CZECH UNIVERSITY OF LIFE SCIENCES PRAGUE

Faculty of Tropical AgriSciences

SMALL SCALE BIOGAS TECHNOLOGY IN NIGERIA: PERSPECTIVE OF RURAL AREAS

MASTER'S THESIS

Prague 2022

Author: Liasu Babatunde Tijani

Chief supervisor: Associate Professor Doc. Hynek Roubík, Ph.D.

Declaration

I hereby declare that I have done this thesis entitled "Small Scale Biogas Technology in Nigeria: Perspective Of Rural Areas" independently, all texts in this thesis are original, and all the sources have been quoted and acknowledged by means of complete references and according to Citation rules of the FTA.

In Prague 19th April 2022

....

Liasu Babatunde Tijani

Acknowledgements

All thanks be to Allah for the grace of a good health and sound mind, for knowledge wisdom and understanding. I am grateful to my mum, Aishat Liasu for her never-ending support and encouragement. I am also indebted to my late dad Chief Adio Liasu for laying the foundations which I could build upon. I am eternally grateful to my supervisor, Associate Professor Dr. Hynek Roubík for his unrelentless efforts to see this into a logical conclusion. His simplicity and kindness are so much appreciated, and his guidance was invaluable. I thank all my lecturers who one way or the other have made a positive impact during my studies at the university with special mention to Paco who in the final days of my studies encouraged me so much with positive words.

To my brothers, Ibrahim and Abisoye Liasu and the whole Liasu family, I thank you so much for your support and to Edwin Liasu, I hope this encourages you to forge further than I ever dared. I am grateful.

….. Liasu Babatunde

Abstract

Sustainable energy has remained every country's desire for its citizens in Sub-Saharan Africa. Biological wastes, which are low-valued products with high waste management environmental issues, are being converted into eco-friendly and renewable fuels. This study sought to assess if small-scale production of biogas technology can be used as a tool for rural development in Nigeria. The methodology includes selection and analysis of administered questionnaires to randomly selected one hundred (100) biogas installations and conducting interviews with both plant users and service providers via a descriptive statistics method. The study also revealed that most of the respondents were knowledgeable about biogas technology (84%) and solar power (74%) while they knew a little about wind power, energy-conserving electrical appliances, hydrogen powered vehicles, biomass energy and carbon capture and storage technology. Majority of the respondents also agreed with the use of biogas, solar power and wind power. Main household occupation (8.1%), highest household education (52.3%), average household monthly income (7.5%), knowledge of solar power (61.3%), wind power technology (27.5%), energy-saving vehicles (24.8%), and biogas technology (41.7%) significantly ($p<0.05$) influenced the respondents to adopt biogas technology as alternative energy source in the study area. The majority of the respondents (82%) were those that had attained post-secondary education. Increase in education level was positively associated with adoption of biogas. This study therefore concludes that in order to address the inconsistency of electricity in Nigeria, Biogas can provide a solution that will increase business while also attracting the attention of investors. Hence, the government should provide appropriate financial support, practical training, favourable Biogas technology laws and regulations to promote biogas development in Nigeria.

***Key words**: Biogas, Renewable Energy, Climate Change, Biofuel, Sustainable environment*

Table of Contents

Content Page

List of Figures

List of Tables

List of Abbreviations

AD – Anaerobic Digestion

ECN – Electricity Corporation of Nigeria

FAO – Food and Agriculture Organization of the United Nations

GoN – Government of Nigeria

IEA – International Energy Agency

LPG – liquefied petroleum gas

MDGs – Millennium Development Goals

MSW – Municipal solid waste

NEMA – Nigeria National Emergency Management Agency

NEP – Nigeria Electrification Project

NPC – Nigerian population Commission

NREEEP – National Renewable Energy and Energy Efficiency Policy

REAP – Renewable Electricity Action Program

REMP – Renewable Energy Master Plan

REPG – Renewable Electricity Policy Guidelines

RMP – Red Mud Plastic

SDGs – Sustainable Development Goals

UNDEP – United Nations Development Programme

UNEP – United Nations Environment Programme

UNICEF – United Nations Children's Fund

WHO – World Health Organization

1 Introduction and Literature Review

1.1 Introduction

Energy is significant in providing essential services, and the domestic services considered basic are, cooking, heating and lighting. Communities in rural areas face challenges in accessing energy compared to those in urban areas (FAO 2006). Energy use doubles with every generation and this affects the environment and the society, more than any other human activity. Estimates indicate that the number of people using wood fuel will rise by more than 40% to about 700 million people in Africa by 2030 (IEA 2006). This status is an indicator of great danger for human and climate security and is a major barrier to progress against poverty and growth of Africa's Sub-Saharan economies. The world is now shifting from petroleum-based to a bio-based global economy (Dahunsi and Oranusi 2013). In this case, the biological wastes which are considered to be low-valued materials and high quantity waste disposal environmental problems are being transformed to form eco-friendly and sustainable fuels (Gomez et al. 2008).

Nigeria has been nicknamed, the giant of Africa, this is largely due to its potentials which many have agreed the country has long failed to live up to. Now, it is not uncommon to hear the country called the sleeping giant of Africa. The potentials are so vast and numerous, that no citizen of the country has any business being poor. So, it is such a great surprise that the country still grapples with poor power supply at this time when other countries are faced with more modern and advanced problems. Constant power supply is the hallmark of a developed country and any nation whose energy need is epileptic in supply, prolongs her development and risks losing potential investors (Okoro & Chikuni 2007).

The problem of constant power supply can be traced to the centralization of the power supply whereby the Federal Government is in charge of all sections of the power supply. It is only of recent that the government decided to privatize some sections. This has made almost every citizen become a mini government in his or her own capacity in relation to power generation. Every individual who can afford it has a power generator which massively contributes to environmental pollution and also noise pollution.

Energy plays a key role in the socio-economic growth and development of countries. A shortage of energy is however one of the acute problems facing mankind today (Abraha 1984). In rural areas in Nigeria, most of the energy used for cooking in the homes come from firewood, charcoal and kerosene which is a fossil fuel. Charcoal is widely used by high percentage of the population in the country for cooking and other uses that is what makes it a major threat to forest reserves. About 31% of the world land surface is covered by forest, while in Nigeria it falls gradually from 16.6% in 1996 to 7.7% in 2015 (Mba 2018).

Modern fuels for example liquefied petroleum gas (LPG), electricity and kerosene are expensive (Kerekezi & Kimani, 2009). In order to meet energy needs, there is continued overdependence on wood fuel and other kind of biomass as the main source of energy and this has far-reaching environmental and health effects (UNEP 2012). Therefore, there is need for an alternative source of energy that would be cost-effective and socially equitable (NEMA 2009). According to Susanne (2011), biogas fuel is a clean form of energy compared to traditional biomass. It has the potential to prevent environmental and adverse health impacts related to the use of wood fuel. Biogas helps in reducing energy poverty which is one of the greatest challenges for developing countries. The use of biogas will overcome the problem linked with achieving the United Nations Sustainable Development Goals.

Nigeria stands to benefit a lot from the production of biogas through anaerobic digestion of voluminous amounts household wastes, residues from agricultural outputs and even water wastes from industries. This will provide cleaner fuel in the form of biogas and these are renewable stocks which will greatly help in the area of energy and poverty elimination. The conditions are favourable, and the advantages far outweigh the disadvantages. Unfortunately, this has not been the case due to economic reasons. It will be very important to find out why Nigeria has not embraced biogas on a large scale despite the evidence that this will bring a lot of economic benefit. It is appropriate that Nigeria invest in new technologies and new sources of energy that will leave less of environmental "footprint" than the traditional biomass, coal or oil and that will be more sustainable.

It is of the view that the development of biogas technology which will serve as a viable source of alternative energy has come at the very right time.

1.2 Biogas Technology Background

Biogas is not a new technology as the concept was found out in the 18th century by Jan Baptiste Van Helmont, a Flemish chemist who noticed that decomposing organic matter could create a gas which is combustible (Banchetti-Robino 2016). This was eventually confirmed to be methane gas by Humphrey Davy and John Dalton (Hartley 1967). According to He (2010), biogas might have been used as far back as the 10th century B.C in Assyria for heating bath water and also suggestions of anaerobic digestion of solid wastes were rife in ancient China. These might have not been well documented. However, attempts to utilize anaerobic digestion of biomass in New Zealand and India in mid Nineteenth century were well documented (University of Adelaide 2010). And as Deublein and Steinhauser (2008) suggested, around 3000 BC, the Sumerians practiced anaerobic cleansing of waste. In 1859 in Bombay, the first anaerobic digestion plant was established and in 1897, an anaerobic digester at Matunga Leper Asylum in Bombay used human waste to generate biogas (Khanal 2008).

After this, the UK also employed this technology of anaerobic digestion for the conversion of sewage into biogas. This was used to light up the streets (University of Adelaide 2010).

According to Deublein and Steinhauser (2008), other countries also took a bold step to evolutionise biogas technology. These were: France, in 1987 the streets lamps of Exeter started running on biogas produced from wastewater; China, rural biogas system developed in 1920, while the national program started in 1958; Potential of Organic Waste for Biogas and Biofertilizer Production in Nigeria 61 Germany, agricultural products were used to produce biogas in 1945. China had an estimated 100,000 modern biogas plants and 43 million residential-scale digesters in 2014, generating about 15 billion m^3 of biogas, equivalent to 9 billion m^3 biomethane (324 TJ primary energy). The Medium-and-Long Term Development Plan for Renewable Energy requires reaching by 2020 about 80 million household biogas plants, 8000 large-scale biogas projects with an installed capacity of 3000 MW and an annual biogas production of 50 billion m_3. The biogas potential was estimated at 200 – 250 billion m^3 annually (Adib et al. 2015; Jingming 2014). In the last years, modern biogas plants have been built, with the installed electricity capacity of biogas plants reaching 330 MW in 2015 and 350 MW in 2016 (Li et al. 2020).

Provision of energy is pivotal in the development of a nation, primarily because it is a factor of production that consequently affects the price of most goods and services. It is also a critical element closely associated with industrialization and ensuring essential services are provided, whilst increasing the standard of living, hence, contribute to the national economic growth (Singh & Sooch 2004). Energy is one of the main drivers of Nigeria's economic growth and development as it has its tentacles spread across different sectors like agriculture, transportation, health, commerce and is even used and an instrument for politics and security (Oyedepo 2012). Economic growth and development can be traced to an increased access to energy which in turn improves the standard of living (Nguyen 2007).

The Nigerian environment as a case study, provides a wealthy source of fossil fuel and the raw materials for the production of biogas that if properly harnessed can help the country develop a practical national energy policy. Unfortunately, as Anowor et al. (2014) concludes, the country depends mostly on the conventional source of energy with a whole lot of opportunity cost associated with its production based on its inability to refine its product independently thereby making its cost relatively inaccessible to the general masses, especially the rural dwellers.

A scorecard that the Nigerian government can reference to fully understand how energy can be used as a tool for rural development is in the report of the United Nation Development Program in Mali, which launched the proliferation of locally adapted biogas plant prototype in rural settlements very close to the city of Bamako (Amigun et al. 2008). This initiative performed the dual function of providing an alternative source of renewable energy and supplying high grade fertilizers for the local farmers. The program is also helping to achieve some of the MDGs like reduction of child mortality, better health status to battle diseases while also guaranteeing environmental sustainability (Amigun et al. 2008). This is not to assume that the adaptation of biogas technology in a developing country like Nigeria will not pose any form of challenge to operate.

1.2.1 Schematics of A Biogas plant

Most times, biogas reactors are connected directly to private or public toilets while an additional access point can be added for organic materials. As shown in Figure 1, at the household level, reactors can be made out of plastic containers or bricks. Sizes can vary from 1,000 L for a single family up to 100,000 L for institutional or public toilet applications. Because the digestate production is continuous, there must be provisions made for its storage, use and/or transport away from the site.

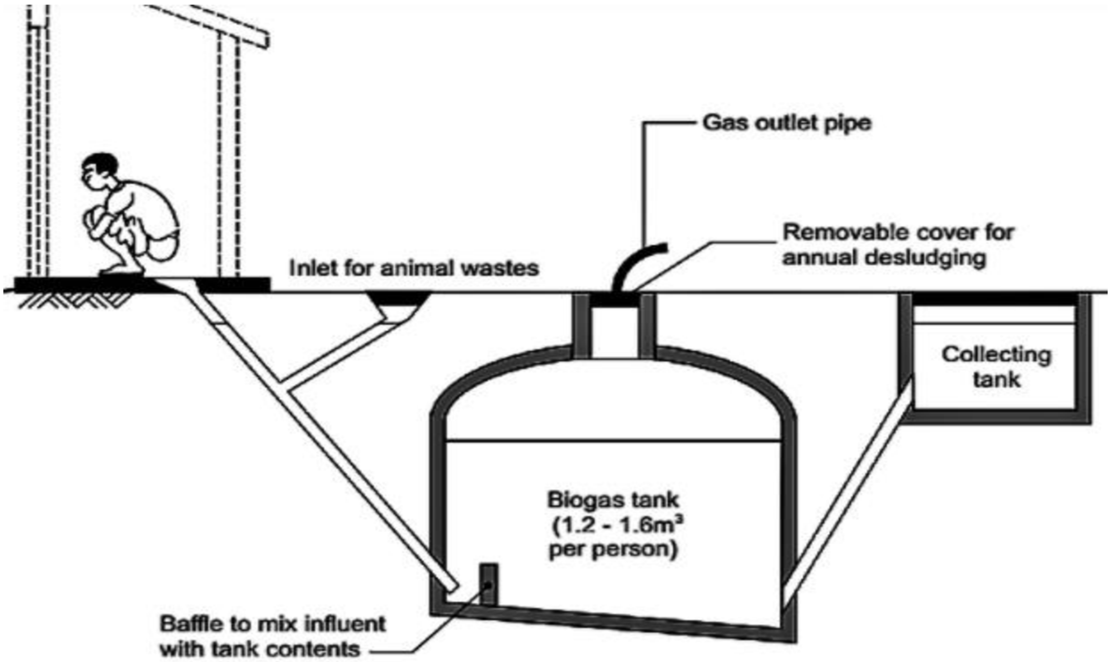


Figure 1: Schematic of a biogas reactor.

Source: Cook (2010)

Besides kitchen waste, garden wastes, animal waste and plants can be added to the reactor to increase the biogas generation. Green plants are well suited for anaerobic digestion and their gas yields are high, usually above that of manure (Werner et al. 1989). Feed material containing lignin, such as straw or wood resist anaerobic fermentation and should therefore not be used in biogas plants (Werner et al. 1989) or at least be pre-composted and preferably chopped before digestion (Sasse 1988).

1.3 Biogas as an Alternative Source of Domestic Energy in Nigeria

Energy generation remains one of the biggest challenges of developing or third world counties like Nigeria. About 80 million (44.4%) out of 180 million Nigerians living in 8000 villages across the country lack access to electricity according to World Bank report for sustainable energy to all (World Bank, 2016). This can be attributed to the inadequate infrastructure, spare parts shortage and inefficiency in management.

Biomass and solar resources are widely and abundantly available in Nigeria (Aliyu et al. 2015). The available sustainable biomass resources in Nigeria include wood, grasses, shrubs, plantain peels, forage, cocoa pods, animal waste, and livestock manure (Aliyu et al. 2015). In General, the biomass resources can be categorized into agricultural crops, forestry resources, agricultural crop residues, municipal solid waste, and animal wastes (Giwa et al. 2017). The potential for bioenergy in Nigeria is 144 million tons per year (Ibitoye & Adenikinju 2007).

But in Nigeria, most of the states are still faced with the challenges of ensuring energy supply which is sustainable and safe waste management and AD meets the requirements of sustainable alternative fuels and is a viable environmental disposal method. Producing clean alternative biogas energy from waste is also one of the best ways to meet these challenges (Okoro et al. 2020).

Biogas can be considered as an eco-friendly fuel that can be used to replace the compressed natural gas. In developing countries, wood can be supplemented or replaced by use of biogas as an energy source for cooking and lighting. It is a widely accessible source of energy that considerably reduces greenhouse gas emission (Aremu & Agarry 2013).

According to Akinbomi *et al*. (2014) making use of biogas technology provides a means of maintaining a balance between production and consumption of waste and energy, since the technology helps in converting organic waste materials into energy in form of biogas. The waste converting process in order to produce biogas could be one of the most resourceful ways of ensuring that there is proper waste disposal, production of energy and protection of the environment.

Advancing the plentiful biomass in Africa to cleaner energy sources could help change the energy situation in Africa. Increased awareness and extensive research on the accessibility of new and renewable energy resource, such as biogas has come about due to the problem arising from non-sustainable use of fossil fuels and traditional biomass fuels (Oyedepo 2014). In order to help reduce the over reliance on non-renewable energy resources and in return minimize the social impacts and environmental degradation problems associated with fossil fuel, the development of renewable energy technologies for instance biogas technology can be of essence (Oyedepo 2014). Renewable energy provides the much-desired sustainable rural regeneration in most developing countries. This is a perfect alternative source of energy because it is less costly for the low-income communities (Amigun *et al*. 2008).

The quality of life in the rural areas can improve if there is reduction in labour among women and children, this can be achieved by use of biogas that has the potential to improve their way of living. This is due to the fact that there is reduction in the workload of women and children collecting firewood (Mwakaye 2007), indoor smoke is reduced, sanitation is improved and there is better lighting when biogas is used (Amigum & Blottnitz 2010).

1.4 A Review of Small-Scale Biogas Technology in Nigeria

We currently live in an energy-intensive society, and it is very important to research and benefit from renewable energy and also energy sources which are eco-friendly (Emetere et al. 2016). The case of Nigeria is quite peculiar as Over 60% of Nigeria's population depend on firewood for cooking and other domestic uses (ECN 2003). More damning is the statistic from the rural areas as it has been estimated that as much as 86% of rural households living in Nigeria depend on firewood as their source of energy (Williams 1998). In order to grab the situation of things, it is important to note the rapid rise of Nigeria’s population as indicated in Figure 2.

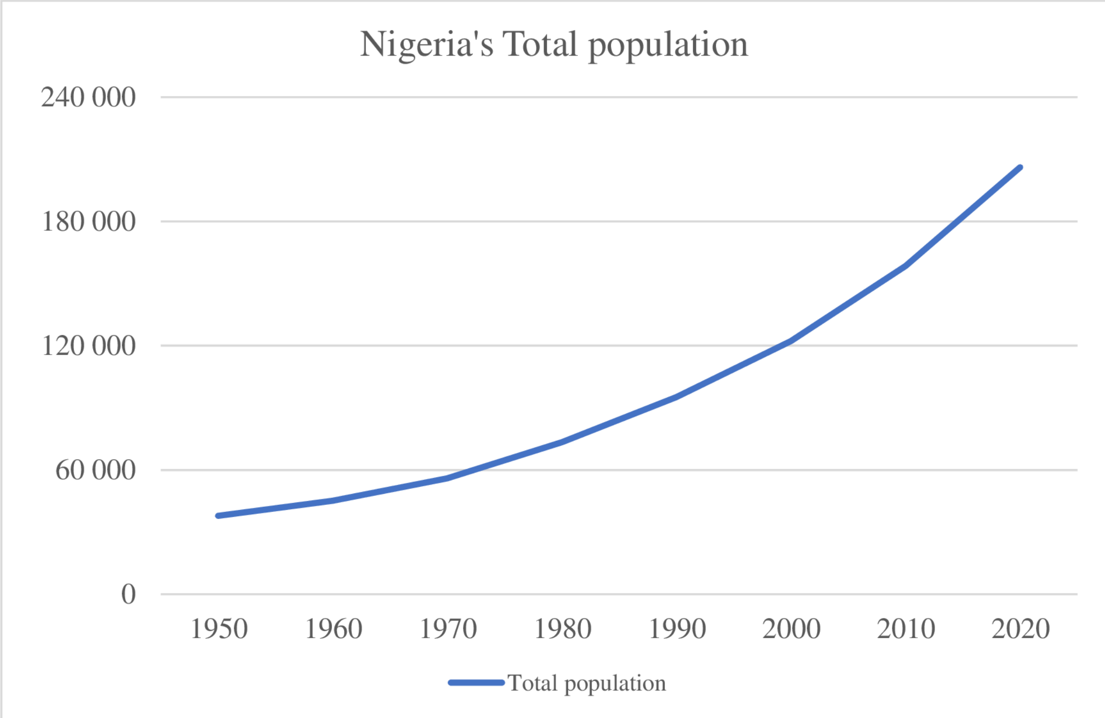


Figure 2: Nigeria's growing population (Data adopted from UNDEP, 2019)

In Nigeria, biogas plants are not yet so familiar in the energy market (Akinbami et al. 2001) but it is not non-existent. Given the many technological advantages and the population of Nigeria, biogas technology is expected to spread widely in the region (Biodun et al. 2021). Nevertheless, developments in biogas technology are hindered by lack of policy commitments, lack of sufficient processing expertise, insufficient waste management, inadequate technology awareness and related benefits (Baky et al. 2014). Biogas technology has excellent potential in Nigeria. It is estimated that Nigeria generates about 542.5 million tons annually, and these are majorly comprising of organic waste. It had been estimated that Nigeria will generate 169,541.66 MW of energy or 25.53 billion m^3 of biogas if the organic waste materials generated in the country are channelled into anaerobic digestion. This will address some of the immediate energy issues of the country (Baky et al. 2014).

