste, and agricultural by-products such as cassava and sugarcane. Waste is defined as material that is no longer useful for production, processing, or consumption.

Despite numerous efforts by successive Nigerian governments to manage waste, the problem remains largely unresolved. The piles of waste are common in almost all residential, commercial and industrial zones throughout the country (Ikpen et al. 2018). Residential areas, marketplaces, lakes, roadsides, and vacant lands are frequently turned into dumping sites. Alarmingly, it is estimated that only 20% to 70% of Nigeria's annual production of 32 million tonnes of solid waste—generated by a population exceeding 160 million—is effectively collected (Biodun et al. 2020).

Approximately 70% of Nigeria's population lives in areas without formally organized waste disposal systems. As a result, there is an abundant supply of biogas feedstock across the country. A study evaluating the minimum biogas potential from solid waste and livestock excreta in Nigeria estimated that in 1999, the country had a total biogas potential of 1.38×10^9 m^3 per year, equivalent to 4.81 million barrels of crude oil. The increasing population, the growing number of industries, and the evolving agricultural practices have all contributed to a rising volume of solid waste (Swayerr et al. 2019).

Although biogas technology is widely recognized, limited progress has been made in converting Nigeria’s vast municipal solid waste into usable gas (Ikpen et al. 2018). Given the abundant feedstock, biogas technology holds substantial economic potential in Nigeria. It is a non-polluting method of energy generation. Poor urban waste management, the high cost of living, unreliable energy supply, increasing waste management expenses, and the rising cost of fertilizers make biogas technology an especially viable option for Nigeria. In addition to waste disposal, it can serve as a source of employment and energy security (Egbere et al. 2011).

Table 7. Renewable Energy Potential in Nigeria and their Estimated Reserve

Energy Resources	Estimated Reserve
Large Hydropower	11,250 MW
Small Hydropower (< 30MW)	3500 MW
Fuel Wood	11 million Hectares of wood land and forest
Agricultural Residue and energy crops	72 million hectares of agricultural of agricultural land
Animal wastes	245 million assorted animals
Municipal wastes	30 million tonnes/year
Solar Radiation	3.5 to 7.0 KWh/m^2/day
Wind	2 to 4m/s at 10m height

Source: IEA 2015

In Nigeria, wind speeds range from 1.4 to 3.0 m/s in the southern regions (excluding coastal areas), and between 4.0 to 5.1 m/s in the northern regions. Particularly notable is the Plateau region, which displays promising wind characteristics (Sambo 2009; Ohunakin et al. 2011; Umar et al. 2017).

4.4. Small Scale Anaerobic Digester Plants and Companies in Nigeria

Biogas technology has become a crucial tool for the supply of sustainable energy in several African countries (Berhe et al. 2017). In Nigeria, the increasing energy demands of farm households have exacerbated issues related to indoor air quality, land degradation, and rural economic development. Environmental deterioration—exacerbated by declining soil quality and reduced carbon sequestration—continues to pose significant challenges.

In response, the Nigerian government is exploring the deployment of biodigesters across rural communities, with the aim of addressing these interconnected problems. However, little is known about the energy source preferences of rural households, making it difficult to predict the potential economic and ecological impact of biogas energy adoption (Egbere et al. 2011).

