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Vegetable and Fruit Waste as a source of biogas for energy generation: Case of Ipokia, Nigeria.

MASTER'S THESIS

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Declaration

I hereby declare that I have done this thesis entitled Vegetable and Fruit Waste as a source of biogas for energy generation: case of Ipokia, Nigeria independently, all texts in this thesis are original, and all the sources have been quoted and acknowledged by means of complete references and according to Citation rules of the FTA.

In Prague 11/04/2023

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Opeyemi Oshundaro

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Abstract

Biogas production is a clean and sustainable energy source that is good for households and uses organic waste products for the purpose of generating biogas. In our society, the perception of biogas is low and yet to fully gain its full capacity, thereby undermining the importance of the technology. Generally, this study examined vegetable and fruit waste as a source of biogas for energy generation. case of Ipokia, Nigeria. Specifically, the study evaluated the waste disposal and management methods available in the study area, understood the perception of the resident of the use and awareness of biogas from vegetable and fruit waste. The study also looked at the level of adoption of biogas, the level of vegetable and fruit waste generated, the willingness to use waste generated from vegetable and fruit sources to generate biogas, the factors that influence the use of vegetable and fruit waste as a source of biogas and possible barriers to the use of vegetable and fruit waste for the generation of biogas. A comprehensive review of biogas production and vegetable and fruit waste was carried out, while an exploratory and quantitative research design was used in the study. A multistage sampling procedure was used to select 150 respondents who participated in this study. Primary data was obtained using questionnaires, while frequency count, mean, percentage, chi-square, and logistic regression were used to analyse the data The results revealed that the majority (66.6%) of the respondents were between the ages of 19 and 22 years while 26.9% were between the ages of 31 and 50 years. The mean age of the respondents was found to be about 48 years implying that the respondents are within the active working age range and further results shows that the majority (68%) of the respondents were male and this implies that males are more involved in vegetable and fruit production. Furthermore, some waste disposal methods used include open burning, composting, government certified waste collectors, among others. Vegetable and fruit waste was found to be mainly disposed of by leaving them in the open to rot while open burning was the second most likely way of disposing of fruit and vegetable waste in the locality. The perception of the respondents on the use and awareness of biogas derived from vegetable and fruit waste showed that the perception of the respondents was on its energy use and the complication in its use. Furthermore, the sources of energy in the study area were evaluated and it was discovered that charcoal and wood were among the main primary energy sources in the vicinity, while it was observed that households have more than one energy source through which they meet their energy need. Biogas awareness was found to be low while there were

scarcely any biogas facilities available in the vicinity of the study area. The level of adoption of the respondent showed that most of the respondent were still in the first and second stages of adoption while the rest were in the third and fourth stages of adoption. The willingness to use vegetable and fruit waste for biogas production was found to be influenced by the educational status of the respondents and their income from vegetable production, while their level of adoption was influenced by their income, educational level, age and sex. Based on the findings, the study concluded that the awareness about biogas utilisation in the vicinity is low and there might be a need for interventions such as subsidies, trainings and credit incentives in other countries to encourage people to adopt the use of technology in the management of their vegetable and fruit waste.

Key words: Biogas, Vegetable, Fruit, Waste, Energy

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List of the abbreviations used in the thesis

CFC – Chlorofluorocarbons

CH_4 – Methane

CO_2 – Carbon Dioxide

FAO – Food and Agriculture Organisation

FAOSTAT – Food and Agriculture Organisation Statistics

GDP – Gross Domestic Product

GHG – Greenhouse Gases

GWP – Global Warming Potential

NBS – Nigerian Bureau of Statistics

NREEEP – National Renewable Energy and Energy Efficiency Policy

pH – Hydrogen Potential

UNFCC – United Nations Framework Convention on Climate Change

1. Introduction

1.1. Background Statement

The agricultural industry serves as the foundation and pillar of the world economy due to the major role it plays in maintaining life and in the promotion of industrial development through the supply of raw materials (Barichello, 2020). Therefore, agriculture can be linked to both economic and social growth of any economy due to the level of activity that is taking place in the agricultural sector. Activities in the agricultural sector include production, processing, sales, and logistics, among others (Karamushka *et al.*, 2018). With the growth in the agricultural sector coupled with the increase in population, food waste issues have been a major challenge for agricultural production around the world and even in Nigeria, thus contributing to environmental degradation through the release of greenhouse gases that are detrimental to the environment (O'Connor *et al*., 2021; Mama *et al*., 2021). Therefore, the challenge over the years has been to identify effective and efficient ways of managing waste generated in the agricultural sector.

Generally, all production activities are characterised by the generation of waste (Mama *et al.*, 2021). This waste in turn forms a major component of the environment through land, air, or water and has consequences on the well-being/welfare of the human population because of the environmental, health, and social impact. The cost of waste generated in agricultural production may not be easily quantifiable, but according to a FAOSTAT estimate, approximately 76.9 million tons of food are lost per year, which represents approximately 40% of the total agricultural production in Nigeria, are lost as food waste yearly and this contributes approximately 5% to the annual emission of greenhouse gases and 9.1% in terms of GDP losses (FAOSTAT, 2017).

The increase in population is also expected to escalate the issue of waste management in Nigeria if not efficiently managed (Nanda and Berruti, 2021). This is due to the increasing expectation from food systems in terms of production and the level of inefficiency in the management of food systems in the country at present. Food waste can be described as the losses, degradation, contamination, and disposal of food items in the food supply chain. Food waste is a major challenge for agricultural commodities due to

the perishable nature of food products, especially when in raw form. Kintoja *et al.* (2019), noted that losses are reported in the food system in Nigeria due to inadequate food storage, processing and handling facilities. Food waste/disposal in agriculture occurs at almost every stage of the food transition in the food chain from production to processing to distribution before it finally gets to the consumer. The challenge of food waste is that it affects the quantity of food available and could compound the problems of food security and environmental degradation in Nigeria. The situation of food waste in Nigeria is quite multifaceted in terms of the various factors that contribute to the waste recorded in the food chain in Nigeria. Food waste/disposal occurs in almost every food chain and leads to economic loss for the actor in the food chain that bears the burden of food waste. Gustavsson *et al*. (2013) found that food waste occurs more along the value chain of the agricultural commodity. This means that there is a need to identify ways through which waste in the value chain can be used to reduce the negative impact of this waste on the environment.

From a global perspective, energy use has been mainly composed of fossil energy sources such as oil, natural gas, and electricity, and renewable energy sources have the lowest proportion among sources of energy generation around the world. In 2018, around 85% of energy sources are believed to come from fossil fuel sources (Abanades *et al*., 2020). Renewable and other clean energy sources, such as biogas, account for the least percentage. Evidence has shown that fossil fuel sources are mostly not good for the environment and contribute to environmental degradation compared to biogas sources, which serve as a better alternative in generating renewable and clean energy with little or no consequences on the environment.

To achieve a clean and renewable energy source, biogas produced from organic materials serves as an important source to consider. Specifically, biogas can be generated from plant and animal products and further broken down by bacteria in an anaerobic environment to release the energy stored in organic materials for the purpose of generating energy (Koul *et al*., 2022). The advantage of biogas is that it helps utilize waste that would easily have been left to decompose/dispose in a non-environmentally friendly manner.

In communities in Nigeria, waste disposal has been a challenge due to the uncoordinated effort in waste management. As such, waste disposal among communities

includes the use of open burning, leading to the release of harmful gases into the atmosphere, the disposal into sewage systems, canals, and water channels, which could lead to pollution of the water channels and erosion, and the use of open disposal on abandoned land, open fields, and roadsides, which also has implications for health and safety (Ike *et al*., 2018). However, biogas can be seen as an alternative to managing the level of waste generated, especially through agricultural activities among communities, and can serve as a proper way of managing our environment to promote sustainability and environmental safety. Consequently, the level of waste generated, though high, can be put to economic use in such a way that the losses incurred as a result of wastage generated along the value chain of these agricultural commodities are reduced to the bare minimum.

1.2. Problem Statement

Waste generation around the world is a great challenge due to the level of industrialisation and the growth of the population, which has spiralled the need to create efficient waste management systems (Yadav *et al.*, 2022). In Nigeria, conventional waste disposal methods are unorthodox and lack safety due to the level of pollution and dangerous gases released into the atmosphere through various waste disposal methods (Ike *et al.*, 2018). Many households in Nigeria rely on burning, disposal in channels and disposal in wastelands and open fields as means of disposing of waste. Only about 20% of the population relies on well-coordinated means of waste disposal. As such, the challenge facing policy makers is to identify means to mitigate the impact of unorthodox means of waste disposal, which negatively affect our environment and cause serious headaches for policymakers.

Furthermore, the government of Nigeria has over the years promoted self-sustenance in agriculture by investing heavily in it. However, this investment is not productive due to the level of waste generated through agricultural production caused by inadequate storage facilities, a lack of steady electricity supply, and the high cost of transportation, among others. Studies (Babatunde, 2019; Okoro *et al.*, 2019) have shown that in communities there is a high level of post-harvest waste generated and there is always the challenge of disbursing due to the non-functional waste disposal system. The level of financing required to implement an effective waste management system has

forced the Nigerian government to resign from implementing effective waste management coupled with dwindling government revenues. Therefore, considering this, it is best to look at how biogas can be used effectively to manage waste produced in agriculture in a cost-effective manner.

Furthermore, the increased level of production of fruits and vegetables has increased the level of waste generated through such food products (Afolabi *et al.*, 2021). This is caused as a result of the short shelf life of this product and is further compounded by instability in the market and lack of storage, processing, and transport facilities, resulting in a high volume of waste (Afolabi *et al.*, 2021). Vegetable and fruit waste can easily be overlooked because they are easily biodegraded by microorganisms. However, the biodegradation process is not safe for the environment, as there is a release of a pungent smell that pollutes the environment, and greenhouse gases are released through this process, which is not good for human safety. They can also contribute to soil and groundwater pollution, as a result of waste being washed into water bodies when it rains, thus contaminating the water bodies. Therefore, an appropriate method for the treatment of waste is needed to overcome the problems caused by the accumulation of fruit and vegetable waste.

1.3. Rationale of the study

The level of waste generated in the agricultural sector, especially through the production of vegetables and fruits (Oguntoke *et al.*, 2019), has been a major motivation for this work. Over the years of travelling through agrarian communities, the sight and market of decomposing vegetables and fruits have been terrible, and this has continually impacted the level of production over the years (Afolabi *et al.*, 2021). If nothing is done to find a solution, it could escalate beyond the present level and create an environmental disaster. Therefore, this study will explore ways in which the waste generated from vegetable and fruit waste can be used for the production of biogas, which can also be used for the production of energy in homes.

Furthermore, the need to promote cleaner and sustainable means of energy generation has further heightened the need to look at how best to obtain raw materials that can be efficiently used in production without further compounding environmental problems on the ground (Mohammed *et al.*, 2017). This is to help policy to drive the call

for cleaner energy sources that are renewable and sustainable to the environment. The awareness of biogas in a developing country is quite low because little has been done to promote it as a viable energy source among the population (Sen and Ganguly, 2017) and as such this study will bring to the fore the benefits that can be derived from the use of waste as biogas.

1.4. Contributions of the study

Every study has a purpose for which it was conducted. This study, as such, has its own way of improving the policy environment by helping decision makers know what to do and shedding light on an area of research that has not been fully delved into. This is done in other ways to help with information gathering and also to point out critical areas where urgent attention is needed, in other ways to help in the efficient management of the environment. The research findings will be disseminated through various channels to ensure widespread awareness and understanding of the benefits of biogas technology. Community engagement activities such as town hall meetings and awareness campaigns will educate residents and stakeholders about the potential of biogas to address waste management challenges and provide sustainable energy. Additionally, publications in academic journals, presentations at conferences and workshops, and engagement with government parastatals will raise awareness among academics, researchers, and professionals in the field of renewable energy and waste management. These efforts will help to ensure that the research findings are incorporated into policy development and implementation and promote the use of biogas technology for the efficient management of organic waste and sustainable energy production in Ipokia, Nigeria.

2. Literature Review

2.1. Theoretical Framework

2.1.1. Concept of Sustainability

The aim of sustainability is to have a system in place that would guide the activities of man in the present to protect the future generations (Janker and Mann, 2020). The idea of sustainability is an age-long issue, as it has evolved through the ages, and this has been one of the main issues guiding the development of the millennium development goals and the sustainable development goals (Halkos and Gkampoura, 2021). The concept of sustainability in the world conservation strategy report attempted to explain sustainability by nothing that a development is sustainable when it takes into account the sociological and ecological impact of an action while satisfying human needs (Dacko *et al.*, 2021). In essence, for us to enjoy a world where sustainability is maintained, we must be able to balance our activities so as to protect future generations. The challenge today is to manage the environment to make it liveable for future generations. However, the challenge before us is that of development, which has neglected sustainability and therefore has more impact on the way we live in terms of the climatic conditions such as rising temperature, erosion, rise in water levels, amongst others. All of which can be traced to the depletion of the ozone layer in the atmosphere, which has exposed the atmosphere to greater challenges for the future (Barnes *et al*., 2019). However, for a problem to be solved, it goes beyond just identifying the problem, but accessing ways through which that problem can be eradicated and that has given birth to the term sustainability. Sustainability is the key word for accessing the future from the present by taking actions in the present that will improve the well-being of humans and, on the other hand, protect the environment.

We can see environmental sustainability following the input output rule as proposed by Goodland and Daly (Anderson and Smith, 2022). The output rule opines that any waste that is emitted from any activity should be within the capacity of the immediate environment to absorb such waste without affecting the future capacity of the environment (Anderson and Smith, 2022). This output layer of the rule is one of the reasons why waste management for agricultural products is important due to the high

level of waste generated from agricultural activities. On the other hand, the input rule proposed was that for renewable resources they should be used at the same rate or less to what is being generated by the environment and not be over-used while non-renewable resources should be used at the same rate at which they are replaced and not more (Anderson and Smith, 2022). For instance, the use of forests, which has been one of the bones of contention in sustainability because it is not being regenerated at the rate at which it is being depleted, is against the rule. Therefore, it can be said that to provide a sustainable solution, there must be a balance between the source and the sink (Safder *et al*., 2022). For example, agriculture has been confirmed to generate a lot of waste that is detrimental to the environment due to the level of greenhouse gases that are released from the decomposition of such waste with no provision in the environment to absorb it (sink) (Elbasiouny *et al.*, 2020). Therefore, this causes more danger to the already endangered environment. As such, having a sink in place to take care of the source is one of the ways through which sustainability of our environment can be sustained. Therefore, environmental sustainability can be said to be an effective management of waste, pollution, and emission, and an efficient use of energy.

Purvis *et al.* (2019); Pelletier *et al.* (2019) and von Braun *et al*. (2021), in their study noted some key concepts which complement the rules by Godland and Daley about sustainability and noted that for sustainability to be applicable in the facet of the management of the environmental resources the key concept must be put into consideration. Some of the highlights of the concept proposed include the fact that choices are important to ensure that the sustainability of the environment is maintained (Pelletier *et al.*, 2019). This is because having to maintain sustainability must be a choice between what we have known to be and what is acceptable within the context of the environment. The concept of choices is important because the path to sustainability is dynamic, and as such changes need to be constantly made that will affect what we have known to be right and what is the right thing to do towards having a sustainable environment. As such, the choice to be made in our case is the trade-off between the conventional waste disposal system and the application of waste for the generation of biogas, which is more environmentally friendly.