1.5 Renewable Energy Policies in Nigeria

Nigeria has developed many successive policies relevant to energy and renewable energy, since the first policy – the Draft National Policy on the Environment – was created in 1998. The goal of the Nigeria's energy policy is the promotion of energy security through a robust energy system. The Government of Nigeria plans to diversify the energy sources based on the principle of "an energy economy in which modern renewable energy increases its share of energy consumed and provide affordable access to energy through-out Nigeria, thus contributing to sustainable development and environmental conservations" (Emodi 2016).

Currently, there are about 39 policy documents in the energy sector, the majority of which are still in draft form with no definite date for receiving government approval (Federal Republic of Nigeria 2016). Since 2003, when the NEP was adopted, the GoN has created (among others) the 2005 Renewable Energy Master Plan (REMP); the 2006 Renewable Electricity Policy Guidelines (REPG) and the Renewable Electricity Action Program (REAP); the National Renewable Energy and Energy Efficiency Policy (NREEEP); the Vision 20:20 Program (2009); and the Sustainable Energy for All Agenda (Joshua et al. 2020).

1.6 Small-Scale Biogas Plants: A Tool for Rural Development in Nigeria

According to Roubík et al. (2016) a piece of equipment that uses an anaerobic digestion process for biodegradable waste treatment is known as biogas plant. Biogas could serve as a tool for rural development in Nigeria if all stakeholders play their roles effectively (Ngumah et al. 2013). As explained by Deublein and Steinhauser (2008), biogas technology came into first usage in Africa between 1930 and 1940, when Ducellier and Isman began to build simple biogas machines in Algeria to which were used to supply farmhouses with needed energy. Despite the early start of biogas usage in Africa, the development of large-scale biogas technology is still in its early stages in this region and has failed to take off on a big stage, although there are a lot of potentials which could be of utmost benefit to the continent (Ngumah et al. 2013).

In Nigeria, biogas technology is still at institutional level of research work and pilot schemes Its progress being suppressed by ignorance, research at universities frequently considered as being too academic, absence of political will, and inadequate coordinating framework. (Ngumah et al. 2013). The earliest record of biogas technology in Nigeria was in the 1980s, when a simple biogas plant that could produce 425 litres of biogas per day was built at Usman Danfodiyo University, Sokoto (Dangogo and Fernado 1986). About 21 pilot demonstration plants with a capacity range of between 10m3 -20m3 have been installed in different parts of the country (Ngumah et al. 2013). As analysed by Akinbami et al. (2001), if biogas displaces kerosene, at least between 357 - 60, 952 tons of carbon dioxide emission will be avoided.

Domestic biogas can create an opportunity to overcome a lot of challenges facing the rural communities due to the fact that biogas uses existing domestic sources can provide poor rural women and men in developing countries like Nigeria with clean and renewable energy all year round. (Amigun et al. 2012). Thanks to biogas fuel, rural kitchens can now be free of smoke and ash, for a healthier household environment. As fertilizer, the organic residue that is an end agricultural product. Biogas units should become and more widely used in rural areas of Nigeria due to the fact that biogas units are environmentally friendly and do not require large investments, biogas has the potential to become the 'fuel of the poor’ (Amigun et al. 2008).

1.6.1 Factors Preventing Adoption of Biogas in Nigeria Rural Areas

In Africa, Biogas technology is gradually gaining grounds and countries like, Zimbabwe, Mali and Nigeria are taking advantage of the technology as an alternative to the traditional fuel (Akinbami et al. 2001) Knowledge deficit has been identified as a major deterrent to biogas technology application and adaptation across the African continent due to limited laboratorybased research on biogas in most African countries (Mshandete & Parawira 2009). According to Akinbami et al. (2001), three main factors were identified as the main problems which is preventing a general adoption of biogas technology in Nigeria, and they are economic, technical and socio-cultural factors.

1.6.2 Future Prospects of Biogas Technology in Nigeria

Making use of the Nigerian population Commission (NPC) census of 1991 and using the population growth rate as shown in Table 1 and also an average household size of 9 people, Akinbami et al. (2001) envisaged the population projection and biogas usage by population using three scenarios with 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 Scenarios=1.5% of the households per annum adopt biogas digesters.

Table 1: Total Population and Corresponding Number of Household's Projections

	1995	2000	2005	2010	2015	2020	2025	2030
Population 10^6	98.84	113.47	130.27	149.56	171.70	197.13	226.31	259.82
No. of Households 10^6	10.98	12.61	14.47	16.62	19.08	21.90	25.15	28.87

Source: Akinbami et al. 2001.

Table 2: Total Number of Digesters Projected for the Country for the Period 2000–2030

Projected biogas digesters	2000	2005	2010	2015	2020	2025	2030
Low growth scenario	63,050	72,350	83,100	95,400	109,500	125,750	144,350
Moderate growth scenario	315,250	361,750	415,500	477,000	547,500	628,750	721,750
High growth scenario	945,750	1,085,250	1,246,500	1,431,000	1,642,500	1,886,250	2,165,250

Source: Akinbami et al. 2001

Table 2 envisaged that within the next decade it is possible to have between 144,350–2,165,250 family-sized biogas digesters in the national energy supply mix. Based on a study that a 6.0m^3 family-sized biogas digester will generate 2.7 m^3 of biogas (about 79.11 MJ), the likely trend of energy that can be obtained from the projected number of family-sized biogas digesters in the country in the future is depicted in Figure 3. However, in 2015, Aliyu et al. (2015) estimated the biogas potential in Nigeria as 6.8 million cubic meters per day from animal manure and 913,440 tonnes of methane from MSW, equivalent to 482 MW of electricity.

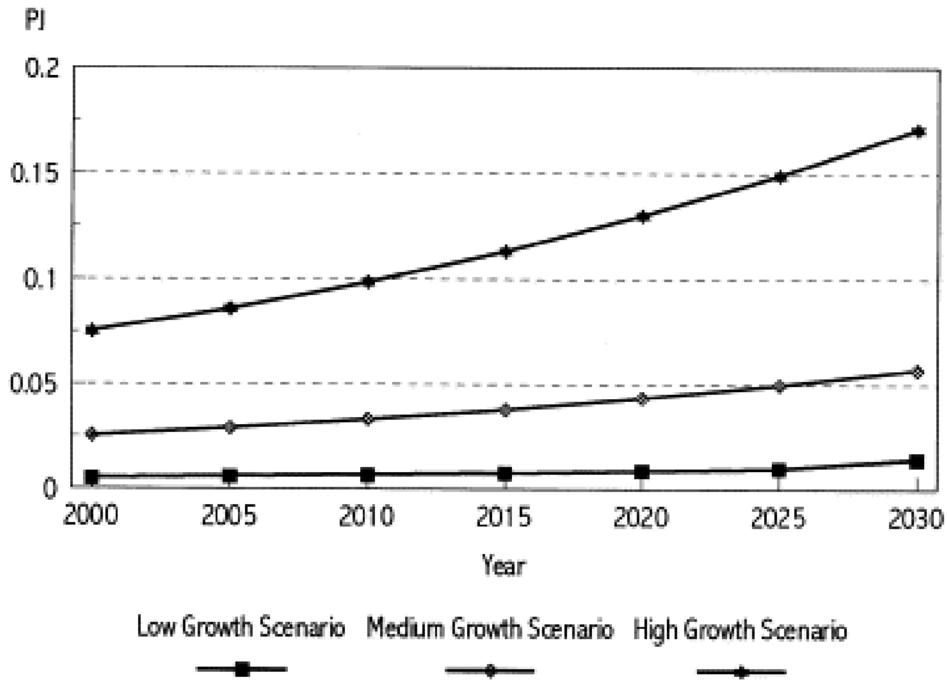


Figure 3: Energy consumption trend from projected family-sized biogas digesters in Nigeria for the period 2000–2030 projections (Chart Adapted from Akinbami et al. 2001)

1.6.3 Household biogas plants for rural areas

Biogas appliances are essential parts of biogas technology (Roubik & Mazancova 2019). In terms of small-scale biogas plants applied in rural households, biogas cook stoves and biogas lamps are the most common appliances (in our study, 100% of owners of biogas plant had a biogas cook stove); however, other appliances do exist (Roubik & Mazancova 2019). In Nigeria, digester suitability could be based on feedstock type and availability, geopolitical zones, population, and climatic vulnerability (*i.e.* rainfall decline, coastal flooding, and erosion) (Akinbomi et al. 2014). It is not always easy to decide on a specific type of digester for household uses. The geographical location plays a key part in the design of the digesters. In tropical countries like Nigeria, it is better to have underground digesters due to the geothermal energy (Bin C, 1989). Two main types of household digesters are commonly used in Nigeria.

Fixed Dome Digester

The fixed dome digester is also called the Chinese digester due to the fact that it is mostly used in China for biogas production. They are mostly built underground (Santerre & Smith, 1982). The size will be dependent on location, number of people who intend to use it and the amount of substrate which is available daily. In Nigeria, for a family of 9, about 6 m3is sufficient (Adeoti et al. 2000). Due to the clustered houses in Nigeria, fixed dome biogas digesters are better (Akinbami et al. 2001)

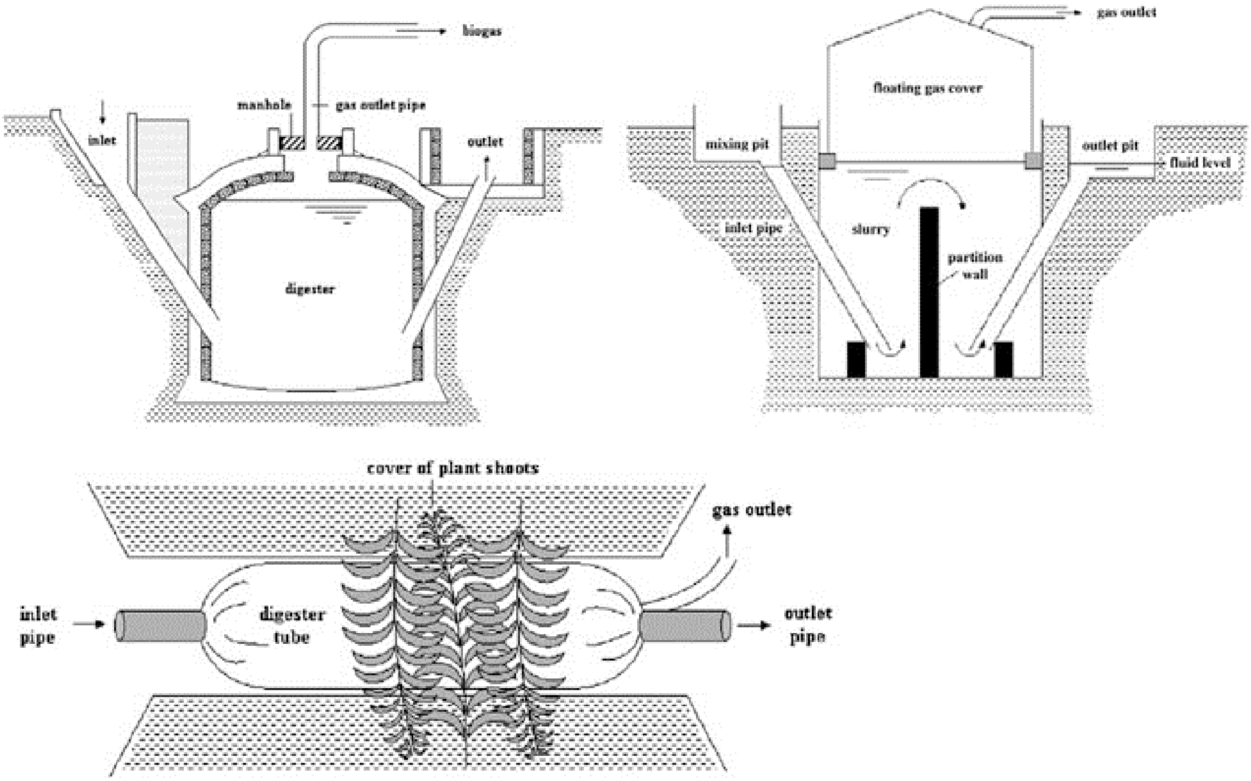
Floating Drum digester

These types of digesters produce biogas with constant pressure and variable volume (Green and Sibisi 2002). It involves adding a movable drum which is inverted on a digester, the drum is able to move up and down depending of the level of gas in the digester. When the weight of the inverted drum presses on the gas, it provides pressure which the gas flows through the pipe inlet for use. (Singh and Sooch 2004) These digesters have an average size of 1.2 m^3 (Gosling, 1982).

Balloon Plants

This digester is made of plastic in the upper region of the digester where the gas is stored. The inlet and the outlet are directly attached to the balloon skin. When the space for holding the gas is full, it works like a fixed dome plant. The fermentation of slurry gets activated due to the movement of the skin of the balloon. This helps in the digestion process. Even different materials for feed such as water hyacinths can be used. The materials of the balloon plant should be UV resistant. Red Mud Plastic material (RMP) is also used in fabrication of this type of digester.

The advantages of the balloon plant are: low cost, can be easily transported from one place to another and easy in construction. Also, it has less complexity of cleaning and maintenance issues. The disadvantages associated with this plant are: has a very small life span and is prone to damage. It is mainly used where it is less prone to damage (Roy et al. 2018).



Fixed dome (top left), floating cover (top right), and balloon type (bottom). Source: Bond et al. (2011)

Figure 4: Types of Biogas Digesters

1.7 Perspective of Rural Dwellers to Biogas Technology

Small-scale biogas technology is one of the fastest growing and highly promising renewable energy sources, mainly for rural households (Roubik et al. 2018). How people react when presented with biogas technology solely depends on their attitudes or perceptions regarding its use and cost, among other factors. (Gakuu *et al*. 2013). In Nigeria, it was found out that there is considerable significant sociocultural acceptability of biogas from faecal waste (Ajieh et al. 2021).

1.8 Rural Generated Waste as a source of fuel for biogas plants

For biogas programme to be feasible in Nigeria, feedstock substrate which have been identified include but not limited to, water hyacinth, leaves from cassava, refuse from the urban areas, solid waste including industrial waste, dung, sewage and agricultural residues, on estimate, it has been found that Nigeria produces 227,500 tons daily of fresh animal wastes. So, if 1 kilogram(kg) of fresh animal waste can produce 0.03 m^3 in gas, it is then assumed that Nigeria has the capacity to produce about 6.8 million m^3 in biogas daily (Akinbami et al. 2001).

Nigeria has warm climatic conditions, and these conditions are quite adequate for anaerobic digestion process of organic wastes and so, there is no need for extra heating, therefore, converting wastes into biogas production could be one of the most efficient ways of waste disposal, energy production, and environmental protection. (Bin 1989).

Potential sources of biogas energy include:

1.8.1 Agricultural wastes in Nigeria

Nigeria seems to have such wastes in abundant quantity especially in Nigerian rural areas where farming is quite prevalent. It is not uncommon to see a lot of agricultural products rotting away especially in the North. These wastes could serve as a source of fuel to biogas plants if properly utilised. Adelekan and Bamgboye (2009) have studied the productivity of ACD of several mixture ratios of cassava peels with each major livestock (poultry, piggery and cattle) wastes. They concluded that ACD in each case led to enormous improvement in biogas yield and that each mixture type gave the best yield at 1:1 ratio of constituents by mass. At any ratio, ACD with piggery waste gave the best yield followed by cattle waste then poultry waste.

There is availability of large amounts of non-plantation biomass resources in Nigeria for modern energy applications. These resources are residues from maize, cassava, millet, plantain, groundnuts, sorghum, oil palm, palm kernel, and cowpeas. The amount of residues generated in 2004 varies from 311,000 tonnes for oil palm shells to 14 million tonnes for sorghum straw. It is estimated that all totalled more than 70 million tonnes of agricultural residues were potentially produced in the year 2004, out of which only 58 million tonnes are energetically available. There is due availability projection for 2010 is about 80 million tonnes (Jekayinfa et al. 2009).

1.8.2 Municipal solid waste (MSW)

Mountains of waste and dumps are a common site in Nigeria. All the waste management institutions which have been saddled with waste management have continuously failed in their tasks. Open waste dumps are mostly incinerated, thereby facilitating the release of toxic fumes which eventually threaten public health. Other consequences are odour emission, breeding area for pathogens and disease vectors, continuous and uncontrollable recycling of goods which have been contaminated and pollution of water sources (Agunwamba 1998). The standard of living in a given region will determine the quantity and also the composition of MSW which is being generated in a particular region. The region's local climate, pattern of consumption as well as cultural and educational differences are also other factors which play a role in the MSW generated. A typical dumpsite in Lagos contains about 50% food waste. (Jobaye environmental solutions 2021).

The waste generation rate in developing countries has been found to be within the range of 0.4 to 0.6 kg/person/day (Chandrappa & Das 2012). This can be compared to the waste generation rate of 0.44 to 0.66 kg/capita/day generated in some regions in Nigeria (Ogwueleka 2009). The moisture and organic content of the waste generated in developing countries are reportedly reasonably high, which makes them to be suitable for anaerobic digestion (Babayemi & Dauda 2009).

1.8.3 Human Wastes

Human waste, also referred to as black water, consists of faeces and urine and forms part of sewage which is generated from a given community. The other part of the sewage is called grey water, which represents wastewater from all sources including bathroom, kitchen, and laundry without human wastes (Katukiza et al. 2012; Uwidia & Ademoroti 2011). In Nigeria, sewage treatment plants are not common therefore human wastes are managed indiscriminately. Human excreta are mostly managed in a separate way via Water closets, septic tanks, latrines or pit, while in other areas like public areas and markets, excreta ends up mixed with solid waste (Sridhar & Hammed 2014)

Within Nigerian urban communities, pit latrines are common in low-income households (Chaggu et al. 2002; Sederberg et al. 2003; Kulabako et al. 2010; WHO and UNICEF 2010), while water closet toilets are common in middle and high-income households. In Nigerian rural communities, soil pit and open defection are still the common forms of human waste disposal, since many rural dwellers do not have any form of toilets (Esrey et al. 1998). Nigeria is a developing country and consist of communities and old cities, it is common to see that the sewage which is generated are most times, discharged into the pit latrines in most rural areas. The problem with such systems is that the soils will become saturated with effluents and pollutants and with a high amount of suspended or dissolved solids which will eventually cause environmental pollutions (Adesogan 2013). Therefore, the sewage should undergo treatment before it is disposed so as to prevent pollution of surface and also groundwater. This will reduce eventual spread of diseases which are communicable and caused by pathogenic organisms which are found in sewage (Ogedengbe, 2001).

1.8.4 Livestock waste: livestock manure and abattoir waste

A significantly huge amount abattoir waste is usually generated daily in Nigeria because of high consumption of meat. Most times, these wastes do not get treated before they are being discharged into the streams and rivers, and this causes an environmental and health hazard to people who live in the neighbourhood. abattoir wastes composition mostly includes animal blood, intestinal content, waste tissue, and bone. From the common reared livestock in Nigeria, an estimated amount of 0.83 million tonnes (Table 4) abattoir waste could be generated annually, which could be harnessed using biogas technology to produce about 0.34 billion cubic metres of methane gas.

Dead livestock from diseases, manure from livestock, wastes from slaughterhouses such as feathers, bones, hair, feather, undigested food, blood and meat from animal and poultry processing industries are what constitutes livestock wastes. Livestock manure management is a big challenge for low income economies (Roubík et al. 2017). Of all livestock which are reared in Nigeria, only goats, cattle, sheep, chicken and pigs are produced in large quantities, and the amount of animal dung that could be obtained from the average annual population of the livestock was estimated to be approximately 32 million tonnes, from which 3.7 billion cubic metres of methane gas could be produced), (Adeshinwa et al. 2003; Akinfolarin & Okubanjo 2010).

1.9 Biogas Production and Use

Energy shortage belongs to one of the key factors limiting progress in developing countries. The local population faces challenges in accessing appropriate energy while keeping a clean environment, health conditions and experiencing economic growth. (Roubik & Mazancova 2020). Therefore, exploring new, reliable, renewable and sustainable energy sources has become a key quest to tackle the worldwide crises of energy shortages (Chang et al. 2014).

This is why it is essential for developing countries to source for reliable and cleaner alternative energy sources. Biogas technology is one which comes with a lot of benefits especially in rural areas of developing countries as it makes use of readily available sources which are in abundant supply in rural areas. Biogas is generated by the process of anaerobic digestion (AD). AD will occur under conditions which are anaerobic while making use of biodegradable materials as fuel. Biogas which is eventually produced can be used lighting and cooking (Roubik & Mazancova 2019).