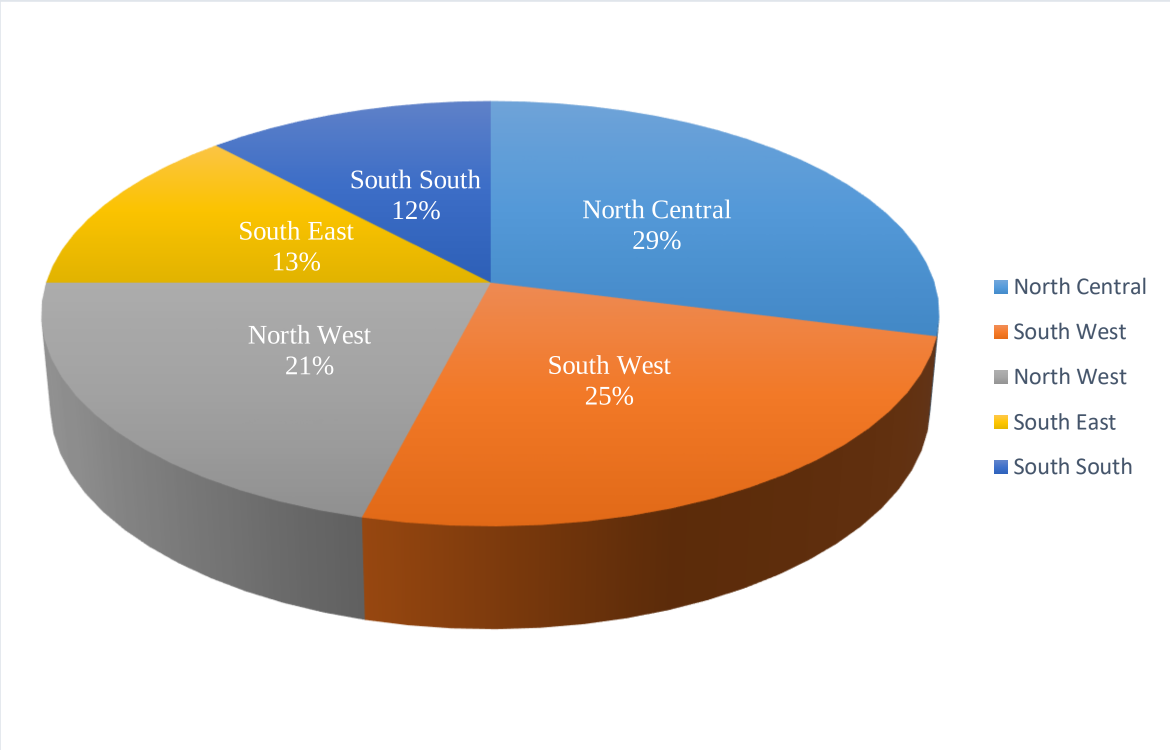
According to Akintade (2021), Nigeria has a relatively small number of installed anaerobic digester plants, largely due to the country's nascent stage in biogas technology development. Most of these facilities are owned by smallholder farms, agricultural processing companies, and private households—some of whom have retrofitted their latrines for gas generation. His survey results indicate that fewer than 200 biogas systems exist nationwide, with their distribution illustrated in Table 8 and Figure 13.

Table 8. Small Scale Anaerobic Digesters in Nigeria

Establishments	Number of Biogas Plants
Government Agencies	0
Agricultural establishments	75
Individuals	45
Total	120

Source: Akintade 2021

Figure 13. Percentage Distribution of Biogas Plants Across Regions in Nigeria



Source: Akintade 2021

There are several biogas plant companies operating in the southern part of Nigeria. One of the prominent firms is Avenam Links International Limited, located in Lagos. It is a leading renewable energy company incorporated to provide affordable anaerobic digesters and generator technology solutions. Another notable company is Grinoz, based in Aba, which offers a green alternative to the use of fossil fuels in homes, restaurants, and food establishments. Grinoz has developed a biogas digester system that enables users to generate methane gas for lighting and cooking from domestic and kitchen waste. The company is reportedly working on increasing the digester's capacity and developing models that integrate generator sets for electricity generation.

Additionally, Agadaga Enterprise in Jos operates an above-ground oil refinery that produces and distributes biogas and biofuels to businesses, consumers, and retailers. It also supplies biofertilisers to small-scale farmers and agribusinesses. The company primarily uses biomass, including agricultural residues and biogenic municipal waste, as feedstock (Energy Expert 2023).

4.5. Acceptance of Biogas Technology in Nigeria

According to Sasse (2011), a technology is considered suitable if it gains acceptance. Many emerging and industrialised nations, including oil-exporting countries, have embraced biogas as a renewable energy source to reduce the uncertainties commonly associated with economic development. National biogas programmes have been implemented in various countries, using India's technology as a model. For example, Cambodia's National Biodigester Programme (NBP) was designed after Nepal's initiative and targets small-scale farmers. Rwanda's early deployment of biogas was also motivated by a government-subsidised programme. Denmark, by 1998, had about 35 farm-scale facilities and 20 centralised plants for digesting manure and organic waste.