Secondly, sustainability was noted to be ‘normative’ and this is closely related to choices because for every sustainable behaviour there is an alternative that can be

explored (Von Braun *et al*., 2021). Therefore, people are often subjective in their decision about sustainability by looking for the alternative that fits their desire rather than the choice that is environmentally friendly and has the component of sustainability. From the normative concept, people may decide to use waste on their farm as manure by allowing it to decay on their farms or open source with the mindset of adding to soil nutrient, which may be harmless and cheaper way of waste disposal to them, but the end point is the release of GHGs into the atmosphere, which may have been controlled if a more environmentally friendly approach was used.

Furthermore, sustainability is seen as a "fuzzy concept" and different meanings are given to it by different people (Pelletier *et al.*, 2019). As such, the view about sustainability may be subjective based on the locality to which it is applied. This could mean that some environment may view biogas as the best sustainable way of managing their waste, while in some environment this may not be so because of their own definition and knowledge about sustainability. As such, it is best to understand the knowledge of people about sustainability before suggesting an approach for adoption. Also, in pushing for the sustainability approach, scale and place matter, this is because what may be applicable in urban areas may not be applicable in rural areas while also noting that some aspect of sustainability may not be applicable on a small scale for rural dwellers in local settlement who are still struggling to meet their end needs. Therefore, for us to have a sustainable approach to waste management, it must be sustainable on a scale that is applicable to those in that setting and must also be applicable within the context of their environment.

Von Braun *et al*. (2021) further went on to note that the issue of sustainability derives from systems and is an interaction of many different components of the system and not just one part of the system. As such, we cannot derive sustainability from just an abstract of the environment, but we must consider the economic aspect, the social aspect, and also the human factor that all affect the sustainable approach to the environment. Other key concepts that were noted include the fact that limits exist in sustainability and although modification can be made to favour the environment, however, there are still limits that should be maintained (Farsari, 2021). Further points include the fact that sustainability is linked to other key concepts such as adaptive capacity, resilience, and vulnerability, which are some of the reasons why sustainability might be a difficult

approach in some communities or vicinities because they believe in the easy way and, as such, they are not willing to go the extra mile to protect the environment (Farsari, 2021). Finally, change is an important consideration in sustainability. This is due to the dynamic nature of our environment and activities that are changing exponentially with little or no consideration being taken to promote the sustainability of the environment (Wolf *et al*., 2019). As such, adaptive measures are sometimes required to deal with the issues of changes that were not considered.

2.1.1.1. Principles of Sustainability

The idea behind sustainability is that it must balance and focus on three main dimensions, social, economic, and environment. Without balance with these three concepts, the idea of sustainability may be out of balance (Trigo *et al.*, 2021). Understanding these three key principles is important to initialising a sustainable development transformation and staying on the right track along the way.

Economic sustainability focusses on the financial aspect and capital gain of the sustainable model (Colapinto *et al.*, 2020). As such, the economic sustainability of the management of vegetable and fruit waste will look at the context if the pocket of the people in those regions to see if, in fact, the waste management being proposed to them is economically viable in this sense that they are able to put their waste to proper uses and can as well gain something from it that can enhance their productivity. So, the economic sustainability looks at the economic advantage that the method provides and when the economic gain is within an acceptable limit of the community, we can then say that the project is economically sustainable (Trigo *et al.*, 2021).

The concern of social sustainability is to improve social equality and improve the standard of living of individuals in the society with no one better off or worse off from the use of technology (Talan *et al*., 2020). As such, bringing about the sustainable effort of producing is not to make some people within the community better off at the expense of the other, but to promote equality for all. The social sustainability aspect must also ensure that the waste management process must be acceptable to the people of the communities where it is introduced. The lack of social sustainability would affect the long-term sustainability of the use of waste as a means of biogas generation, as myths

could become about to arise that would cause people to withdraw from such opportunities (Abdelfattah, 2020).

The focus on environmental sustainability is principally on improving the environment as a result of the intervention (Talan *et al.*, 2020). The idea of environmental sustainability is to ensure that the needs of individuals are met without compromising those of future generations. As such, the focus of this is to ensure that the use of vegetable and fruit waste does not further challenge the environment but improves it for future generations.

In conclusion, it can be seen that for us to really say that a technology is sustainable, it must be acceptable by the people to whom it is being taken, it must have elements of affordability in terms of being economically viable, and it must contribute to the improvement of our environment.

2.1.2. Vegetable and Fruit Production

Vegetable and fruit production is essential for human well-being because it contains essential vitamins and minerals (Kulshresstha, 2018). According to a FAOSTAT report, fruit production worldwide increased by approximately 55% from 2000 and 2020, while that of vegetables increased by 65% within the same period, implying that effort is being made to increase the production of this essential food item (FAO, 2022). Fruits and vegetables are highly perishable crops and have a short shelf life, leading to food loss and waste (Nicastro and Carillo, 2021). In the world, food loss and waste are a serious challenge in the management of any food chain, and losses can occur at any point within the food supply chain (Nicastro and Carillo, 2021).

Specifically, the vegetable and fruit chain in Nigeria comprises a diversity of crops that are traded for their economic value (Aworh, 2021). It is quite interesting to note that vegetables are one of the crops commonly produced by farmers and are also easy to grow. Similarly, fruit production is common among many rural settlers and even in urban areas where people plant tress to produce fruits in their backyards (Aworh, 2021). The main fruits and vegetables produced in Nigeria are mango, orange, pineapple, guava, lemon plantain, tomato, pepper, onion, okra, jutes mallow, Amaranthus, cucumber, cabbage, carrot, melon, cherry, pawpaw, among many others that exist in abundance. The production estimate for these fruits and vegetables are not definitive of the actual

production as these vegetables and fruits are sometimes consumed by households before getting to the market while others are lost because of the little economic gain derived from the production of these fruits and vegetables (Afolabi *et al*., 2021). As such, only products that eventually get to the market are eventually taken into account as the estimated production figure. For instance, the production estimate for onions was taken to be 3.8 million tonnes, tomatoes were estimated to be 6 million tonnes, and this estimate only accounts for products that eventually got to the market (Ibeawuchi *et al.*, 2015). This implies that the potential for the production of vegetables and fruits in Nigeria is quite high.

The potential for fruits and vegetable production in Nigeria is quite high. However, there is little industrial support to encourage the production aspect of the sector (Aworh, 2021). Consequently, limiting the ability of the sector to produce more. It is also very important to note that most of those involved in vegetable and fruit production in Nigeria are small-holder famers with only a few running commercial farms and others using greenhouse technologies (Aworh, 2021). The idea of ensuring that the supply chain for vegetable and fruit is sustained as seen most industries and formal market opt for the option of patronising commercial producers. Therefore, rural producers are left to manage with very competitive open and informal markets (Ibeawuchi *et al*., 2015). This challenge has led to quite a lot of waste being generated from the supply chain of vegetable and fruit products. Furthermore, due to the high level of fruit and vegetable production and the challenge of transporting this product from the farm to the market, a lot of it is wasted at the farm gate causing environmental nuisance in terms of pollution and other environmental damage (Akintola *et al*., 2019). For example, during high intensity of rain, farmers in rural areas sometimes find it challenging to access their farmers and during these periods fruits and vegetables that have not been harvested begin to spoil (Aworh, 2021). This phenomenon is quite disturbing, as the farmer loses all their product, causing a heavy damage to the soil. This affects the market value of the product and leads to heavy losses for the farmers.

It should be noted that the challenge for fruits and vegetable management is their short shelf life and little is being done to help farmers in this regard (Ibeawuchi *et al*., 2015). Furthermore, it is quite a sight aftermarket day in major markets in Nigeria to see the high level of waste generated from vegetables and fruits such as rotten tomatoes and

peppers to spoilt fruits. All this constitutes an environmental issue that the government has not been fully able to manage and therefore has even affected the production side (Akintola *et al.*, 2019). However, the massive production of fruits and vegetables is always encouraged due to its nutritional benefit, the ability to stimulate the rural economy, and the cheap way to guarantee food security. However, production could be restricted if farmers and marketers do not have enough to sell and also do not have alternative uses to use the amount of product generated from the product supply chain (Akintola *et al.*, 2019).

2.2. Waste management practices in Nigeria

Nigeria generates approximately 32 million tonnes of waste per year, and this includes all stages of the agricultural value chain and household waste (Aziz *et al.*, 2021). Waste in Nigeria is a combination of solid waste and liquid waste. Waste is generated from every human activity, from agricultural to industry and even in homes (Aziz *et al.*, 2021). Waste cannot be completely eliminated but can be properly managed to get the best out of it. It is not a myth that waste management is one of the major challenges facing Nigeria. This is because waste management practise is not yet at the level of best practises required worldwide (Ike *et al.*, 2018). Furthermore, compared to urban areas in Nigeria, waste management in rural areas of Nigeria is non-existent (Ike *et al*., 2018).

According to Biodun *et al.* (2021), waste management is generally at the lowest level in Nigeria and the pattern does not appear to be improving in any part of the country. The few states in the country that have an organised waste management system still struggle to get people and households to subscribe to the waste management system. In some other cases the system for managing the waste does not conform to best practices and as such causing environmental nuisance.

One of the main characteristics of the waste management system is that it is not organised and people are used to dumping their waste at illegal sites where nature acts on it to decompose. Studies (Biodun *et al.*, 2021; Aziz *et al.*, 2021) have shown that these dump sites, which are found in different places such as bushes, abandoned buildings, waterways, rivers, among so many other areas, have negative consequences on the environment. An examination of such an environment reveals an environment that smells of stench from decaying waste. However, with the challenges at hand, there seems to be no hope on site for a better and effective waste management system in Nigeria.

According to Olusunmade (2019), who studied market waste revealed that the environmental condition in most markets is poor creating a situation that is detrimental to the health of the people using such markets. It should be noted that in some states of Nigeria, initiatives such as the introduction of sanitation exercise have not improved the situation in any way. Even the use of sanitation officers has not even helped the matter, as the government seems to be short of ideas on the best ways to handle waste. Ogundele *et al.* (2018) revealed that waste is continuously being generated across different parts of the country with little or no arrangement for its proper collection, transportation, or disposal.

A survey of some households range from traditional mud huts and thatched-roof bungalows to modern brick and concrete structures single-family homes, with families typically consisting of parents and their children reveals that the per capita solid waste generated is estimated to be approximately 0.129 kg, with around 75.4% of the total waste generated being organic waste that is subject to decomposition (Ike *et al.*, 2018). As such, it can be subject to reuse and recycling for the generation of biogas. Odejobi *et al.* (2022) noted that most of farm and market waste is decomposable and can be recycled through composting or anaerobic digestion. Another study by Ugwu *et al*. (2021) revealed that most of the waste generated across the country comes from food waste that is not disposed of using the best means possible, as it constitutes an environmental hazard during decomposition. Environmental hazard include pollution through leaching and flooding.

Some of the challenges of the current waste management system across the country include the fact that waste is not usually separated, and thus the issue of recycling is not even considered during waste management (Odejobi *et al.*, 2022). Most of the waste generated across the country is subject to open burning or used as landfills as a way of waste reduction, and this in itself is not safe for the environment as dangerous gases are released during the process that are harmful to human health and even the environment (Olusunmade, 2019). On the other hand, waste that is dumped on open ground is not also safe for the environment and is common in areas where there is no organised waste collection system (Olusunmade, 2019). One of the main challenges facing the country at present is the lack of an effective waste management system.

The challenges of solid waste management in Nigeria are that there are inadequate environmental policies and legislation and this has affected the way waste is handled at

different locations. According to Odejobi *et al.* (2022), the legislation backing waste management is weak, and it is not even enforced to the fullest where it exists. The weak institutional framework is argued to be a challenge to any policy that would improve waste management system practises, such as the use of it for biogas (Aziz *et al.*, 2021). Furthermore, the lack of awareness and education of the public about the waste management system and the dangers of an ineffective waste management system is a great challenge. The awareness of waste management in Nigeria is low and, as such, people are free to do what they want with their waste (Akintola *et al*., 2019). Therefore, to promote a sustainable and effective waste management system, a concerted effort must be made to raise the level of awareness of the local population about the different productive uses for which waste can be put.

Other challenges facing waste management in Nigeria include the lack of funding, which has hampered other means of improving the waste management system (Afolabi *et al.*, 2021). This may be because people see waste in an arbitrary term and do not seem to get another use in which it can be put. As such, the funding affects the provision of technologies or facilities that aid the waste management system.

2.2.1. Vegetable and Fruit Waste

Vegetable and fruit waste can be classified as food waste. It should be noted that food waste constitutes the highest form of household waste in Nigeria, and this waste can easily be put to other uses due to its decomposing nature. Waste occurs at every point within the supply chain for vegetable and fruits. According to FAO (2022), the highest level of vegetable and fruit waste in sub-Saharan Africa occurs at the on-farm level while the wholesale and retail level has the highest level of losses. Losses also occur during storage, transportation, processing and packaging. However, this cannot be compared to what occurs on the farm level due to the level of challenges farmers face in moving their products across the supply chain. A study carried out by Lawal et al. (2019) valued post-harvest losses in Nigeria for different commodities and observed that it is 5% to 20% for grains, 20% for fish while tubers, fruits, and vegetables have the highest level of loss between 50% and 60%. This high level of losses for fruits and vegetables is as a result of the lack of modern facilities for the management of this food product, which has a short shelf life immediately after harvest from the field.

According to Akande and Olorunisola (2018), the food chain that contributes the most to food loss is those associated with vegetables and fruit products such as tomatoes, green Amaranth, and Lagos spinach, among many others. This is due to the lack of the technology necessary to manage the chain for these products, limiting their development. However, despite the losses reported for vegetable and fruit waste, much can still be done to ensure that farmers still benefit from this waste without having to resort to an environmentally degrading way of discharge of this waste.

2.3. Climate Change Effects in Nigeria

Climate change is the change in the climatic state of an environment caused by changes in temperature, rainfall, and other climatic conditions that have persisted for a long time (Raimi *et al*., 2021). The effect of climate change in Nigeria is multifaceted, as it covers a lot of things, such as increased temperature, high water levels, among other sectors (Abraham and Fonta, 2018). The agricultural sector is one of the main contributors of GDP to the Nigerian economy and employs a large number of rural people (Ikhuoso *et al.*, 2020). Agriculture is so important for the development of a nation's economy that climate change has a limiting effect on it. Although there are many causes of climate change, some practises in agriculture are one of the main causes of climate change (Ikhuoso *et al.*, 2020). If care is not taken, the quest to solve food insecurity might create more environmental challenges through actions such as poor waste management occasioned by food losses that occur along the food supply chain (Raimi *et al*., 2021).

Agriculture has played a dominant role in ensuring that the populace is fed and changes in the climate can have a negative effect on the social, economic and other facet of human life (Raimi *et al*., 2021). Efforts to curb the effect of climate change by reducing the effects of fossil fuels such as oil, gas and carbon have not yielded much effort (Idris-Idah and Abdulkadir, 2022). This is because of the impact this fuel plays in the daily life of individuals from movement from one place to another, to the generation of electricity to other economic impact. However, the dependence on fossil fuels has contributed to the challenges of the environment that we face generally.