1.9.1 Phases of Anaerobic Digestion

This literature will divide the process of anaerobic digestion into four phases, and these are done according to the different reactions which are seen to be taking place, they are as follows: hydrolysis, acidogenesis, acetogenesis and methanogenesis. As indicated in Figure 5 below, the organic matter is seen to be converted into forms which are much simpler.

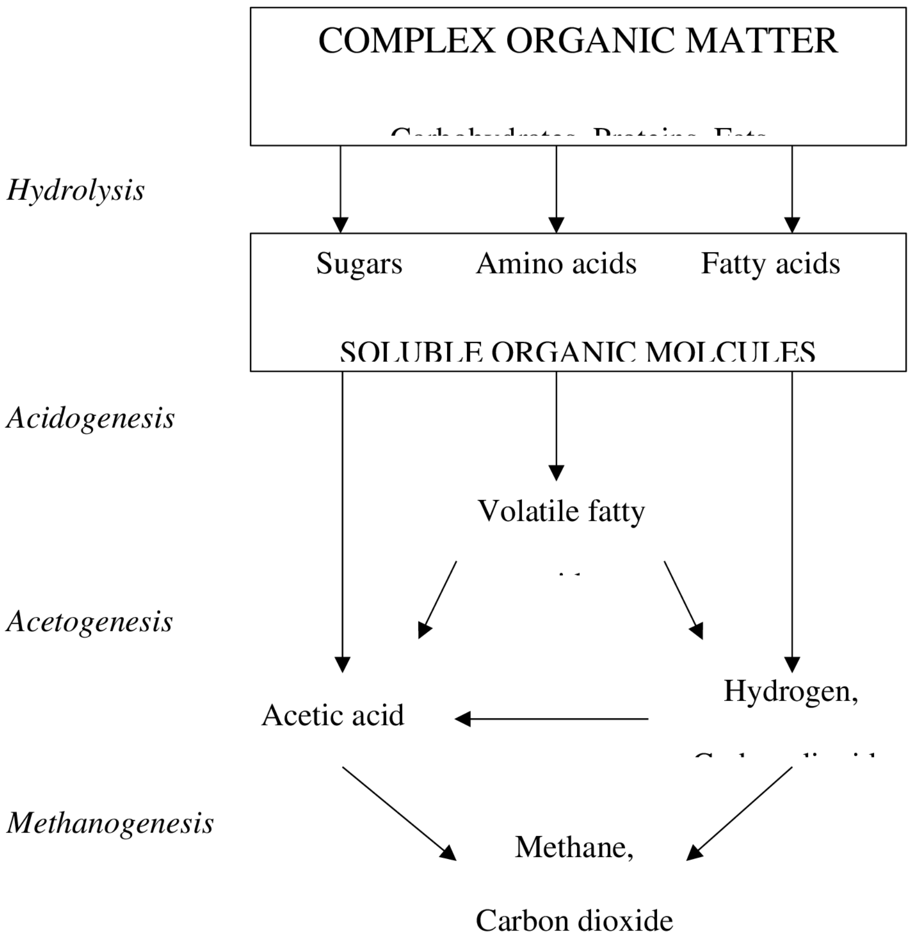


Figure 5: Stages of anaerobic digestion

Inspired by Mountain Empire Community College, 2013)

1.9.2 Factors Affecting Anaerobic Digestion

AD process is one which takes place in the absence of oxygen. i.e in an anaerobic environment. (Roubik & Mazancova 2020). Active bacteria in this reaction are usually contained in the liquid manure present in the anaerobic ecosystems. Addition of bacteria to liquid mixture is not really necessary but if the desire is to accelerate the initial phase of the process, bacteria can be added as a sample from an already functioning reactor. The conditions for the bacteria should be continually sustained for further development. Some bacteria are strictly anaerobic and are capable of surviving in low oxygen environment or even in an oxygen free environment. Examples of such bacteria are methanogenic bacteria. According to Botheju and Bakke (2011), an inhibition of process can be triggered in case of a damage to the reactor and subsequent of access to oxygen.

Temperature is a very important factor to AD as it is a very sensitive process (Roubik and Mazancova 2019). Therefore, stabilization of the process is very important by sustaining a constant temperature which will prevent a decrease in effectivity. The microorganisms which are responsible for AD are active in two ranges. Mesophilic microorganisms are the primary microorganism active in temperature from 30 to 40 °C. Thermophilic microorganisms are active in a range of 50 to 60 °C. In the case of mesophilic digestion, it is not necessary to keep supplying heat as it is a more reliable and stable reaction, its downside is that it takes place at a much slower rate which makes it incapable to process high loadings. In reality, most of the BGP's which are operated in developing countries are designed to operate at mesophilic conditions.

It is important to note that the optimum temperature for AD is around 35 °C. In countries with tropical climate, it is not common to control the temperature in the digester. The temperatures may be ambient in relation to weather and daytime conditions, which may differ in 5 - 10 °C (Zhang et al. 2006). In developed countries however, the impact due to temperature fluctuations may be avoided by building the plants underground. This will provide insulation for the plants which is necessary during winter conditions. Reactor temperature is primarily affected by outdoor air temperature, degree of heat exchange, soil and input temperature (Pham et al, 2014). Also important for the reaction is a high C/N ratio should be sustained. This can be influenced by the organic input composition. Nitrogen is used for synthetic reaction of amino acids, proteins and nucleic acids. When nitrogen is converted to ammonia, it will help to keep a neutral environmental pH. While rapid nitrogen consumption occurs if the proportion of nitrogen is too high. When this happens, an effective reaction with carbon is reduced due to lack of nutrients. On the other hand, when there is too low proportion of nitrogen ammonia toxicity can occur. These two scenarios are bad for the biogas as it leads to lower production of biogas. According to many studies the optimal C/N ratio for methane production is between 25-30:1 (Yen 2007).

However, when temperature rises, sustaining a higher ratio is preferable in order to reduce the possibility of ammonia inhibition. According to Wang et al. (2014), For mesophilic conditions between 30 - 40 °C the optimal ratio is 25:1 and for thermophilic conditions between 50 - 60 °C the ratio is 30:1. To achieve the recommended C/N ratio, appropriate combination of organic matters is quite important. Different materials input will have different C/N ratio. Location might also affect the ratio especially due to the various diet of livestock consumption. Overall, a sufficiently high C/N ratio is in pig and cattle manure, while human and poultry are low. (SNV 2011). pH plays a major role in the whole process of AD by influencing the enzyme activity (Mathew et al. 2014). Distinctive optimal pH values exist for the growth and the activity of different microorganisms. Hydrolysis and acidogenesis will take place efficiently at the pH value 5.5 pH respectively 6.5. Microorganisms which produce acid can sustain low pH environment down to 5 pH. For occurrence of methanogenesis a pH in range of 6.5 - 8.2 is suitable (Lee et al. 2009).

2 Aims of the Thesis

The aim of this research work is to examine the perspective of rural areas on small scale biogas technology in Nigeria. However, in order to achieve the aim, the objectives were to:

- identify the various levels of climate change and environmental awareness in Nigeria
- examine the perception of rural dwellers on biogas technology in Nigeria,
- determine the level of usage of biogas technology in rural areas in Nigeria
- investigate small-scale production of biogas as a tool for rural development in Nigeria.

2.1 Research Hypothesis

The following null hypothesis was generated to guide the research

H_0: There is no significant relationship between the socio-economic characteristics and adoption of small-scale biogas technology in Nigeria.

2.2 Justification of the Study

Over the years, the development and harnessing of clean energy have been termed "the golden thread" by the International Energy Agency and World Bank, linking economic growth, social equity and environmental sustainability of a country (Armah et al. 2019). Hence, striving for sustainable economic development cannot be achieved without making clean energies accessible to all at the household level. This makes clean energy a topical issue in international development and environmental management (Makonese et al. 2018). Majority of sub-Saharan African (SSA) countries including Nigeria still depend extensively on traditional cooking fuels at the household level (Bryant and Afitiri, 2021).

Although households' reliance on traditional biomass fuels for cooking is seen as a first-order health threat, a decline in climate change mitigation and the associated environmental effects

(Ifegbesan et al. 2016), renewable fuel usage such as biogas combustion with high efficiency in simple devices at the household level comes up with numerous advantages not observed with traditional cooking fuels methods, such as substantial local benefits as well as a reduction of GHG emissions and particulate matter into the atmosphere (Amigun et al. 2008), meeting the energy demands of households (Akinbam et al. 2001) and moving towards sustainable development goals (Amigun et al. 2011).

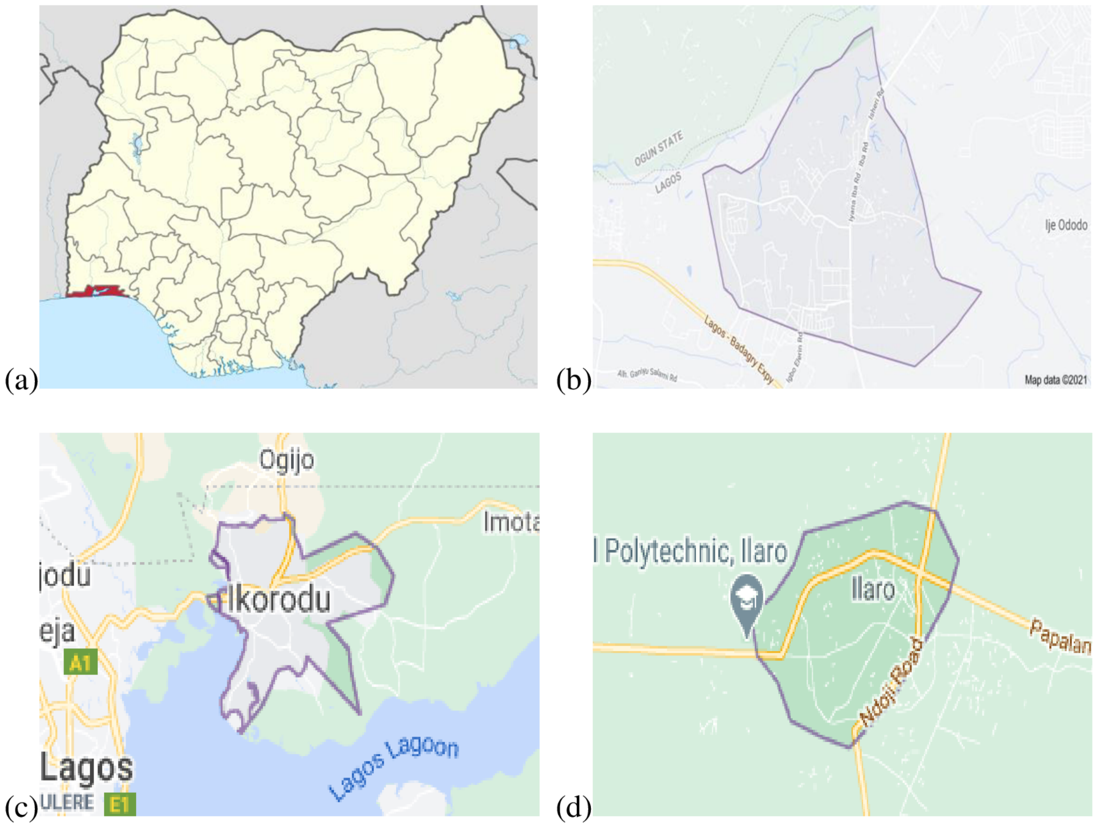
This realization has compelled several countries to adopt different clean cooking fuels and energies (renewable energy technologies). For instance, Mozambique and South Africa introduced wind pumps and wind generators (Jan & Akram 2018), while Tanzania introduced electric stoves for biomass fuel burning (Mwakaje, 2008). Additionally, biogas technologies were equally adopted in Nigeria (Akinbami et al. 2001).

According to Paul (2021), despite the numerous benefits of biogas technology, it is only being adopted at a very slow pace, and the vast number of individuals in third world countries still depend on conventional energy systems primarily in the form of wood-fuel and charcoal. This is due to the different barriers facing its adoptions include a lack of infrastructure and high industrial production costs, which cause cash flow issues for businesses and a reluctance to invest in technology renewal as a result, policy inconsistencies, conflicting laws, and regulations wilt consumer trust in new government initiatives; weak execution of stimulus packages due to policy inconsistencies, conflicting laws, and regulations; Inadequate inter-agency coordination; insufficient incentives for transitioning to low-carbon energy technologies; Financial constraints, as the Nigerian financial market is currently insufficiently developed to offer long-term loans at competitive interest rates; and a lack of public knowledge (Paul 2021). Hence, this study sought to investigate the perspective of rural areas on small scale biogas technology in Nigeria.

3 Methods

3.1 Description of Study Area

Situated in the south western corner of the country, Lagos state spans the Guinea coast of the Atlantic Ocean for over 180 km, from the Republic of Benin on the west to its boundary with Ogun state in the east. It extends approximately from latitude 6˚23' North to 6˚41' North, and from longitude 2˚42' East to 3˚42' East. It has a total area of 3577sq. km, about 787sq. km or 22% is water. Three (3) rural areas that cut across the landscape of Lagos state from the shoreline to the inland boundary were used for this study based on available data. The areas are as shown on the map of Lagos State below in Figure 6. The areas are Iba, Ilaro and Ikorodu.



Map of Nigeria showing Lagos State (a), Iba locality (b), Ikorodu village (c) and Ilaro village (d).

Figure 6: Map of the Study Area

3.2 Research Design

The study involves the use of a mixed method approach. This mixed method involves the application of quantitative and qualitative analysis to the data. Questionnaires and semi-structured interview were used as the research instruments to obtain data from the research respondents.

3.3 Target Groups

The population for this study consists of rural dwellers that have benefitted or are benefitting from the small-scale production of biogas within the rural areas of Lagos, Nigeria, and biogas plant owners and operators within the region. It is important that all the respondents have experience with biogas technology whether directly or indirectly.

3.4 Interviews (Qualitative Analysis)

The interview was conducted with the CEO of Jobaye gas with whom I collaborated. The company is at the forefront in dissemination of information regarding biogas and installation of small-scale biogas for individual use as well as big bio plants for institutions. The interviews were undertaken just to have a general overview of the challenges facing the company in terms of spreading awareness of biogas to the general public and how these challenges are overcome.

3.5 Administering the Questionnaire (Quantitative Analysis)

The questionnaires were administered in different rural areas in Lagos. Ikorodu, Iba and Ilaro.

3.6 Sample Size and Sampling Procedure

In determining the sample size that is adequate for this study, the Bartlett et al.'s (2001) model was used. The research sought to define sample of biogas plant operators and users to ensure at least 95% level of confidence and that probable error of using a sample rather than surveying the whole population did not exceed 0.03. The sample size was obtained from the number of biogas plants in the study area. For the purpose of this study, a total of 100 respondents were selected for the purpose of collecting data for this study.

In arriving at the sample size, two key factors were considered, these are the risk that the researcher was willing to accept, commonly called the margin of error, and consideration of the alpha level which is the level of acceptable risk in a way that true margin of error exceeds the acceptable margin. This means the probability that the differences revealed by statistical analyses really do not exist. Such errors occur when statistical procedures result in a judgment of no significant differences when these differences do indeed exist. These were addressed in this study to make the research finding reliable.

In most research studies, alpha level used in determining sample size is either 0.05 or 0.01 (Ary et al. 1996). The general rule of acceptable margin of error in general terms is 5% for categorical data and 3% for continuous data. A 3% margin of error to give a confidence that the true mean of a seven-point scale is within + 0.21, that is, 0.03 times seven points on the scale of the mean calculated from the sample size. For this study, categorical data were used at the alpha level of 0.05.

3.7 Data Analysis and Presentation

Results from this research will contribute to the limited knowledge and awareness of biotechnology within the shores of Nigeria. It has become urgent for Nigeria to consider other sources of energy especially with the oil reserve upon which a huge percentage of the economy is hinged has greatly depleted. The analysis in this study was done to represent data in an easy-to-understand and intelligible way to enhance and provide insight as to the instrument of biogas technology as a tool for rural development. Descriptive statistics, such as frequency distribution, means and percentages were used to describe the socio-economic characteristics of the respondents, examine public perception on biogas technology, and investigate small-scale production of biogas as a tool for rural development. However, Likert scale was used to identify the various levels of climate change and environmental awareness in the study area and determine the level of usage of biogas technology in rural areas in Nigeria. Also, for easy analysis and computation, all statistical computations were done with the use of Statistical Package for Social Sciences (SPSS) version 26.

3.7.1 Regression Analysis

The evaluation of relationship between dependent and independent variables was carried out using the multiple regression models. The first step consisted of defining the variables of interest. In this study, the attitudes of rural dwellers towards adoption of biogas technology were expressed along a set of socioeconomic characteristics (age, gender, educational qualification, household size, highest household educational qualification and average household monthly income), climate change and environmental awareness, and knowledge about low carbon techniques. This was to determine the relationship between the combined explanatory variables and adoption of biogas technology. The adoption of biogas technology in this case is the dependent variable (Y) and the socioeconomic characteristics, climate change and environmental awareness, and knowledge about low carbon techniques are the independent variables (x).

The most general form for the model is:

$$Y = a + b_1x_1 + b_2x_2 + b_3x_3 + \cdots\ b_nx_n + e$$

where,

Y = the dependent variable is a measure of adoption of biogas technology.

a = constant

x1, x2, x3, …, …, …, …, …, xn are independent variables (age, gender, educational qualification, household size, highest household educational qualification, average household monthly income, climate change and environmental awareness, and knowledge about low carbon techniques)

b1, b2, b3, …, …, …, …, …, bn are the regression coefficients which determines the contribution of the independent variables.

e = residual or stochastic error (which reveals the strength of b1x1 ... bnxn; if e is low the amount of unexplained factors will be low and vice versa.

4 Results and Discussion

4.1 Socio-economic characteristics of the respondents

The age distribution of the respondents is presented in Table 3. A large number of the respondents were between 25 – 34 years of age, specifically 45 and this represents 45% of the total sample, 32% of the respondents aged between 35 – 44 years, 20% of the respondents aged between 18 – 24 years, while 2% of the respondents were 55 years of age and 1% of the respondents aged between 45 – 54 years. Similar result was reported in Lagos rural community by Agbor (2014).

The gender distribution of the respondents is presented in Table 3. It shows that 64 of the total respondents were male representing 64% of the total sample size while 36 were female representing 36% of the total sample size. The educational level of the respondents is presented in Table 3. The result revealed that 85% of the respondents had tertiary education, 10% of the respondents had secondary education, 3% of the respondents were primary school certificate holders and 2% of the respondents had no formal education.

The information about the main household occupation of the respondents is presented in Table 3. Majority of the respondents were private firm workers (55%), 36% of the respondents were civil servants, while 9% of the respondents were farmers. Table 3 contains information on the household size of the respondents. 48% of the respondents had household size between 4-6 persons, 43% of the respondents had household size of 7 and above persons while 9% of the respondents had household size of 1-3 persons.

The highest household educational qualification of the respondents is presented in Table 3. Majority of the respondents (95%) had tertiary education as their highest household educational qualification while the highest household qualification of 5% of the respondents was Senior Secondary Certificate Examination (SSCE). Table 3 presents information on average monthly household income of the respondents. 90% of the respondents earned above ₦100,000(214.69 EUR) monthly household income, 6% of the respondents earned between ₦51,000 - ₦100,000 (109.49 – 214.69 EUR) monthly household income, 2% of the respondents earned between ₦10,000 - ₦50,000(21.47 - 107.35 EUR) monthly household income, while 1% of the respondents earned below ₦10,000(21.47 EUR) monthly household income.

Table 3: Socio-Demographic Characteristics of the Respondents (n=100)

Variable	Frequency	Percent
Age		
18-24	20	20.0
25-34	45	45.0
35-44	32	32.0
45-54	1	1.0
55 and above	2	2.0
Gender		
Male	64	64.0
Female	36	36.0
Educational qualification		
Primary school	3	3.0
Secondary school	10	10.0
Tertiary institution	85	85.0
No formal education	2	2.0
Main household occupation		
Farming	9	9.0
Civil servant	36	36.0
Private company worker	55	55.0
Household size		
1-3	9	9.0
4-6	48	48.0
7 and above	43	43.0
Highest household educational qualification		
SSCE	5	5.0
Tertiary	95	95.0
Average household monthly income (₦)		
Below 10,000	1	1.0
10,000-50,000	2	2.0
51,000-100,000	6	6.0
Above 100,000	90	90.0

Source: Author, 2021

4.2 Climate change and environmental awareness of respondents

This study sought to provide information on the level of climate change and environmental awareness of the respondents. The result presented in Table 4 revealed that 33% of the respondents that they were satisfied with the environmental awareness of the community, 22% agreed with the statement, 19% were uncertain about the statement, 14% strongly agreed with the statement and 12% strongly disagreed with the statement. This finding is in agreement with Nnaemeka (2017) and Ovuyovwiroye (2013) who reported a low level of climate change and environmental awareness among rural inhabitants in Nigeria.