In Nigeria, despite being a major oil-exporting country, a national biogas programme has been launched. However, its implementation has been hampered by economic, technical, and sociocultural constraints. As a result, only a few hundred small biogas digesters exist, mostly operated by small-scale agricultural enterprises and private individuals (Raja & Wazir 2017; Akintade 2021).

A report by the United Nations Development Programme (UNDP) on energy for sustainable development highlights the lack of clarity in the roles and responsibilities of various institutions, ministries, and agencies involved in rural energy service delivery. This overlap leads to inefficiencies and overstretches limited resources in developing countries (Raja & Wazir 2017).

Commercial biogas plants have not gained significant traction in Nigeria or across most of Africa. The country faces several challenges hindering the widespread adoption of biogas, especially commercial-scale plants. Key issues include poor institutional and infrastructural frameworks, weak environmental regulations, insufficient policy planning, and lack of coordination among biogas stakeholders (Kemausuor et al. 2018). Additional barriers include price distortions that disadvantage renewable energy, high initial investment costs, ineffective dissemination strategies, lack of skilled labour, and inadequate maintenance and after-sales services (Kemausuor et al. 2018; Khayal 2019).

4.5.1. Technical and Infrastructural Factors

A major technical impediment to the development of biogas in Nigeria is the country's poor infrastructure. The distribution and utilisation of biogas are hindered by the lack of underground pipelines, non-connectivity to the national grid, and technical challenges related to proper waste segregation, collection, allocation, and storage (Nevzorova & Kutcherov 2019).

Infrastructure-related issues also include the limited availability of feedstock. Many rural households lack a sufficient number of cattle or poultry to generate the volume of animal dung required for biogas production. According to Nevzorova and Kutcherov (2019), an average of eight cattle per household would be needed to provide sufficient energy for cooking, electricity, and clean drinking water. Furthermore, unregulated systems for collecting liquid effluents from agro-industrial activities have led to contamination of soil and water sources.

While some level of technical expertise exists for small-scale family biogas systems in Nigeria, experience with commercial-scale systems is minimal. Commercial digesters are larger and more complex, requiring advanced design, construction, and maintenance skills. The availability and reliability of feedstock are the first constraints of biogas operations. Many Nigerian communities suffer from inadequate transportation infrastructure, which disrupts feedstock supply chains, particularly where biomass sources are distant from biogas plants (Kemausuor et al. 2018).

In areas where biogas systems have been tested, technical failures have occurred, often attributed to poor government support, weak energy policy, limited understanding of the economic value of the technology, poor digester design, operational errors and user neglect. Users' limited understanding of the technology makes troubleshooting difficult and affects the maintenance and long-term viability of installed systems (Mwirigi et al. 2014; Kemausuor et al. 2018).

Generally, Nigeria and many developing nations lack the technical capacity to construct and maintain commercial biogas plants. Successful examples in South Africa, Kenya, and Ghana have depended on foreign engineering and construction firms. However, employing foreign labour has financial implications, as it tends to be more expensive than using local labour. Moreover, limited biogas education and training are available in Nigeria across all academic levels, further compounding the issue (Kemausuor et al. 2018).

A critical infrastructural barrier is the weak and unreliable power grid, which challenges even existing power plants. The inadequate grid infrastructure limits the integration of renewable energy systems, including biogas, into the national grid (Okoro et al. 2020).

4.5.2. Economic and Financial Factors

Economic considerations significantly influence the choice of energy source. Small-scale biogas systems, which generate digestate for fertiliser and gas for cooking in farm households, are relatively easy and inexpensive to construct. However, large-scale biogas plants capable of digesting significant quantities of sludge and slurry require substantial financial investment and advanced technical skills. The cost of installing such systems includes technology implementation, infrastructure, equipment, and skilled labour (Okoro-Shekwaga & Horan 2015).

Although feedstock is readily available in Nigeria, the costs associated with its treatment and transportation—especially over long distances—negatively impact large-scale operations. Installing gas conditioning and purification units further increases capital costs, particularly when aiming to produce bio-methane suitable for grid injection. Furthermore, access to bank loans with favourable terms is limited, making it difficult to finance biogas projects in both urban and rural agricultural areas (Nevzorova & Kutcherov 2019).