2.3.1. Agriculture and its impact on Climate change

Agriculture in Nigeria employs about 70% of the population due to the diversity in the sector. Nigeria's agriculture is made up of small-scale and resource-poor farmers who rely on rain-fed agriculture to produce their crops (Raimi *et al.*, 2021). Activities engaged in by the farmers include crop production, livestock production, fishery and post-harvest activities such as transportation, processing among other activities. In crop production, there are many uncertainties as a result of the impact of climate change. Many farmers are faced with the challenge of irregular rainfall and unpredictable sunshine periods that cause crop production failure, increased pests and diseases, and other extremities that affect crop production (Durodola, 2019). For livestock production, the availability of pasture for grazing has been influenced by climate change, putting pressure on available land and, thus, leading to conflict (Liverpool-Tasie *et al*., 2019). The level of pest and disease is also a challenge for livestock production because of the changes in humidity, rainfall pattern, and temperature, all factors that are factors for animal diseases. Seasonal variations and the likes also affect the production of animals as livestock are easily susceptible to shocks in the environments (Ikhuoso *et al*., 2020). Also, post-harvest activities such as storage, transportation, processing, and the like are also influenced by climate change, as variations in weather conditions affect the quality and shelf life of food (Agriculture and Fonta, 2018). However, agriculture contributes a significant part to climate changes as a result of the way waste is handled in agriculture. It should be noted that agriculture is one of the main contributors of methane (a greenhouse gas) to the atmosphere (Odejobi *et al.*, 2022). Likewise, other agricultural activities, such as the use of fertilisers, mechanisation, post-harvest losses, and waste, among others, contribute to the changes that are being experienced.

Therefore, it is important to find a sustainable solution that can help mitigate the impact of changes caused by agriculture. A study by Ganesh *et al.* (2022) shows that vegetables and fruits are one of the most consumed food items by households and are also one of the food items with the highest level of waste due to their short shelf life. As can be seen, a lot of waste is generated from losses from vegetable and fruits but is not put to use but rather left in open fields to rot and decay, from where their inherent gases are released, which pollute the environment and contribute to greenhouse gases that affect

the environment. Therefore, the use of vegetable and fruit waste can go a long way to slowing the effects of climate change on our environment at large.

2.4. Global warming potential of vegetable and fruit waste and its implications on Livelihood

Global warming is the increase in the average temperature of the near-surface air and oceans of the Earth since the mid twentieth century and its projected continuation (Gillett *et al.*, 2021). Global warming is believed to be the main cause of human activities (Rockstrom *et al.*, 2021). The average global temperature of the Earth has continued to increase with devastating effects (Sun *et al.*, 2019). Global warming is directly related to climate change. Global warming is directly and highly related to human activities, while other natural factors also contribute in small quantities (Rockstrom *et al.*, 2021). Global warming occurs as the ozone layer in the atmosphere that is meant to act as a buffer is being depleted. The ozone layer serves as a thin layer protecting the extreme ultraviolet rays of the sun from reaching the earth (Dixon *et al.*, 2021). However, as human activities increase, the ozone layer is being depleted and this is getting faster by the day, making us susceptible to the ultraviolet rays of the Sun. The most dangerous one is the greenhouse effect which increases global warming. About 70 % of the rays released by the Sun pass through the atmosphere (Jaeger, 2021). These rays are absorbed by the land, seas, oceans, and other earthly bodies with the heat radiated back into space (Jaeger, 2021). The presence of greenhouse gases prevents the radiated rays from leaving into space, thereby trapping them in the earth surface and causing further warming of the earth surface (Jaeger, 2021).

These greenhouse gases that contribute to global warming are carbon dioxide, methane and water vapour, nitrous oxide and, among others (Saklani and Khurana, 2019). These greenhouse gases are produced from different sources, part of which is the disposal of waste of which methane is the most significant gas produced during this process (Khare *et al.*, 2020). This methane is released when organic matter decomposes, and these gases are released. Also, when these food wastes are burnt, there is also release of harmful gases into the atmosphere (Khare *et al.*, 2020). Therefore, it is important that the management of vegetable and fruit waste is important in other ways to stop the methane and CO_2 flow

that is released during the decomposition and burning of the waste from which they are disposed.

About one-third of all food produced in the world goes to waste (Baysal and Ulku, 2022). That's equal to about 1.3 billion tons of fruits, vegetables, meat, dairy, seafood, and grains that never leave the farm, get lost or spoil during distribution, or are thrown away in hotels, grocery stores, restaurants, schools or home kitchens. It could be enough calories to feed every undernourished person on the planet (Baysal and Ulku, 2022). The irony about this is that these foods are dumped and left to decay in landfills where they cause environmental havoc (Tran *et al.,* 2020). It should be noted that the global warming potential of fruits and vegetables increases as they move across the food value chain, and this alone should be a concern for us as to even adding to the value by allowing this food to even contribute more to the global warming potential by allowing them to decay in landfills (Tran *et al.,* 2020). This is because human-caused greenhouse gas emissions could be reduced if we stop wasting food (Levin *et al.,* 2019). In the US alone, the production of lost or wasted food generates the equivalent of 32.6 million cars worth of greenhouse gas emissions (Kim *et al.*, 2020). This value is quite outrageous, and our environment may be at greater risk if we do not act fast in using our waste to reduce its negative effect on the environment.

2.5. Major sources of Household Energy in Ipokia area of Ogun state

Ipokia area of Ogun state is an agrarian settlement in Ogun state that is made up of the rural and semi urban settlements. There are different energy sources for households in the area. Among the major sources in the area are the fossil fuels which is made up of diesel, petrol, kerosine and gas (Adamu *et al*., 2020). The use of fossil fuel among households in this vicinity is quite common because it is easier to access and many of the households have means through which they can use. For example, households use gasoline and diesel to power their generators for household use, while gas and kerosene are used in cooking. These energy sources are one of the most commonly used within the vicinity due to the fact that it is one of the major products from Nigeria and because petrol in itself is highly subsidised by the government. However, this energy source cannot be said to be safe for the environment as it is not a clean energy source and contributes to the release of greenhouse gases into the atmosphere (Adewuyi, 2020).

The use of firewood and charcoal is another major source of energy common among households in the Ipokia area of Ogun State, Nigeria. The reason for the popularity of this energy sources is because of its easy accessibility to the people in the vicinity. This is because these people live in rural and semi-urban areas where they have access to forest resources and, as such, use these resources for the production of energy (Adamu *et al.*, 2020). However, the challenge is that these forest resources that are used for the production of firewood and charcoal are being depleted so fast and are not being replaced thereby destroying the environment. Furthermore, energy sources release greenhouse gases into the atmosphere while being used for cooking, which cannot be classified as a clean energy source for the environment (Ajibola *et al.*, 2020).

However, some households in the vicinity make use of the solar energy sources, which is quite on the small scale to power lights, charge phones and other small appliances (Adamu *et al.*, 2020). However, the cost of acquiring this energy source has made most of the households rely on the government power supply scheme which is erratic and in some locations within the vicinity not available (Agbo *et al.*, 2021). However, the use of biomass through the utilisation of vegetable and fruit waste seems to be new among the people of the vicinity as there is little or no information on the use of the technology among people in that vicinity. As such this could be a gamechanger for energy generation as it could herald an efficient and environmentally friendly means of energy generation which is safer and cheaper.

2.6. Potential of Biogas as an Energy source in Nigeria

The potentials of Biogas as an energy source are unlimited. This is because it is safer for the environment and can help reduce the heaps of waste that cause environmental pollution and contribute to the level of greenhouse gases in the atmosphere (Ajieh *et al.*, 2021). In addition to that, the use of biogas as an energy source creates an efficient energy source that is clean and safe for the environment through the use of vegetable and fruit waste (Ganesh, 2022). The use of biogas also has the potential to improve the livelihood of people living in communities where it is used, especially where it is used in the generation of power that is used to power electrical appliances (Kabeyi and Olanrewaju, 2022). As it is often said that 'electricity brings life', the use of biogas can serve as a cheap energy source to revive communities that have hitherto been off the grid by using waste

from their farms to give them what they need to create a viable economic unit that can earn them more income (Kabeyi and Olarenwaju, 2022).

There is currently insufficient commercial production of biogas in Nigeria, which prevents it from being used to generate energy or for other commercial purposes on a large scale (Mbachu *et al.*, 2022). This is because only lip services have been paid to its use by those in power. However, a state such as Lagos in Nigeria has attempted to generate power through the use of biogas generated from landfills (Ayodele *et al.*, 2019). However, this has not seen the light of the day and remains a plan in the pipeline. The reality of biogas use is that it allows an easy disposal of a huge amount of organic waste in an environmentally friendly manner while generating energy from it. Come to think of the amount of open waste dump we have across the country, and how much these landfills keep expanding because of the lack of a well-structured waste management system, which can be easily solved if we can just dispose of such waste through biogas while also giving something back to the society through the generation of energy that households can use.

Vegetable and fruit waste used as biogas can also be used for the production of biofertilizers, which can help increase crop production (O'Connor *et al.*, 2021). This fertiliser unlike the inorganic one is much safer and more environmentally friendly, and this even gives a further alternative to the use of waste products. Furthermore, the use of vegetable and fruit waste for biogas production would help reduce the pollution caused by the unethical ways in which these wastes are disposed of in our immediate environment. This would be done by totally eliminating or reducing the total waste of this product and making something that is economically beneficial from it.

Other potentials of the use of biogas are that it stimulates economic and social development through the creation of new jobs as a result of power generated through the use of biogas (Imoisi and Okongwu, 2020). It should be noted that electricity is one of the challenges of businesses in Nigeria, and businesses have crumbled because they lack the capacity to survive in a harsh business environment caused by epileptic power supply. However, with the use of biogas, the challenges of power generation in rural areas can be solved and rural activities such as processing, production and other business activities can be sustained efficiently.

2.7. Biogas production process

Biogas is a combination of gas consisting of methane (CH4), carbon dioxide (CO_2), hydrogen sulphide and others that is produced from waste materials derived from agriculture, households, and other sources of organic waste (Kasulla *et al.*, 2021). Biogas is classified as a renewable and sustainable energy source which is produced by the anaerobic digestion by anaerobic organisms using a biodigester (Abraham *et al.*, 2020). The gases released from the biodigester are oxidised with oxygen. This energy release allows biogas to be used as a fuel; it can be used in fuel cells and for any heating purpose, such as cooking (Abraham *et al.*, 2020). It can also be used in a gas engine to convert the energy in the gas into electricity and heat (Andriani *et al.*, 2020).

Factors such as process design, type of substrate, production process, retention period, conditions within the biodigester such as temperature and pH, and presence of inhibitors determine the composition of biogas (Andriani *et al*., 2020). The gas produced from the biodigester which is a greenhouse gas is dangerous for the environment (Kasulla *et al.*, 2021). However, the combustion process destroys methane and makes it less dangerous to the environment (Kasulla *et al.*, 2021). Additionally, the carbon produced during combustion is also safer because it is derived from organic materials.

2.7.1. Economics of Biogas generation from fruit and vegetable waste

The production of biogas has a profound impact on the livelihoods of the people of Ipokia and general Ogun state at large. Demand and supply seem to be the two main economic forces that determine the flow of goods and services. These demand and supply are usually stimulated by factors such as technology availability and price, among others (Okonkwo *et al.*, 2018). The economics of biogas shows that as a result of the low demand for this technology, generally only few marketers are interested in the sales of the technology used for the production of biogas as such, and are not readily accessible to households. Households that use technology usually have the advantage of having the financial capacity to afford it, since the minimum price for the technology is about 500,000 which is far above the financial capacity of farming households within rural and semi-urban areas of Nigeria (Ajieh *et al*., 2021). The low level of demand has influence on the availability of technology and the ability of producers and marketers to invest in the market since they are not even sure of patronage (Koval *et al.*, 2019). Therefore, to

increase the demand for biogas, there must be an effort to ensure that the market is stimulated by ensuring that the technology for the generation of biogas is readily available.

Some of the economic issue for biogas include the fact that the initial cost of installing a biodigester is considered to be quite high by many people and this can have a negative impact on the level of adoption (Ajieh *et al.*, 2021). However, studies (Ajieh *et al.*, 2021; Koval *et al.*, 2019) have shown that in the long run the benefits outweigh the cost and the payback value for the use of the technology is high compared to the other technologies available.

2.7.2. Biogas Utilisation

Biogas can be used for different purposes, such as cooking, heating, lighting, powering machines, and household appliances (Okonkwo *et al.*, 2018). Biogas is usually classified as a high-grade fuel and the most common use of gas among households in Ogun state is for cooking. However, the utilisation of biogas among households is still quite low and might even be non-existent. In developed climate, biogas plays an important role in electricity generation, cooking, heating, and lightening. Cars, trains and other moving vehicles can even be powered by biogas, which implies that biogas can be used for a variety of purposes while also serving the purpose of conserving or preserving the environment (Okonkwo *et al.*, 2018). Challenges such as respiratory diseases, eye irritation, smoke inhalation, high cost of supply and accessibility associated with the use of other fuel sources, especially wood and charcoal (Okoronkwo *et al.*, 2018) which are common within the Ipokia locality, are reduced with the use of biogas. The challenges created using fossil fuels that cause climate change can be tackled with the use of biogas (Okoro *et al.*, 2020). This is because compared with other fuels, biogas is much safer and less risky to use. It also helps to combat the issue of unreliable electricity from the national grid, and the energy source is affordable, clean, and a sustainable means of generating energy (Okoro *et al.*, 2020).

2.8. Government's Policy on Renewable Energy and Biogas Production

Nigeria is one of the major suppliers of crude oil in the world and also has one of the largest deposits of natural gas. It should be noted that the largest chunk of the country's

income comes from the production of this fossil fuel and as such any effort to reduce the use of fossil fuels has an impact on the nation's economy (Ahonle and Adeoye, 2019). Although there has been discussion about the country investing in alternative sources of energy such as ethanol, solar amongst others (Imoisi and Okongwu, 2020). However, these projects have not seen the light of the day. This is because of the fear in governments quarters of the impact that this might have on the national income of the country. Let us take, for example, more than 80% of government income, about 95% of foreign exchange and export earnings come from oil (Ahonle and Adeoye, 2019). Therefore, any attempt to reduce this dependence has faced deep resistance from the people in government. Furthermore, the issue of corruption has also been a major concern in enabling renewable energy, as policies have been enacted to govern the use of renewable energy sources for energy generation (Kemausuor *et al*., 2018). However, because of the benefit accruing from the use of fossil fuel in terms of monetary value, little is done to promote renewable energy sources which are good for the environment. For example, the Nigerian government subsidises the use of fossil fuels such as petrol to encourage it use by citizens, while over the years the country has neglected safer fuel mechanisms such as biogas, which can help renewing the environment.

It is a certain fact that the demand for energy will continue to increase and as such will put more strain on the fossil energy sources, which are unrenewable. Nigeria being a signatory to the United Nations Framework Convention on Climate Change (UNFCC) has a commitment to reduce the greenhouse gases being emitted from within its borders (Okokpujie *et al.*, 2022). However, this is not being seen in reality as the government has focused more on solving the country's energy crises through the use of fossil fuels with only a few coming from renewable energy sources. The development of a policy plan known as National Renewable Energy and Energy Efficiency Policy (NREEEP) by the government seems to be the solution on paper (Okokpujie *et al.*, 2022). However, the plans outlined in the policy document are yet to materialise physically and still remain a vision to be accomplished. Some of the outlined plans by NREEEP include that by 2015 which is the short terms plan biomass, wind and solar will be contributing 5, 15 and 117MWof electricity by 2015, it would increase to 57, 632, 1,343 MW by 2020 while by 2030 it would have reached a capacity of 292, 3211, 6832 MW respectively (Patinvoh and Taherzadeh, 2019). However, this is far from reality, as this plan just seems not to be achievable due to the lack of commitment by the government to its implementation.