Majority of the respondents (74%) strongly agreed that climate change has an adverse effect on social and economic development of Nigeria, 20% of the respondents agreed with the statement, 5% of the respondents were uncertain about the statement while 1% of the respondents disagreed with the statement. Most of the respondents (70%) also strongly agreed that climate change is an important issue for Nigeria, 26% of the respondents agreed with the statement, 3% of the respondents were uncertain about the statement, and 1% of the respondents disagreed with the statement. Most of the respondents (73%) strongly agreed that Nigeria should take immediate action to address climate change, 22% of the respondents agreed with the statement, 2% of the respondents were uncertain about the statement, while 2% of the respondents disagreed with the statement and 1% of the respondents strongly disagreed with the statement. A substantial amount of the respondents (36%) disagreed that climate change is of no concern to them while 9% of the respondents strongly disagreed. However, 21% of the respondents agreed that climate change is of no concern to them and 18% of the respondents strongly agreed while 16% of the respondents were uncertain about the statement. These findings corroborate the reports of Akpodiogaga and Ovuyovwiroye (2010), Anabaraonye et al. (2019) and Osuji et al. (2019) on the impacts of climate change in Nigeria.

Table 4: Climate Change and Environmental Awareness of Respondents (n=100)

Climate Change and Environmental Awareness	Strongly disagree (%)	Disagree (%)	Uncertain (%)	Agree (%)	Strongly agree (%)
Satisfied with the environmental awareness of the community	12	33	19	22	14
Climate change has an adverse impact on social and economic development in Nigeria	-	1	5	20	74
Climate change is an important issue for Nigeria	-	1	3	26	70
Nigeria should take immediate action to address climate change.	1	2	2	22	73
Climate change is of no concern to me.	9	36	16	21	18

Source: Author, 2021

4.3 Knowledge of respondents about low carbon technologies

The knowledge of the respondents about low carbon technologies is presented in Table 5. The result revealed that 66% of the respondents knew a lot about biogas technology, 18% of the respondents knew enough about biogas technology, while 6% of the respondents have never heard or read about biogas technology, while 5% of the respondents have heard about biogas technology and 1% of the respondents did not care about biogas technology. Also, 51% of the respondents knew a little about wind power, 24% of the respondents knew enough about it, 9% of the respondents knew a lot about it, and 13% of the respondents while 3% of the respondents did not care about wind power.

Furthermore, 57% of the respondents have heard about energy-conserving electric appliances, 18% of the respondents knew a little about it, 16% of the respondents knew enough about it, and 4% of the respondents knew a lot about it. However, 3% of the respondent have never heard about energy-conserving electronic appliances while 2% of the respondents did not care about energy-conserving electronic appliances. Also, majority of the respondents (48%) knew enough about solar power, 26% of the respondents knew enough about it, and 26% of the respondents knew a lot about it while 2% have heard about it. 35% of the respondents did not care about hydrogen powered vehicles and 4% of the respondents have never heard about it. However, 32% of the respondents have heard about it, 24% of the respondents knew a little about it, while 3% of the respondents knew a lot about it and 2% of the respondents knew enough about it.

More so, 36% of the respondents have heard about biomass energy, 22% of the respondents knew enough about it, 19% of the respondents knew a little about it, 4% of the respondents knew a lot about it, while 13% of the respondents did not care about biomass energy and 6% of the respondents have never heard or read about it. 53% of the respondents have also heard about carbon capture and storage (CCS), 13% of the respondents knew a little about it, 4% of the respondents knew enough about it while 1% of the respondents knew a lot about it. Nevertheless, 11% of the respondents have never heard about it and 18% of the respondents did not care about carbon capture and storage (CCS) technology. Similar findings were reported by Adepoju and Akinwale (2019) and Krozer (2020) who also reported varying levels of awareness about various low carbon technologies in Nigeria, including biogas technology.

Table 5: Knowledge of Respondents about Low Carbon Technologies (n=100)

Knowledge about low carbon technologies	I don't care (%)	I've never heard (or read) about it (%)	I've heard about it (%)	I know a little about it (%)	I know enough about it (%)	I know a lot about it (%)
Biogas Technology	1	6	5	4	18	66
Wind power	3	-	13	51	24	9
Energy-conserving electric appliances.	2	3	57	18	16	4
Solar power			2	26	48	26
Hydrogen powered vehicles	35	4	32	24	2	3
Biomass energy	13	6	36	19	22	4
Carbon capture and storage (CCS)	18	11	53	13	4	1

Source: Author, 2021

4.4 Attitudes towards low carbon technologies

Information about the attitudes of respondents towards low carbon technologies is contained in Table 6. Majority of the respondents (86%) strongly agreed with the use of biogas technology, 3% of the respondents agreed and 11% of the respondents were uncertain about the use of biogas technology. 96% of the respondents strongly agreed with the use of solar energy, 2% of the respondents agreed and 2% of the respondents were uncertain about the use of solar energy. Also, most of the respondents (86%) strongly agreed with the use of wind energy, 3% of the respondents agreed, while 10% of the respondents were uncertain about the use of wind energy and 1% of the respondents strongly disagreed.

Furthermore, 63% of the respondents were uncertain about the use of energy-conserving electronic appliances, 32% of the respondents strongly agreed with its use and 5% of the respondents agree with the use. 82% of the respondents were also uncertain about the use of energy-saving vehicles while 16% of the respondents strongly agreed with the use of energy-saving vehicles and 2% of the respondents agreed with the use. 83% of the respondents were uncertain about the use of carbon capture and storage (CCS) technology, 12 % of the respondents agreed with the use and 5% of the respondents agreed with the use. This finding is in support of the result of Adepoju and Akinwale (2019), who also reported varying degree of willingness to adopt renewable energy by Nigerians.

Table 6: Attitudes Towards Low Carbon Technologies (n=100)

Agreement with the use of low carbon technologies	Strongly disagree (%)	Disagree (%)	Uncertain (%)	Agree (%)	Strongly agree (%)
Biogas Technology	-	-	11	3	86
Solar energy	-	-	2	2	96
Wind energy	1	-	10	3	86
Energy-conserving electric appliances	-	-	63	5	32
Energy-saving vehicles	-	-	82	2	16
Carbon capture and storage (CCS)	-	-	83	5	12

Source: Author, 2021

4.5 Perception of respondents about the most important environmental problem

This study sought to investigate the perception of the respondents about the most important environmental problem. The result presented in Figure 7 revealed that 81% of the respondents were of the view that climate change is the most important environmental problem, 6% of the respondents identified toxic waste as the most important environmental problem, 4% of the respondents opined that resource depletion is the most important environmental problem, 4% of the respondents identified water pollution as the most important environmental problem, while 3% of the respondents opined that acid rain is the most important environmental problem and 2% of the respondents selected ozone depletion as the most important environmental problem. This is consistent with previous research on technological adoption (Liu et al. 2013). Complexity (how much a future consumer knows how a technology works), according to

Rogers (1995), will hinder acceptance. Users also have a negative view of complex-principle-based technologies. Teo (2009) describes technology difficulty as how difficult a person considers technology to grasp and use. Knowledge about how technology works and the consequences of using it influences understanding and, as a result, acceptability (Huijts et al. 2012).

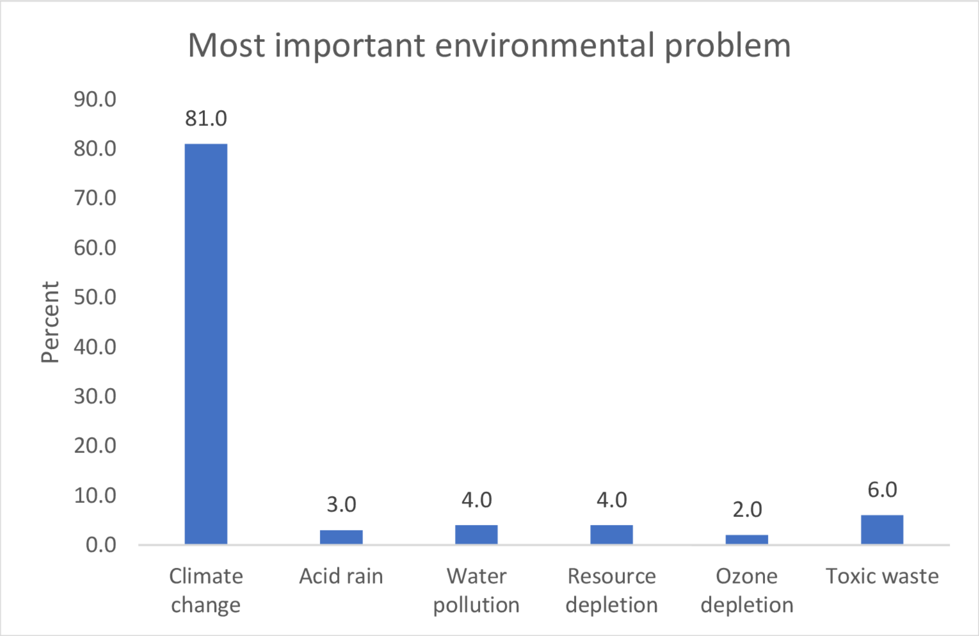


Figure 7: Perception of respondents about the most important environmental problem (n=100)

4.6 Public perception on biogas technology

Public perception on biogas technology is presented in Table 7. Most of the respondents (66%) strongly agreed with integrating carbon biogas technology equipment, 26% of the respondents agreed with the statement while 8% of the respondents had no opinion on integrating carbon biogas technology equipment. Majority of the respondents (71%) strongly agreed to willingness to use a biogas stove, 22% of the respondents agreed to willingness to use a biogas stove while 7% of the respondents had no opinion on the willingness to use a biogas stove. Also, most of the respondents (77%) strongly agreed to be interested in new innovations, 20% of the respondents agreed, 2% of the respondents had no opinion and 1% of the respondents strongly opposed interest in new innovation. According to Gosens et al. (2013), adopting biogas can reduce the amount of time spent collecting solid fuels and reduce the health burdens associated with the burning of solid fuels. However, findings of this study further confirm the claim of Okonkwo et al. (2018) that majority of the households in Nigeria were not aware of biogas technology but were willing to try out the technology if it is proven to be efficient and cost-effective.

Table 7: Public Perception on Biogas Technology (n=100)

Public Perception on Biogas technology	Strongly oppose (%)	Oppose (%)	No opinion (%)	Agree (%)	Strongly agree (%)
Integrating carbon BT equipment	-	-	8	26	66
Willing to use a biogas stove	-		7	22	71
Interested in new innovations	-	1	2	20	77

Source: Author, 2021

4.7 Level of Usage of Biogas technology in Rural areas

4.7.1 Type of biogas plant operated by respondents

This study sought to identify the type of biogas plant operated by respondents in the study area, the result is presented in Figure 8. Most of the respondents (65%) operated fixed dome biogas plant, 21% of the respondents operated plastic bag digester while 14% floating gasholder plant. According to Raymond and Okezie (2011), the fixed-dome type biogas plant otherwise known as the Chinese Model is preferred for use in Nigeria in meeting rural energy needs because its operation and maintenance is relatively simple. Similarly, Okonkwo et al. (2018) reported that fixed dome type biogas plant is assumed because the raw materials for its construction can be accessed locally and with an economic lifespan of 8 years. Also, it does not need large volume of digester to accommodate large volume of the batch hence its initial cost is lower than the continuous type.

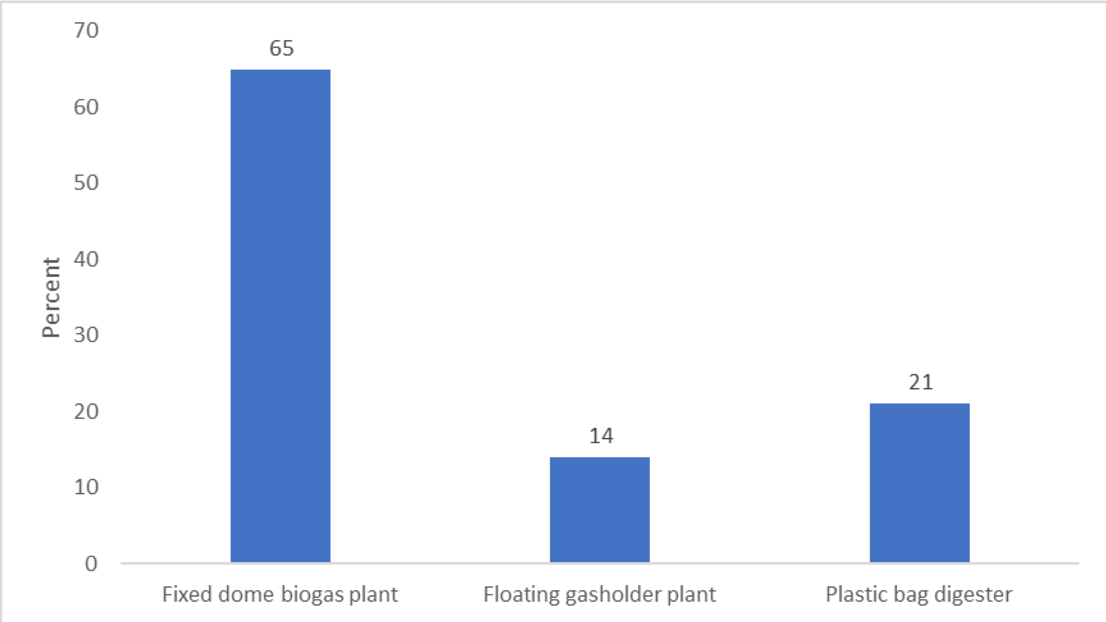


Figure 8: Type of biogas plant operated by respondents (n=100)

4.7.2 Volume (m^3) of Biogas produced daily

Figure 9 presents the volume (m^3) of Biogas produced daily by the respondents. According to the respondents, the volume of biogas generated daily by most of the respondents (45%) is $2m^3$ or less, 38% of the respondents generated above $2m^3$ but less than $5m^3$, while 15% of the respondents generated above $5m^3$ but less than $10m^3$. The result implies that the volume of biogas generated from the wastes daily in the study area may be sufficient to cook three times daily for the household of 3 - 4 persons since 1.0 m^3 of biogas would be sufficient to cook three meals a day for 5 - 6 persons (Nwankwo et al. 2017).

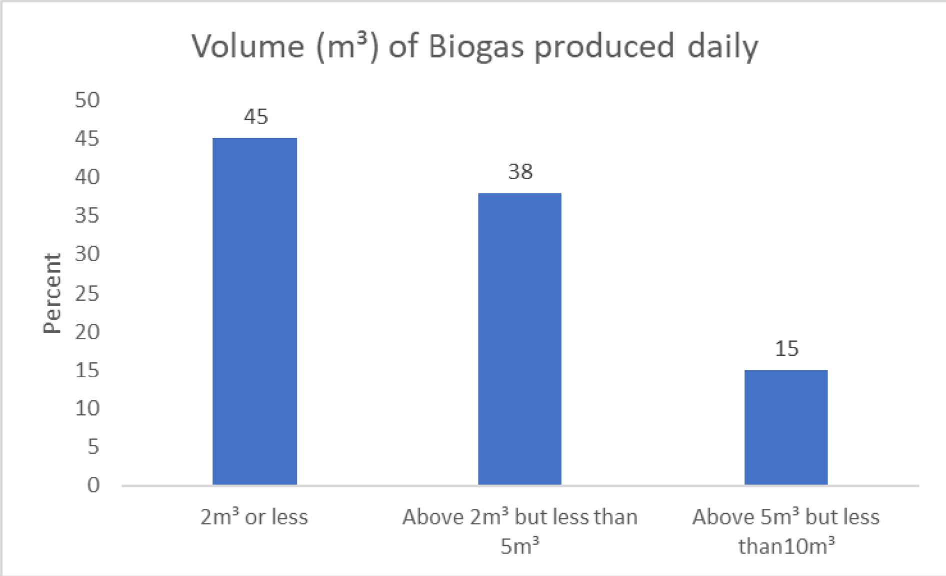


Figure 9: Volume (m³) of Biogas produced daily (n=100)

4.8 Biogas plant owners and workers

4.8.1 Members of household that work at the biogas plant

The result of this study revealed that 1-3 household members of majority of the respondents (92%) work with the biogas plant, 5% of the respondents had no family member working with the biogas plant, 2% of the respondents had 7 and above household members working in the biogas plant and 1% of the respondents had 4-6 household members working in the biogas plant (Figure 10). This implies that daily maintenance and operational activities of the biogas plant were performed by household members. This finding confirms the previous report of Kabir et al. (2012), who stated that the tasks of collection, stirring and feeding the substrates into the biogas digester are largely performed by household's members to whom the biogas technology belongs.

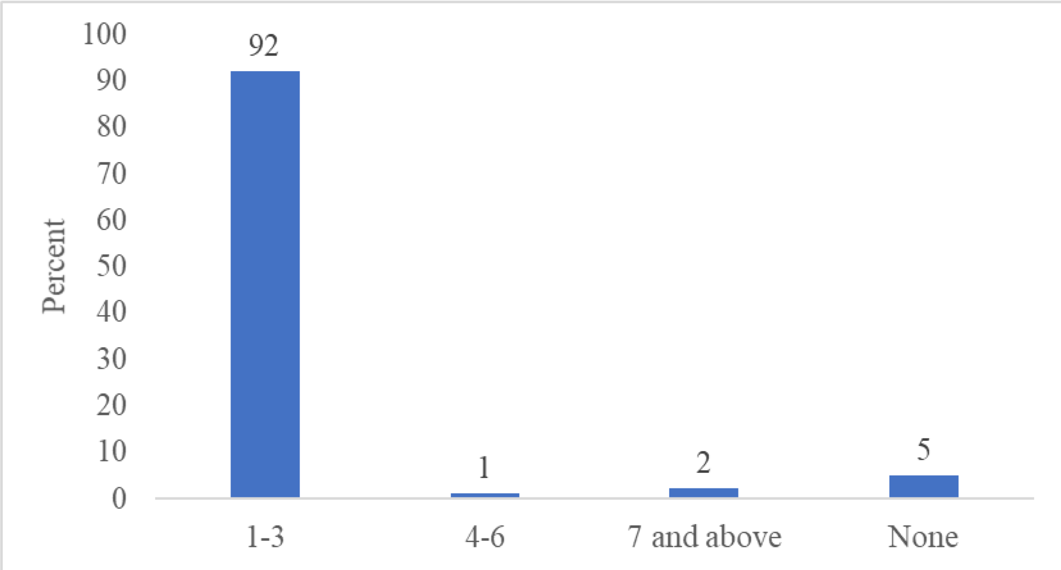


Figure 10: Members of household that work at the biogas plant (n=100)

4.8.2 Mode of training acquisition

Figure 11 presents mode of biogas production training acquisition by the respondents. Majority of the respondents (85%) acquired biogas production training through private training programmes, 8% of the respondents had no training, 5% of the respondents were self-trained and 2% of the respondents acquired biogas production training through government training programme. A huge proportion of the respondents attended private training programmes to learn about biogas production technology. According to Huang et al. (2022), rapid development of biogas technology in China is mainly related to the strong support from the government, which has provided trainings, subsidies and investment. However, the bulk of biogas technology training programs in Nigeria are private efforts because the Nigerian government has not yet provided adequate support for biogas technology in the country.

Figure 11: Mode of training acquisition (n=100)

4.8.3 Duration of training programme

Figure 12 presents the duration of biogas production training attended by the respondents. It took 1 month or less to complete the training by most of the respondents (63%), the training took 2-3 months for 23% of the respondents, it took 4-6 months for 2% of the respondents while it took above 6 months for 1% of the respondents. Majority of the respondents acquired biogas technical skills within a relatively short period of time. This further supports the claims of Muvhiiwa et al. (2017), who reported that the technology involved in biogas production is fairly simple and can be implemented cheaply and efficiently by means of small-scale digesters that are easy to use and maintain.