The high operating and maintenance costs of large biogas plants also affect farmers' willingness to adopt the technology (Kemausuor et al. 2018; Okoro et al. 2020). In Nigeria, widespread poverty and high upfront costs represent major barriers. Although operating costs are relatively low, the initial capital requirement is often prohibitive for many users.

The lack of financial support schemes—such as soft loans or government-backed investment incentives—reduces the attractiveness of biogas projects to potential investors. Additionally, the current economic structure in Nigeria favours fossil fuels, giving them an unfair competitive advantage over renewable alternatives (Khayal 2019).

Another significant barrier is the lack of funding for research and development. Poor R&D investment has led to a shortage of qualified researchers and weak technological innovation in the sector. Furthermore, engineering and technical curricula in Nigerian universities and colleges typically provide limited coverage of energy technologies and their practical implementation (Nevzorova & Kutcherov 2019).

4.5.3. Market Factors and Lack of Awareness

A significant market challenge in Nigeria is the relatively high price of biogas compared to fossil fuels. As the country holds the second-largest fossil fuel reserves in Africa, fossil fuel pricing is considerably lower and often subsidised. According to Nevzorova and Kutcherov (2019), for biogas to be viable in the public sector, its cost must be competitive with that of more accessible fuels, even though it is currently more expensive than natural gas.

Additionally, there is a general lack of awareness among farmers, livestock owners, and agro-processing companies regarding the dual benefits of biogas technology—as both a renewable fuel source and a waste management solution. This challenge is not unique to Nigeria but is common across multiple African countries. Electricity generated from biogas must also compete with cheaper electricity sourced from thermal power plants. Even when substrates are freely available, the technology required for biogas electricity generation remains costly, especially in countries like Nigeria, where most components are imported (Kemausuor et al. 2018).

Municipalities tend to prefer diesel-powered vehicles over biogas alternatives due to a lack of biogas fuelling infrastructure, limited public knowledge, and fear of accidents stemming from misinformation (Nevzorova & Kutcherov 2019). Moreover, traditional biomass sources such as firewood, cow dung, and charcoal remain strong competitors to biogas in rural areas due to their affordability and accessibility (Kemausuor et al. 2018).

In the fertiliser sector, manufacturers of mineral-based fertilisers face stiff competition from well-established producers of organic and soil-enhancing products. Retailers and distributors typically favour suppliers who offer large volumes and a variety of product sizes. These market-related challenges significantly affect the development and acceptance of biogas technology (Nevzorova & Kutcherov 2019).

4.5.4. Institutional Factors

Nevzorova and Kutcherov (2019) noted that the energy sector often receives limited attention in policy discourse within developing countries. Continuous government engagement is essential, but political support and targeted initiatives to promote biogas are frequently absent. Bureaucratic bottlenecks also hinder access to financing for biogas companies. The installation of biogas plants is often delayed by excessive formalities and complex administrative and legal procedures (Akinbami et al. 2014).

Political instability in Nigeria further hampers the adoption of biogas technologies. High levels of internal insecurity discourage private-sector investment and entrepreneurial efforts. Furthermore, the lack of public-private collaboration has been cited as a major impediment. The involvement of private enterprises is critical to bringing biogas solutions to market and ensuring financial sustainability (Nevzorova & Kutcherov 2019).

4.5.5. Socio-Cultural Factors

Socio-cultural factors, including limited public interest and awareness, are among the most significant barriers to the adoption of biogas technology in Nigeria. There is a widespread lack of understanding regarding waste segregation, sustainable development, and the environmental and health benefits of clean energy. Most rural households are unfamiliar with the long-term economic and ecological advantages that biogas presents. Even when exposed to the technology, some farming households do not feel responsible for its use or upkeep (Akinbami et al. 2014).

According to Nevzorova and Kutcherov (2019), societal factors such as stigma also influence biogas acceptance. In some communities, the use of human or animal waste for cooking is culturally unacceptable, leading to rejection of small-scale biogas systems. Some digesters have failed as a result of local opposition tied to traditional beliefs. In several rural parts of Nigeria and sub-Saharan Africa, biogas derived from dung or faecal matter is viewed with suspicion or outright rejection.