Today in Nigeria, the issue of biogas generated from biomass is not yet understood, as little or nothing is being done to ensure its use on a commercial level. With the level of waste generated throughout the country, it is disheartening that no single plant has been designed to ensure that this waste is used for biomass generation (Kemausuor *et al.*, 2018). Based on findings, 91.4 million tons per year of agricultural waste which contains fruit and vegetables are generated in Nigeria, which is the highest (Kemausuor *et al.*, 2018). This implies that harnessing the potentials in generating energy from this is worth a trial by the government.

Furthermore, the government has not made the use of renewable energy sources a priority in national development and as such there is really no clear plan or nationally acceptable roadmap for the development of renewable energy such as biogas in the country (Patinvoh and Taherzadeh, 2019). The countries politics and public discussions are barely addressing the mentioned problems. Furthermore, climate change, its effects, and solution strategies are not really in public discourse, and currently the country's development plan does not recognise the economic threat caused by climate change or the threat of fossil fuel use for it to enact policies that promote clean, affordable, and renewable energy sources (Oguntoke *et al.*, 2019).

2.9. Challenges of Biogas as an Energy source in Nigeria

The challenges in the use of biogas for energy generation in Nigeria are multifaceted as it can be viewed from different angles.

First, the lack of strong government support in the areas of policy and enabling environment has slowed the development of biogas. It should be noted that the development of biogas in the country is pioneered by the private sector and few individuals have developed a passion for it. On the other hand, government has also failed to provide incentives to encourage the use of biogas, as is the case for petrol which is not even as good for the environment as biogas (Mbachu *et al.*, 2022). The failure of government to ensure the business environment is enabled has led people to pay less attention to the development of biogas. Furthermore, there is a lack of will by the government to follow through on the development of a roadmap for the development of affordable renewable energy sources (Oguntoke *et al.*, 2019). At present, there is a challenge of high energy cost, with most households opting for cheaper sources such as

wood and charcoal that are not environmentally friendly due toof high cost of the fossil fuel sources.

In addition, personal characteristics of individuals and households such as income and perception of the use of technology, among others, could be a challenge in the adoption of biogas. For example, the adoption of biogas for use by any household would be first evaluated on the basis of affordability because households would want a technology that would be affordable and would not further worsen their economic situation. Furthermore, ease of use of technology plays an important role in the adoption of technology (Oguntoke *et al.*, 2019). This is because households would want a technology that would ease their stress and not subject them to more stress. Other personal attributes that can influence the use of biogas include age, education level, and affordability of the technology (Mbachu *et al*., 2022).

The challenges that also influence biogas use can also be classified into social factors, economic factors, technological factors, political factors, and environmental factors. For the social factors, one of the major things that drive use of anything by people in an area are social factors which include the community characteristics, household characteristics and even personal characteristics such as age, education and so on. In general, biogas is proposed for the environmental use of people in Ipokia. However, the challenge in this regard is that people sometimes are sceptical of something new when it is generally accepted by all and they might need to first of all go through a stage of conviction in other to appease their social value (Mbachu *et al.*, 2022). As such, biogas use should focus on how it can improve the social value of people in Ipokia.

However, economic factors could also be a challenge for households that are interested in the use of biogas (Patinvoh and Taherzadeh, 2019). This is because most of the households living in the locality are majorly small-holder farmers who are low-income earners and may not have the capacity to adopt a technology that is far above their economic capacity. Additionally, these households may be sceptical to invest in technology that does not improve their economic well-being. Furthermore, the availability of the technology is also a challenge to the adoption of biogas. The technology is not readily available and could even be hard to operate without the pre-requisite training.

The lack of any sustainability framework is a challenge that affects the use of biogas for energy generation (Patinvoh and Taherzadeh, 2019). For example, some countries have an agency that supports the deployment of biogas in the country, while in Nigeria, such a kind of institutional framework is lacking that would improve the use of biogas. Also, the lack of institutional framework has hampered the deployment of resources in the areas of research, regulation, sensitisation, and the deployment of the technology for the use of the people. The lack of an institutional framework also influences the availability of training platforms to improve the adoption of technology. Although the technology is good, only few people have the technical knowhow to have a system that produces biogas from waste, and so it could be a challenge to encourage households to adopt it, if there is no strong institutional framework to support it (Emetere *et al.*, 2021).

Furthermore, there are no financial incentives in terms of loans or grants that support these resource-poor households in using their waste for waste generation (Emetere *et al.*, 2021). Much is being done to develop solar power in Nigeria through financial incentives. However, biogas production appears not to be on the radar of any financial institution or funding agencies.

3. Aims of the Thesis

The aim of this study is to evaluate how vegetable and fruit waste can be used as a source of biogas for energy generation using the Ipokia area of the Ogun state as a case study. The essence of this is to understand the perspective of those in the community on the use of biogas and their willingness to use it in other ways to effectively put their waste to use.

3.1. Objectives of the study

To satisfy the aim of the study, the outlined objectives were addressed in the study.

1. To evaluate the waste disposal and management methods available in the study area.
2. To understand the perception of the resident of the use, use, and awareness of biogas derived from vegetable and fruit waste.
3. To check the level of adoption of biogas in the management of vegetable and fruit waste generated.
4. Estimate the level of vegetable and fruit waste generated in the study area and the implications for biogas production.
5. Assess the willingness to use waste generated from vegetable and fruit sources to generate biogas.
6. To identify factors that influence the use of vegetable and fruit waste as a source of biogas for energy generation.
7. Identify possible barriers to the use of vegetable and fruit waste for the generation of biogas.

4. Methods

The methodology that was be adopted in this study is the quantitative approach. This approach is justifiable based on the use of measurable characteristics to evaluate the subject matter of the study, which is the use of vegetable and fruit waste for biogas. This method is also justifiable because respondents were sampled through a cross sectional survey that required a somewhat large dataset.

4.1. Research Philosophy

Research philosophy are beliefs or guiding principles that influence the conceptualisation of a research work (Alharahsheh and Pius, 2020). The three main philosophy guiding research are Positivism, realism, and interpretivism (Saunders *et al.*, 2019). The philosophy guiding this study is the positivist epistemological approach, which requires that a researcher establishes the relationship between some set of variables in the study. The philosophy also supports the use of statistical tools for drawing inferences, which is in consonance with what has been designed to be achieved within the framework of this research work. As such, the approach which was adopted emphasises the scientific interpretation of data for logical conclusion, which are the limitations of the other philosophical approach (Bryman and Bell, 2011; Hair *et al*., 2014).

4.2. Study Area

The study was carried out in the Ipokia area of Ogun state. This area is known as an agricultural community and is known for the production and marketing of different types of agricultural products, including vegetables, fruits, and other agricultural commodities. The study area is a boundary town between Nigeria and the Benin Republic and has more rural settlements with few semi-urban settlements. Ipokia covers an area of approximately 180,535 sq. km. There are 14 communities and 12 wards in the study area, and the main characteristics of all these communities are that they are all agrarian in nature, with fruits, vegetables and some other crops being their main crops.

4.3. Population for the study

The study population is made up of vegetable producers and marketers in the Ipokia area of Ogun state, Nigeria.

4.4. Method of Data Collection

Primary data was collected for the research work using questionnaires administered to vegetable and fruit producers and marketers in the study area. The data elicited will include Socio-economic characteristics, level of waste generated from vegetable and fruit production and marketing, perception about biogas, and barriers facing the use of vegetable and fruit waste for biogas production in the study area. This was complemented with information from secondary sources such as journals, bulletins, and other materials related to the work.

4.5. Sampling Procedure

A multi-stage sampling procedure was used for this study. The sampling frame will include all farmers and marketers of fruits and vegetables in the Ipokia local government area of Ogun state. However, due to the paucity of data on the exact population of farmers and marketers in the area, it was difficult to use a random sampling procedure. In the other case, the snowball sampling procedure was used to effectively reach the intended population for the study.

The sampling procedure involved selecting 50% of the ward in the vicinity to make up six wards. This process was carried out at random. From each of the wards, 30 vegetable farmers and marketers were selected using a snowball sampling procedure.

4.6. Sample size Determination

The sample size could not be determined using a scientific formula due to the lack of information on the vegetable producers and marketers in the population within the vicinity of the study area. However, based on the estimation, 150 vegetable producers and marketers were sampled for the study in the study area.

4.7. Data analysis

The data for this study was analysed using descriptive statistics and inferential statistics.

Descriptive Statistics: Descriptive statistics such as frequency tables, means, percentages, and standard deviation were used to describe socioeconomic characteristics such as age, sex, household size, and other demographic characteristics of vegetable and fruit producers and marketers.

Likert Scale: The perception and barriers to vegetable and fruit farmers were evaluated using a five-point Likert scale. The five-point scale will be made of Strongly agree = 5, agree = 4, Indifferent = 3, Disagree = 2, Strongly disagree = 1. The Likert scale responses were summarised using percentages, frequencies, and means.

Inferential Statistics: Chi-square analysis was used to estimate the factors that influence the adoption of vegetable and fruit waste as a source of biogas for energy production. Logit regression analysis was used to estimate the factors that influence the willingness of the respondents to use their vegetable and fruit waste for the purpose of biogas production in the study area.

5. Results and Discussion

This section will discuss the result of the field survey findings. The results discussed include the socio-economic characteristics of the respondents, perception of the respondents about using vegetable and fruit waste for biogas generation, the level of adoption of biogas, barriers facing the use of vegetable and fruit waste for biogas among other results will be discussed.

5.1. Socio-economic characteristics of the respondents

The results in Table 1 showed that majority (66.6%) of the respondents were between the ages of 19 and 22 years while 26.9% were between the ages of 31 and 50 years. The mean age of the respondents was found to be about 48 years implying that the respondents are within the active working age range. This is consistent with the findings of (Ayodele *et al.*, 2021) who noted that vegetable and fruit production and marketing is energy intensive because of the practises involved and therefore require people in the active age range to fully engage it. It was also observed that the age range is shifting from the youth age range to an ageing farming population due to the lack of interest of young people in farming due to lack of incentives. The result in Table 1, further shows that the majority (68%) of the respondents were male and this implies that males are more involved in vegetable and fruit production. This is in line with the findings of Olanrewaju *et al.* (2021), who noted that vegetable and fruit production is mainly anchored by males while the marketing aspect is usually seen as a female activity.

The religious affiliation of the respondents revealed that majority (74.7%) were Christians while the remaining were either Muslims or Traditional religious worshippers. The modal group for the educational level of the respondents showed that 49.3% had secondary education, and the result further showed that most of the respondents had at least primary education, while just a few (10.0%) had no form of education. This could have a implication on the ability of the respondents to adopt alternative sources of energy, as their knowledge level would improve their ability to evaluate between different energy sources (Elijah *et al.*, 2017).

The mean household size of the respondents was found to be 5 members, with most households having between 3 and 5 members. This finding is consistent with that of

Oyewola and Sennuga (2020), who reported similar household size in a study carried out in Ogun state. The size of the household could have an implication on the energy needs of the household, as this could influence the level of energy consumed by the household for their different activities and their ability to make decisions towards adopting an alternative energy source.

The mean year of experience in the marketing and production of vegetable and fruit is 13.49 years, with most of the respondents having less than 15 years in the marketing and production of vegetable and fruit waste. This has an impact on the knowledge of the respondents about different waste management practises among other important information relevant to vegetable and fruit waste management (Olukanni *et al.*, 2020). The average monthly total income of the respondents was found to be ₦52,843.33 naira while the average monthly total income from the marketing and production of vegetable and fruit waste is ₦21, 137.33.

Table 1: Socio-economic Characteristics of the Respondents

Variable	Freq	%	Mean
Age			
≤ 31	18	12.0	48.25
31 – 40	31	20.7	
41 – 50	33	22.0	
51 – 60	45	30.0	
61 – 70	16	10.7	
>70	7	4.6	
Total	**150**	**100.0**	
Sex			
Males	102	68.0	
Female	48	32.0	
Total	150	100.0	
Religion			
Christianity	112	74.7	
Islam	20	13.3	
Traditional	18	12.0	
Total	**150**	**100.0**	
Educational Level			
No Education	15	10.0	
Primary Education	25	16.7	
Secondary Education	74	49.3	
Tertiary Education	36	24.0	
Total	**150**	**100.0**	
Household Size			
< 3	2	1.3	5
3 – 5	104	69.3	

6 – 8	43	28.7	
> 8	1	0.7	
Total	**150**	**100.0**	
Experience in Producing and Marketing Vegetables and Fruits (years)			
< 6	44	29.3	13.49
6 – 10	29	19.3	
11 – 15	29	19.3	
16 – 20	14	9.3	
21 – 25	21	14.0	
> 25	13	8.7	
Total	**150**	**100.0**	
Monthly Income (₦)			
≤ 20,000	16	10.7	52,843.33
20,001 – 40,000	59	39.3	
40,001 – 60,000	38	25.3	
60,001 – 80,000	15	10.0	
80,001 – 100,000	7	4.7	
> 100,000	15	10.0	
Total	**150**	**100.0**	
Monthly Income from Vegetable and Fruit Marketing (₦)			
≤ 10,000	36	24.0	21,137.33
10,001 – 20,000	58	38.7	
20,001 – 30,000	30	20.0	
30,001 – 40,000	11	7.3	
40,001 – 50,000	2	1.3	
> 50,000	13	8.7	
Total	150	100.0	

5.2. Waste disposal and management methods in the study area

5.2.1. Availability of waste disposal methods

Generally, there are different methods through which waste can be disposed of and in the study different waste disposal methods were identified. From the identified

methods (figure 1), open burning (100.0%) was found to be the most common among the respondents. The use of government certified waste collectors (98.7%), Landfills (97.3%), Waste Recycling (97.3%), Open dumping (91.3%) and Composting (89.3). The conversion of waste to Biogas among the respondents was found not be a common practice or means of waste disposal among the respondents as only 18.7% said they dispose their waste by using it as Biogas. This shows that the use of sustainable waste management system such as Biogas is not yet common in the study area but waste recycling is common especially for plastic and metal waste which has merchants who deal in conversion of this recyclable products (Olukanni *et al.*, 2020).