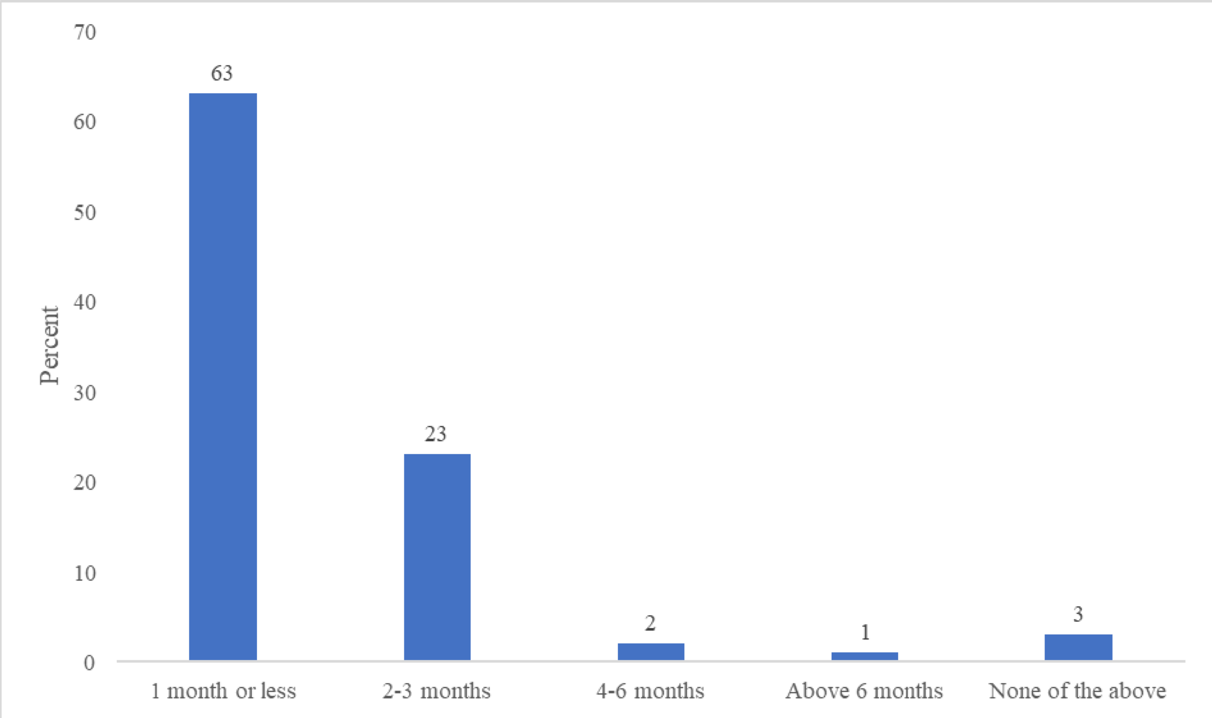


Figure 12: Duration of biogas training programme (n=100)

4.8.4 Certification for biogas training

This study revealed that majority of the respondents (93%) had no certification in biogas production while only 7% of the respondents had a certification (Figure 13). This may be due to the relative novelty and lack of awareness about biogas technology in Nigeria. According to Audu et al. (2020), adapting to a new technology generally requires sensitization, reorientation, and commitment from all stakeholders. They also reported that lack of technical standards and codes for biogas installation and maintenance in Nigeria may be another reason why fewer proportion of the respondents had no biogas training certification.

4.8.5 Most frequently used source of energy

Figure 14 presents information on the most frequently used source of energy in the study area. The modal frequently used source of energy in the study area was identified as fossil fuel (64%), followed by kerosene (26%), firewood (5%), biogas (3%) and other sources (2%).

According to NBS (2016), only about 3.5% of rural households have access to modern cooking fuels. Few households depend on transition fuels like kerosene and the majority rely on traditional biomass for cooking. This result further corroborates the findings of Ibitoye (2013) who reported the main fuels for cooking in Nigerian households as kerosene, LPG, charcoal, wood, and electricity, when and where available. He further added that animal and crop residues are also used in some rural communities.

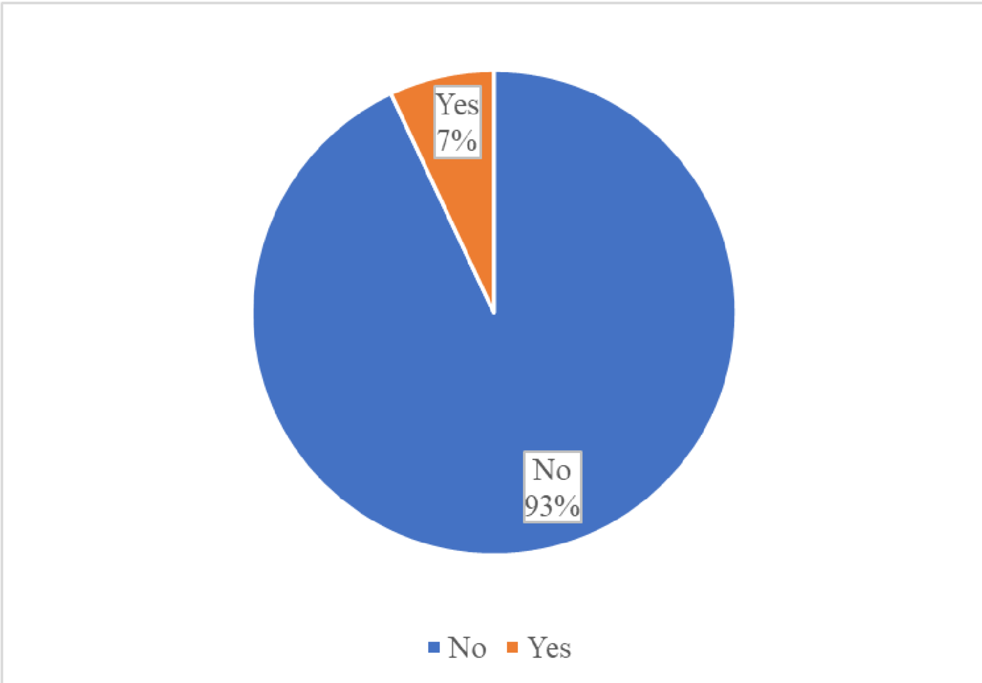


Figure 13: Possession of biogas training certification (n=100)

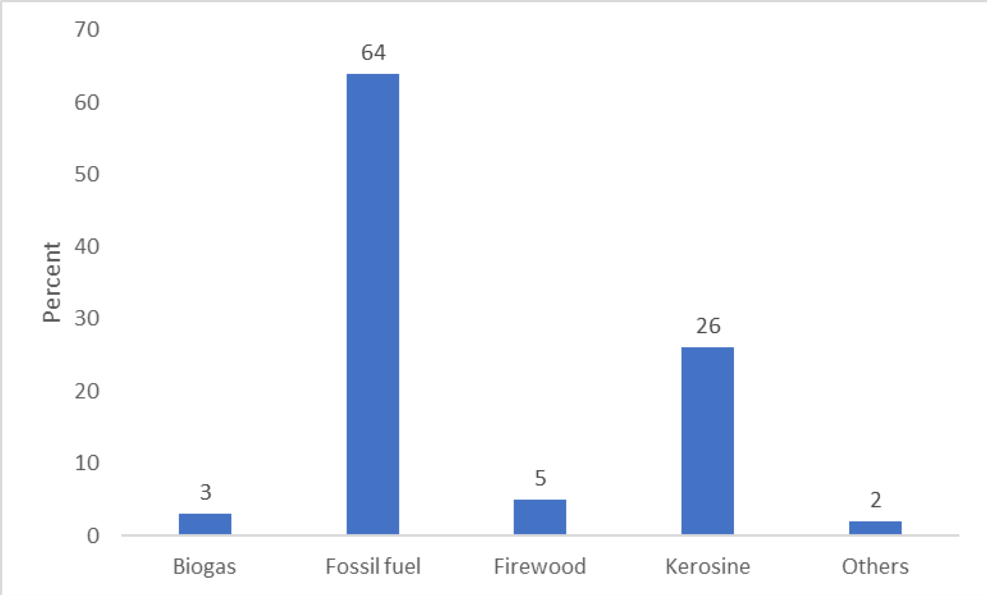


Figure 14: Most frequently used source of energy (n=100)

4.8.6 Popularity of Biogas as a source of energy in the study area

To explore the popularity of biogas in the study area, the respondents were asked whether biogas is a popular source of energy around the study area. As shown in Figure 15, the majority of the respondents (95%) did not identify biogas as a popular source of energy while only 5% of the respondents identified biogas as a popular source of energy in the area. A study by Akinbami et al. (2001) found out that biogas plants are not yet familiar in the Nigerian energy market, although some substantial work has been done and work is still in progress on it. This could be attributed to the high initial cost of biogas plant. The average Nigerian rural household is essentially dependent on farming for its subsistence and hence is not economically buoyant enough to afford the capital investment in a biogas plant given earlier on. At the initial investment and annual running costs, owning a biogas plant resembles the acquisition of a prestigious item which can only be financed from excess funds. Biogas plants can therefore be acquired only by the relatively rich farmers. Even in the urban setting, the same observation is applicable. Hence, a family-sized biogas plant may not be economically feasible unless it is used for productive purposes like irrigation, motive power and other commercial purposes in addition to providing fuel for domestic cooking (Akinbami et al. 2001). Studies have also suggested that the probability of a household adopting biogas technology increases with decreasing age of head of household, increasing household income, increasing number of cattle owned, increasing household size, male head of household and increasing cost of traditional fuels (Walekhwa et al. 2009; Mwirigi et al. 2014).

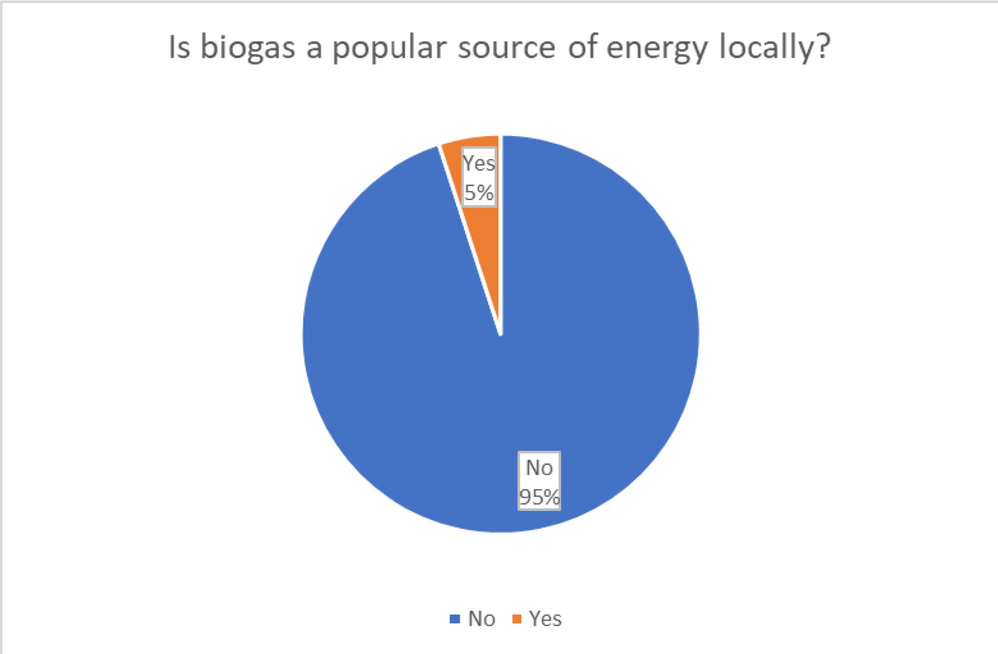


Figure 15: Popularity of biogas as a source of energy (n=100)

4.8.7 Consideration of biogas as an alternative to traditional fuel

Figure 16 presents information about likelihood of biogas to be considered as an alternative to traditional fuel. Most of the respondents (98%) supported that biogas can be considered as an alternative to traditional fuel, while 2% of the respondents opined that biogas cannot be considered as an alternative to traditional fuel. According to the report of Parawira (2009), biogas technology is viewed as one of the renewable technologies in Africa that can be help to ease its energy and environmental problems. Many African countries produce large quantities of organic through the agro-industries. This organic matter can be used to produce biogas and contribute to greatly reduce dependence on fossil fuel, wood fuel and hydroelectricity and at the same time curb environmental pollution (Mshandete et al. 2006; Weiland 2000). Mbuligwe (2002) also reported great potential of anaerobic digestion of the predominantly organic waste as an institutional solid waste management practices in developing countries in a case study of three academic institutions in Tanzania.

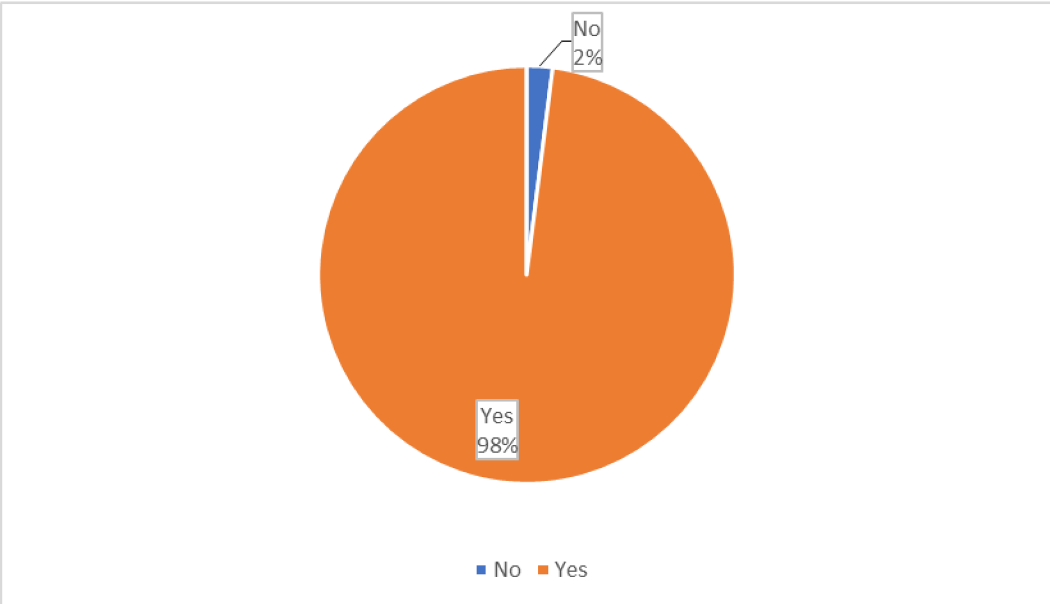


Figure 16: Likelihood of biogas to be considered as an alternative to traditional fuel (n=100)

4.8.8 Sufficiency of biogas produced

The respondents were asked to indicate whether the biogas produced is sufficient to meet their energy demands. The result presented in Figure 17 revealed that biogas produced is sufficient to meet the energy demands of 5% of the respondents. However, 95% of the respondents had to supplement biogas with other sources of energy in order to meet their energy demands. This may be due to the fact that biogas plants are only an option for households with access to a sufficient quantity of dung as generation of enough biogas to cook food exclusively with a biogas stove for a family of five requires about five cows (Hazra et al. 2014). Tucho and

Nonhebel (2017) also reported that biogas produced in rural Ethiopia was not sufficient to meet the cooking energy demand of the farmers.

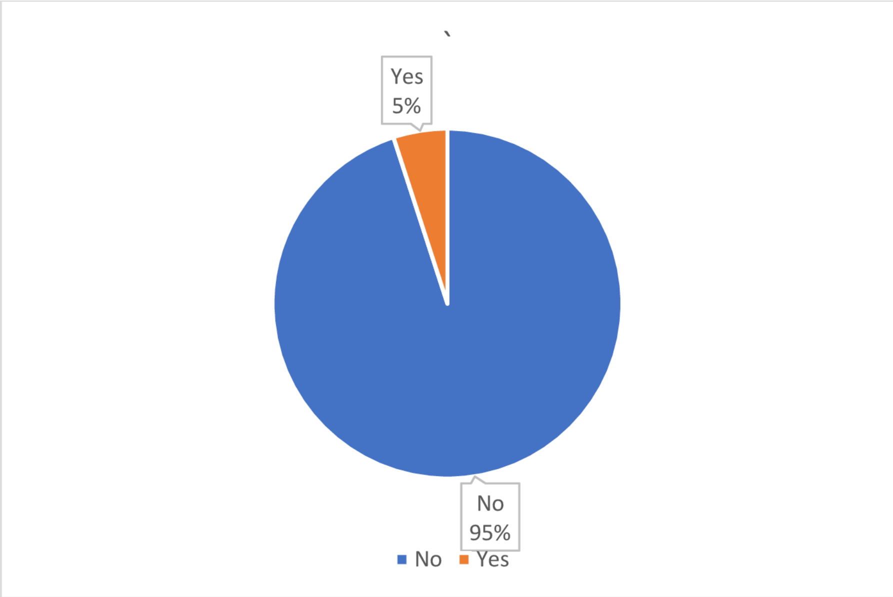


Figure 17: Meeting daily biogas consumption in the household (n=100)

4.8.9 Cultural resistance to the use of biogas

Figure 18 presents information on the respondents view on cultural resistance to the use of Biogas because of its raw materials. Majority of the respondents (97%) were of the view that there are cultural resistances to the use of Biogas because of its raw materials. Contrarily, 3% of the respondents reported no cultural resistance to the use of Biogas because of its raw materials. Some biogas projects failed because they were incompatible with local beliefs (Kumar Ghosh and Mandal 2018). Family-sized biogas plants are disregarded due to usage of dung for cooking. Studies have found that local populations cannot accept the use of biogas because of their traditional beliefs, as it is produced from manure, dung, or some other kind of faecal matter (Shane et al. 2015; Giwa et al.2016; Amuzu-Sefordzi et al. 2018). Gebreegziabher et al. (2014) pointed out that some religions in sub-Saharan Africa have very strict rules with respect to cleanliness, to a large extent in connection with humans but also with animal excrement. A study in Kenya also found that some households expressed doubts over the "cleanliness" of biogas coming from some types of waste (Sovacool et al. 2015).

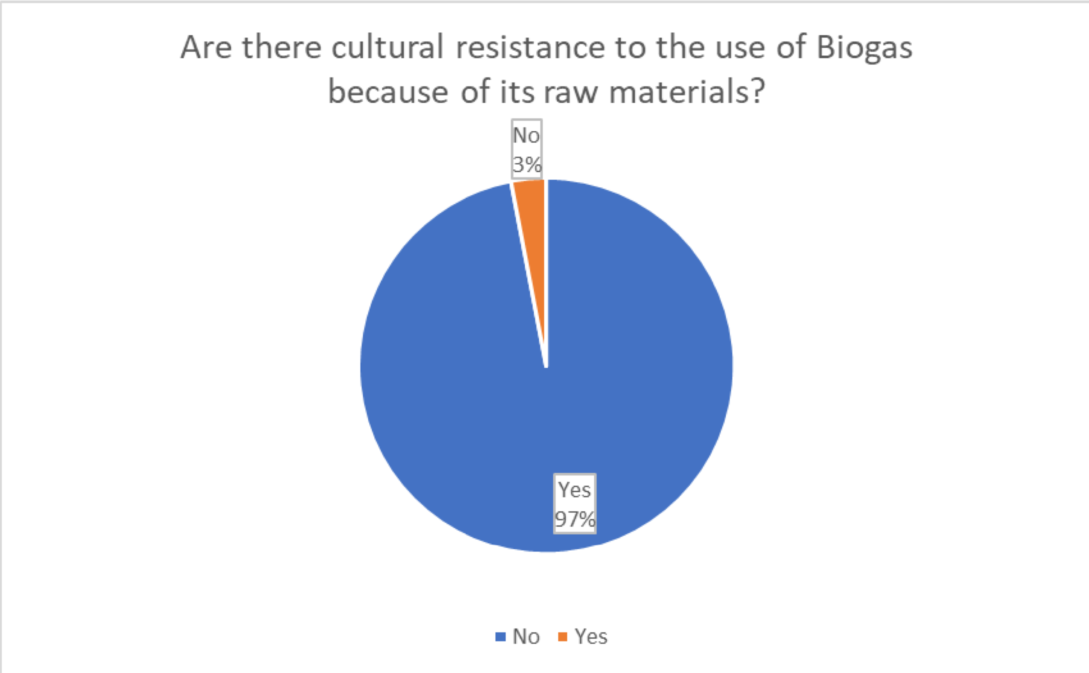


Figure 18: Cultural resistance to the use of biogas (n=100)

4.9 Waste management among biogas users

4.9.1 Wastes generated in the study location

Various categories of waste generated in the study area is presented in Figure 19. Animal wastes were the main wastes generated by 11% of the respondents, human wastes were major wastes generated by 10% of the respondents while plant wastes were the main waste generated by 2% of the respondents. However, 77% of the respondents identified all the three sources as the major wastes generated. This corresponds to the findings of Okoro et al. (2018) who reported that wastes from rural areas consist mainly of biodegradable materials from biological origins. The authors reported that any biodegradable material of animal or plant origin can be used to produce renewable energy (biogas) during anaerobic digestion. According to Alkhalidi et al. (2019), biogas production is best if these materials are mixed with human waste or animal waste. Various agricultural residues, such as wheat straw, rice straw, vegetables, and so on, have been used in combination with animal wastes to produce methane.