Table 9. Summary of the Factors that Affect the Acceptance of Biogas Technology in Nigeria

Factors	Effect
Awareness	The level of awareness of biogas technology among the Nigerian population can significantly affect its acceptance. A lack of awareness or understanding of the technology can make people skeptical about its effectiveness and potential benefits.
Cost	The cost of biogas technology is another factor that can affect its acceptance. If the cost of installing and maintaining the technology is too high, it may not be accessible or affordable for many Nigerians.
Infrastructure	The availability of infrastructure such as pipelines for gas distribution can affect the adoption of biogas technology. If the infrastructure is lacking, it may be difficult to distribute biogas to users, limiting its use.
Government policies	Government policies and incentives can also affect the acceptance of biogas technology. If the government provides favourable policies and incentives, such as tax breaks or subsidies, it can encourage the adoption of the technology.
Cultural and traditional practices	The cultural and traditional practices of Nigerians can also play a role in the acceptance of biogas technology. If the technology conflicts with traditional practices, it may face resistance.
Availability of feedstock	The availability of feedstock such as animal waste or organic waste can also affect the adoption of biogas technology. If there is a lack of feedstock, it may not be feasible to install and operate biogas plants.
Financing and access to capital	Access to financing and capital can also affect the adoption of biogas technology. If there are inadequate financing options or if the cost of financing is high, it may be challenging for people to invest in biogas technology.

Energy policies	The energy policies of the Nigerian government can also impact the adoption of biogas technology. If the government prioritizes other sources of energy, such as fossil fuels, it may not provide adequate support for the development and use of biogas.
Availability of skilled manpower	The availability of skilled manpower for the installation, operation, and maintenance of biogas plants can significantly affect their acceptance. If there is a shortage of skilled personnel, it may be difficult to ensure that the technology is being used effectively and efficiently.

Overall, addressing the aforementioned technical, economic, institutional, market, and socio-cultural barriers can significantly enhance the acceptance of biogas technology in Nigeria. This, in turn, could lead to its wider adoption, contributing to environmental sustainability, improved energy access, and economic development.

5. Conclusions

Nigeria's energy crisis is not due to a lack of natural resources, but rather to the failure to properly utilise those resources through appropriate technologies, infrastructure, and policies. Energy is vital to the growth and advancement of any society and should not be wasted, as it offers essential benefits required for the sustainability of any economy. The Nigerian economy currently relies heavily on fossil fuels such as crude oil and natural gas. Although it is the eighth largest oil exporter in the world, the country continues to experience a growing demand for energy, particularly for domestic consumption and to support ongoing reforms in electricity generation, transmission and distribution.

Commercial biogas facilities offer a viable option for supplementing the national energy supply by converting organic resources, including agricultural waste, animal waste, municipal solid waste, and industrial wastewater, into clean energy. These systems could serve as baseload power sources in off-grid regions, working alongside solar, wind, hydro, and other renewable technologies to ensure energy security.

However, the successful development and deployment of biogas systems in Nigeria will require more than technical knowledge. It will require coordinated attention to economic, environmental, energy, and policy frameworks, as well as the barriers previously discussed. Nigeria is considered one of the countries with a strong potential for the expansion of the biogas market, but significant efforts are still required to realise this potential. Despite the numerous opportunities biogas offers for sustainable energy generation, the country has not effectively recognised or used these opportunities.

To address the obstacles that hinder biogas development, the Nigerian government must take a multi-pronged approach. Strengthening environmental and energy legislation, implementing financial and economic incentives, advancing research and development, and introducing institutional support programmes are all essential steps. In terms of legal and regulatory frameworks, an effective and coordinated government structure is needed to overcome institutional, technical, and policy-related barriers to adoption. Government agencies responsible for energy, environment, agriculture, science, and technology must play an active role in supporting the biogas initiative.

Key government policies, such as those governing grid access, quota obligations, and competitive bidding, should not only be enacted but also be properly enforced. For example, although Nigerian law currently permits grid access for registered biogas power facilities, implementation remains weak. Stronger environmental legislation must be used to uphold waste management standards, particularly in urban areas, and promote integrated solutions for sustainable energy. National development and environmental goals should include biogas as a key component, emphasising both its economic value and its broader environmental benefits.