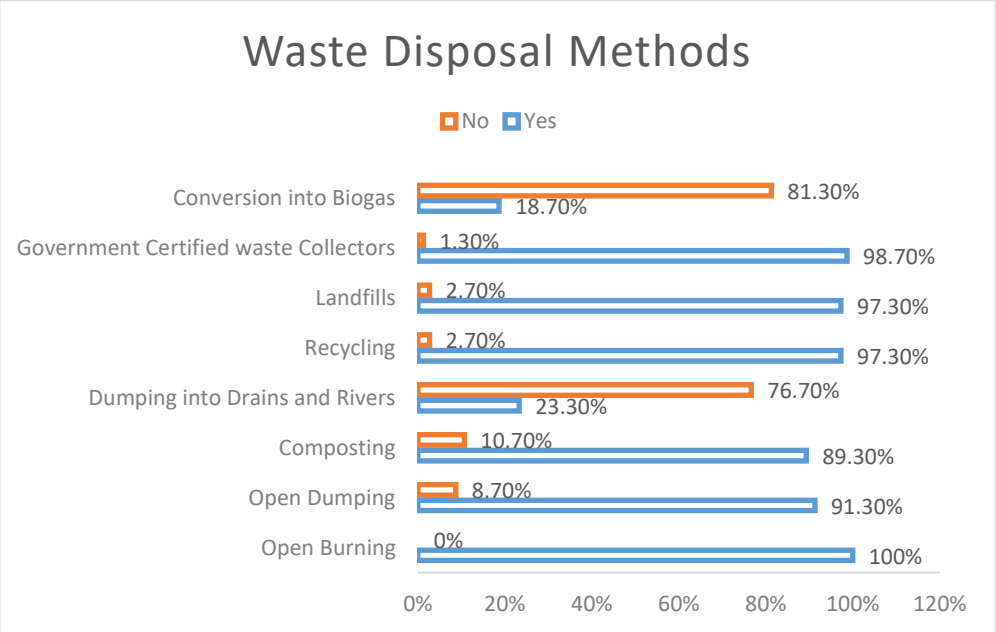

Figure 1: Waste Disposal Methods in the study Area

5.2.2. Frequency of use of the Waste Disposal Methods

Although there are different methods of waste disposal used by respondents, their frequency of use varies from one method to the other. From the study (table 2), it was found out that open dumping ($\bar{x}$ = 4.16) was the most frequent used means of waste disposal. This situation is actually true and supported by the findings of Ojo and

Adejugbgbe (2017) who reported that people resort to dumping their refuse in open areas because of the non-functional/ineffective organised waste disposal system in place.

Government certified waste collectors ($\bar{x}$ = 4.61) were also very commonly used by the respondents and this is due to the availability of large waste containers in strategic locations in the community where the respondents empty their waste for an amount based on the volume of the waste and then the waste collectors arrive once a week to carry the bins to the landfill site. Open burning ($\bar{x}$ = 3.12) was also found to be the third most frequently used means of waste disposal in the study area. This is evident in the ability of the respondents to easily gather their waste at any free area and put fire. However, the use of this method could portend danger for the environment as it releases dangerous gases into the atmosphere and not safe for the health of the people in the community (Elehinafe *et al.*, 2022).

Conversion of waste into Biogas was found to be the least frequently used means of waste management. This could be as a result of the lack of adequate knowledge of people in the area about the processes involved in biogas processing, among other constraints they might face in the use of the approach for their waste disposal (Ahonle and Adeoye, 2019).

Table 2: Frequency of Use of the Waste Disposal Method

	Always		**Very Often**		**Sometimes**		**Rarely**		**Never**		**Mean**
	Freq	%	Freq	%	Freq	%	Freq	%	Freq	%	

Open Burning	6	4.0	8	5.3	132	88.0	4	2.7	0	0.0	3.12
Open Dumping	99	66.0	12	8.0	16	10.7	10	6.7	13	8.7	4.16
Composting	0	0.0	2	1.3	8	5.3	124	82.7	16	10.7	1.97
Dumping into drain Channels, Rivers and Streams	6	4.0	2	1.3	12	8.0	15	10.0	115	76.7	1.46
Recycling	0	0.0	8	5.3	130	86.7	8	5.3	4	2.7	2.95
Landfills	2	1.3	4	2.7	10	6.7	130	86.7	4	2.7	2.13
Government Certified Waste Collectors	121	80.7	12	8.0	6	4.0	9	6.0	2	1.3	4.61
Conversion into Biogas	0	0.0	2	1.3	22	14.7	4	2.7	122	81.3	1.36

5.2.3. Methods of Disposal of Vegetable and Fruit and Waste

Specifically, the methods that was most used by the respondent in the disposal of their vegetable and fruit waste was to leave the waste in the open to rot (55.3%). According to Odugbose et al. (2020), who reported about vegetable and fruit waste, the author noted the site of rotten vegetables and fruits in market areas which are already rotten and releasing stench smell in the market place. Basically, leaving the waste in the open to rot is a very convenient means of waste disposal by the marketers and producers and reliefs them of the burden of having to transport the waste to the disposal site. Secondly, open burning (39.3%) was found to be another means of waste disposal. This method is mainly adopted by the respondents because it reduces the stress of finding a dumping site. However, the use of this approach is also similar to leaving in the open to rot as the waste is left on the ground to dry before being burnt. As such it is not safe for the environment and even the people within the vicinity of the where the burning is taking place (Ojo and Adejugbagbe, 2017).

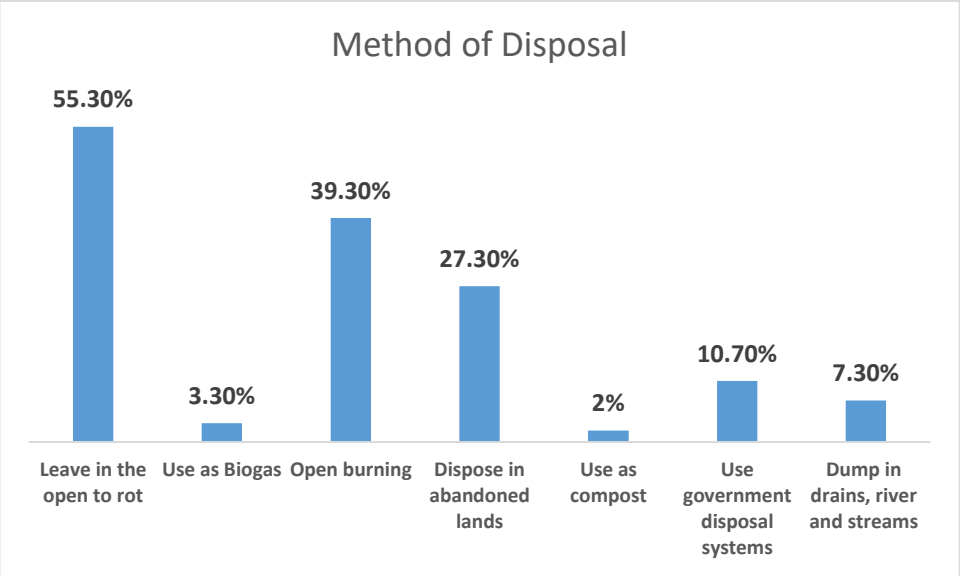

Figure 2: Methods of Disposal of the Vegetable and Fruit Waste

5.3. Perception of the respondents of the use and awareness of biogas derived from vegetable and fruit waste.

The perception shows the mindset of the respondents about the use of the vegetable and fruit waste for the purpose of Biogas generation. As shown in Table 3 shows that respondents ($\bar{x}$ = 4.63) believe that biogas can be an alternative fuel for cooking, while it is also perceived that biogas can be used to generate electricity ($\bar{x}$ = 3.95). This implies that the respondents have the perception that biogas can solve all their major energy needs. They also have the perception that the technology is complicated to use ($\bar{x}$ = 3.89) when compared to other energy sources. This opinion is supported by Ahonle and Adeoye (2019), who found that most people are not aware of biogas technology and perceive that it has been too complicated to apply as an energy source. The view of Biogas being a cheaper energy source ($\bar{x}$ = 3.71) when compared to other energy sources was a perception that was viewed to be true by the respondent in the study area. This could be due to the understanding of the respondents about the ease of getting the main starting material for the waste and the time it could use to convert the waste into biogas energy. Respondents also noted that the use of biogas was an environmentally

friendly way to dispose of vegetable and fruit waste, while it can also create viable employment opportunities for people who participate in collecting waste material and converting it into biogas for the use of households in the vicinity.

However, it was also found that the perception of it being expensive to install and not being able to totally solve the problem of vegetable and fruit waste in the vicinity was true among the respondents. This is due to the belief that technology is not readily available and the waste generated through vegetable and fruit waste is too huge to be converted into biogas (Oguntoke *et al.*, 2019).

Table 3: Perception about the use of Biogas from Vegetable and Fruit Waste

	Strongly Agree		**Agree**		**Neutral**		**Disagree**		**Strongly Disagree**		**Mean**
	Freq	%	Freq	%	Freq	%	Freq	%	Freq	%	
The Biogas can be an alternative fuel for cooking	94	62.7	56	37.3	0	0.0	0	0.0	0	0.0	4.63
Biogas can be used to generate electricity	48	32.0	68	45.3	18	12.0	10	6.7	6	4.0	3.95
Using biogas can create job opportunities	50	33.3	53	35.3	8	5.3	25	16.7	14	9.3	3.67
Using biogas can improve public health	39	26.0	34	22.7	36	24.0	26	17.3	15	10.0	3.37
Biogas is an environmentally friendly way of disposing vegetable and fruit waste.	44	29.3	54	36.0	24	16.0	16	10.7	12	8.0	3.68
Biogas is expensive to install	42	28.0	43	28.7	39	26.0	20	13.3	6	4.0	3.63
The technology is too complicated to use	64	42.7	41	27.3	18	12.0	19	12.7	8	5.3	3.89
Adoption of Biogas will not totally solve the problem of vegetable and fruit waste in the vicinity.	38	25.3	60	40.0	25	16.7	13	8.7	14	9.3	3.63

Biogas is cheaper when compared to other energy sources	67	44.7	29	19.3	18	12.0	16	10.7	20	13.3	3.71
Biogas is only for the rich and those with financial capacity	42	28.0	47	31.3	19	12.7	18	12.0	24	16.0	3.43

5.4. Sources of Energy in the Study Area

From the study, different sources of energy are commonly used for the purpose of lightening, cooking and other functions. The survey result shows that charcoal (32.0%) was the most common primary source of energy used by the respondents, while wood was the second most commonly used primary source of energy by the respondents. The reason for the use of these sources of energy was due to the availability of these sources in the community and it is even cheap or even free to get within the vicinity of the study area (Bamiro and Ogunjobi, 2015). About 22.7% of the respondents use gas as their primary source of energy and this is due toof the the proximity of gas station to their locality and the presence of small gas cylinders that allow the respondents to purchase the quantity that they desire at any point in time. Other primary sources include Kerosine (14%) and Solar energy (1.3%). Of the energy sources identified, the use of charcoal and wood has an impact on user health, as the smoke released has an impact on health and, therefore, may not be safe for users (Elijah *et al.*, 2017). On the other hand, the use of natural gas is safe and clean, but the cost of procurement is high and with the rate of poverty, many of them may not be able to purchase it for use (Elijah *et al*., 2017).

Further observation shows that most of the respondent use more than one energy source for different purpose and as such there may be need to have an energy source which can cater for all the primary needs of the respondents such as cooking and lighting. Therefore, with this challenge there may be a need for the respondent to have an energy source that is safe health wise and environmental wise and also cost effective for the users (Samuel and Oladapo, 2022).

Table 4: Primary source of Energy

Primary Source of Energy	Frequency	Percentage

Charcoal	48	32.0
Gas	34	22.7
Solar	2	1.3
Wood	45	30.0
Kerosine	21	14
Total	**150**	**100.0**

5.5. Awareness About Biogas

The awareness level about biogas looks at the information that the respondents have about biogas and the availability of the necessary facilities for the adoption of biogas in the vicinity of the respondent. The study findings, as shown in Table 5, reveal that most of the respondents (61.3%) are aware that vegetable and fruit waste can be used as a means of generating biogas. This shows that the respondents have some form of knowledge about the use of biogas for their operations. Furthermore, the majority (68.7%) of the respondents have a biogas facility within their locality. The source of information further reveals that majority of the respondents get their information about biogas from educational institutions (74.7%) probably through trainings and other formal educational gatherings while other source of information includes social gatherings (9.3%), radio (8.0%), internet (4.0) and books (4.0). Also 91.3% of those samples in the survey reported that they are not aware of agents that deal in the technology for biogas in the vicinity. This implies that the technology for biogas is not readily available and this could be a major constraint in the adoption of the technology by the respondents in the study area. This assertion is supported by the findings of Ayoade *et al.* (2017).

Table 5: Awareness of the Respondents about Biogas

	Frequency	**Percentage**

Awareness that Vegetable and Fruit waste can be used to Generate Biogas		
Yes	92	61.3
No	58	38.7
Total	**150**	**100.0**
Availability of Biogas Facility		
Yes	47	31.3
No	103	68.7
Total	**150**	**100.0**
Source of Information About Biogas		
Books	6	4.0
Internet	6	4.0
Radio	12	8.0
Educational Institutions	112	74.7
Social Interaction	14	9.3
Total	**150**	**100.0**
Availability of Agents that sell digesters or biogas facility		
Yes	13	8.7
No	137	91.3
Total	**150**	**100.0**

5.6. Level of adoption of biogas in the management of vegetable and fruit waste generated.

Figure 3 shows the level of adoption of biogas by the respondents in the study area. This section made use of the stages of adoption in looking at the stage where each of the respondent is on the graph (Cruz-Jesus, 2019). From the findings, it was discovered that a high percentage of the respondents (41.3%) are still at the stage of awareness of the adoption model, while around 36.7% of the respondents noted that they are not even aware of the use of vegetable and fruit waste for the generation of biogas. About 10.7% of the respondents were at the interest stage of the adoption model while 11.3% were at the evaluation stage of the model. However, none of the respondents is at the trial stage, the adoption stage, and the post-adoption stage. This shows that the people in the study area who are even aware of the technology are sceptical about its use and as such still contemplating on further engagement with the technology before use or probably because of the cost (Poopnarain and Adeleke, 2017). This could mean that more awareness effort may be needed to move respondents from one stage of adoption to the other.

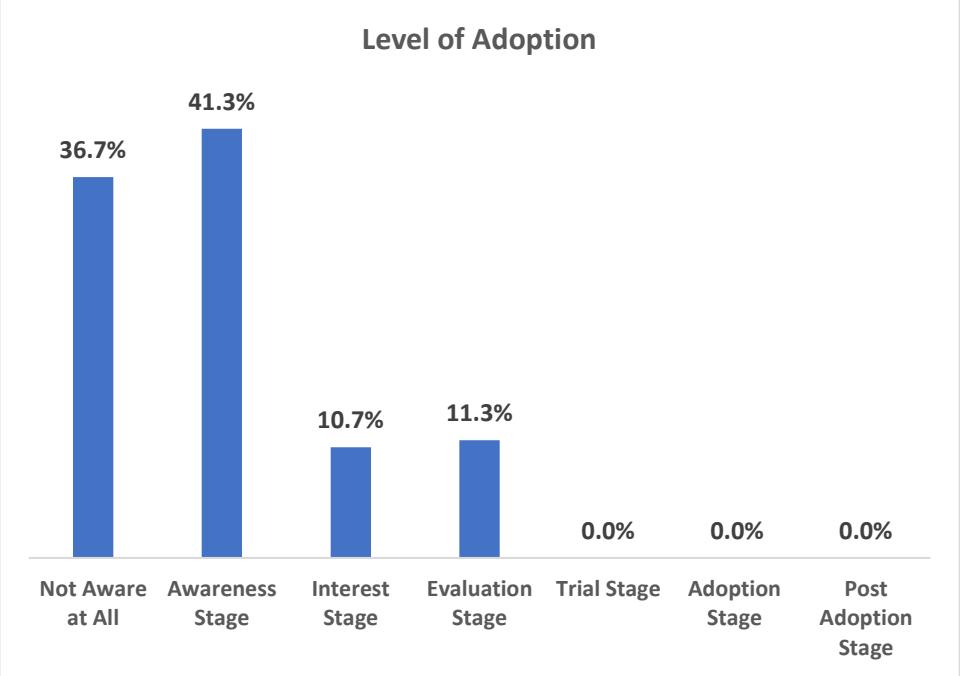

Figure 3: Level of Adoption of Biogas

5.7. Level of vegetable and fruit waste generated in the study area and the implications for biogas production.

The average volume of vegetable waste produced per month by households and the local market in the study area is approximately 89.80 kg, which is about 19.76% of the vegetable and fruit that is produced combined for consumption and sale in the local market within the study location. This shows that approximately a fifth of the vegetable and fruit produced is lost as waste due to different factors ranging from lack of market to sell, short shelf life of the vegetables, lack of storage facilities, among others, and this waste is not put into any form of use in the study area (Isitor *et al.*, 2016). Therefore, causing a threat in the market place and even in the field of farmers, as observed in some of the fields visited in the course of the study. Furthermore, the average cost of disposing this waste through the formal waste disposal system is about 87.67 Naira depending on the volume of the waste and the price range from between 50 and 150 Naira. It should be noted that if the vegetable and fruit waste generated on the market could be properly used, it can save the cost of disposal, reduce the threat of dirt and decaying vegetable and fruit on the market, and help promote clean energy sources in the study area (Oguntoke *et al.*, 2019).