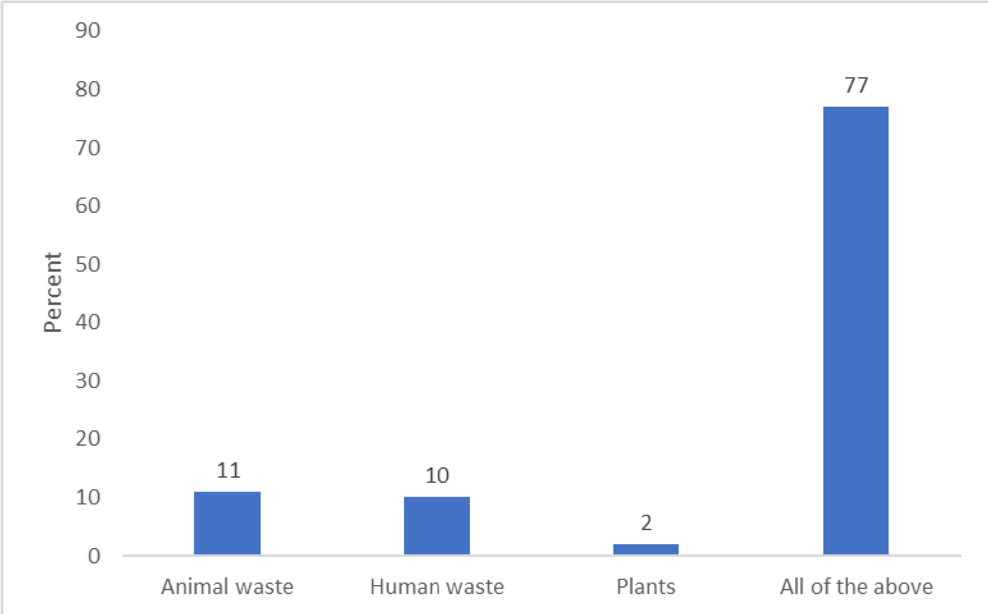


Figure 19: Wastes generated in the study location (n=100)

4.9.2 Waste disposal methods in the study area

The waste disposal method in the study area is shown in Figure 20. The result of this study revealed that in order to dispose wastes, 58% of the respondents made use of government disposal trucks, 12% of the respondents dump on the street, 4% of the respondents bury at home while 26% of the respondents used all the three ways. Abila and Kantola (2013) also reported that in rural communities, solid waste quantity is less and managed in household backyards by burning, composting, as feeds to animals and occasionally disposed at dump sites.

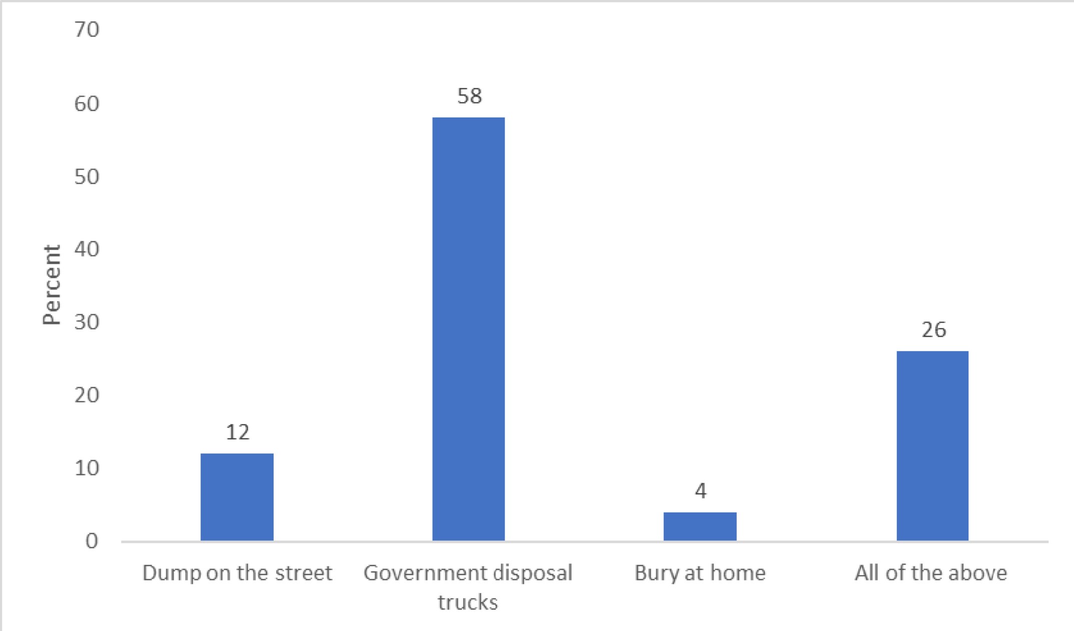


Figure 20: Waste disposal methods in the study area (n=100)

4.9.3 Toilet systems used in the study area

The various type of toilet systems used in the study area is presented in Figure 21. Majority of the respondents (80%) use water closet toilets, 11% of the respondents use latrine toilets while 9% of the respondents use mobile toilets. The use of water closet toilets was found to be prevalent in the study area which is contrary to the findings of Garn et al. (2017) and Back et al. (2018) who reported that the commonly used toilet system in rural areas is household pit latrines. The dominance of water closet toilets in the study area may be attributed to the higher educational and income levels of the respondents. According to Adams et al. (2016), the relative costs of different sanitation facilities make the likelihood of using unimproved facility and practicing open defecation increase with decreasing wealth. For example, the likelihoods of using improved sanitation facilities and VIP latrines were more than twice higher in higher-income households than in lower income households in rural Ethiopia (Yohannes et al. 2014) and Tanzania (Kema et al. 2012).

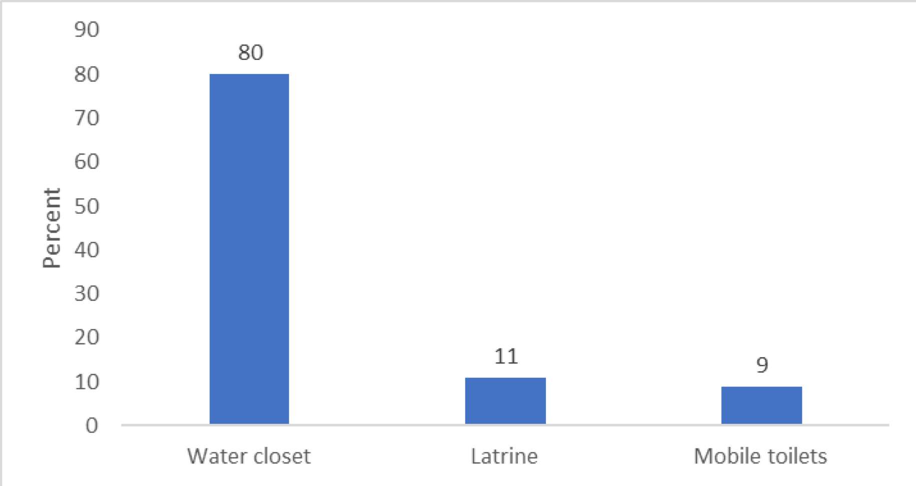


Figure 21: Toilet systems used in the study area (n=100)

4.9.4 Waste materials used as primary source for production of Biogas in the plants

The various waste materials used as primary source for production of Biogas in the plants is presented in Figure 22. This study revealed that 65% of the respondents made use of animal waste, 11% of the respondents made use of human wastes, 3% of the respondents made use of plants while 21% of the respondents made use of all the sources. This study agrees with the findings of Smith et al. (2014), who reported that suitable substrates for biogas production can originate from a variety of organic sources, including animal manure, human faeces, and crop residues, although each source yields different levels of biogas and quality of bioslurry, depending on carbon and nutrient contents.

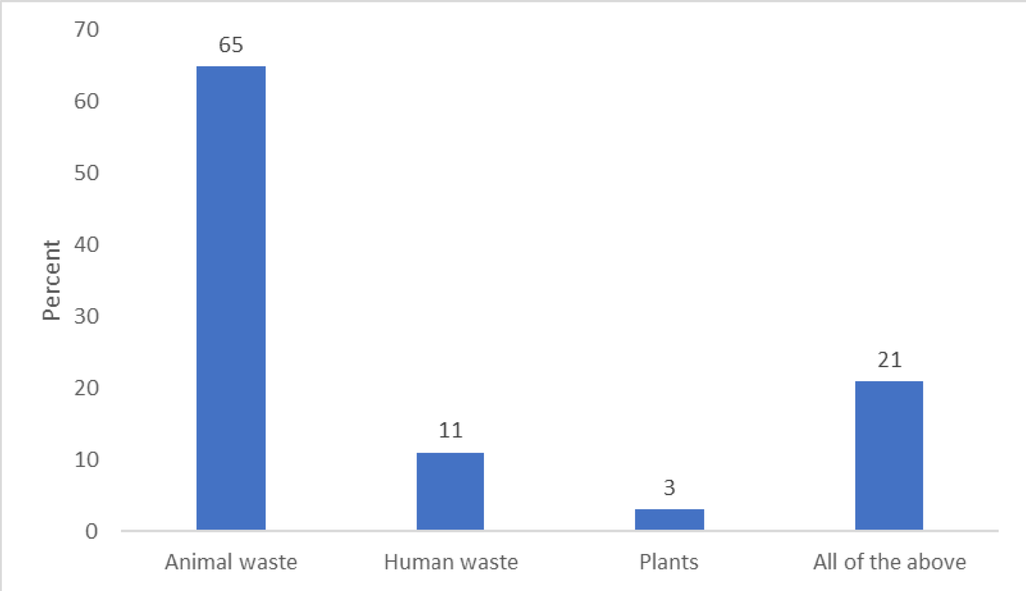


Figure 22: Waste materials used as primary source for production of Biogas in the plants (n=100)

4.10 Usage of biogas lamp and stove in the study area

Figure 23 presents information on the usage of biogas lamp in the study area. Majority of the respondents (99%) do not use biogas lamp, while only 1% of the respondents use biogas lamp. The low usage rate of biogas lamp explains the unfamiliar status of biogas technology in the study area which is as a result of the high initial cost of biogas plant. Findings of this study agree with those of Bensah and Brew-Hammond (2011) that technology cost was a major impediment to rapid biogas uptake in Ghana. Gebreegziabher (2007) also found that the incapacity of households to meet full investment cost hindered widespread dissemination of biogas in Ethiopia. A study conducted by (Mwakwaje, 2008) in Tanzania also had similar observations that rural farmers were willing to install biogas systems but they were barred from doing so by high initial costs.

Figure 23: Usage of biogas lamp in the study area (n=100)

.

4.10.2 Duration of usage of biogas stove per day in the study area

The duration of biogas stove usage per day in the study area is presented in Figure 25. As indicated in the figure, the duration of biogas stove usage per day by 57% of the respondents is 1 – 5 hours, 32% of the respondents use biogas stove for less than one hour per day while 11% of the respondents use biogas stove for 6-13 hours per day. According to Hazra et al. (2014), household size is significantly associated with a greater number of hours of stove use regardless of stove type. Roubík and Mazancová (2019) also reported similar findings in central Vietnam where the biogas stoves were in use for over 3 hours per day (3.17 ± 1.22 h per day), with a minimum of 0.5 hour per day and a maximum of 8 hour per day.

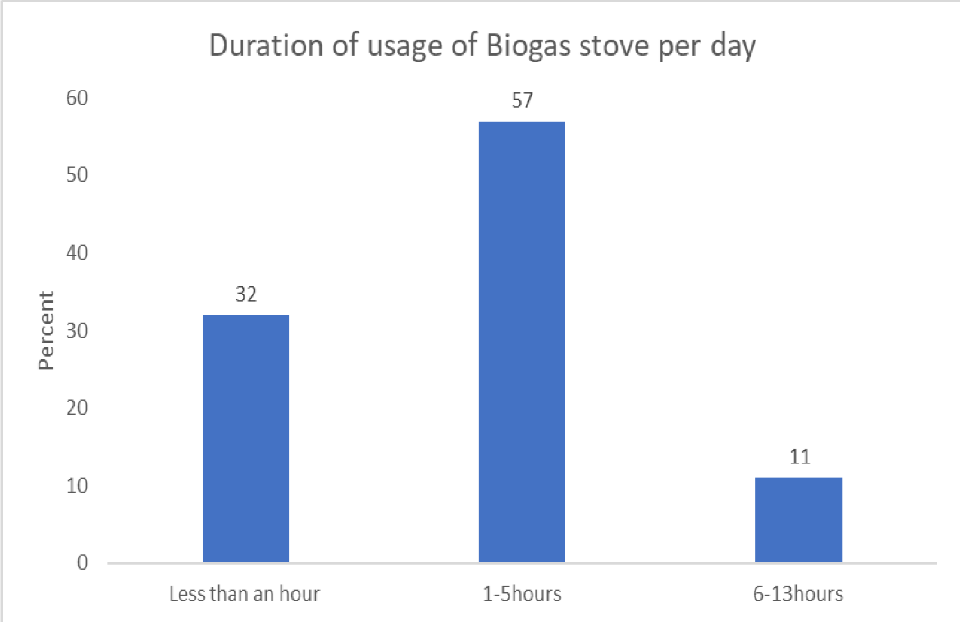


Figure 24: Duration of usage of biogas stove per day in the study area (n=100)

4.10.3 Burning of excess biogas by the respondents

The respondents were requested to indicate whether they burn excess biogas or not and the result is presented in Figure 26. Majority of the respondents (97%) do not burn excess biogas while only 3% of the respondents burn excess biogas in the study area. If a household has a biogas plant that produces more biogas than they can use, then they may have to burn the excess biogas for safety reasons. This can occur if an over-sized biogas plant has been built by mistake or if it has been designed to manage a waste problem. In the study area, only 3% of the respondents generated enough biogas and have excess to burn due to safety reasons. Vu et al. (2015) reported that burning of excess biogas instead of releasing it significantly improved the environmental profile of the biogas solution in comparison with traditional manure management. They however suggested that an even better option than burning excess biogas would be to use it for purposes where it saves on other types of fuels. It is likely that this requires the implementation of new technologies, such as systems for removing corrosive gases, mainly hydrogen sulfide (H_2S), from the gas, systems for compressing and storing the gas or distribution systems allowing the gas to be shared with neighbors (Kapdi et al., 2005). These technologies do exist, but they involve some outlay by the farmer and may therefore not be implemented unless incentives are given through legislation or subsidies.

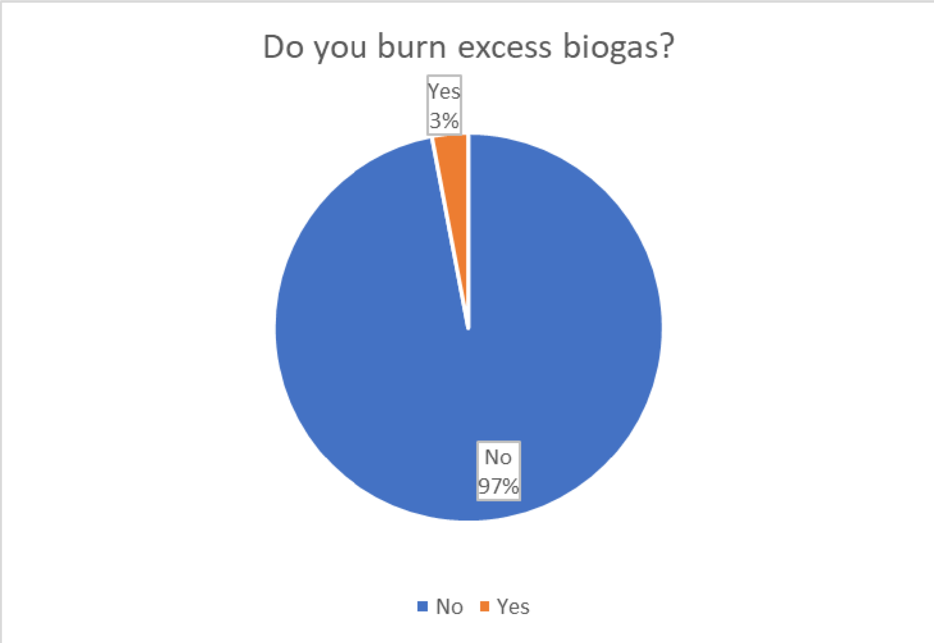


Figure 25: Burning of excess biogas by the respondents (n=100)

4.11 Small-scale Production of Biogas as a Tool for Rural Development

The respondents were asked if they have had any form of government assistance or external finance to help with small-scale production of Biogas. Majority of the respondents (95%) have never received any form of government assistance or external finance to help with small-scale production of Biogas while only 5% of the respondents have received government or external assistance to help with small-scale production of biogas. Majority of the respondents (95%) suggested that government policies with respect to energy have stagnated rate of development in rural areas while 5% of the respondents suggested that government policies with respect to energy is not responsible for stagnated rate of development in rural areas. 51% of the respondents were familiar with Renewable Energy Division, while 49% of the respondents were not familiar with the division. The role of government in stimulating biogas production cannot be overrated, and thus, for easy penetration of biogas energy into energy market, the government needs to play an active role in ensuring that the biogas energy is sufficient, efficient, affordable, steady, and dependable (Winkler et al. 2011).

Government interventions through subsidy provisions and tax holidays are needed to reduce the initial cost of investing in biogas technology. Uninterrupted development of biogas technology and dissemination requires unwavering and long-term government support in many areas, including financial support, legislative support, and technical support. The high level of biogas technology in most developed countries has been attributed to favourable policy formulation and implementation (Palvas et al. 2010; Stehlik 2010). It is therefore obvious that government support and development of biogas technology are inseparable. Government has an important role to play in the creation of an enabling environment for private sector participation in biogas technology in such a way that the produced biogas will be affordable to meet energy needs of the citizenry (Akinbomi et al. 2014).

4.12 Policies for promoting Nigeria's Biogas technology development

This study sought to identify policies that will promote biogas development in Nigeria. The result presented in Table 8 revealed that 78% of the respondents strongly agreed that financial support will promote biogas development in Nigeria, 11% of the respondents agreed with the statement, 6% of the respondents were uncertain, while 3% of the respondents strongly disagreed and 2% of the respondents disagreed with the statement. Also, 63% of the respondents strongly agreed that reforms of the power sector will promote biogas development in Nigeria, 23% of the respondents agreed with the statement, 9% of the respondents were uncertain, while 3% of the respondents disagreed and 2% of the respondents strongly disagreed with the statement. 71% of the respondents also strongly agreed that Biogas technology laws and regulations will promote biogas development in Nigeria, 18% of the respondents agreed with the statement, 7% of the respondents were uncertain, while 2% of the respondents strongly disagreed and 2% of the respondents disagreed with the statement. The lack of government incentives has been reported to contribute to the low adoption rate of biogas technologies (Roopnarain and Adeleke 2017; Lönnqvist et al. 2018). Cong et al. (2017) pointed out that the government needs to consider policy instruments such as subsidising the investment of biogas plants with new technologies, or subsidising the purchase of gas-driven vehicles. Mwirigi et al. (2014) and Rupf et al. (2015) also reported that installation costs for conventional biogas systems are unaffordable for many potential users because of insufficient credit schemes and other financial support.

Furthermore 77% of the respondents strongly agreed that incentive policies will promote biogas development in Nigeria, 12% of the respondents agreed with the statement, 7% of the respondents were uncertain, while 3% of the respondents disagreed and 1% of the strongly respondents disagreed with the statement. More so, 78% of the respondents strongly agreed that international cooperation will promote biogas development in Nigeria, 13% of the respondents agreed with the statement, 6% of the respondents were uncertain, while 2% of the respondents disagreed and 1% of the respondents strongly disagreed with the statement. Also, 84% of the respondents strongly agreed that Biogas technology will promote biogas development in Nigeria, 10% of the respondents agreed with the statement, 4% of the respondents were uncertain, while 1% of the respondents disagreed with the statement. These findings agree with the study by Adewuyi (2020) who reported that access to new technology for biogas production is a challenge in Nigeria due to cost and maintenance but government can help to give interventions and subsidies to ease procurement and maintenance.

Table 8: Policies for Promoting Nigeria's Biogas Technology Development (n=100)

Policies for promoting Nigeria's Biogas technology development	Strongly disagree (%)	Disagree (%)	Uncertain (%)	Agree (%)	Strongly agree (%)
Financial support	3	2	6	11	78
Reforms of the power industry	2	3	9	23	63
BT laws and regulations	2	2	7	18	71
Incentive polices	1	3	7	12	77
International Cooperation	1	2	6	13	78
Biogas Technology	1	-	4	10	84

Source: Author, 2021

4.13 Hypothesis testing

The regression analysis of the relationship between the adoption of biogas technology and the socio-economic characteristics of the respondents as well as their environmental awareness and knowledge of low carbon technologies is presented in Table 9. The result revealed no significant ($p<0.05$) relationship between adoption of biogas technology as alternative energy source in the study area and age of respondents, gender of respondents, Educational qualification, household size, environmental awareness and knowledge of hydrogen powered vehicles. However, the result revealed that main household occupation (8.1%), highest household education (52.3%), average household monthly income (7.5%), knowledge of solar power (61.3%), wind power technology (27.5%), energy-saving vehicles (24.8%), and biogas technology (41.7%) significantly ($p<0.05$) affected the respondents to adopt biogas technology as alternative energy source in the study area. The findings of this study agree with the report of Shallo et al. (2020) that households' socio-economic characteristics usually determine the adoption of a biogas plant.