Research and development (R&D) will also play a critical role in fostering biogas acceptance in Nigeria. Existing research institutions lack sufficient coordination and continuity. This gap can be addressed by allocating specific funding from relevant ministries to support studies on large-scale biogas systems. In addition, the government should explore financial tools such as targeted subsidies, soft loans, and tax incentives to reduce the high cost of biogas production and encourage investment.

Beyond regulation and policy, the government must also develop long-term national strategies for biogas adoption. New technologies, such as biogas, often require extended periods of support before achieving widespread acceptance and socio-technical momentum. Setting clear goals and developing strategic plans for the deployment of biogas in Nigeria are essential for long-term sustainability.

Finally, successful biogas adoption cannot occur without strong public-private partnerships. Collaboration between the government and private sector stakeholders is vital to achieving national energy goals. Government initiatives must actively promote cooperation, providing the foundation for biogas development through existing infrastructure and support programmes. Unity between the public and private sectors will be essential in ensuring that biogas becomes a reliable, scalable, and sustainable energy solution in Nigeria.

6. References

Akande OK, Fabiyi O, Mark IC. 2015. Sustainable Approach to Developing Energy Efficient Buildings for Resilient Future of the Built Environment in Nigeria. American Journal of Civil Engineering and Architecture 3: 144-152.

Akinbami J, Brandberg T, Sanni SA, Taherzadeh MJ. 2014. Nigerian Biogas Technology Development and Dissemination Strategies for Accelerating Biogas Production in Nigeria. BioResources 9: 1 – 31.

Akintade AF. 2021. Biogas a Viable Source of Energy: Case Study, Nigeria. (B.Sc. Thesis). Centria University of Applied Sciences. Finland.

Alhassan KA, Abdullahi HT, Shah MM. 2019. A review on biogas production as an alternative source of fuel. Journal of Applied and Advanced Research 42):6l-65.

Ayodele TR, Ogunjuyigbe ASO, Alao MA. 2018. Economic and Environmental Assessment of Electricity Generation Using Biogas from Organic Fraction of Municipal Solid Waste for the City Ibadan, Nigeria. Journal of Cleaner Production 203: 718 – 735.

Berhe M, Hoag D, Tesfay G, Keske C. 2017. Factors Influencing the Adoption of Biogas Digesters in Rural Ethiopia. Energy, Sustainability and Society 7, 10.

Bharathiraja DB, Sudharsana T, Jaymuthunagai J, Ramanujam PK, Sivasankaran C, Iyyappan J. 2018. Biogas Production – A Review on Composition, Fuel Properties, Feed Stock and Principles of Anaerobic Digestion. Renewable and Sustainable Energy Reviews 90: 570 – 582.

Carbry-Muzyka A, Madi H, Rusch-Pfund F, Gandiglio M, Biollaz S. 2022. Biogas Composition from Agricultural Sources and Organic Fraction of Municipal Solid Waste. Renewable Energy 181: 1000 – 1007.

Chanchangi YN, Adu F, Ghosh A, Sundaram S, Mallick TK. 2022. Nigerian's Energy Review: Focusing on Solar Energy Potential and Penetration. Environment, Development and Sustainability.

Chasnyk O, Solowski G, Shkarup 0. 2015. Historical, technical and economic aspects of biogas development: Case of Poland and Ukraine. Renewable and Sustainable Energy Reviews 52:227-239.

Egbere JO, Omogo EG, Henry MU, Henry UI, Chollom P. 2011. Generation of Biogas from Segregates of Municipal Solid Wastes in Jos, Nigeria. Global Journal of Pure and Applied Sciences 17: 41 – 45.

Energy Expert 2023. Biogas Plant Companies in Nigeria. Available from: https://www.energy.xprt.com. (Accessed December 2022).

Herout M, Malatak J, Kucera L, Dlabaja T. 2011. Biogas Composition Depending on the Type of Plant Biomass Used. Res. Agr. Eng. 57: 137 – 143.

Ifegbesan AP, Rampedi IT, Annegarn HJ. 2016. Nigerian Households' Cooking Energy Use, Determinants of Choice, and Some Implications for Human Health and Environmental Sustainability. Habitat International 55: 17 -24.