Table 6: Vegetable and Fruit Waste in the study Area

	Mean
Average Volume of Vegetable Waste Generated per week	89.80kg
Average percentage of the vegetable and Fruit that is wasted per week	19.76%
Average cost of disposal of waste	87.67 Naira

5.8. Willingness to use waste generated from vegetable and fruit sources to generate biogas.

To understand the willingness of the respondents to use vegetable waste to generate biogas, the respondents were samples to understand their level of willingness. This result is presented in Table 7. From the result, it was deduced that majority (93.3%) of the respondents see vegetable and fruit waste as an environmental challenge. The implication of this is that seeing it as an environmental challenge could motivate the respondents towards finding a solution towards it especially one that would be highly beneficial. This motivated the next question which sort to understand the willingness the respondent to accept an alternative means to dispose of their vegetable and fruit waste of which barely majority (52.7%) of them agreed on an alternative means of disposal for their fruit and waste. To further elucidate the responses and obtain their level of willingness, respondents were asked about their willingness to use their waste in the generation of energy, of which only 48.0% of the respondents showed their willingness. This shows that the commitment of the respondents is reduced as they move from a general solution to waste management to a specific solution. This could be due to the fact that respondents are not yet willing to commit themselves to a sustainable waste management system for vegetable and fruit waste because they do not yet understand the benefit that is embedded in it (Osibote *et al.*, 2017).

Table 7: Willingness to use Vegetable and Fruit waste for Biogas

	Freq	**Percentage**
Is Vegetable and Fruit waste an Environmental Challenge?		
Yes	140	93.3
No	10	6.7
Total	**150**	**100.0**
Willingness to accept and Alternative means to Dispose Vegetable and Fruit Waste?		
Yes	79	52.7
No	71	47.3
Total	**150**	**100.0**
Willingness to Utilise Vegetable and Fruit Waste for the Generation of Energy		
Yes	72	48.0

No	78	52.0
Total	**150**	**100.0**

5.9. Factors influencing the use of vegetable and fruit waste as a source of biogas for energy generation.

The factors that influence the use of vegetable and fruit waste as biogas are accessed through the responses of the respondents and the mean value used in the discussion. From the result of the study as shown in Table 8, the availability of vegetable and fruit waste ($\bar{x}$ = 4.72) is considered a major factor that could influence the use of vegetable and fruit waste as a source of energy. The implication of this is that its availability in abundance in the locality could be a positive outlook for the introduction of a biogas facility into the community for the generation of biogas (Akande and Olorunnisola, 2018).

Capital ($\bar{x}$ = 3.95) was the second most important factor that could influence the use of vegetable and waste for the purpose of biogas generation. Capital is important as a factor because of the perceive importance of it in procuring the facilities that would be needed and getting the services of those that would install the biogas facility. Government support ($\bar{x}$ = 3.83) was the third important factor among respondents as a factor influencing the use of vegetable and fruit waste. This is not far-fetched because of the lack of government policies that supports the use of biogas in the study area and the limited number of incentives from government quarters to promote the use of biogas in the study area (Patinvoh and Taherzadeh, 2019).

Technical expertise ($\bar{x}$ = 3.73) and availability of technology ($\bar{x}$ = 3.72) in close proximity to market and farms is also another major factor that influence biogas generation from vegetable and fruit waste in the study area. The implication of the proximity and technical expertise factors is that it might hamper even those with interest in adopting the technology for use or those even interested in giving out their waste to generate biogas in the study area (Odejobi *et al.*, 2022). Other factors influencing use of vegetables and fruits as source of biogas include awareness about biogas ($\bar{x}$ = 3.72), access to information ($\bar{x}$ = 3.51), access to credit ($\bar{x}$ = 3.51) among others.

Table 8: Factors Influencing the use of Vegetable and Fruits waste for Biogas

Factors	Strongly Agree		Agree		Neutral		Disagree		Strongly Disagree		Mean
	Freq	%	Freq	%	Freq	%	Freq	%	Freq	%	
Availability of vegetable and fruit waste	115	76.7	28	18.7	7	4.7	0	0.0	0	0.0	4.72
Capital	39	26.0	70	46.7	35	23.3	6	4.0	0	0.0	3.95
Technical Expertise	44	29.3	42	28.0	47	31.3	13	8.7	4	2.7	3.73
Awareness about Biogas	40	26.7	56	37.3	34	22.7	12	8.0	8	5.3	3.72
Closeness of Biogas production facility	41	27.3	30	20.0	33	22.0	30	20.0	16	10.7	3.33
Access to Information	41	27.3	41	27.3	38	25.3	14	9.3	16	10.7	3.51
Access to credit	24	16.0	4	2.7	34	22.7	48	32.0	40	26.7	3.51
Government Support	56	37.3	42	28.0	28	18.7	18	12.0	6	4.0	3.83
Availability of technology in close proximity to market and farms	45	30.0	54	36.0	27	18.0	12	8.0	12	8.0	3.72

5.10. Barriers to the use of vegetable and fruit waste for the generation of biogas.

The use of vegetable and fruit waste among respondents in the study area is faced with different barriers in the study area and this is accessed from the perspective of respondents to understand what areas could need to be improved or worked on to improve

the use of biogas among respondents. These barriers serve as a limiting factor in the actualisation of the use of vegetable and fruit waste for generation of biogas (Okoro *et al.*, 2020) in the study area as shown in Table 9.

From the findings, the high cost of Biodigester ($\bar{x}$ = 4.51) was found to be one of the main limitations facing the effective use of vegetable and fruit waste for the generation of biogas. Additionally, limited knowledge of the benefit of the technology for respondents and the environment is part of the main constraint ($\bar{x}$ = 3.97). This is due to the lack of adequate awareness of the people in these areas of the need to effectively manage their waste and also to look for better and alternative sources of waste generation. The third major constraints faced in the use of vegetable and fruit waste for biogas generation is the climatic condition ($\bar{x}$ = 3.87). This being seen as a challenge by the respondents may be due to lack of knowledge on how biogas functions, and as such they tend to see it as being climate controlled and, thus pushing to the fore, the need for sensitisation and trainings about biogas can help combat this challenge.

Furthermore, low level of demand for biogas ($\bar{x}$ = 3.71) as a constraint, limits investment in facilities that would sustain its use and for investment to be made the demand for it must be in place. Lack of parts for the construction of the biogas digester and other facilities ($\bar{x}$ = 3.65) within the locality. This assertion is supported by Odejobi *et al.* (2022), who also reported the same with regard to the availability of parts and infrastructure for the support of biogas. It should be noted that due to the location of the study area which is classified as semi-rural area. The parts for the construction of the biogas plant are not readily available in the vicinity and people have to go as far as city centres such as Abeokuta and Lagos to obtain the facility.

Table 9: Barriers to the use of Biogas as an energy Source

Constraints	Very High		High		Medium		Low		Very Low		Mean
	Freq	%	Freq	%	Freq	%	Freq	%	Freq	%	
High Cost of Biodigester	87	58.0	57	38.0	2	1.3	4	2.7	0	0.0	4.51
Lack of parts for the construction of the biogas facility	41	27.3	41	27.3	52	34.7	6	4.0	10	6.7	3.65
No knowledge about the importance of biogas in utilisation in waste management	39	26.0	31	20.7	46	30.7	26	17.3	8	5.3	3.45
Lack of skills to manage the waste and biogas facility	32	21.3	50	33.3	34	22.7	30	20.0	4	2.7	3.51
High cost of moving the vegetable and fruit waste to the biogas facility	28	18.7	16	10.7	40	26.7	38	25.3	28	18.7	3.15
Low level of Demand for Biogas	41	27.3	43	28.7	49	32.7	15	10.0	2	1.3	3.71
Climatic condition	53	35.3	32	21.3	49	32.7	32	21.3	53	35.3	3.77
Lack of finance and capital to procure the technology	22	14.7	60	40.0	39	26.0	21	14.0	8	5.3	3.45
Low Awareness Level	37	24.7	46	30.7	26	17.3	27	18.0	14	9.3	3.43
Limited Knowledge on the Benefits of Adopting the Technology	57	38.0	39	26.0	35	23.3	15	10.0	4	2.7	3.87
Inability to test the efficacy of the Technology	36	24.0	31	20.7	46	30.7	17	11.3	20	13.3	3.31

5.11. Factors Influencing the Level of Adoption of vegetable and Fruit waste for biogas production.

The result of the chi-square analysis on table 10 shows that some socio-economic factors influence the adoption of vegetable and fruit waste for the production of biogas.

Among the significant factors is the sex of the respondents. This implies that a significant level of decision making for the adoption of vegetable and fruit waste for biogas production is influenced by the sex orientation of the respondents. The age of the respondent also influenced the level of adoption of vegetable and fruit waste for the production of biogas. This implies that the age of the respondents has a way of influencing their thought process and could confer on the respondent the ability to take an informed decision towards the adoption of vegetable and fruit waste for the production of biogas.

The educational level of the respondent was also significant and influenced the adoption level. This may imply that the level of information and knowledge could affect the decision making of respondents toward adoption and could further enhance their ability to evaluate their decision based on available information (Zhou *et al.*, 2018). The monthly income and the income from vegetable production also influenced the level of adoption for the adoption of vegetable and fruit waste for the production of biogas. This implies that the income of the respondent has a lot to do with their adoption process. This is because the income of the respondent has an impact on their ability to obtain biogas technology (Uhunamure *et al.*, 2019).

Table 10: Factors influencing the Level of adoption of Vegetable and Fruit waste for Biogas Production.

Variable	Chi-square (χ^2)	P values
Age	229.54	0.000*
Sex	17.83	0.000*
Education	98.97	0.000*
Household Size	23.909	0.298
Experience in Marketing and Producing Vegetable and Fruit	92.79	0.080
Monthly Income	266.62	0.011*
Income from Vegetable and fruit Production	412.03	0.000*

5.12. Factors Affecting the Willingness of the Respondents to Utilise their Vegetable and Fruit Waste for Biogas Production.

The logistic regression model shown in Table 11 was used to determine the factors that affect the willingness of the respondents to use their vegetable and fruit waste for biogas production. The overall logistic model was significant based on the chi-square estimates, implying that the explanatory variables are relevant in determining the willingness to use their vegetable and fruit waste for biogas production. Out of the seven (7) explanatory variables fitted into the model, two (2) of them were found to be statistically significant, these are: educational level ($p<0.01$) and income from vegetable production ($p<0.01$).

The coefficient of educational level was positive and statistically significant at 1% suggesting that the likelihood of vegetable and fruit farmers using their waste as a source of biogas increases as their educational level increases. This may be attributed to the knowledge level of exposure to knowledge based on their level of education where they may have been taught on the effect of bad waste management and the importance of renewable energy sources (Atinkut *et al.*, 2020).

The income from vegetable and fruit marketing and production was also found to be significant and positive at 1% level of significance. This implies that the fruit and vegetable marketers and producers will be willing to utilise their waste for biogas production as their income from vegetable production increases. This is because these marketers might want to become more efficient as their income increases and will thus engage in any activity that will help ensure and, among those, the proper use of their waste through the use of biogas (Florkowski and Klepacka, 2018).

Table 11: Factors Affecting the Willingness of the Respondents to Utilise their Vegetable and Fruit Waste for Biogas Production

Variables	Coefficient	Standard Error	Z
Age	-0.0201	0.0208	-0.97
Sex	0.1934	0.4750	0.41
Household Size	0.1455	0.1470	0.99
Educational Level	0.7448***	0.3123	2.38
Farming Experience	-0.0207	0.0238	-0.87
Monthly Income	1.63e-07	5.30e-06	0.03
Income from Vegetable	0.0001***	0.0000	3.43
Constant	-3.1635	1.7446	-1.81
Pseudo R^2	0.2973		
Wald Chi-square	61.75		
Prob > Chi^2	0.0000		
Log likelihood	-72.9752		

6. Conclusions

This study has examined, among other things, how vegetable and fruit waste can be used as a source of biogas for energy generation. The study evaluated waste disposal and management methods, estimated the level of vegetable and fruit waste generated in the study area, and the implications for biogas production. The study also estimated the factors that influenced the level of adoption and the willingness to use vegetable and fruit waste for biogas. Based on the findings of the study, some conclusions were reached.

Firstly, it was concluded that the awareness of biogas in the vicinity is low and that there seems to be little to no effort ongoing within the vicinity of the study area to improve that. The current waste disposal approach in the study area is deemed unsustainable and presents environmental concerns. Therefore, it is imperative to explore alternative waste disposal methods within the community to mitigate the detrimental effects associated with the current approach. The study also concluded that vegetable and fruit waste is a viable means of generating biogas in the study area because the level of waste generated between marketers and producers can sustain the production of biogas. The continued engagement of the respondents also led to the conclusion that the respondents see their waste as a challenge to the environment, but as they move towards a commitment towards managing this waste through biogas production, their willingness reduces.

The study also concluded that the lack of organisations involved in the sale and installation of biodigesters and their parts or biogas facilities in the vicinity of the study areas has affected the use of the facility in the area, which serves as a barrier to further development. However, it was found that education and income of respondents is very important in the willingness of respondents to use technology and the desire to adopt. However, barriers such as high cost of digesters, low level of awareness, and technicality of technology, among other barriers, need to be addressed.

Therefore, the following recommendations were made based on the findings of the study:

1. There is a need to further educate respondents about the dangers of unsustainable means of waste disposal and then introduce them to biogas technology through advocacy efforts.

2. Short-term training should be provided to vegetable and fruit marketers and producers on biogas production to improve their knowledge on the use of biogas.
3. Government support may help strengthen the use of biogas in the study area through incentives that encourage the use of biogas. This support should include subsidies to support biogas development and purchase and the development of a policy framework that will guide the adoption of biogas.
4. The level of teaching of the fundamentals of biogas technology and its advantages, the kinds of waste that can be utilized to produce biogas, technical know-how in building and maintaining biogas digesters in secondary and tertiary levels.
5. Low interest credit should be provided to the farmers and marketers to enable them in the procurement of the technology for their use.