Table 9 shows that highest household educational level had positive significant influence on biogas adoption (B=0.523; p=0.040). The majority of the respondents (82%) were those that had attained post-secondary education. Increase in education level was positively associated with adoption of biogas. This can be explained by the fact that education helps in changing attitudes and perceptions which in turn creates favourable mental attitude for acceptance of new technology. Higher education also enhances analytical capability of information and knowledge necessary to implement new technology. These findings concur with the findings of Mwakaje (2008) that the likelihood of adoption of biogas energy increased with more years of formal education of the household's head in Tanzania.

The result also indicates that household income had positive significant influence on biogas adoption (B = 0.075; p = 0.039). This can be attributed to the fact that biogas technology is a high cost investment which can be affordable, most likely, by higher income earners. The cost of a biogas plant varies with individual plant type and size since bigger sizes requires more construction materials hence higher cost. Expenditure involved in biogas construction included cost of cement, building stones, sand, ballast, pipings, valves and fittings, gas stove and labour (mason fee). Findings of this study agree with observation of (Arthur et al. 2011) that the inability of farmers to meet installation costs remains the key barrier to biogas adoption by rural cattle farmers. Similarly, Walekhwa et al. (2009), observed that empirical evidence suggested that probability of a household adopting biogas technology was directly proportional to a household's income.

According to Mwirigi et al. (2009), the socio-economic status of Kenyan farmers also affected their decision to adopt biogas technology. In another study conducted by Amir et al. (2019), household income and householders' education influence the adoption of low carbon technologies. Kabir et al. (2013) found that education, income, and the gender of household heads had a significant impact on biogas technology adoption in Bangladesh. This study further establishes positive significant relationship between knowledge of some low carbon technologies and adoption of biogas technology. This implies that the higher the knowledge about these low carbon technologies, the higher the willingness to adopt biogas technology. From the result of the regression analysis, there is significant relationship between the socio-economic characteristics and adoption of small-scale biogas technology in the study area. Hence, the null hypothesis which states that there is no significant relationship between the socio-economic characteristics and adoption of small-scale biogas technology in Nigeria should be rejected.

Table 9: Relationship between adoption of biogas technology and socio-economic characteristics of the respondents

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	1.676	.758		2.212	.030
Age	.091	.055	.120	1.670	.099
Gender	.100	.086	.082	1.164	.248
Education	.063	.095	.047	.669	.506
Main household occupation	.081	.021	.376	3.782	**.000**
Household size	.130	.070	.130	1.853	.067
Highest household education	.523	.251	.188	2.086	**.040**
Average household monthly income	.075	.036	.234	2.096	**.039**
Environmental awareness	.108	.063	.109	1.717	.090
Knowledge of solar power	.613	.175	.313	3.509	**.001**
Knowledge of wind power technology	.275	.072	.325	3.807	**.000**
Knowledge of energy-saving vehicles	.248	.085	.301	2.912	**.005**
Knowledge of hydrogen powered vehicles	.020	.045	.043	.447	.656
Knowledge of biogas technology	.417	.038	.802	10.865	**.000**

R = 0.814
R^2 = 0.662
P = 0.000

5 Conclusion

The aim of this study was to assess if small-scale production of biogas technology can be used as a tool for rural development in Nigeria. Both quantitative and qualitative research approaches were employed to collect data for this study. The findings of this study revealed that the level of climate change knowledge and environmental awareness of the respondents was generally low. However, the respondents identified climate change as the most important environmental problem as well as an important issue for Nigeria and has an adverse effect on social and economic development of Nigeria. Hence, immediate action should be taken to address climate change.

This study also revealed that 1-3 household members of majority of the respondents works at the biogas plant and acquired biogas production training through private training programmes that took a month or less to complete. However, majority of the respondents had no certification in biogas production. The most frequently used source of energy in the study area was identified as fossil fuel, followed by kerosene, firewood, biogas and other sources. The use of biogas was also found to be less popular in the study area. It was also revealed that most of the respondents operated fixed dome biogas plant and generated $2m^3$ or less of biogas per day using plant, animal and human wastes. Majority of the respondents made use of government disposal trucks for wastes disposal and the most common toilet system found was water closet toilet.

Majority of the respondents have never benefited from any form of government assistance or external finance to help with small-scale production of Biogas and majority of the respondents suggested that government policies with respect to energy have stagnated rate of development in rural areas. The respondents were also not familiar with the Renewable Energy Division and Nigerian Bio-fuel Policy and Incentives. This study therefore concludes that providing appropriate financial support, reforms of the power sector, favourable Biogas technology laws and regulations, incentive policies and international cooperation will promote biogas development in Nigeria. In order to address the inconsistency of electricity in Nigeria, Biogas can provide a solution that will increase business while also attracting the attention of investors. In a bid to make biogas an accepted and appreciable means of curbing energy challenges, the government should regulate good policies that will support the use of biogas, practical study area should also be made available which will train individuals on the technicality in anaerobic plant installation and biogas production and storage.

6 REFERENCES

Abila, B. and Kantola, J., 2013, January. Municipal solid waste management problems in Nigeria: Evolving knowledge management solution. In *Proceedings of World Academy of Science, Engineering and Technology,* **78**: 292. World Academy of Science, Engineering and Technology (WASET).

Adams, E.A., Boateng, G.O. and Amoyaw, J.A., 2016. Socioeconomic and demographic predictors of potable water and sanitation access in Ghana. *Social Indicators Research*, **126(2):** 673-687.

Adegbulugbe, A.O. and Akinbami, J.F.K. 1995, May. Urban household energy use patterns in Nigeria. In *Natural Resources Forum*, **19(**2): 125-132. Oxford, UK: Blackwell Publishing Ltd.

Adelekan, B.A. and Bamgboye, A.I. 2009. Comparison of biogas productivity of cassava peels mixed in selected ratios with major livestock waste types. *African Journal of Agricultural Research*, **4(7)**: 571-577.

Adeoti, O. 1998. Engineering economy studies of biogas as a renewable energy source at household level in Nigeria. *Unpublished MSc thesis in Technology Management, Technology Planning and Development Unit, Faculty of Technology, Obafemi Awolowo University, Ile-Ife, Nigeria*.

Adeoti, O. Ilori, M.O. Oyebisi, T.O. and Adekoya, L.O. 2000. Engineering design and economic evaluation of a family-sized biogas project in Nigeria. *Technovation*, **20(2)**: 103-108.

Adepoju, A. O. & Akinwale, Y. O. 2019. Factors influencing willingness to adopt renewable energy technologies among micro and small enterprises in Lagos State Nigeria. *International Journal of Sustainable Energy Planning and Management*, **19**: 69-82.

Adeschinwa, A.O.K. Makinde, G.E.O. and Oladele, I.O. 2003, September. Demographic characteristics of pig farmers as determinant of pig feeding pattern in Oyo State, Nigeria. In *Proceeding 8th Annual Conference of Animal Science Association (ASAN), September* (pages 16-18).

Adesogan, S. 2013. Sewage technology in Nigeria: a pragmatic approach. *Science Journal of Environmental Engineering Research*, *2013*.

Adewuyi, A., 2020. Challenges and prospects of renewable energy in Nigeria: A case of bioethanol and biodiesel production. *Energy Reports*, **6**: 77-88.

Agbo, I.N.E. 2014. A comparative study of household willingness to pay for community-based health insurance in urban and rural local government areas in Lagos state. *Public Health*.

Ajieh, M.U. Isagba, E.S. Ihoeghian, N. Edosa, V.I. Amenaghawon, A. Oshoma, C.E. Erhunmwunse, N. Obuekwe, I.S. Tongo, I. Emokaro, C. and Ezemonye, L.I. 2021. Assessment of sociocultural acceptability of biogas from faecal waste as an alternative energy source in selected areas of Benin City, Edo State, Nigeria. *Environment, Development and Sustainability*, pages 1-18.

Akinbami, J.F. Ilori, M.O. Oyebisi, T.O. Akinwumi, I.O. and Adeoti, O. 2001. Biogas energy use in Nigeria: current status, future prospects and policy implications. *Renewable and Sustainable Energy Reviews*, **5(1)**: 97-112.

Akinbami, J.F., Ilori, M.O., Oyebisi, T.O., Akinwumi, I.O. and Adeoti, O., 2001. Biogas energy use in Nigeria: current status, future prospects and policy implications. *Renewable and Sustainable Energy Reviews*, **5(1):** 97-112.

Akinbomi, J. Brandberg, T. Sanni, S. A. and Taherzadeh, M. J. 2014. Development and dissemination strategies for accelerating biogas production in Nigeria. *BioResources*, **9(3)**: 5707-5737.

Akinbomi, J., Brandberg, T., Sanni, S.A. and Taherzadeh, M.J., 2014. Development and dissemination strategies for accelerating biogas production in Nigeria. *BioResources*, **9(3)**: 5707-5737.

Akinfolarin, B.O. and Okubanjo, A.O. 2010. Human Population Growth Rate and Meat Supply in Lagos state (1991–2000). *Acta. SATECH*, **3(2):** 19-24.

Akpodiogaga, P. and Ovuyovwiroye, O. 2010. General Overview of Climate Change Impacts in Nigeria. *J Hum Ecol*. **29**: 47-55. 10.1080/09709274.2010.11906248.

Aliyu, A.S. Dada, J.O. and Adam, I.K. 2015. Current status and future prospects of renewable energy in Nigeria. *Renewable and sustainable energy reviews*, **48**: 336-346.

Alkhalidi, A., Khawaja, M.K., Amer, K.A., Nawafleh, A.S. and Al-Safadi, M.A., 2019. Portable biogas digesters for domestic use in Jordanian Villages. *Recycling*, **4(2)**: 21.

Amigun, B. and Von Blottnitz, H. 2010. Capacity cost and location cost analyses for biogas plants in Africa. Resource, *Conservation and Recycling* **55**: 63-73.

Amigun, B. Parawira, W. Musango, J.K. Aboyade, A.O. and Badmos, A.S. 2012. Anaerobic biogas generation for rural area energy provision in Africa. *Biogas*, pages 36-62.

Amigun, B. Sigamoney, R. and von Blottnitz, H. 2008. Commercialisation of biofuel industry in Africa: a review. *Renewable and sustainable energy reviews*, **12(3):** 690-711.

Amir, S.M., Liu, Y., Shah, A.A., Khayyam, U. and Mahmood, Z., 2020. Empirical study on influencing factors of biogas technology adoption in Khyber Pakhtunkhwa, Pakistan. *Energy & Environment*, **31(2)**: 308-329.

Amuzu-Sefordzi, B., Martinus, K., Tschakert, P. and Wills, R., 2018. Disruptive innovations and decentralized renewable energy systems in Africa: A socio-technical review. *Energy research & social science*, **46**: 140-154.

Anabaraonye, B. Okafor, C. J. and Ikuelogbon, O. J. 2019. Educating farmers and fishermen in rural areas in Nigeria on climate change mitigation and adaptation for global sustainability. *International Journal of Scientific & Engineering Research*, **10(4)**: 1391-1398.

Anderson, D and Fishwiek, R. 1984. Fuelwood Consumption and Deforestation in African Countries World Bank staff working papers, The World Bank, Washington, DC

Anowor, O.F. Achukwu, I.I. and Ezekwem, O.S. 2014. Sustainable sources of energy and the expected benefits to Nigerian economy. *International Journal of Sustainable Energy and Environmental Research*, **3(2)**: 110-120.

Aremu, M.O. and Agarry, S.E. 2013. Enhanced biogas production from poultry droppings using corn-cob and waste paper as co-substrate. *International Journal of Engineering Science and Technology*, **5(2)**: 247-253.

Arthur, R., Baidoo, M.F. and Antwi, E., 2011. Biogas as a potential renewable energy source: A Ghanaian case study. *Renewable energy*, **36(5)**: 1510-1516.

Audu, I.G., Barde, A., Yila, O.M., Onwualu, P.A. and Lawal, B.M., 2020. Exploring biogas and biofertilizer production from abattoir wastes in Nigeria using a multi-criteria assessment approach. *Recycling*, **5(3):** 18.

Babayemi, J.O. and Dauda, K.T. 2009. Evaluation of solid waste generation, categories and disposal options in developing countries: a case study of Nigeria. *Journal of Applied Sciences and Environmental Management*, **13**(**3**).

Back, J. O., Rivett, M. O., Hinz, L. B., Mackay, N., Wanangwa, G. J., Phiri, O. L., … Kalin, R. M. (2018). Risk assessment to groundwater of pit latrine rural sanitation policy in developing country settings. *Science of the Total Environment*, **613–614:** 592–610.

Banchetti-Robino, M.P. 2016. Van Helmont's hybrid ontology and its influence on the chemical interpretation of spirit and ferment. *Foundations of Chemistry*, **18(2):** 103-112.

Bensah, E.C. and Brew-Hammond, A., 2010. Biogas technology dissemination in Ghana: history, current status, future prospects, and policy significance. *International Journal of Energy and Environment*, **1(2):** 277-294.

Blight, G.E. and Mbande, C.M. 1996. Some problems of waste management in developing countries, *Journal of Solid Waste Technology Management* **23(1)**: 19-27.

Botheju D. and Bakke R. 2011. Oxygen Effects in Anaerobic Digestion–A Review. *The Open Waste Management Journal*, **411**: 1-19.

Cointrea. (1982). "Environmental management of urban solid wastes in developing countries: A project guide," W. B. Urban Development Department, (ed.), City, Washington.

Cong, R.G., Caro, D. and Thomsen, M., 2017. Is it beneficial to use biogas in the Danish transport sector?–an environmental-economic analysis. *Journal of cleaner production*, **165**: 1025-1035.

Cook, P.A. 2010. Design of a Household Human Waste Bioreactor. *Article link*.

Dahunsi, S.O. and Oranusi, U.S. 2013. Co-digestion of food waste and human excreta for biogas production. *Biotechnology Journal International*, pages 485-499.

Deublein, D. and Steinhauser, A. 2008. Biogas from waste and renewable resources. Wiley-VCH Verlag GmbH & Co. *KGaA*. pages 27-83.

Ebohon, O.J. 1996. Energy, economic growth and causality in developing countries: a case study of Tanzania and Nigeria. *Energy policy*, **24(5):** 447-453.

Emetere, M.E. Akinyemi, M.L. and Edeghe, E.B. 2016. A simple technique for sustaining solar energy production in active convective coastal regions. *International Journal of Photoenergy*, *2016*.

Energy Commission of Nigeria, 2003. National Energy Policy, Federal Republic of Nigeria, Abuja.

FAO. 2006. Global Forest Resources Assessment 2005. FAO Forestry Paper147. Rome, Italy FAO.

Farrugia, P. Petrisor, B.A. Farrokhyar, F. and Bhandari, M. 2010. Research questions, hypotheses and objectives. *Canadian journal of surgery*, **53(4):** 278.

Fernando, C.E.C. and Dangogo, S.M. 1986. Investigation of some parameters which affect the performance of biogas plants.

Gakuu MC, Njoroge WR & Nyonje RO, 2013. Adoption of Biogas Technology Projects among Rural Household of Lanet Location-Nakuru County. Available online: http://erepository.uonbi.ac.ke/ handle/11295/36399?show=full

Garn, J. V., Sclar, G. D., Freeman, M. C., Penakalapati, G., Alexander, K. T., Brooks, P., … Clasen, T. F., 2017. The impact of sanitation interventions on latrine coverage and latrine use: A systematic review and meta-analysis. *International Journal of Hygiene and Environmental Health*, **220(2, Part B):** 329–340.

Gebreegziabher, Z., 2007. *Household fuel consumption and resource use in rural-urban Ethiopia*. PhD thesis, Wageningen University, Netherlands.

Gebreegziabher, Z., Naik, L., Melamu, R. and Balana, B.B., 2014. Prospects and challenges for urban application of biogas installations in Sub-Saharan Africa. *Biomass and bioenergy*, **70**: 130-140.

Giwa, A. Alabi, A. Yusuf, A. and Olukan, T. 2017. A comprehensive review on biomass and solar energy for sustainable energy generation in Nigeria. *Renewable and Sustainable Energy Reviews*, **69**: 620-641.

Gomez, L.D. Steele-King, C.G. and McQueen-Mason, S.J. 2008. Sustainable liquid biofuels from biomass: the writing's on the walls. *New Phytologist*, **178(3):** 473-485.

Gosling, D. 1982. Biogas for Thailand's rural development: transferring the technology. *Biomass*, **2(4):** 309-316.

Green, J.M. and Sibisi, N.T. 2002 Domestic biogas digester - A comparative study. Community Resources, University of Natal, Pietermaritzburg. Domestic use of Energy Conference 2002.

Hartley, H.B. 1967. John Dalton, FRS (1766-1844) and the Atomic Theory—A lecture to commemorate his bicentenary. *Proceedings of the Royal Society of London. Series B. Biological Sciences*, **168(1013)**: 335-359.

Hazra, S., Lewis, J., Das, I. and Singha, A.K., 2014. *Adoption and use of improved stoves and biogas plants in rural India* (Vol. 86). Kathmandu, Nepal: South Asian Network for Development and Environmental Economics.

He, P.J. 2010. Anaerobic digestion: An intriguing long history in China. *Waste Management (New York, NY)*, **30(4)**: 549-550.

Huang, X., Wang, S., Shi, Z., Fang, L. and Yin, C., 2022. Challenges and strategies for biogas production in the circular agricultural waste utilization model: A case study in rural China. *Energy*, **241**: 122889.

Chaggu, E. Mashauri, D. Van Buuren, J. Sanders, W. and Lettinga, G. 2002. Excreta disposal in Dar-es-Salaam. *Environmental Management*, **30(5):** 0609-0620.

Chandrappa, R. and Das, D.B. 2012. Waste quantities and characteristics in: *Solid Waste Management, Environmental Science and Engineering*, Springer-Verlag, Heidelberg, Berlin.

Chang, I. S. Wu, J. Zhou, C. Shi, M. and Yang, Y. 2014. A time-geographical approach to biogas potential analysis of China. *Renewable and Sustainable Energy Reviews*, *37*, 318-333.

Chen, Y. 2006. *Polychlorinated biphenyls (PCBs)-induced gene expression profiling in human kidney cells: genomic biomarkers* (Doctoral dissertation, Howard University).

Ibitoye, F.I. and Adenikinju, A. 2007. Future demand for electricity in Nigeria. *Applied Energy*, *84*(5), pp.492-504.

IEA, 2006. Energy for cooking in developing countries. *World Energy Outlook*, **4**: 19-45.

Jekayinfa, S.O. and Scholz, V. 2009. Potential availability of energetically usable crop residues in Nigeria. *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, **31(8)**: 687-697).

Kabir, H., Palash, M.S. and Bauer, S., 2012. Appraisal of domestic biogas plants in Bangladesh. *Bangladesh Journal of Agricultural Economics*, **35(454-2016-36351)**: 71-89.

Kabir, H., Yegbemey, R.N. and Bauer, S., 2013. Factors determinant of biogas adoption in Bangladesh. *Renewable and Sustainable Energy Reviews*, **28**: 881-889.

Kapdi, S.S., Vijay, V.K., Rajesh, S.K. and Prasad, R., 2005. Biogas scrubbing, compression and storage: perspective and prospectus in Indian context. *Renewable energy*, **30(8):** 1195-1202.

Karekezi, S. and Kimani, J. 2004. Have power sector reforms increased access to electricity among the poor in East Africa?. *Energy for Sustainable Development*, **8(4):** 10-25.

Katukiza, A.Y. Ronteltap, M. Niwagaba, C.B. Foppen, J.W.A. Kansiime, F.P.N.L. and Lens, P.N.L. 2012. Sustainable sanitation technology options for urban slums. *Biotechnology advances*, **30(5)**: 964-978.

Kayhanian M, Tchobanoglous G. 1992. Computation of C/N ratios for various organic fractions. *Biocycle* **33**: 58–60.

Kema, K., Semali, I., Mkuwa, S., Kagonji, I., Temu, F., Ilako, F. and Mkuye, M., 2012. Factors affecting the utilisation of improved ventilated latrines among communities in Mtwara Rural District, Tanzania. *The Pan African medical journal*, **13**(Suppl 1).

Khanal, S.K. 2008. Anaerobic reactor configurations for bioenergy production. *Anaerobic Biotechnology for Bioenergy Production: Principles and Applications*, 93-114.

Kharbanda, V.P. and Qureshi, M.A. 1985. Biogas Development in India and the PRC. *The Energy Journal*, **6**(3)**.**

Krozer, Y. 2020. Low-Carbon Technologies in Global Energy Markets. In *Advances in Carbon Management Technologies* (23-39). CRC Press.

Kulabako, R. N. Nalubega, M. Wozei, E. & Thunvik, R. (2010). Environmental health practices, constraints and possible interventions in peri-urban settlements in developing countries–a review of Kampala, Uganda. *International journal of environmental health research*, **20(4):** 231-257.

Kumar Ghosh, S. and Mandal, S., 2018. Evaluation of biogas as an alternative driving force of electrically operated vehicles: a case study. *International Journal of Engineering*, **31(5)**: 834-840.