Ikpe AE, Imanitie DI, Ndon AE. 2019. Investigation of Biogas Energy Derivation from Anaerobic Digestion of Different Local Food Wastes in Nigeria. Academic Platform Journal of Engineering and Science 7: 332 – 340.

International Energy Agency (IEA). 2012. Energy Balance for Nigeria. OECD/IEA. Available from: https://data.iea.org. Accessed (October 2022).

International Energy Agency (IEA). 2020. Energy Supply Indicator. Total Energy Supply (TES) by source. International Energy Agency. Available from: https://www.iea.org/countries/nigeria. Accessed (October 2022).

International Renewable Energy Agency (IRENA) 2021. Renewable Capacity Statistics. International Renewable Energy Agency, Abu Dhabi.

Itodo IN, Bala EJ, Abubakar SS. 2021. Biogas Technology in Nigeria. C. R. C. Press, Taylor and Francis Group. Boca Raton, Florida.

Jelinek M, Mazancova J, Dang DV, Phung LD, Banout J, Roubik H. 2021. Quantification of the Impact of Partial Replacement of Traditional Cooking Fuels by Biogas on Global Warming: Evidence from Production. 292.

Kabir MM, Niklasson C, Taher -Zadeh MJ, Horvath IS. 2014. Biogas Production from Lignocelluloses by N-methylmorpholine-N-oxide (NMMO) Pre-Treatment: Effects of Recovery and Reuse of NMMO. Bioresource Technology 161: 446 – 450.

Kemausuar F, Adaramola MS, Morken J. 2018. A Review of Commercial Biogas Systems and Lessons for Africa. Energies 11, 2984.

Khayal OMES. 2019. Advantages and Limitations of Biogas Technologies. Laboratory Experiments in Mechanical Engineering Utilization of Renewable Energy in Sudan. Nile Valley University, Atlanta, Sudan.

Khoiyangbam RS, Gupta N, Kumar S. 2011. Biogas Technology: Towards Sustainable Development. TERI Press. The Energy and Resources Institute. New Delhi.

Korbag I, Orner SMS, Boghazala LI, Abusasiyah MAA. 2020. Recent advances on biogas production and future perspective. Intechopcn. in biogas 1-41.

Kouglas PG, Angelidaki I. 2018. Biogas and it’s opportunities- A review. Frontiers of Environmental Science and Engineering 12(3): 14.

Macharia FN. 2015. Biogas production for domestic use. Common Wealth of Learning. Available from: http:/fcreativecommon.orgì licensesby-saì4.0/.

Mengistu MG, Simane B, Eshete G, Workneh S. 2016. Factors Affecting Household’s Decisions in Biogas Technology Adoption, The Case of Ofla and Mecha Districts, Northern Ethiopia. Renewable Energy 93, 215 – 227.

Mushtaq K, Zaidi AA, Askari SJ. 2016. Design and Performance Analysis of Floating Done Type Portable Biogas Plant for Domestic Use in Pakistan. Sustainable Energy Technologies and Assessments. 14: 21 – 25.

Mwirigi J, Balana BB, Mugisha J, Walekhwa P, Melamu R, Nakami S, Makenzi P. 2014. Socio-economic Hurdles to Widespread Adoption of Small-scale Biogas Digesters in Sub-Saharan Africa: A Review. Biomass and Bioenergy 70: 17 – 25.

Nevzorovaa T, Kutcherov V. 2019. Barriers to the Wider Implementation of Biogas as a Source of Energy: A State-of-the-Art Review. Energy Strategy Reviews 26, 100414.

Ngumah CC, Ogbulie JN, Orji JC, Amadi ES. 2013. Biogas Potential of Organic Waste in Nigeria. Journal of Urban and Environmental Engineering 7: 110 -116.

Nigeria Energy Support Programme (NESP) 2014. The Nigerian Energy Sector – An Overview With A Special Emphasis on Renewable Energy, Energy Efficiency and Rural Electrification. P.50.

Nigeria High Commission (NHC) 2022, About Nigeria. Nigeria High Commission, London, UK. Available from: https://www.nigeriahc.org.uk. Accessed (October 2022).

Ofualagba G, Ejofodomi O. 2020. Optimal Embedded Generation (EG) Units for 24 hours Electricity in Nigeria. Journal of Electrical and Power System Engineering 6: 33-42.

Okoro E. E., Okafor l. S., lgwilo K. C., Orodu K. B., Mamudu A. O. 2020. Sustainable biogas production from waste in potential states in Nigeria- alternative source of energy. Journal of Contemporary African Studies 38: 627-643.

Okoro-Shekwaga C, Horan N. 2015. Suitability of Anaerobic Digesters for West Africa: Nigeria as a Case Study. International Journal of Environmental Science and Development 6: 155 – 159.

Oladipo K, Agbetuyi AF, Owolabi B, Obiakor C, Fagbuaro OE. 2018. Power Sector Reform in Nigeria: Challenges and Solutions. 10P.conf.series: Materials Science and Engineering 413: 012037.

Olugasa TT, Odesola IF, Oyewola MO. 2014. Energy Production from Biogas: A Conceptual Review for Use in Nigeria. Renewable and Sustainable Energy Reviews 32: 770 – 776.

Osunkwo FOC, Onwusogbulu RDD, Uma KE. 2020. Rural and Urban Households Choice of Energy Use in Nigeria. Problems and Prospects. International Journal of Research in Engineering, IT and Social Science. 10: 25 – 33.

Oyedepo SO. 2012. Energy and Sustainable Development in Nigeria: The Way Forward. Energy, Sustainability and Society 2, 15.

Paolini V, Petracchini F, Segreto M, Tomassetti L, Naja N, Cecinato A. 2018. Environmental Impact of Biogas: A Short Review of Current Knowledge. Journal of Environmental Science and Health 53: 899 - 906.

Prakash O, Kumar A, Pandey A, Kumar A, Laguri V. 2005. A Review on Biogas Plant. International Journal of New Technologies in Science and Engineering 2: 84 – 93.

Raja IA,Wazir S. 2017. Biogas Production: The Fundamental Processes. Universal Journal of Engineering Science 5: 29 – 37.

Ramirez M, Gomez JM, Cantero D. 2015. Biogas: Sources. Purification and Uses. In U.C. Sharma.,S. Kumar., R. Prasad (Eds). Hydrogen and other technologies pp. 296-323. Studium press LLC.

Roubik H, Mazancova J, Rydual J, Kvasnicka R. 2020. Uncovering The Dynamic Complexity of the Development of Small-Scale Biogas Technology Through Casual Loops. Renewable Energy 149: 235 – 243.

Roubik H, Mazancova J. 2020. Suitability of Small-Scale Biogas Systems Based on Livestock Manure for the Rural Areas of Sumatra. Environmental Development 33, 100505.

Roubik H, Barrera S, Dung DU, Phung LD, Mazancova J. 2020. Emission Reduction Potential of Household Biogas Plants In Developing Countries: The Case of Central Vietnam. Journal of Cleaner Production. 27, 122257.

Saleh A. 2015. Comparison among Different Models of Biogas Plants. Biomass Conversion Research Centre. COMSATS. LAHORE.

Sawyerr N, Trois C, Workneh T, Okudoh VI. 2019. An Overview of Biogas Production: Fundamentals, Applications and Future Research. International Journal of Energy Economics and Policy 9: 105 – 116.

World Bank Population, Total – Nigeria, World Development Indicators. The World Bank Group, 2022. Available from: https://data.worldbank.org/Indicator/SP.POP .TOTL?locations=NG. Accessed (September 2022).

World Bank (WB) 2020. Access to Clean Fuels and Technologies for Cooking (% of Population) Nigeria. World Development Indicators. World Bank Group. Available from: https://data.worldbank.org/indicator/EG.CFT.ACCS.ZS?locations=NG. Accessed (October 2022).

World Bank (WB). 2020. Access to Electricity (% of population) Sub-Saharan Africa. World Bank Global Electrification Database from Tracking SDG 7: The Energy Progress Report. World Bank Group. Available from: https://data.worldbank.org/indicator/EG.ELC.ACCS.ZS?locations=ZG. Accessed (October 2022).