7. References

Abanades, S., Abbaspour, H., Ahmadi, A., Das, B., Ehyaei, M. A., Esmaeilion, F. & Bani-Hani, E. H. (2021). A critical review of biogas production and usage with legislations framework across the globe. *International Journal of Environmental Science and Technology*, 1-24.

Abdelfattah, A. F. (2020). Sustainable development practices and its effect on green buildings. In *IOP Conference Series: Earth and Environmental Science* (Vol. 410, No. 1, p. 012065). IOP Publishing.

Abraham, A., Mathew, A. K., Park, H., Choi, O., Sindhu, R., Parameswaran, B., ... & Sang, B. I. (2020). Pretreatment strategies for enhanced biogas production from lignocellulosic biomass. *Bioresource Technology*, *301*, 122725.

Abraham, T. W., & Fonta, W. M. (2018). Climate change and financing adaptation by farmers in northern Nigeria. *Financial innovation*, *4*(1), 1-17.

Adamu, M. B., Adamu, H., Ade, S. M., & Akeh, G. I. (2020). Household energy consumption in Nigeria: A review on the applicability of the energy ladder model. *Journal of applied sciences and environmental management*, *24*(2), 237-244.

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

Afolabi, O. O., Leonard, S. A., Osei, E. N., & Blay, K. B. (2021). Country-level assessment of agrifood waste and enabling environment for sustainable utilisation for bioenergy in Nigeria. *Journal of Environmental Management*, *294*, 112929.

Agbo, E. P., Edet, C. O., Magu, T. O., Njok, A. O., Ekpo, C. M., & Louis, H. (2021). Solar energy: A panacea for the electricity generation crisis in Nigeria. *Heliyon*, *7*(5), e07016.

Ahonle, J. E., & Adeoye, P. A. (2019, October). Potential, Barriers and Prospects of Biogas Production in North-Central Nigeria. 3rd International Engineering Conference (IEC 2019) Federal University of Technology, Minna, Nigeria.

Ajibola, A. F., Raimi, M. O., Steve-Awogbami, O. C., Adeniji, A. O., & Adekunle, A. P. (2020). Policy Responses to Addressing the Issues of Environmental Health Impacts of Charcoal Factory in Nigeria: Necessity Today; Essentiality Tomorrow. *Communication, Society and Media, ISSN*, 2576-5388.

Ajieh, M. U., Isagba, E. S., Ihoeghian, N., Edosa, V. I., Amenaghawon, A., Oshoma, C. E., ... & 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*, *23*(9), 13182-13199.

Akande, O. M., & Olorunnisola, A. O. (2018). Potential of briquetting as a waste-management option for handling market-generated vegetable waste in Port Harcourt, Nigeria. *Recycling*, *3*(2), 11.

Akintola, O. A., Idowu, O. O., Lateef, S. A., Adebayo, G. A., Shokalu, A. O., & Akinyoola, O. I. (2019). The use of waste management techniques to enhance household income and reduce urban water pollution. In *Elements of Bioeconomy*. IntechOpen.

Anderson, H. N., & Smith, Z. A. (2022). Sustainable development governance in action: the United States. In *Handbook on the Governance of Sustainable Development* (pp. 294-304). Edward Elgar Publishing.

Andriani, D., Rajani, A., Santosa, A., Saepudin, A., Wresta, A., & Atmaja, T. D. (2020, March). A review on biogas purification through hydrogen sulphide removal. In *IOP Conference Series: Earth and Environmental Science* (Vol. 483, No. 1, p. 012034). IOP Publishing.

Atinkut, H. B., Yan, T., Arega, Y., & Raza, M. H. (2020). Farmers' willingness-to-pay for eco-friendly agricultural waste management in Ethiopia: A contingent valuation. *Journal of cleaner production*, *261*, 121211.

Aworh, O. C. (2021). Food safety issues in fresh produce supply chain with particular reference to sub-Saharan Africa. *Food Control*, *123*, 107737.

Ayoade, A. A., Salako, S. G., Yusuf-Babatunde, A. M., Lawal, O. A., & KuKu, M. A. (2017). Assessment of Perceived Health and Environmental Problems of Household Energy Consumption among Ilese Ijebu Residents Southwestern Nigeria. *Asia Pacific Journal of Energy and Environment*, *4*(2), 41-48.

Ayodele, O. O., Aboaba, K. O., Oladeji, S. O., & Tolorunju, E. T. (2021). Factors affecting productivity and intensity of market participation of leafy vegetable growers. *International Journal of Vegetable Science*, *27*(1), 96-101.

Ayodele, T. R., Alao, M. A., Ogunjuyigbe, A. S. O., & Munda, J. L. (2019). Electricity generation prospective of hydrogen derived from biogas using food waste in south-western Nigeria. *Biomass and Bioenergy*, *127*, 105291.

Aziz, A. N., Mahmoud, S., Al-Dadah, R., Dhesi, S., Kuznetsova, I., Effiong, C., & Kanu, E. (2021). Conversion of Mixed Waste of Wood and Plastic to Clean Fuels Using Pyrolysis in Nigeria–Numerical Study. In *The 7th World Congress on Mechanical, Chemical, and Material Engineering (MCM'21)*.

Babatunde, A. I. (2019). Impact of Supply Chain in Reducing Fruit Post-Harvest Waste in Agric Value Chain in Nigeria. *Electronic Research Journal of Social Sciences and Humanities*, *1*, 150-163.

Bamiro, O. M., & Ogunjobi, J. O. (2015). Determinants of household energy consumption in Nigeria: Evidence from Ogun State. *Research Journal of Scial Science and Management*, *4*(12), 35-41.

Barichello, R. (2020). The COVID-19 pandemic: Anticipating its effects on Canada's agricultural trade. *Canadian Journal of Agricultural Economics/Revue canadienne d'agroeconomie*, *68*(2), 219-224.

Barnes, P. W., Williamson, C. E., Lucas, R. M., Robinson, S. A., Madronich, S., Paul, N. D., ... & Zepp, R. G. (2019). Ozone depletion, ultraviolet radiation, climate change and prospects for a sustainable future. *Nature Sustainability*, *2*(7), 569-579.

Baysal, S. S., & Ülkü, M. A. (2022). Food loss and waste: a sustainable supply chain perspective. *Disruptive Technologies and Eco-Innovation for Sustainable Development*, 90-108.

Biodun, M. B., Fayomi, O. S. I., & Okeniyi, J. O. (2021, April). The possibility of biogas production in Nigeria from organic waste material: A review. In *IOP Conference Series: Materials Science and Engineering* (Vol. 1107, No. 1, p. 012166). IOP Publishing.

Colapinto, C., Jayaraman, R., Ben Abdelaziz, F., & La Torre, D. (2020). Environmental sustainability and multifaceted development: multi-criteria decision models with applications. *Annals of Operations Research*, *293*(2), 405-432.

Cruz-Jesus, F., Pinheiro, A., & Oliveira, T. (2019). Understanding CRM adoption stages: empirical analysis building on the TOE framework. *Computers in Industry*, *109*, 1-13.

Dacko, M., Płonka, A., Satoła, Ł., & Dacko, A. (2021). Sustainable Development According to the Opinions of Polish Experts. *Energies*, *14*(17), 5325.

Dixon, C., Edelmaier, K., Nozka, A., Safranek, E., Thomas, Q., & Walker, A. (2021). The Success of the Montreal Protocol in Healing the Ozone Hole. *Group*, *2*, 19.

Durodola, O. S. (2019). The impact of climate change induced extreme events on agriculture and food security: a review on Nigeria. *Agricultural Sciences*, *10*(4), 487-498.

Elbasiouny, H., Elbanna, B. A., Al-Najoli, E., Alsherief, A., Negm, S., El-Nour, A., ... & Sharabash, S. (2020). Agricultural waste management for climate change mitigation: some implications to Egypt. In *Waste management in MENA regions* (pp. 149-169). Springer, Cham.

Elehinafe, F. B., Okedere, O. B., Ayeni, A. O., & Ajewole, T. O. (2022). Hazardous Organic Pollutants from Open Burning of Municipal Wastes in Southwest Nigeria. *Journal of Ecological Engineering*, *23*(9), 288-296.

Elijah, A. A., Balikis, L. I., & Ambali, O. I. (2017). Comparative analysis of access, and preferences of rural and urban households for cooking energy, and the determinants in Nigeria: A case of Ogun State. *Agric. Trop. Subtrop*, *50*, 45-53.

Emetere, M. E., Agubo, O., & Chikwendu, L. (2021). Erratic electric power challenges in Africa and the way forward via the adoption of human biogas resources. *Energy Exploration & Exploitation*, *39*(4), 1349-1377.

FAO. 2022. Agricultural production statistics. 2000–2020. FAOSTAT Analytical Brief Series No. 41. Rome.

FAOSTAT (2017). Food and agriculture data. URL: http://www.fao.org/faostat/en/#home

Farsari, I. (2021). Exploring the nexus between sustainable tourism governance, resilience and complexity research. *Tourism Recreation Research*, 1-16.

Florkowski, W. J., Us, A., & Klepacka, A. M. (2018). Food waste in rural households support for local biogas production in Lubelskie Voivodship (Poland). *Resources, Conservation and Recycling*, *136*, 46-52.

Gillett, N. P., Kirchmeier-Young, M., Ribes, A., Shiogama, H., Hegerl, G. C., Knutti, R., ... & Ziehn, T. (2021). Constraining human contributions to observed warming since the pre-industrial period. *Nature Climate Change*, *11*(3), 207-212.

Halkos, G., & Gkampoura, E. C. (2021). Where do we stand on the 17 Sustainable Development Goals? An overview on progress. *Economic Analysis and Policy*, *70*, 94-122.

Ibeawuchi, I. I., Okoli, N. A., Alagba, R. A., Ofor, M. O., Emma-Okafor, L. C., Peter-Onoh, C. A., & Obiefuna, J. C. (2015). Fruit and vegetable crop production in Nigeria: The gains, challenges and the way forward. *Journal of Biology, Agriculture and Healthcare*, *5*(2), 194-208.

Idris-Idah, K. M., & Abdulkadir, M. (2022, August). Hydrogen Production from Petroleum Fields; An Effective Solution to Nigeria's Energy Needs and Climate Change Mitigation. In *SPE Nigeria Annual International Conference and Exhibition*. OnePetro.

Ike, C. C., Ezeibe, C. C., Anijiofor, S. C., & Daud, N. N. (2018). Solid waste management in Nigeria: problems, prospects, and policies. *The Journal of Solid Waste Technology and Management*, *44*(2), 163-172.

Ikhuoso, O. A., Adegbeye, M. J., Elghandour, M. M. Y., Mellado, M., Al-Dobaib, S. N., & Salem, A. Z. M. (2020). Climate change and Agriculture: The competition for limited resources amidst crop farmers-livestock herding conflict in Nigeria-A review. *Journal of Cleaner Production*, *272*, 123104.

Imoisi, S., & Okongwu, J. (2020). Need For a Policy Framework for Sustainable Renewable Energy Technologies in Nigeria: Biogas Utility. *Chukwuemeka Odumegwu Ojukwu University Journal of Commercial and Property Law*, *2*(1).

Isitor, S. U., Otunaiya, A. O., & Iyanda, J. O. (2016). Efficiency of vegetable marketing in peri-urban areas of Ogun State, Nigeria. *Journal of Agricultural Science*, *8*(3), 67-78.

Jaeger, L. (2021). A Brief History of the Climate: What Makes Current Global Warming so Special. In *Ways Out of the Climate Catastrophe* (pp. 63-77). Springer, Cham.

Janker, J., & Mann, S. (2020). Understanding the social dimension of sustainability in agriculture: a critical review of sustainability assessment tools. *Environment, Development and Sustainability*, *22*(3), 1671-1691.

Kabeyi, M. J. B., & Olanrewaju, O. A. (2022). Biogas production and applications in the sustainable energy transition. *Journal of Energy*, *2022*.

Karamushka, O., Moroz, S., & Vasylieva, N. (2018). Information component of innovative support for agricultural enterprises capital. *Baltic Journal of Economic Studies*, *4*(4), 145-150.

Kasulla, S., Malik, S. J., Zafar, S., & Saraf, A. (2021). A Retrospection of hydrogen sulphide removal technologies in biogas purification. *International Journal of Trend in Scientific Research and Development*, *5*(3), 857-863.

Kemausuor, F., Adaramola, M. S., & Morken, J. (2018). A review of commercial biogas systems and lessons for Africa. *Energies*, *11*(11), 2984.

Khare, N., Singh, D., Kant, R., & Khare, P. (2020). Global Warming and Biodiversity. In *Current State and Future Impacts of Climate Change on Biodiversity* (pp. 1-10). IGI Global.

Kim, D., Parajuli, R., & Thoma, G. J. (2020). Life cycle assessment of dietary patterns in the United States: a full food supply chain perspective. *Sustainability*, *12*(4), 1586.

Koul, B., Yakoob, M., & Shah, M. P. (2022). Agricultural waste management strategies for environmental sustainability. *Environmental Research*, *206*, 112285.

Koval, V., Mikhno, I., Hajduga, G., & Gaska, K. (2019). Economic efficiency of biogas generation from food product waste. In *E3S Web of Conferences* (Vol. 100, p. 00039). EDP Sciences.

Kulshrestha, K. (2018). Horticultural crops value addition for nutritional security. *International Journal of Research-Granthaalayah*, *6*(10), 110-120.

Lawal, R. A., Ogunseitan, T. O., Oluwagbayide, S. D., & Aako, O. L. (2019). Waste Analysis in Post-Harvest Fruit Marketing: A Measure to Reduce Economic Wastage in Ilaro, Ogun State, Nigeria. *Scientific Journal of Mehmet Akif Ersoy University*, *4*(1), 27-32.

Levin, K., Fransen, T., Schumer, C., Davis, C., & Boehm, S. (2019). What does" net-zero emissions" mean? 8 common questions, answered.

Liverpool-Tasie, L. S. O., Sanou, A., & Tambo, J. A. (2019). Climate change adaptation among poultry farmers: evidence from Nigeria. *Climatic Change*, *157*(3), 527-544.

Mama, C. N., Nnaji, C. C., Nnam, J. P., & Opata, O. C. (2021). Environmental burden of unprocessed solid waste handling in Enugu State, Nigeria. *Environmental Science and Pollution Research*, *28*(15), 19439-19457.

Mbachu, V. M., Okwu, M. O., Chiabuotu, C. C., & Tartibu, L. K. (2022). Biogas for Electricity Generation in Nigeria: A Systematic Review of the Prospects, Efforts and Contemporary Challenges. *Advances in Biofeedstocks and Biofuels, Production Technologies for Solid and Gaseous Biofuels*, *4*, 91.

Mohammed, Y. S., Mustafa, M. W., Bashir, N., & Ibrahem, I. S. (2017). Existing and recommended renewable and sustainable energy development in Nigeria based on autonomous energy and microgrid technologies. *Renewable and Sustainable Energy Reviews*, *75*, 820-838.

Nanda, S., & Berruti, F. (2021). Municipal solid waste management and landfilling technologies: a review. *Environmental Chemistry Letters*, *19*(2), 1433-1456.

Nicastro, R., & Carillo, P. (2021). Food loss and waste prevention strategies from farm to fork. *Sustainability*, *13*(10), 5443.

O'Connor, J., Hoang, S. A., Bradney, L., Dutta, S., Xiong, X., Tsang, D. C., ... & Bolan, N. S. (2021). A review on the valorisation of food waste as a nutrient source and soil amendment. *Environmental Pollution*, *272*, 115985.

Odejobi, O. J., Ajala, O. O., & Osuolale, F. N. (2022). Review on potential of using agricultural, municipal solid and industrial wastes as substrates for biogas production in Nigeria. *Biomass Conversion and Biorefinery*, 1-13.

Odugbose, B. D., Dada, O. I., Bakare, B. O., Adelase, A. B., & Arowosafe, K. O. (2020). Development and Assessment of Locally Improvised Biogas Reactor for Biogas Production from Co-Digestion of Cow Dung with Fruit and Vegetable Wastes. *Journal of Agricultural Engineering and Technology*, *25*(2), 72-88.

Ogundele, O. M., Rapheal, O. M., & Abiodun, A. M. (2018). Effects of municipal waste disposal methods on community health in Ibadan-Nigeria. *Polytechnica*, *1*(1), 61-72.

Oguntoke, O., Amaefuna, B. A., Nwosisi, M. C., Oyedepo, S. A., & Oyatogun, M. O. (2019). Quantification of biodegradable household solid waste for biogas

production and the challenges of waste sorting in Abeokuta Metropolis, Nigeria. *International Journal of Energy and Water Resources*, *3*(3), 253-261.

Ojo, O. O., & Adejugbagbe, J. A. (2017). Solid waste disposal attitude in Sango Ota, Ogun state: Implication for sustainable city development in Nigeria. *Journal of Environment and Waste Management*, *4*(3), 253-260.

Okokpujie, I. P., Okokpujie, K., Omidiora, O., Oyewole, H. O., Ikumapayi, O. M., & Emuowhochere, T. O. (2022). Benchmarking and Multi-Criteria Decision Analysis Towards Developing a Sustainable Policy of Just in Time Production of Biogas in Nigeria. *Planning*, *17*(2), 433-440.

Okonkwo, E. C., Okafor, K. I., & 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., Okafor, I. S., Igwilo, K. C., Orodu, K. B., & Mamudu, A. O. (2020). Sustainable biogas production from waste in potential states in Nigeria–alternative source of energy. *Journal of Contemporary African Studies*, *38*(4), 627-643.

Okoro, E. E., Samuel, S. E., & Moses, E. E. (2019). Importance of Rural Biomass Post-Harvest Waste–An Overview. In *IOP Conference Series. Earth and Environmental Science* (Vol. 331, No. 1). IOP Publishing.

Olanrewaju, K. O., Akintunde, O. K., Adeoye, I. B., & Bamiwuye, O. A. (2021). Gender differential in leafy vegetable production in Lagelu Local Government Area of Oyo State, Nigeria. *Journal of Agriculture and Food Sciences*, *19*(1), 120-133.

Olukanni, D. O., Pius-Imue, F. B., & Joseph, S. O. (2020). Public perception of solid waste management practices in Nigeria: Ogun State experience. *Recycling*, *5*(2), 8.

Olusunmade, O. F. (2019). Plastic wastes separation practice and disposal mechanism by households, hospitals, markets and waste management body. *Int. J. Hum. Capital Urban Manage*, *4*(3), 189-204.

Osibote, E. A. S., Odesany, B. O., & Soetan, G. S. (2017). Generation and analysis of biogas from some animal and vegetable wastes. *Int J Biochem Res Rev*, *20*(4), 1-5.

Oyewole, S. O., & Sennuga, S. O. (2020). Factors influencing sustainable agricultural practices among smallholder farmers in Ogun state of Nigeria. *Asian Journal of Advances in Agricultural Research*, *14*(1), 17-24.

Patinvoh, R. J., & Taherzadeh, M. J. (2019). Challenges of biogas implementation in developing countries. *Current Opinion in Environmental Science & Health*, *12*, 30-37.

Pelletier, N., Bamber, N., & Brandão, M. (2019). Interpreting life cycle assessment results for integrated sustainability decision support: can an ecological economic perspective help us to connect the dots? *The International Journal of Life Cycle Assessment*, *24*(9), 1580-1586.

Purvis, B., Mao, Y., & Robinson, D. (2019). Three pillars of sustainability: in search of conceptual origins. *Sustainability science*, *14*(3), 681-695.

Raimi, M. O., Vivien, O. T., & Oluwatoyin, O. A. (2021). Creating the healthiest nation: Climate change and environmental health impacts in Nigeria: A narrative review. *Morufu Olalekan Raimi, Tonye Vivien Odubo & Adedoyin Oluwatoyin Omidiji (2021) Creating the Healthiest Nation: Climate Change and Environmental Health Impacts in Nigeria: A Narrative Review. Scholink Sustainability in Environment. ISSN*.

Rockström, J., Beringer, T., Hole, D., Griscom, B., Mascia, M. B., Folke, C., & Creutzig, F. (2021). We need biosphere stewardship that protects carbon sinks and builds resilience. *Proceedings of the National Academy of Sciences*, *118*(38), e2115218118.

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

Safder, U., Tariq, S., & Yoo, C. (2022). Multilevel optimization framework to support self-sustainability of industrial processes for energy/material recovery using circular integration concept. *Applied Energy*, *324*, 119685.

Saklani, N., & Khurana, A. (2019). Global warming: Effect on living organisms, causes and its solutions. *International Journal of Engineering and Management Research*.

Samuel, A. A., & Oladapo, A. O. (2022). Analysis of household cooking energy consumption and sustainable energy resources in Abeokuta South Local Government Area, Ogun State, Nigeria. *African Geographical Review*, 1-16.

Sawyerr, N., Trois, C., & Workneh, T. (2019). Optimization of Biogas Yield through co-digestion of Cassava Biomass and Vegetable & Fruits waste at Mesophilic Temperatures. *Int. J. Renew. Energy Res*, *9*(2), 771-782.

Sen, S., & Ganguly, S. (2017). Opportunities, barriers and issues with renewable energy development–A discussion. *Renewable and Sustainable Energy Reviews*, *69*, 1170-1181.

Sun, Q., Miao, C., Hanel, M., Borthwick, A. G., Duan, Q., Ji, D., & Li, H. (2019). Global heat stress on health, wildfires, and agricultural crops under different levels of climate warming. *Environment international*, *128*, 125-136.

Talan, A., Tyagi, R. D., & Surampalli, R. Y. (2020). Social dimensions of sustainability. *Sustainability: Fundamentals and Applications*, 183-206.

Tran, Q. B., Nguyen, T. P. T., Le, T. N., Schnitzer, H., Braunegg, G., Le, S., ... & Van Le, Q. (2020). Integrated farming system producing zero emissions and sustainable livelihood for small-scale cattle farms: Case study in the Mekong Delta, Vietnam. *Environmental Pollution*, *265*, 114853.

Trigo, A., Marta-Costa, A., & Fragoso, R. (2021). Principles of sustainable agriculture: Defining standardized reference points. *Sustainability*, *13*(8), 4086.

Ugwu, C. O., Ozoegwu, C. G., Ozor, P. A., Agwu, N., & Mbohwa, C. (2021). Waste reduction and utilization strategies to improve municipal solid waste management on Nigerian campuses. *Fuel Communications*, *9*, 100025.

Uhunamure, S. E., Nethengwe, N. S., & Tinarwo, D. (2019). Correlating the factors influencing household decisions on adoption and utilisation of biogas technology in South Africa. *Renewable and Sustainable Energy Reviews*, *107*, 264-273.

Von Braun, J., Afsana, K., Fresco, L., Hassan, M., & Torero, M. (2021). Food Systems–definition, concept and application for the UN food systems summit. *Sci. Innov*, *27*.

Wolf, J., Borges, M., Marques, J. L., & Castro, E. (2019). Smarter decisions for smarter cities: Lessons learned from strategic plans. In *New paths of entrepreneurship development* (pp. 7-30). Springer, Cham.

Yadav, S., Patel, S., Killedar, D. J., Kumar, S., & Kumar, R. (2022). Eco-innovations and sustainability in solid waste management: An Indian upfront in technological, organizational, start-ups and financial framework. *Journal of Environmental Management*, *302*, 113953.

Zhou, Y., Zhou, Q., Gan, S., & Wang, L. (2018). Factors affecting farmers' willingness to pay for adopting vegetable residue compost in North China. *Acta Ecologica Sinica*, *38*(6), 401-411.

8. Appendices

Appendix 1: Schedule of Project Activities

Table 12: Schedule of Project Activities

	Activity	Time Frame
1	Approval of Master's Thesis Topic	May
2	Writing and Approval of Proposal	August
3	Review of Literature	3 weeks
4	Design of Methodology and Approval	1 week
5	Questionnaire Design and Approval	3 days
6	Data Collection and Collation	December 5th – 30th
7	Data Entry and Analysis	January 6th – 20th
8	Interpretation of Result	January 23rd - 29th
9	Conclusion and Recommendation	February 1st – 8th
10	Review of Thesis	February 13th – 24th
11	Final Submission	April

Appendix 2: Images of study area

Annex 1: Dump site of waste products

Annex 2: waste being disposed using fire

Appendix 3: Questionnaire

Questionnaire no……

TOPIC: VEGETABLE AND FRUIT WASTE AS A SOURCE OF BIOGAS: CASE OF IPOKIA, NIGERIA

Dear Sir/Ma,

This Questionnaire is designed to collect data for use in the above stated research. Your sincere responses to the questions will be of great value to the study. Kindly supply the information and please be assured that the information provided will be treated with a high level of confidentiality and will be used for the advancement of the course for which the study is intended. Thanks for your anticipated co-operation.

Section A

Socio Economic Characteristics of the Respondents

Please fill/tick (√) the boxes with the most appropriate response

1. Age Group (Years): ……
2. Sex: Male ☐ Female ☐
3. Religion: Christian ☐ Islam ☐ Traditional ☐ Others ☐
4. Marital Status: Single ( ) Married ( ) Divorced ( )
5. Household Size: ……
6. What is your Highest Level of education: ……
7. How long have you been producing/marketing vegetables and Fruits (Years): ……
8. Average Monthly Income (₦): …….
9. Average monthly income from Vegetable and fruit production and Marketing ……

Section B

Waste Disposal Method

10. Is there a formal waste disposal system in your vicinity?
11. What form of waste disposal system is available in your vicinity and how frequently do you use it (Please tick appropriately and select the frequent of use)

	Availability	**Frequency of Use**				
	Y=Yes N=No	Always	Very Often	Sometimes	Rarely	Never

Open Burning						
Open Dumping						
Composting						
Dumping into drain Channels, Rivers and Streams						
Recycling (Conversion into other uses)						
Landfills						
Government Certified Waste Collectors						
Conversion into Biogas						

Section C

Vegetable and Fruit Waste

12. What is the volume of Vegetable and fruit waste that you produce weekly …….. kg

13. What percentage of it is lost as waste ……..%

14. What method do you use in the disposal of your vegetable and fruit waste

Leave in the open to rot ( )
Use as Biogas ( )
Open burning ( )
Dispose in abandoned lands ( )
Use as compost ( )
Use government disposal systems ( )
Dump in drains, river and streams ( )
Others…… ( )

15. Is there any cost associated with the disposal of the waste using any of the system? Yes ( ) No ( )
16. What is the financial cost? …….
17. Do you see the disposal of your vegetable and fruit waste as an environmental challenge? Yes ( ) No ( )
18. Are you willing to accept an alternative means of disposing your vegetable and fruit waste? Yes ( ) No ( )
19. Are you willing to utilise your vegetable and fruit waste for the generation of energy in your vicinity? Yes ( ) No ( )

Section D

Biogas utilisation, use and Perception

20. What is the Present source of energy you are using (You can select more than one option if it applies to you).

Please tick the one's that applies to you and your household stating the main source of energy and the secondary sources

Energy Source	**Main Source (Select only one option that serves as your main energy source)**	**Secondary Source (Select as many other sources that apply to you apart from the main source)**
Charcoal		
Wood		
Gas		
Kerosene		
Gas (LPG)		
Biogas		
Electricity		
Solar		
Others ……		

21. Are you aware of biogas? Yes ( ) No ( )
22. How did you get to know about biogas? ……..
23. Are you aware that Vegetable and fruit waste can be used to produce biogas? Yes ( ) No ( )
24. Are there any biogas facility within your vicinity Yes ( ) No ( )

25. Select your level of awareness and adoption from the option in the table below as regards the use of biogas. (Please select only one of the options from the table that applies to you)

Level of awareness and adoption of technology	
Not Aware at all	
Awareness (You have heard about it)	
Interest (You are Aware and interested in using it but need more information)	
Evaluation (You have the information but want to be sure about the technology)	
Trial Stage (You are giving the technology a trial on a small scale)	
Adoption Stage (You have started using it but not sure of using it continually)	
Post Adoption (You feel contented using it and will continue using it)	

26. Are there agents who sell digesters and service the facility available in your vicinity? Yes ( ) No ( )

27. Perceptions about Biogas

What are your perceptions about the use of Biogas?

Tick (√) the appropriate response.

SA= Strongly Agree, A=Agree, N= Neutral, D=Disagree, SD= Strongly Disagree.

	Item	**SA**	**A**	**N**	**D**	**SD**
1	The Biogas can be an alternative fuel for cooking					
2	Biogas can be used to generate electricity					
5	Using biogas can create job opportunities					
6	Using biogas can improve public health					

7	Biogas is an environmentally friendly way of disposing vegetable and fruit waste.					
8	Biogas is expensive to install					
9	The technology is too complicated to use					
10	Adoption of Biogas will not totally solve the problem of vegetable and fruit waste in the vicinity.					
11	Biogas is cheaper when compared to other energy sources					
12	Biogas is only for the rich and those with financial capacity					

Section E

Factors Influencing the Use of Vegetable and Fruit Waste as a source of Biogas

Tick (√) the appropriate response to understand the factors influencing the use of vegetable and fruit waste as a source of biogas. **SA= Strongly Agree, A=Agree, N= Neutral, D=Disagree, SD= Strongly Disagree.**

	Constraints	**SA**	**A**	**N**	**D**	**SD**
1	Availability of vegetable and fruit waste					
2	Capital					
3	Technical Expertise					
4	Awareness about Biogas					

5	Closeness of Biogas production facility					
6	Access to Information					
7	Access to credit					
8	Government Support					
9	Availability of technology in close proximity to market and farms					
10						

Section F

Barrier to the Use of Vegetable and Fruit Waste for the generation of Biogas

	Constraints	**Very High**	**High**	**Medium**	**Low**	**Very Low**
1	High Cost of Biodigester					
2	Lack of parts for the construction of the biogas facility					
3	No knowledge about the importance of biogas in utilisation in waste management					
4	Lack of skills to manage					

	the waste and biogas facility					
5	High cost of moving the vegetable and fruit waste to the biogas facility					
6	Low level of Demand for Biogas					
7	Climatic condition					
8	Lack of finance and capital to procure the technology					
9	Low Awareness Level					
10	Limited Knowledge on the Benefits of Adopting the Technology					
11	Inability to test the efficacy of the Technology					

Other barriers affecting the use of vegetable and fruit waste for biogas ……. .....

Thank You