Lönnqvist, T., Sandberg, T., Birbuet, J.C., Olsson, J., Espinosa, C., Thorin, E., Grönkvist, S. and Gómez, M.F., 2018. Large-scale biogas generation in Bolivia–a stepwise reconfiguration. *Journal of cleaner production*, **180**: 494-504.

Marchaim, U. and Krause, C. 1993. Propionic to acetic acid ratios in overloaded anaerobic digestion. *Bioresource technology*, **43(3):** 195-203.

Mba, E.H. 2018. Assessment of environmental impact of deforestation in Enugu, Nigeria. *Resources and Environment*, **8(4):** 207-215.

Mbuligwe, S.E., 2002. Institutional solid waste management practices in developing countries: a case study of three academic institutions in Tanzania. *Resources, Conservation and Recycling*, **35(3)**: 131-146.

Meribe, N.C. 2017. The political economy of climate change reporting in Nigeria. *African Journalism Studies*, **38(1)**: 40-65.

Millington, A.C. Critchley, R.W. Douglas, T.D. and Ryan, P. 1994. *Estimating woody biomass in sub-saharan Africa*. World Bank.

Mshandete, A., Björnsson, L., Kivaisi, A.K., Rubindamayugi, M.S. and Mattiasson, B., 2006. Effect of particle size on biogas yield from sisal fibre waste. *Renewable energy*, **31(14)**: 2385-2392.

Muvhiiwa, R., Hildebrandt, D., Chimwani, N., Ngubevana, L. and Matambo, T., 2017. The impact and challenges of sustainable biogas implementation: moving towards a bio-based economy. *Energy, Sustainability and Society*, **7(1)**: 1-11.

Mwakaje, A.G. 2008. Dairy farming and biogas use in Rungwe district, South-west Tanzania: A study of opportunities and constraints. *Renewable and Sustainable Energy Reviews*, **12(8):** 2240-2252.

Mwirigi, J., Balana, B.B., Mugisha, J., Walekhwa, P., Melamu, R., Nakami, S. and 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.

National Bureau of Statistics (NBS), 2016. LSMS-integrated Surveys on Agriculture: General Household Survey Panel 2015/2016.

NEMA. 2009. Effects of Climate Change and Coping Mechanism in Kenya. Nairobi, Kenya: NEMA/UNDP.

Ngumah, C. Ogbulie, J. Orji, J. and Amadi, E. 2013. Potential of organic waste for biogas and biofertilizer production in Nigeria. *Environmental research, engineering and management*, **63(1):** 60-66.

Nguyen, K.Q. 2007. Alternatives to grid extension for rural electrification: Decentralized renewable energy technologies in Vietnam. *Energy Policy*, **35(4)**: 2579-2589.

Nwankwo, C.S., Eze, J.I. and Okoyeuzu, C., 2017. Design and fabrication of 3.60 m3 household plastic bio digester loaded with kitchen waste and cow dung for biogas generation. *Scientific Research and Essays*, **12(14)**: 130-141.

Ogedengbe, M.O. 2001 Waste Management Systems Potential impacts, Paper presented during a course on Environmental Impact Assessment by National centre for Technology Management, OAU, Ile-Ife

Ogwueleka, T. 2009. Municipal solid waste characteristics and management in Nigeria. *Journal of Environmental Health Science & Engineering*, **6(3)**: 173-180.

Okonkwo, E.C., Okafor, K.I. and Akun, E., 2018. The economic viability of the utilisation of biogas as an alternative source of energy in rural parts of Nigeria. *International Journal of Global Energy Issues*, **41(5-6)**: 205-225.

Okoro, E.E., Igwilo, K.C. and Orodu, K.B., 2018. A review on waste to biogas sources and its potential in Nigeria. *International Journal of Engineering & Technology*, **7(4)**: 5960-5966.

Okoro, O.I. and Chikuni, E. 2007. Power sector reforms in Nigeria: opportunities and challenges. *Journal of Energy in Southern Africa*, **18(3)**: 52-57.

Osuji, E.E. Okwara, M.O. Essien, U.A. Balogun, O.L. and Agu, C.G. 2019. Sustainability of climate change adaptation measures in south-south, Nigeria. *Agricultural, and Food Science Journal. USA*, **6(1)**: 120-126.

Otiti, T. and Karekezi, S. 1995, August. Renewable energy technologies dissemination in Sub-Saharan Africa region. In *Regional Workshop on Greenhouse Gas Emissions for African countries, Arusha, Tanzania* (Vol. 5).

Ovuyovwiroye, P.A. 2013. Analysis of climate change awareness in Nigeria. *Scientific Research and Essays*, **8(26)**: 1203-1211.

Oyedepo, S.O. 2012. Energy and sustainable development in Nigeria: the way forward. *Energy, Sustainability and Society*, ***2*(1)**: 1-17.

Oyedepo, S.O. 2014. Towards achieving energy for sustainable development in Nigeria. *Renewable and sustainable energy reviews*, **34**: 255-272.

Parawira, W., 2009. Biogas technology in sub-Saharan Africa: status, prospects and constraints. *Reviews in Environmental Science and Bio/Technology,* **8(2):** 187–200. doi:10.1007/s11157-009-9148-0

Pavlas, M., Touš, M., Bébar, L. and Stehlík, P., 2010. Waste to energy–An evaluation of the environmental impact. *Applied Thermal Engineering*, ***30*(16)**: 2326-2332.

Raymond, O. and Okezie, U., 2011. The significance of biogas plants in Nigeria's energy strategy. *J. Physical Sci. Innov*, **3**: 11-17.

Roopnarain, A. and Adeleke, R., 2017. Current status, hurdles and future prospects of biogas digestion technology in Africa. *Renewable and Sustainable Energy Reviews*, **67**: 1162-1179.

Roubík, H. and Mazancová, J. 2019. Small-scale biogas plants in central Vietnam and biogas appliances with a focus on a flue gas analysis of biogas cook stoves. *Renewable Energy*, **131**: 1138-1145.

Roubik, H. and Mazancová, J. 2020. Suitability of small-scale biogas systems based on livestock manure for the rural areas of Sumatra. *Environmental Development*, **33**: 100505.

Roubík, H. and Mazancová, J., 2019. Small-scale biogas plants in central Vietnam and biogas appliances with a focus on a flue gas analysis of biogas cook stoves. *Renewable Energy*, **131**: 1138-1145.

Roubík, H. Mazancová, J. Heller, T. Brunerová, A. and Herák, D. 2016, September. Biogas as a promising energy source for Sumatra. In *6th International Conference on Trends in Agricultural Engineering* (pages 537-544).

Roubík, H. Mazancová, J. Le Dinh, P. Dinh Van, D. and Banout, J. 2018. Biogas quality across small-scale biogas plants: A case of central Vietnam. *Energies*, **11(7)**: 1794.

Rupf, G.V., Bahri, P.A., de Boer, K. and McHenry, M.P., 2015. Barriers and opportunities of biogas dissemination in Sub-Saharan Africa and lessons learned from Rwanda, Tanzania, China, India, and Nepal. *Renewable and Sustainable Energy Reviews*, **52**: 468-476.

Sasse, L. 1988. Biogas plants. *Vieweg & Sohn. Wiesbaden*.

Sederberg, P.B. Kahana, M.J. Howard, M.W. Donner, E.J. and Madsen, J.R. 2003. Theta and gamma oscillations during encoding predict subsequent recall. *Journal of Neuroscience*, **23(34)**: 10809-10814.

Shallo, L., Ayele, M. and Sime, G., 2020. Determinants of biogas technology adoption in southern Ethiopia. *Energy, Sustainability and Society*, **10(1)**: 1-13.

Shane, A., Gheewala, S.H. and Kasali, G., 2015. Potential, barriers and prospects of biogas production in Zambia. *Journal of Sustainable Energy and Environment*, **6**: 21-26.

Singh, K.J. and Sooch, S.S. 2004. Comparative study of economics of different models of family size biogas plants for state of Punjab, India. *Energy Conversion and Management*, **45(9-10):** 1329-1341.

Sovacool, B.K., Kryman, M. and Smith, T., 2015. Scaling and commercializing mobile biogas systems in Kenya: a qualitative pilot study. *Renewable Energy*, **76**: 115-125.

Sridhar, M.K.C. and Hammed, T.B. 2014. Turning waste to wealth in Nigeria: An overview. *Journal of Human Ecology*, **46(2)**: 195-203.

Stehlík, P., 2009. Contribution to advances in waste-to-energy technologies. *Journal of Cleaner Production*, **17(10)**: 919-931.

Susanne, S. 2011. *Overcoming barriers to rural electrification*: An analysis of micro energy lending and its potential in the international carbon market. Solar home systems in Bangladesh. Aarhus, Denmark: Aarhus University.

TatlİdİI, F.F. Bayramoglu, Z. and Akturk, D. 2009. Animal manure as one of the main biogas production resources: case of Turkey. *Journal of Animal and Veterinary Advances*, **8(12)**: 2473-2476.

Tucho, G.T. and Nonhebel, S., 2017. Alternative energy supply system to a rural village in Ethiopia. *Energy, Sustainability and Society*, **7(1):** 1-14.

UNEP, F. 2012. Financing renewable energy in developing countries. *Drivers and barriers for private finance in Sub-Saharan Africa*.

United Nations, Department of Economic and Social Affairs, Population Division, 2019. *World Population Prospects 2019,* Available at https://population.un.org/wpp/DataQuery/ [Accessed 19th August 2021].

University of Adelaide, 2010. University of Adelaide Brief History of Biogas Retrieved from http://www.adel-aide.edu.au/ biogas/history/ [Accessed 19th August 2021].

Uwidia, I.E. and Ademoroti, C.M.A. 2011. Characterisation of domestic sewage from an estate in Warri, Nigeria. *International Journal of Chemistry*, **3(3)**: 81.

Vu, T.K.V., Vu, D.Q., Jensen, L.S., Sommer, S.G. and Bruun, S., 2015. Life cycle assessment of biogas production in small-scale household digesters in Vietnam. *Asian-Australasian Journal of Animal Sciences*, **28(5)**: 716.

Walekhwa, P.N., Mugisha, J. and Drake, L., 2009. Biogas energy from family-sized digesters in Uganda: Critical factors and policy implications. *Energy policy*, **37(7)**: 2754-2762.

Walekhwa, P.N., Mugisha, J. and Drake, L., 2009. Biogas energy from family-sized digesters in Uganda: Critical factors and policy implications. *Energy policy*, **37(7):** 2754-2762.

Wang, X. Lu, X. Li, F. and Yang, G. 2014. Effects of temperature and carbon-nitrogen (C/N) ratio on the performance of anaerobic co-digestion of dairy manure, chicken manure and rice straw: focusing on ammonia inhibition. *PloS one*, **9(5)**: e97265.

Weiland, P., 2000. Anaerobic waste digestion in Germany–Status and recent developments. *Biodegradation*, **11(6)**: 415-421.

Werner, U. Stöhr, U. and Hees, N. 1989. Biogas plants in animal husbandry. *Deutsches Zentrum für Entwicklungstechnologien-GATE.*

WHO and UNICEF, 2010. Progress on drinking water and sanitation. *Joint Monitoring Program Report (JMP).*

Williams, C.E. 1998, June. Reaching the African female farmers with innovative extension approaches: Success and challenges for the future. In *international workshop on women* *agricultural intensification and household food security at university of cape coast, Ghana, 25th-28th June*.

Winkler, H., Simões, A.F., La Rovere, E.L., Alam, M., Rahman, A. and Mwakasonda, S., 2011. Access and affordability of electricity in developing countries. *World development*, **39(6)**: 1037-1050.

Worldometers, 2019. Available on https://www.worldometers.info/world-population/nigeria-population/

Yohannes, T., Workicho, A. and Asefa, H., 2014. Cross sectional study: availability of improved sanitation facilities and associated factors among rural communities in Lemo Woreda, Hadiya Zone, Southern Ethiopia. *Open Access Library Journal*, **1(8):** 1-10.

Appendix

Appendix A: Questionnaire

QUESTIONNAIRE

[Research Focus: Public Perceptions of Biogas Technology in Rural Areas of Nigeria.]

Target Area: Lagos, Nigeria

SECTION 1 General Questions

Basic and Regional Information:

1. Age: 18 – 24 ☐ 25 – 34 ☐ 35 – 44 ☐ 45 – 54 ☐ 55 and above ☐
2. Gender: ☐Male ☐Female
3. Education level: ☐ Primary school☐ Secondary school ☐University ☐ No formal education
4. What is your main household occupation?
   Fishing ☐
   Farming ☐
   Civil Servant☐
   Private Firm Worker☐
5. How many members live in your household?
   1-3members☐
   3-5members ☐
   5 and above ☐
6. What is the highest level of education within your household?
   None ☐
   First School Leaving Certificate☐
   Senior Secondary School Certificate (SSCE) ☐
   Bachelor Degree and above ☐
7. What is the average income of your household? ☐
   N10,000 or less ☐
   Between N10,000- N50,000 ☐
   Between N50,000- N100,000 ☐
   N100,000 and above ☐

Section II *Climate Change and Environmental Awareness*

Are you satisfied with the environmental awareness of your community?

(1-Strongly disagree, 2-Agree,3-Uncertain, 4-Disagree 5-Strongly agree)

0	1	2	3	4	5
☐	☐	☐	☐	☐	☒

How strongly do you agree with the following statements about climate change and environmental awareness?

(1-Strongly disagree, 2-Agree,3-Uncertain, 4-Disagree 5-Strongly agree)

	0	1	2	3	4	5
Climate change has an adverse impact on social and economic development in Nigeria.	☐	☐	☐	☐	☐	☒
Climate change is an important issue for Nigeria.	☐	☐	☒	☐	☐	☐
Nigeria should take immediate action to address climate change.	☐	☐	☒	☐	☐	☐
Climate change is of no concern to me.	☒	☐	☐	☐	☐	☐

9. Have you heard of the following low carbon technologies?
(0-Indifferent, 1-Have never heard (or read) about it, 2-Have heard about it, 3-Know a little about it , 4- I know enough about it,5- I know a lot about it)

	0	1	2	3	4	5
Biogas Technology	☐	☐	☐	☐	☐	☒
Wind power	☐	☐	☐	☐	☐	☒
Energy-conserving electric appliances.	☐	☐	☐	☐	☐	☒
Solar power	☐	☐	☐	☐	☐	☒
Hydrogen powered vehicles	☐	☒	☐	☐	☐	☐
Biomass energy	☐	☐	☐	☐	☐	☒
Carbon capture and storage (CCS)	☐	☐	☐	☐	☒	☐

10. Attitudes towards low carbon technologies.
How strongly do you agree with the use of the following technologies?
(1-Strongly disagree, 3-No opinion, 5-Strongly agree)

	1	2	3	4	5
Biogas Technology	☐	☐	☐	☐	☑
Solar energy	☐	☐	☐	☐	☑
Wind energy	☐	☐	☐	☐	☑
Energy-conserving electric appliances	☐	☐	☐	☐	☑
Energy-saving vehicles (including hybrid vehicles and hydrogen powered vehicles)	☐	☐	☐	☐	☑
Biomass energy	☐	☐	☐	☐	☑
Carbon capture and storage (CCS)	☐	☐	☐	☐	☑

Section III *Public Perception on Biogas technology*

11. What is the most important environmental problem that biogas technology addresses?

	1	2	3
Climate change	☐	☐	☑
Smog	☐	☐	☑
Acid rain	☐	☐	☑
Water pollution	☐	☐	☑
Resource depletion	☐	☑	☐
Ozone depletion	☐	☐	☑
Toxic waste	☐	☑	☐

12. Do you agree with integrating carbon BT equipment into your daily cooking routine?
(1-Strongly agree, 2-Agree, 3-No opinion, 4-Oppose, 5-Strongly oppose)

❑ 1 ❑ 2 ❑ 3 ❑ 4 ❑

13. Are you willing to use a biogas stove?
(1-Strongly agree, 2-Agree, 3-No opinion, 4-Oppose, 5-Strongly oppose)

❑ 1 ❑ 2 ❑ 3 ❑ 4 ❑

14. I am interested in new innovations.

❑ 1 ❑ 2 ❑ 3 ❑ 4 ❑

SECTION IV *Biogas plant owners/workers*

15. How many members of your household work at the Biogas Plant?

1-3members ☐

3-5members ☐

5 and above ☐

16. How did you acquire training before working in the BiogasPlant?

Government Training Programme ☐

Private Training Programme ☐

None of the above ☐

17. How long did the training take?
1 month or less ☐

☐ Above a month but less than 3 months

Above 3 months but less than 6 months

6 months and above
None of the above

18. Have you received any form of certification for your training?

Yes
☐
No
☐

19. Which source of energy is mostly used around here?

☐ Biogas ☐ Fossil fuel ☐Firewood ☐Kerosene ☐Others

20. Is Biogas a popular source of energy aroundhere?

☐ No ☐Yes

21. Should Biogas be seriously considered as an alternative to traditional fuel?

☐ No ☐ Yes

22. How often does small-scale production of Biogas occur here?

☐ Very often ☐ Often ☐Sometimes ☐Rarely

23. Is the Biogas produced sufficient to meet your energy demands?

☐ No ☐Yes ☐Yes, it is produced in excess

24. Is there any cultural resistance to the use of Biogas because of its raw materials?

☐ No ☐ Yes If Yes, kindly explain.

....

....

………………………………………………………………………………………………

………

SECTION V: ***Level of Usage of Biogas technology in Rural areas***

25. What type of Biogas Plant is yours?

☐Fixed dome biogas plant ☐Floating gasholder plant ☐Plastic bag digester

26. What volume (m^3) of Biogas does your Plant produce daily?

☐2m^3 or less ☐Above 2m^3 but less than 5m^3 ☐Above 5m^3 but less than10m^3

27. What sort of wastes are mostly generated around here?

☐ Animal waste ☐Human waste ☐Plants ☐ All of the above

28. How do you dispose these wastes?

☐ Dump on the street ☐ Government disposal trucks ☐Bury at home ☐All of the above

29. What sort of toilet systems are used here?

☐ Water closet ☐Latrine ☐Mobile toilets ☐No toilets available

30. Which waste materials does the plant use as its primary source for production of Biogas? (Kindly tick as applicable)

☐ Animal waste ☐Human waste ☐Plants ☐All of the above

31. Do you use any Biogas lamps?

☐ No ☐Yes If No, Proceed to39

32. What is the average power rating of your lamp? (Write the number in hours)

………………………………………………………………………………………………

32. On the average, how many hours per day do you use your lamp?

☐ less than an hour ☐1-5hours ☐6-13 hours ☐14-24hours

34. What is the power rating of the burner on your biogas stove? (Kindly write inhours)
....

35. On the average, how many hours per day do you use your burner for cooking and boiling water?
☐ less than an hour ☐1-5hours ☐6-13 hours ☐14-24hours

36. Do you also burn excess biogas?

☐ No ☐Yes

37. On the average, how many hours per day do you use your burner to burn excess biogas?
☐ less than an hour ☐1-5hours ☐6-13 hours ☐14-24hours

SECTION VI: *Small-scale Production of Biogas as a Tool for Rural Development*

38. Have you had any form of government assistance or external finance tohelp with this small-scale production of Biogas? ☐ No ☐Yes

39. Do you think that government policies with respect to energy have stagnated rate of development in rural areas? ☐ No ☐ Yes

40. Are you familiar with the Renewable Energy Division (RED) created by the Federal Government in 2005 through Nigeria National Petroleum Corporation (NNPC) saddled with the responsibility of developing the Biogas industry in Nigeria?☐No ☐Yes

41. Are you familiar with the Nigerian Bio-fuel Policy and Incentives, a policy document that was approved by the Federal Executive Council as a national bio-fuels policy?
☐ No ☐Yes

42. How strongly do you agree with the following policies for promoting Nigeria's BT development?
(1-Strongly disagree, 2-Agree,3-Uncertain, 4-Disagree 5-Strongly agree)

	1	2	3	4	5
Financial support	❑	❑	❑	❑	❑
Reforms of the power industry	❑	❑	❑	❑	❑
BT laws and regulations	❑	❑	❑	❑	❑
Incentive polices	❑	❑	❑	❑	❑
International Cooperation	❑	❑	❑	❑	❑

43. How strongly do you agree with developing biogas technology in Nigeria?
(1-Strongly disagree, 2-Agree,3-Uncertain, 4-Disagree 5-Strongly agree)

	1	2	3	4	5
Biogas Technology	❑	❑	❑	❑	❑

End of survey.

Thank you for your support and cooperation.

2021/1

END NOTES

I appreciate your contribution to this study, which will contribute to the body of knowledge with respect to small-scale Biogas production in Nigeria.

Your responses will help understand and explore the impact of small-scale biogas production within Nigeria from a rural perspective. All responses will be treated with utmost confidentiality.

Please use the space below to write additional comments with respect to the research focus, whether or not it was covered in the questionnaire.

Additional Comment: