Original Research Article

# Assessment of biowaste for bioenergy and its sustainable adoption strategies in the Federal Capital Territory, Nigeria

Abstract

This study investigates the potential of biowaste as a resource for bioenergy development in the Federal Capital Territory (FCT). A quantitative approach was employed, using 99 completed questionnaires from artisans and small- and medium-sized enterprises, including food vendors, grocers, and vegetable vendors in the FCT. The research tool evaluated the types and amounts of biowaste generated from agricultural residues, food waste, and organic matter from their businesses. The questionnaires also collected information on socioeconomic characteristics, bioenergy adoption strategies, and waste management techniques. Findings revealed that (i) most enterprises are operated by young adults aged between 31 and 41 years; (ii) respondents mostly hold university degrees or Higher National Diplomas, with an average daily customer count of 20; (iii) the enterprises mainly produce food waste (both solid and liquid), averaging 8 kg daily; (iv) they do not use reliable waste management practices such as sorting; (v) they spend approximately 15,000 Naira weekly on cooking fuel, primarily Liquefied Petroleum Gas; and (vi) financial constraints are a significant barrier to adopting biogas as a clean energy source. Additionally, statistical tests showed that the type of waste (animal and plant-based or both) and the frequency of waste generation are strongly significant factors in bioenergy adoption. The study concludes that biowaste is frequently generated among small- to medium-sized food vendors, offering substantial opportunities for bio-entrepreneurs in the FCT. The study also provides pertinent recommendations.

Keywords: Biowaste, Federal Capital Territory, Biowaste adoption, food waste, socioeconomic of biowaste, Biowaste management

1.0.Introduction

Reliable energy is a prerequisite to achieving sustainable economic and national development. However, compared with their developing African counterparts, most developed economies in Europe, America, and Asia have significant electricity per capita, contributing to their economic growth and national prosperity. For instance, electricity Per Capita in the sub-Saharan African (SSA) region, excluding South Africa, is 180 kWh, compared to 13,000 kWh per capita in the United States and 6,500 kWh in Europe (Hafner & Raimondi, 2022). The high electricity consumption in developed economies is the main reason for their socioeconomic development as they reduce business costs, unlock economic potential, and create jobs. This is attributed to the ability of developed countries to harness energy content from different energy sources, especially alternative energy sources, among others. Meanwhile, the low electricity per capita in developing nations could be attributed in part to their inability to effectively harness other energy sources, such as renewable energy sources, including biowaste and residues. They have led to hundreds of thousands of deaths annually due to the use of wood-burning stoves for cooking, handicaps in the operations of hospitals and emergency services, compromises educational attainment, and increases in the cost of doing business.

The technical potential of solar, biomass, wind, and geothermal energy is significant in SSA. However, only a fraction of it is currently employed to meet the region's modern energy demand. Although solar, wind and hydropower are consumed in their refined form to generate electricity in some SSA countries, and biomass and biowaste are still consumed in their raw forms to meet heating demands. Consuming biomass and biowaste in their raw forms, such as burning forest wood, decomposed forest resources, food waste, and animal and plant residues, has high inefficient, providing energy content and causes environmental pollution. Burning biomass for heating has made children and women vulnerable to its negative impacts and is linked to several severe health challenges and negatively impacting their socioeconomic well-being (US-EPA, 2024).

In terms of environmental pollution, plant residues and kitchen waste, such as rice stalks, bean shafts, and kitchen waste in the form of oil, food waste, etc., that are generated from food processing industries, have not usually been transformed to meet modern energy demands. Such residues and wastes have been used to feed animals and have sometimes been indiscriminately disposed, causing significant environmental pollution. Many indiscriminately disposed wastes have decomposed in the neighborhoods and found their way into waterways and blocked drainages, causing flooding (Nnamani & Odoh, 2021). This menace. Environmental pollution caused by the indiscriminate disposal of biowaste and kitchen residue is a major issue in major cities in developing countries, making the population vulnerable and susceptible to viruses and bacteria-caused diseases.

Nigeria, with a population of over 200 million, has over 90 million people who are energy insecure and is referred to by the World Bank as the World Energy Poverty. The largest black nation has a significantly degradable plants, animal residue and waste that is not effectively harnessed to meet modern energy demands. However, this waste is trashed indiscriminately or incinerated. The country is also experiencing significant environmental degradation caused by the indiscriminate disposal of both plant and animal wastes. In many major cities in Nigeria, waste disposal is a major challenge, as much waste is found in waterways and drainage systems, contaminating water bodies, blocking water channels, and causing several variants of catastrophic health challenges.

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Several studies have investigated the types of waste, modes of transformation, adoption strategies, efficiency, and approaches to sustainable utilization to meet modern energy demands. –For instance, Xu et al. (2022) found that biowaste transformation is significant for achieving a circular economy. Transformation technologies that incorporate biowaste recycling and bioconversion into high-value energy will enable a circular bioeconomy (Hasan et al., 2023). Moreover, the thermochemical conversion of biowaste into usable products could help achieve the United Nations Sustainable Goals, and biowaste-derived materials can be used as multidimensional biomaterials that could contribute to reducing greenhouse gas emissions (Atinafu et al., 2024). In addition, Chavan et al. (2022) reviewed a study that claimed that the bioconversion of organic wastes into value-added products, such as biodegradable matter, could be used in biorefineries and bioeconomy, and that the use of industrial biowaste as a feedstock can lead to ecological sustainability.

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~~In addition,~~ Escalante (2013) used a dynamic approach to investigate the adaption of biowaste among households and revealed that insufficient awareness was a major limitation among

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households that have yet to adopt energy from biowaste. In separate studies, Alsaleh et al. (2021) and Shari et al. (2022) stressed that awareness and other socioeconomic variables, such as income and household size, are relevant to adoption, especially for heating. Similarly, Singh et al. (2021) and Nwankwo et al. (2024), in a review study, outlined that strategic policy design and its implementation are as significant as other variables in adopting bioenergy to meet a nation's energy demand.

Several studies have reviewed and investigated bioenergy adoption in Africa (Dahunsi et al., 2020), sub-Saharan Africa (World Bank, 2014) and Nigeria (Okoro et al., 2024; Onwumelu, 2023). Similarly, Adeiza et al. (2024) investigated the mode of solid waste collection at the Municipal Area Council of the Federal Capital Territory. The study revealed that approximately 46.23% of waste is organic waste, which is the major type of waste generated in the Federal Capital Territory (FCT). In the same study, approximately 55.71% of residents who generated these wastes preferred the government-approved dump site to dispose of their waste. However, these studies have not looked into adoption methods that make use of the waste produced and strategic initiatives that might use biowaste to meet energy demand. ~~However~~Though, it is estimated that Nigeria generates around 183.3 ± 8.9 MT of agri-food waste per annum, of which approximately 27% of edible agri-food is lost before reaching the market and final consumers (Afolabi et al., 2021). The author further revealed that bioenergy potential generated annually from inedible agrifood loss waste is estimated to be 1,816.8 ± 117.3 PJ and is enough to meet the 2030 bioenergy targets and replace a third of the total grid, off-grid and self-generated supply target.

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Against this backdrop, there is evidence that biowaste and bioenergy hold significant promise and potential for achieving Nigeria's energy security in the present and future. This study is placed in the same framework as dovetailing efforts to harness energy from biowaste in the Federal Capital Territory, Nigeria. Thus, this study will investigate a region-specific evaluation of how agri-food loss, especially non-edible waste, is effectively utilized. Some studies, such as Adeiza et al. (2024), have evaluated household disposal approaches to discard their biowaste in the FCT. A few studies have estimated the amount of biowaste generated in Nigeria (Afolabi et al., 2021). However, no studies have investigated biowaste adoption strategies in FCT. More so, the method of investigation in the study is a mixed-method approach, which makes a unique blend that ensures a reliable outcome from samples through a probability and non-probability framework.

Thus, the current study adds significant value to existing research by investigating how biowaste generated from households and small, medium, and scale enterprises in the FCT is used. Objectively, the current study aimed to evaluate the strategic adoption and effective utilization of bioenergy from biowaste for national development. Accordingly, the following research questions were addressed in the study: 1) What are the categories of biowaste generated in the FCT across several sectors and modes of disposal? (2) Is biowaste effectively used to provide and promote clean energy solutions? 3) What Will initiatives best enhance the effective utilization of biowaste in the FCT?

2.0. The Study Methodology

2.1. Study Area

The Federal Capital Territory (FCT) is Nigeria's capital, with over 3 million people as of 2020, and is one of the fastest-growing cities in Africa (National Bureau of Statistics, 2020; Bashir et al., 2021; Statista, 2022). FCT provides diverse opportunities to different population strata, ranging from low-to high-income earners. In the FCT, many, especially low-income earners, are engaged in roadside food ventures, such as transforming harvested farm produce, such as maize, plantains, and pears, etc., by roasting them into edibles (Ahmed et al., 2019; Ajah, 2015).

In the capital city, there are also significant roadside vendors of edible fruits, vegetables, sugarcane, and sachet water, as shown in Figure 1. Roadside vendors generate a significant amount of vegetable waste (Jun et al., 2022). It is interesting to note that many passersby depend on roadside vendors to meet their daily food needs because they are cheaper and accessible, as vendors will not have to pay large amounts for shops or office spaces, thus resulting in cheaper edible items, which makes them have a significant number of customers (Adeosun et al., 2023). Thus, more agri-food waste is generated in the form of banana peels, maize cobs, and vegetable waste.

In addition, significant waste is generated from processing industries such as the wood processing and grain milling industries in the Federal Capital Territory. Figures 2 and 3 show cross-sectional views of some grain processing and wood mill factories, respectively, in the FCT. Similar to high- and middle-income vendors, there are few regulated food and processing industries, especially eateries, grocery stores, and rice processing industries, where significant kitchen waste is generated.

Figure 1. Roadside vendors of fruits, vegetables and perishable food items (source: current study)

It is estimated that there is a significant amount of waste: approximately 1.3 billion tonnes of kitchen waste generate and approximately one-third of the food produced worldwide (World Bank, 2020). These amounts of waste could generate approximately $4.33 \times 10^9$ kWh of electricity annually (Kurniawan et al., 2024), which is sufficient to meet the energy demand in the form of heat and electricity of approximately 50 million households annually. Therefore, there is a need to investigate different adoption strategies that could enable better harnessing of waste-to-energy for socioeconomic development in developing countries.

In most developing countries like Nigeria, regulated food industries, when compared to non-regulated roadside vendors, generate significant food waste, such as leftover food, vegetables, and used cooking oil, which are mostly trashed (Todd & Faour-Klingbeil, 2024). In addition, most of the garbage is combusted in an incinerator or dump site, causing environmental degradation and pollution (Alabi et al., 2021). However, the generated wastes, including municipal solid waste (Dickson et al., 2023), could be better utilized for generating clean energy to meet the heating and power demands.

Figure 2. Grain shaft in a small-scale enterprise (source: current study)

The National Policy on Solid Waste Management has significantly spelt out management practices for waste generation (NPSWM, 2020). Unfortunately, energy recovery from the generated waste is often not enforced in Nigeria, including the FCT. Often, waste generated is sought after by pastoral farmers to feed their animals, and sometimes a larger part of the waste ends up on the street due to indiscriminate disposal (Hasan & Lateef, 2024).

Figure 3. Wood shavings waste from a sawmill/wood factory source: (current study)

2.2. Research design

Research design adopted in the study is a quantitative. In the quantitative approach, descriptive and correlational designs were considered, which enabled the Authors to understand the characteristics, trends, and relationships and to measure relevant variables that answer the research questions (Finley & Magalis, 2023). Moreso, a verbal consent statement requesting participants' involvement as anonymous respondents in the quantitative survey was issued ab initio.

2.2.1. Population and sampling method

The study population included sources of bio-waste generated in the Federal Capital Territory (FCT). Specifically, the population engages in commercial and non-commercial activities to produce bio-residue. These include commercial road sellers of perishable products such as vegetables, kitchen waste, corn shafts, and banana roasters (Bolie). Thus, the waste generated can be categorized as plant-based, animal-based, and kitchen waste. In addition,, the category-based category includes solid waste, liquid waste, or both. Hence, the study population is focused on those that generate animal- and plant-based waste that could otherwise be used as a bioenergy resource to generate biogas energy.

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Due to the uneven and unique spatial distribution of the FCT, which includes highly urban, peri-urban, and some very rural areas, both probability and non-probability sampling methods were employed to collect data from a sample of the population. As the population is large and the authors cannot reach the entire population equally, a non-probability sampling approach was used to sample participants, according to Sapsford and Jupp (1996). In the non-probability sampling method, convenience, snowball, and purposive sampling techniques were employed based on the following criteria: i) availability and ease of accessing the biowaste or residue; ii) referee from other participants; iii) researcher's judgment of what the sample needs to include due to scarcity of some biowaste generators; and v) method that provides adequate statistical inferences about the population.

The use of probability sampling ensured that each member of the population had a known and non-zero chance of selection, thereby reducing bias and enhancing the representativeness of the findings. A random sampling was used to capture diversity within the population due to the diverse characteristics of the sample and population sizes. The combination of these approaches provided a balance between statistical representativeness and practical feasibility, thereby strengthening the overall reliability and validity of the data collected. The combination of the two approaches, while useful in balancing representativeness and practicality, may also have created inconsistencies in data representativeness. Consequently, results were interpreted with caution, acknowledging that statistical rigour and feasibility were not perfectly aligned.

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2.2.2. Data collection

This study employed a quantitative research method to collect primary data through an elaborate survey of the FCT. Primary data were collected using a structured a questionnaire. The survey focused on respondents involved in at least one of the following commercial activities that generate bio-waste: i) roadside food vendors, ii) grocery stores, iii) the agri-processing industry, and iv) sawmills (as discussed in the research design). The survey combined systematic and purposive, random, and non-random sampling techniques across the study area and respondents (Akpan et al., 2023).

The research tool, which is a questionnaire, was distributed in person and contained three thematic sections that captured relevant aspects to answer the research questions and provide a reliable outcome of the objectives. The sections are a) demography, b) bio-waste categories, and c) potential energy utilization and support. The thematic sections contained closed-ended questions relevant to answering the study's research questions and providing sufficient insights to achieve the study’s research objectives.

To ensure valid and reliable outcomes, measurement materials (questionnaires) were thoroughly researched and carefully designed. In addition, the procedures used to dispatch them to the appropriate respondents were consistent among all participants/respondents. As such, about 300 potential respondents were identified through a reconnaissance survey earlier conducted

The research survey process is represented in Figure 4. According to Figure 4, correspondents distributed approximately 150 questionnaires to respondents over a period of three months (August to November 2024). Out of the 150-questionnaire distributed, only approximately 130 questionnaires were returned to correspondents, as some of the respondents did not return their questionnaires.  Of the 130 research instruments recovered, about 24% were either incorrectly fielded or had a lot of missing information relevant to the survey, and this could be largely due to the level of education of respondents, as many of the participants were not educated.

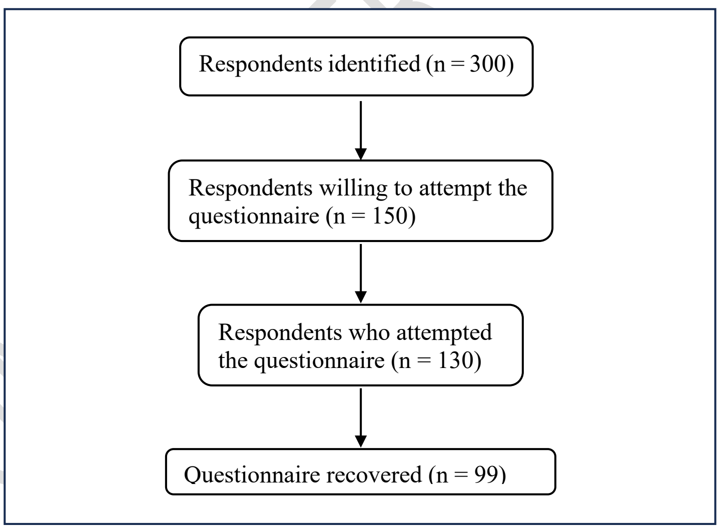


Figure 4. PRISMA-style flow diagram representing questionnaire attendance

As such, approximately 76%, which represents approximately 99 questionnaires, were healthy and fit for the study. Verbal and written consent were obtained from all respondents before data collection, following the guidelines set by the Ethical Committee of the University of Venda. Also, Participants were informed of their rights and the study's objectives.

2.3. Method of analysis.

To achieve this, an appropriate statistical approach was considered, such that it summarized the data through tables and charts. In addition, estimates and test hypotheses about the relationships between thematic variables were conducted through inferential statistical analysis. A logistic regression analysis and chi-square test to investigate the effect of one thematic variable on the other and to determine whether two categorical variables are related were used for inferential statistical analysis and to determine whether data are significantly different from the study expectation, that is,, to test for hypothesis.

Equation 1 shows the equation that represents Pearson's chi-square test, as applied in this study. The Chi-square test is a common nonparametric test used for data that do not follow the assumptions of parametric tests, especially the assumption of a normal distribution. Statistical methods test whether the observed frequency distribution of a categorical variable is significantly different from its expected frequency distribution.

$$X^2 = \sum \frac{(O_i - E_i)^2}{E_i} \quad (1)$$

$$Chi - square\ (X^2) = \frac{(observed\ value - expected\ value)^2}{expected\ value}$$

Where $O_i$ is the observed value and $E_i$ is the expected value.

The study uses the Chi-square test statistical approach to test and investigate the following hypothesis: Here, the following notations are used: $H_o$: Null hypothesis and $H_a$: Alternative hypothesis.

$H_o$: There is no significant relationship between the frequency of waste generated and willingness to adopt bioenergy.

$H_a$: There is a significant relationship between the frequency of waste generation and the willingness to adopt bioenergy.

$H_o$: There is no significant relationship between the category of waste generated and willingness to adopt bioenergy.

$H_a$: There is a significant relationship between the type of waste generated and willingness to adopt bioenergy.

$H_o$: There is no significant relationship between the type of waste generated and willingness to adopt bioenergy.

$H_a$: There is a significant relationship between the type of waste generated and willingness to adopt bioenergy.

3.0. Results and discussion

This section presents the results of the descriptive and statistical analyses. The findings of the analysis and tests associated with the data from the sections of the questionnaire are presented in a descriptive analysis, followed by the findings of the tests and analysis. The outcomes of the test and analysis are outlined accordingly: a) socioeconomic description of biowaste producers in the FCT (section 3.1); b) characteristics of biowaste generated and accompanying knowledge of biowaste to biogas (section 3.2); c) role of biowaste in promoting clean energy solutions (section 3.3), and d) initiative for effective utilization (section 3.4) using both descriptive and inferential statistical approaches.

3.1 Socioeconomic description of biowaste producers

The socioeconomic characteristics of biowaste producers are gender, age, employment status, marital status, household size, average household income, marital status, and level of education. These variables provided a succinct overview of the respondents' socio-economic outlook.

Figure 5 shows the gender of the respondents: 54% were male and 46% were female. The Figure shows that out of the 99 respondents, 53 and 46 were male and female, respectively. Although the male-female gender is about 4% higher than the female gender, this difference is marginal. As such, there is a close balance between male and female participation in the biowaste generation in the FCT. The balance could imply that both genders are actively involved in the selling of perishable products in the capital city.

Similarly, the age distribution of respondents involved in biowaste production in the FCT is shown in Figure 6. Over 44% of respondents were within the age range of 35–44 years, around 30% fell between 25 and 34 years, and approximately 19% were aged 18–24. This indicates that over 90% of the respondents were young. Conversely, older respondents made up less than 10% of those aged 45–65 years. Interestingly, none of the respondents was over 65 years old. The age below 18 years suggests that many teenagers in the FCT are not involved in various artisan activities, such as roadside selling.

Figure 7 shows the employment attributes and choices of artisan enterprises producing biowaste in the study area. Employment attributes and choices included employment status, type of employment, and category of self-employed. Accordingly, about 92% of the respondents claimed that they were employed, and less than 10% claimed to be retained or unemployed. Based on the type of employment, over 90% of respondents claimed that they were either self-employed or belonged to a private organization; meanwhile, about 40% claimed to be self-employed, and less than 10% were employed by the government. This could mean that most of the respondents perceived their business as a form of employment for them, and some were combining working with either the government or private organizations with a medium- and small-scale enterprise.

In addition, approximately 80% of the respondents who claimed to be self-employed operated small- and medium-sized food businesses. Of these, about 50% operate cafeterias or restaurant outlets and local food enterprises (that is, those that largely operate by the roadside using a few small coolers, benches, and tables). In addition, less than 20% of the self-employed are engaged in animal breeding through husbandry.

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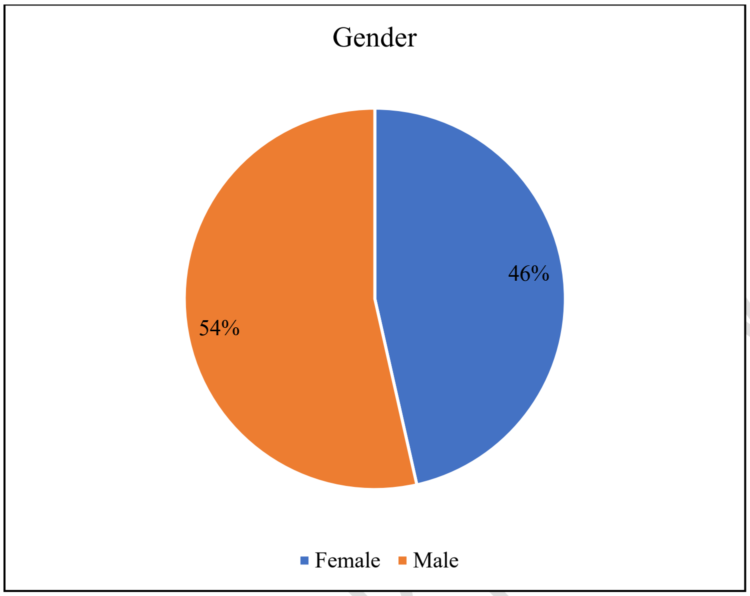


Figure 5. Gender of biowaste producers in the FCT

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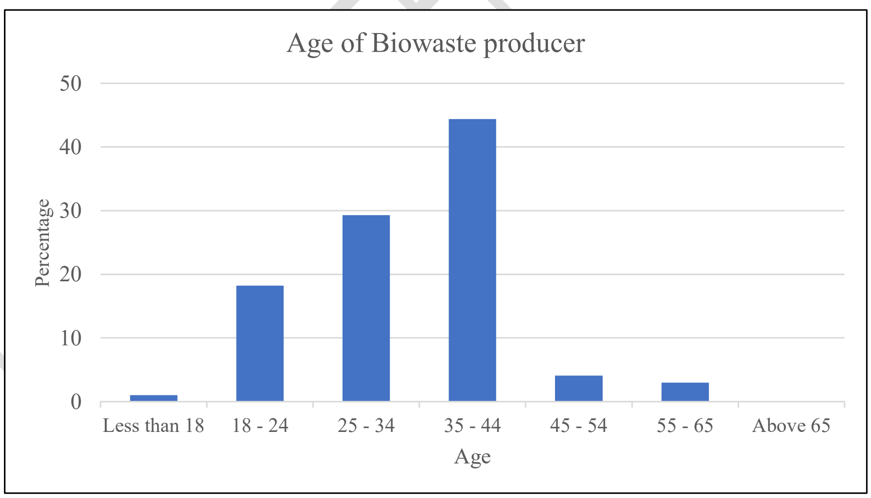


Figure 6. Age distribution of biowaste providers in FCT

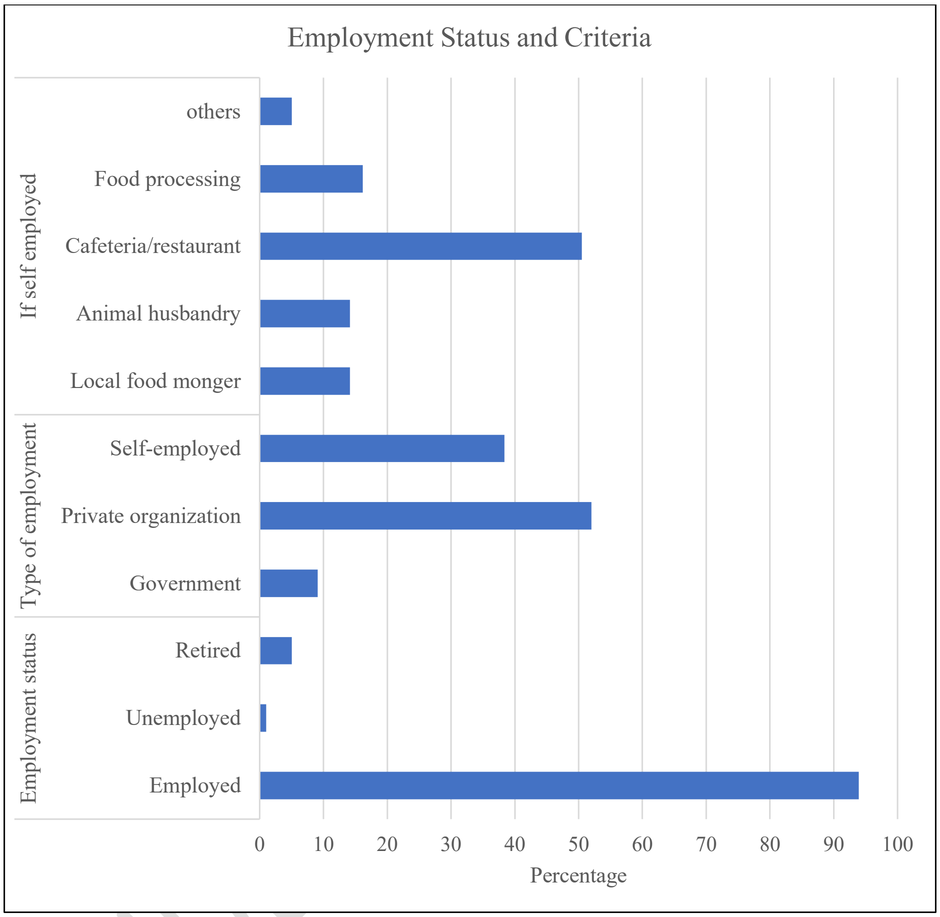


Figure 7. Employment status and other employment attributes of biowaste generators

Furthermore, marital status and education level are significant socioeconomic variables that reveal the marital and educational status of respondents and play a significant role in the overall output of biowaste generation. Figure 8 shows the marital status and educational level of the respondents. A significant number of ~~Almost~~ almost 60% of respondents claimed to be married, followed by about 25% who claimed to be widowed, around 15% were single, and a small number of  less than 3% claimed to be divorced.

About 68% of the respondents were graduates of bachelor's degrees or Higher National Diploma (HND), of which around 38% had bachelor's degrees and 31% had HND. In addition, 20% of the respondents were National Diploma (ND) degree holders, less than 10% were secondary school leavers, and less than 5% were primary school leavers. Similarly, the percentage of master's degree holders was less than 5%. While all the respondents had attained an educational status,, none of the respondents had any education. This implies that more married respondents who have acquired basic and higher education are involved in medium- or small-scale businesses/enterprises that generate plant, animal, or kitchen-based biowaste.

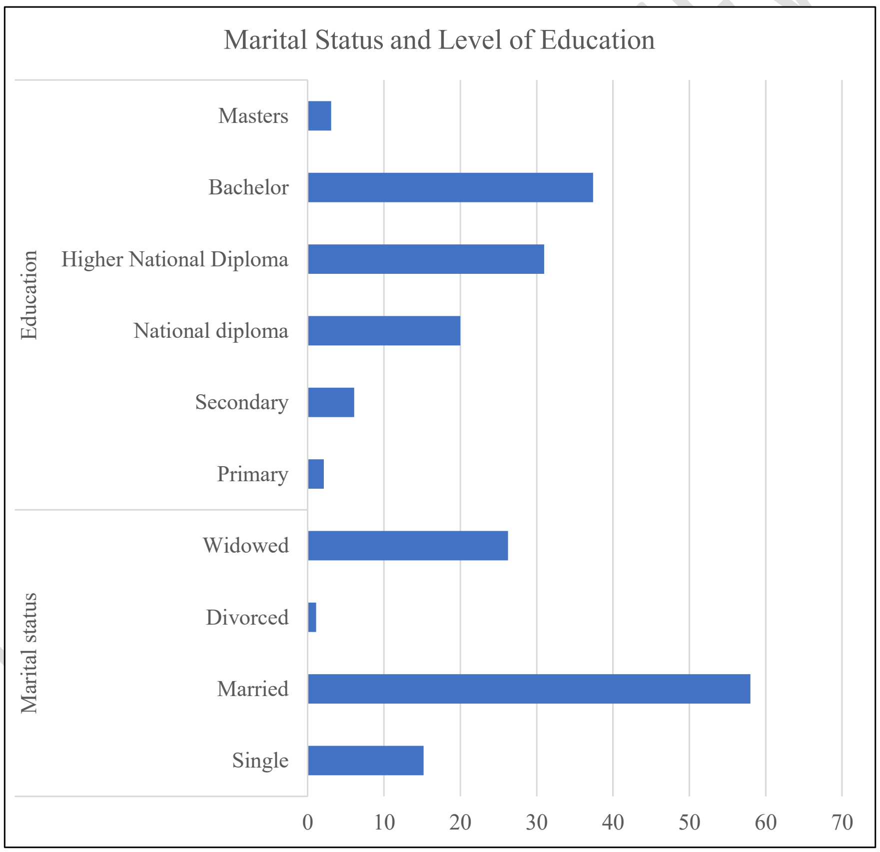


Figure 8. Marital status and Education level of respondents

Further, the socioeconomic descriptive outlook of respondents, the number of customers per day, average monthly income, and the household size are relevant social and economic parameters. These parameters investigated the respondents' economic capacity and estimated expenses through household size, as shown in Figure 8. According to Figure 8, about 54% of respondents claimed that they received around 10 to 15 customers per day, followed by about 30% of respondents who claimed to record over 15 customers who patronized their business outfit per day.

**Comentado [RH6]:** No correct, it is Figure 9

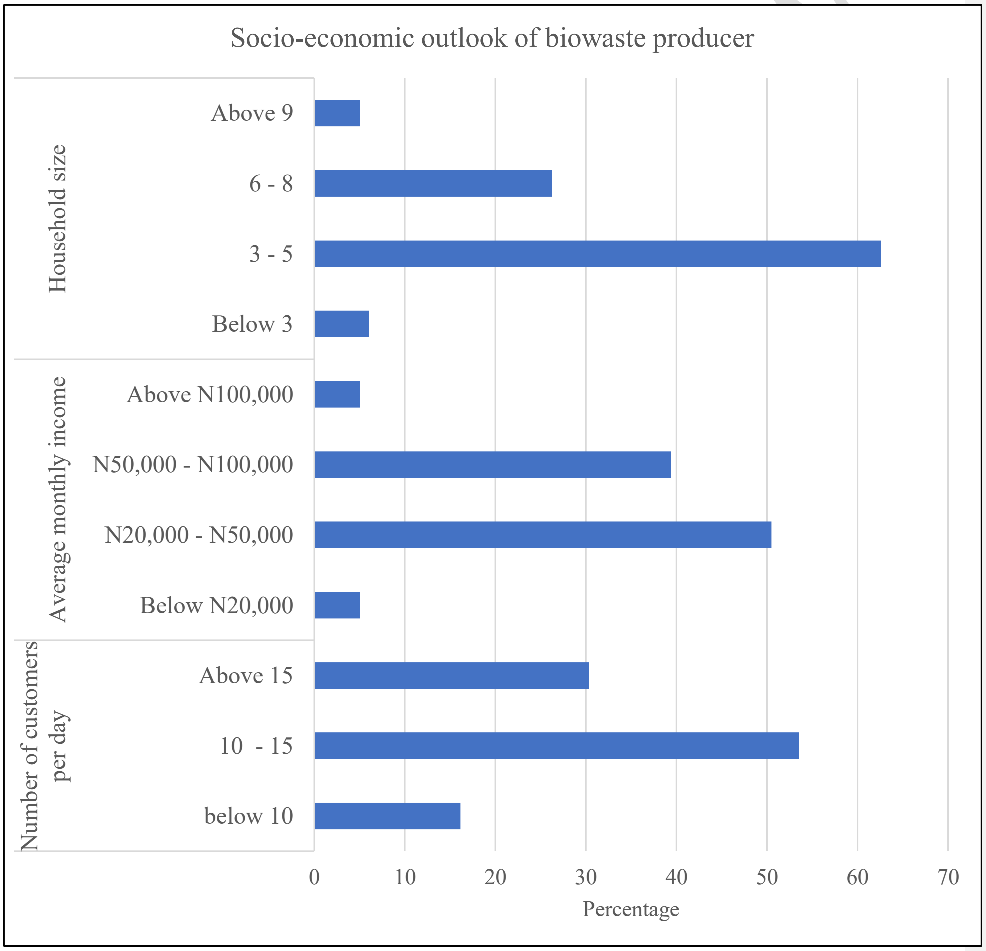


Figure 9. Socio-economic outlook of biowaste producers in the FCT

In addition, about 51% of the respondents claimed they earn between N20,000 and N50,000 a month, around 39% earned between N50,000 and N100,000, and less than 10% claimed to earn above N100,000 and below N20,000 every month. In terms of household size, over 60% of respondents claimed that they had a household size of between three and five people, followed by about 20% who claimed to have between six and eight people in their household.

3.2. Characteristics of biowaste generated and the accompanied knowledge of biowaste to biogas

This subsection presents the characteristics of biowaste, its management, and awareness of its benefits. The characteristics of the generated biowaste (Figure 9), amount of generated waste (Figure 10), biowaste management practices (Figure 11), cooking attributes and biogas awareness (Figures 12 and 13), willingness to use biogas (Figure 13), and support for biogas utilization to meet heating and cooking needs (Figure 14) are presented and discussed.

Figure 9, shows the characteristics of biowaste generation based on i) category of waste source; ii) waste type; iii) frequency of waste generation; and iv) waste generated. The category of waste sources revealed that about 65% of respondents generated kitchen waste, followed by 23% and 11% plant and animal-based waste, respectively. Regarding the type of waste generated, approximately 88% of the respondents claimed that they generated both solid and liquid waste. For the number of times (frequency) waste is generated, ~~Over~~over 50% of respondents claimed that they generated waste daily, about 25% claimed that their wastes were generated weekly, and about 20% generated waste every two days.

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In terms of waste generated, over 80% of respondents claimed that they generated food waste, and less than 10% of respondents claimed that they generated other wastes, such as used cooking oil, poultry waste, and cassava waste. Figure 9 reveals  that most of the biowaste generated from the FCT is food waste, either solid or liquid waste.

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Figure 10 shows the daily waste generation according to respondents. Approximately 38% of respondents claimed that they generated between 2.1 and 5 kg of waste daily. In addition, approximately 25% of respondents claimed that they generated 5.1 and 10 kg of daily waste. Likewise, almost 20% of the respondents reported that they generated over 10 kg of waste daily. This suggests that significant kitchen waste is generated daily.

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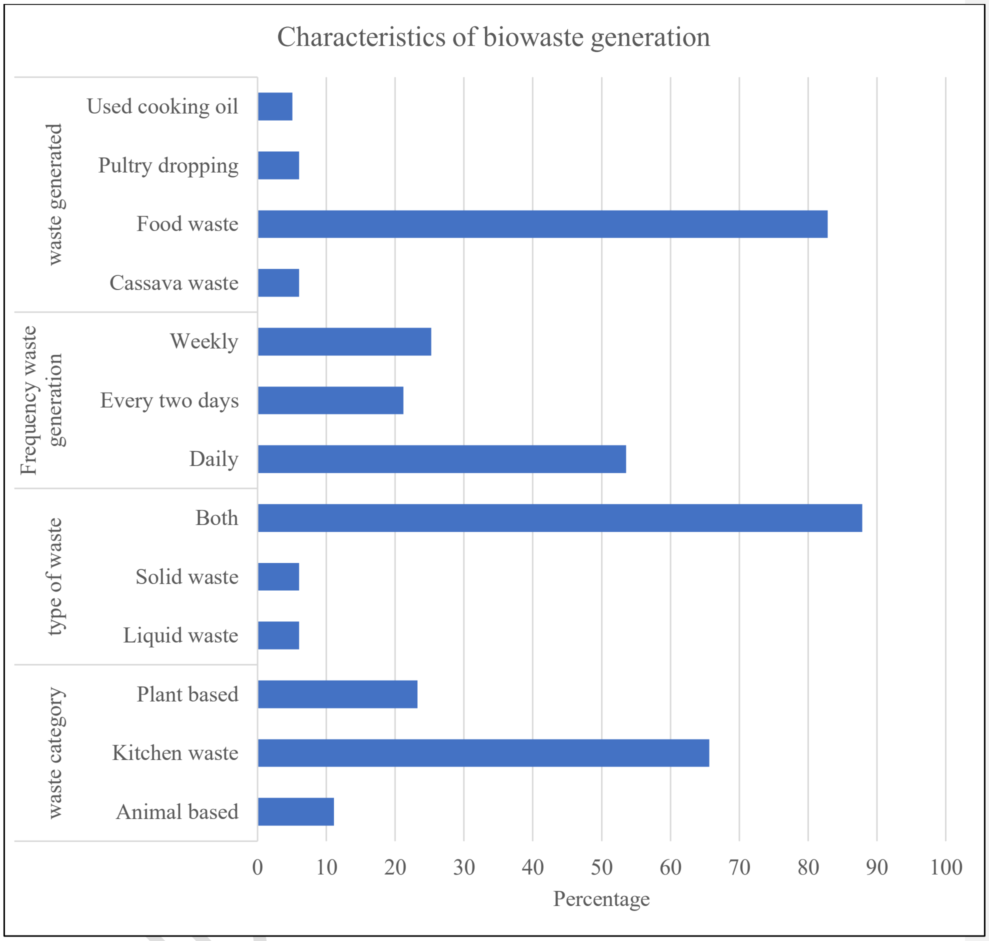


Figure 10. Characteristics of biowaste generated in the FCT

Figure 11 illustrates the biowaste management strategies, which are discussed in the following highlights: waste sorting, methods of solid and liquid waste disposal, and frequency of waste disposal. According to Figure 11, over 75% of respondents claimed that they did not sort their waste before disposing them. For solid waste disposal, over 65% of respondents claimed that they pay some disposal agency to dispose of their waste, while over 50% of respondents claimed they paid disposal agents to dispose of their waste; however, over 30% of respondents claimed they disposed of liquid waste in nearby drainages.

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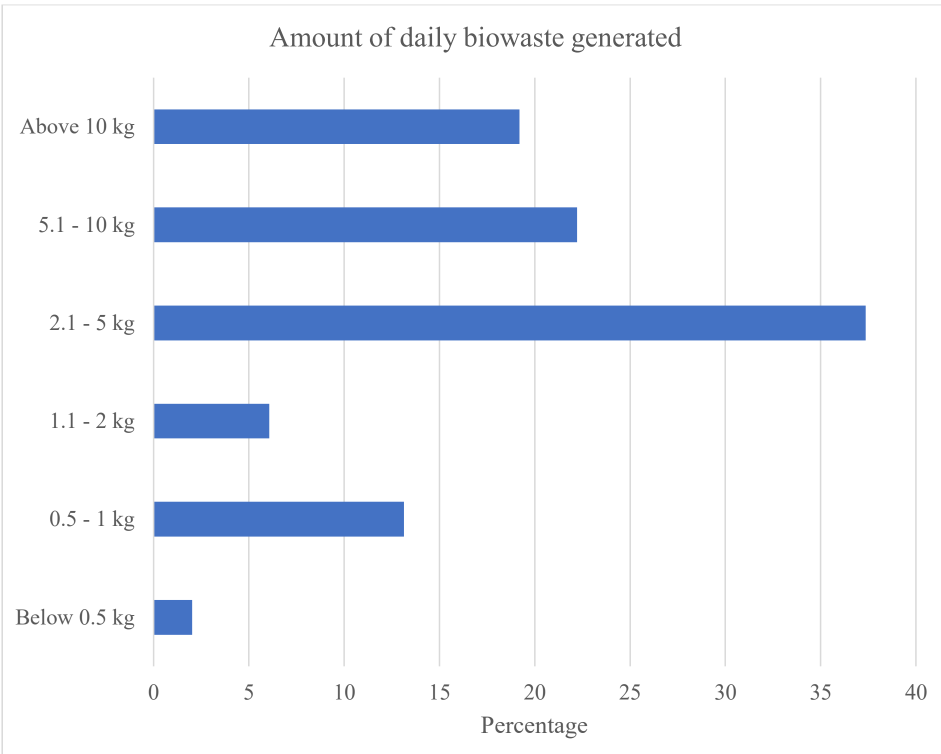


Figure 11. Average daily biowaste generated

In addition, approximately 45% of respondents claimed they dispose of their waste daily; however, approximately 28% of respondents claimed they dispose of their waste twice weekly or weekly.

The choice of providing heat for cooking, cost, and biowaste awareness are shown in Figure 12. About 60% of the respondents claimed that they were not aware of the potential of biowaste to meet their cooking needs; on the other hand, around 22% and 18% of respondents indicated that they were aware and were not sure of the possibility of utilizing energy from biowaste to provide their heating and cooking demands. A significant number of respondents (over 80%) claimed they were willing to meet their cooking demand; in doing so, around 70% claimed that they had been using Liquefied Petroleum Gas (LPG) to provide energy to meet their cooking needs. However, less than 5% claimed that they had already deployed biowaste energy. In addition, less than 15%

of respondents claimed that they used traditional biomass in the form of firewood and charcoal to provide heating and cooking demands.

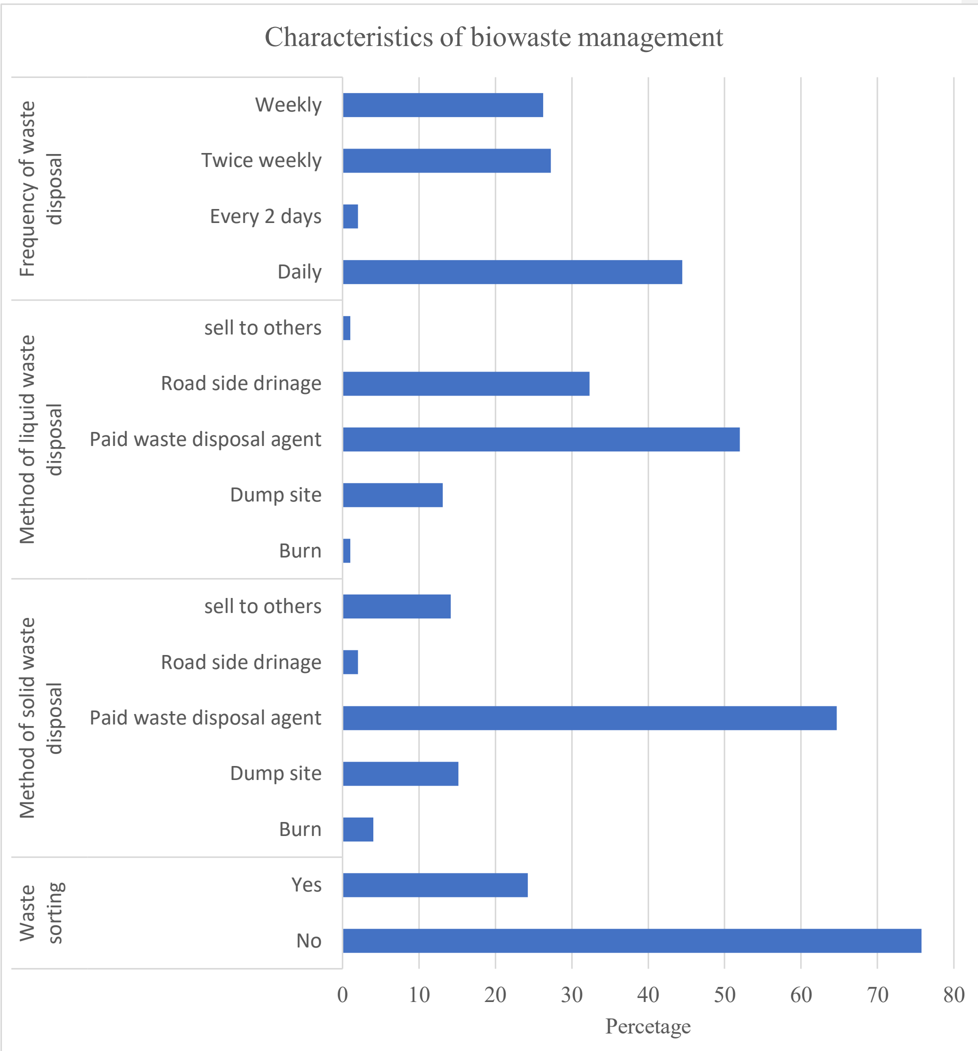


Figure 12. Characteristics of biowaste management techniques

Regarding the cost of providing energy to meet cooking needs, approximately 38% of respondents claimed they spent between N5,000 and N10,000, and 38% claimed they spent over N10,000 every month to meet their cooking needs.

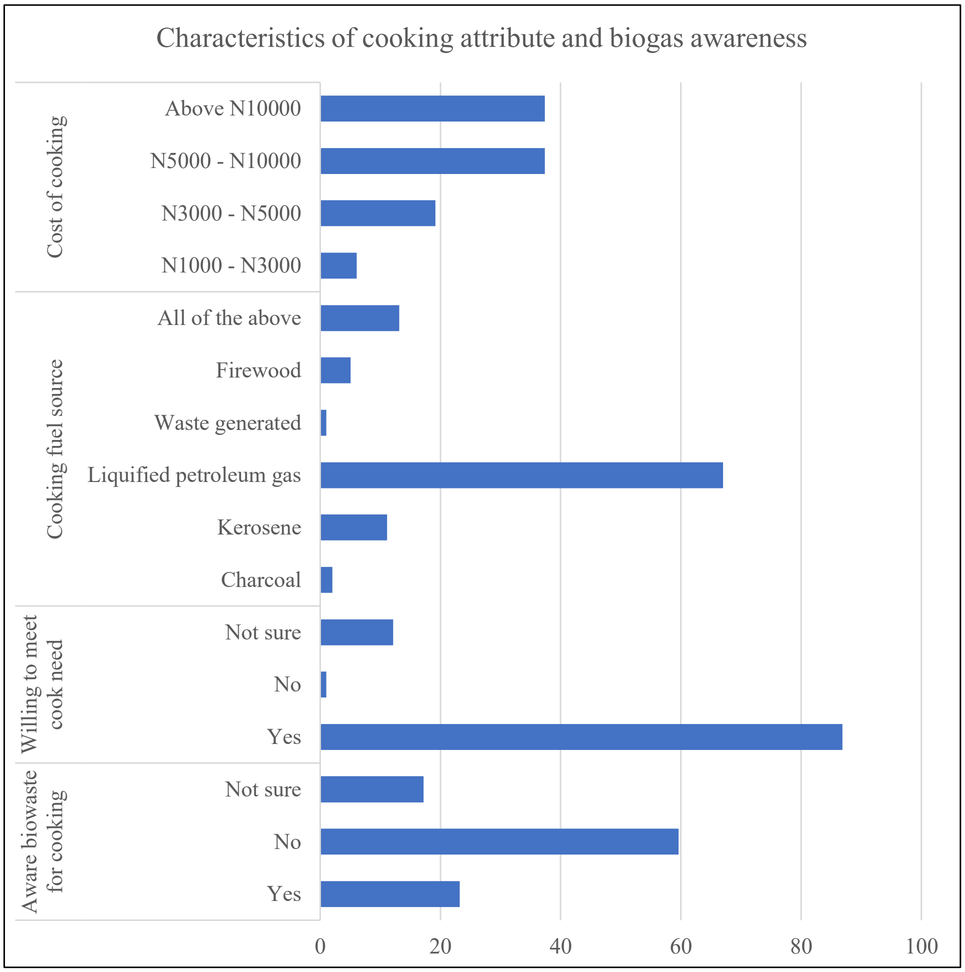


Figure 13. Cooking choice and its cost attributes based on biowaste to biogas awareness

Figure 13 shows the awareness levels of bioenergy and biogas adoption among the respondents. All the respondents claimed that they were aware of biogas as an alternative clean cooking source, and almost 40%, 25%, and 21% revealed that they had received their information about biogas from Television, Radio programs, and social media, respectively. Very few claimed to have received information from their communities and social gatherings, including schools.

Over 75% of the respondents were willing to deploy biogas to meet their heating and cooking needs, and the remaining 25% were indifferent. However, none of the respondents claimed that they were willing to adopt biogas. When asked why they would adopt alternative clean cooking technology, around 45% and 40% of respondents revealed that they would adopt clean technology to meet their heating and cooking needs and generate additional income (i.e., as biogas entrepreneurs), respectively. Similarly, about 10% claimed that they would adopt biogas to become an advocate for supporting the National Clean Energy Program, such as the Sustainable Development Goals (SDGs) and Nationally Determined Contributions (NDCs).

Regarding the support for biogas shown in Figure 14, over 90% of the respondents claimed that they would need support to transform biowaste into bioenergy. About 70% of the respondents revealed that access to finance is the major support they would need, while around 30% claimed that training and access to technical support are the paramount support they would need.

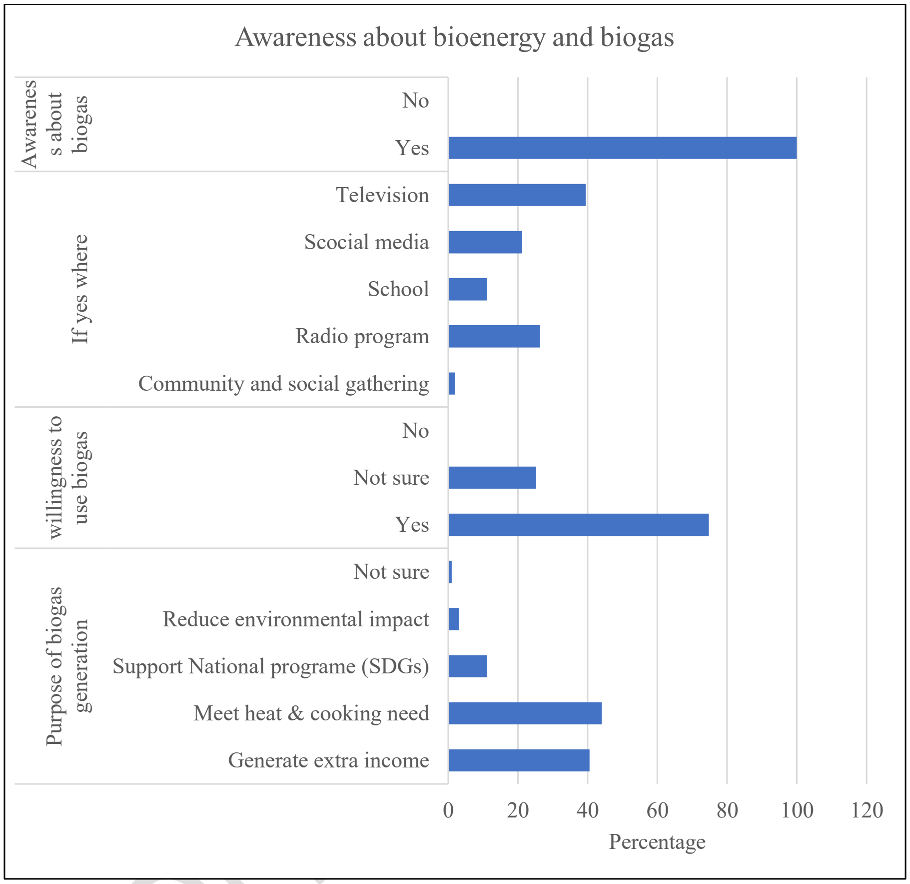


Figure 14. Awareness and willingness to utilize biogas technology

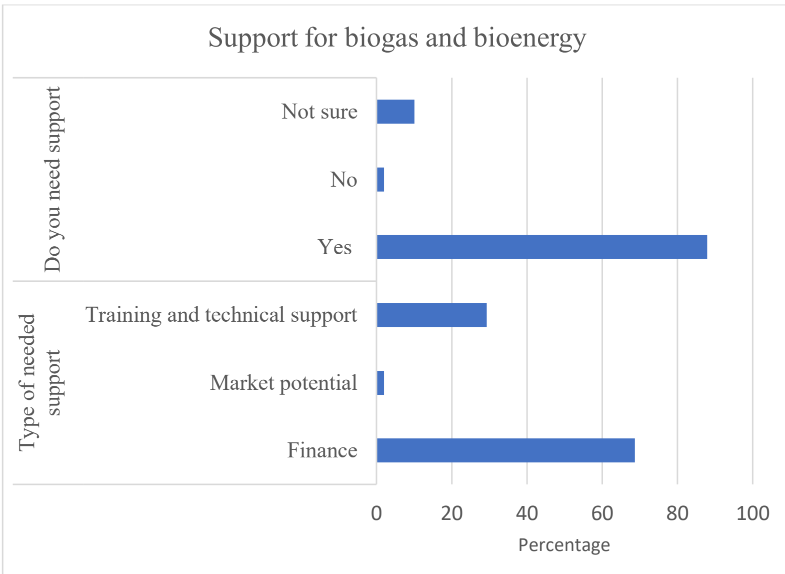


Figure 15. Support for biowaste to biogas

3.2. Test on hypothesis: willingness to adopt biogas from biowaste

A inferential statistical analysis was conducted using the chi-square test to analyze nominal variables, such as the frequency of biowaste generated, category of waste generated, and type of waste generated; the independent variable was the willingness to adopt bioenergy. The associations between the selected variables are presented.

The Chi-square test revealed that the association between the frequency of waste generated and the willingness to use bioenergy is significant $X^2$(2, N = 99) = 6.0383, Pr = 0.049, i.e., p-value < 0.05 at a confidence interval (CI) of 5%, which is considered statistically significant. Thus, the null hypothesis is rejected, and the alternate hypothesis is accepted. Similarly, the association between the categories (animal, plant-based, and kitchen waste) and the willingness to adopt bioenergy is strongly significant; thus, the null hypothesis is accepted, and the alternative hypothesis is rejected, according to $X^2$(2, N = 99) = 13.7314, Pr = 0.001, that is, Pr < 0.05. In addition, the association between the type of waste, that is, liquid, solid waste, or both, and the willingness to use bioenergy as an alternative cooking fuel was not significant $X^2$(2, N = 99) =

3.0383, Pr = 0.137, Pr > 0.05. Thus, the result is not statistically significant at the 5% confidence level; thus, the null hypothesis is accepted.

This implies that the frequency of biowaste generation and the category of waste generated are significantly associated with respondents' willingness to adopt bioenergy technologies. However, adoption is not a function of the type of waste generated, such as liquid or solid waste, or both. This suggests that the two variables, namely the frequency of how biowastes are generated and the category of waste generated, such as from plant, animal-based, or kitchen waste, These are the parameters that government policy and investors could leverage to ensure legislation of bioenergy resources and adoption of its final product, that is, biogas.

4.0. Brief discussion and synthesis

This study investigated the factors and parameters that impact the adoption of bioenergy from the available potential of biowaste from small- and medium-scale commercial enterprises in FCT. The biowaste potential is aimed at investigating the categories of biowaste generated, types of biowaste, cost of meeting their heating and cooking needs, potential/needed support, and overall socioeconomic characteristics of the respondents.

The results revealed the following. 1) Significant biowaste from small- and medium-scale enterprises is mainly generated from food waste, that is, from those involved in the food vendor. Moreover, these vendors produce a significant amount of waste and use an average of 20,000 Naira (N) to provide for their heating and cooking demand in a month to provide food for an average of 15 people daily. Respondents were willing to transition from biowaste to alternative clean cooking, despite the majority being heavily dependent on LPG as the fuel source to meet their heating and cooking needs. Their dependence on LPG as a cooking fuel is in line with that of other regions of the country (Yusuf et al., 2024). In addition, biowaste sorting is important for ensuring seamless bioresource identification and subsequent utilization (Olawade et al., 2024). However, this study revealed that biowaste had not been sorted before disposal, which could be due to inefficient technical capacity and weak implementation of environmental laws in the city and country, Nigeria (Anne et al., 2025). In addition, the outcome of the study agrees with studies from other developing countries that the category of biowaste is an essential factor for biowaste potential and is a major determining factor that enhances the adoption of bioenergy (Bose et al., 2022) and

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supports conversion technology (Pilarska & Pilarski, 2023). Hence, it will foster sustainability and a circular economy (Garg et al., 2024). This means that a successful bioenergy-adopting strategy should consider the availability of biowaste (Kazawadi et al., 2021) and the frequency of biowaste generation (Jameel et al., 2024) as potential resources for generating bioenergy. Moreover, biowaste from agriculture is an important bioenergy source that should be investigated because of its vast potential to enhance bioenergy (Anvari et al., 2024).

## 4.0. Conclusion and Recommendation

Biowaste is crucial when citing bioenergy facilities because proximity to bioresources is important for the sustainable adoption of biogas (Singh et al., 2023). This study leveraged this fact. Having identified the analysis and conducting relevant statistical tests on relevant variables that could enhance bioenergy in the Federal Capital Territory (FCT). Data collection focused on artisans who are small- and medium-scale ventures, especially those that generate food waste. Data analysis revealed that bioresources are readily available in the FCT, but they are thrown away by employing the services of waste disposal agencies. This was due to the limited understanding that biowaste could further be utilized to generate bioenergy that meets their heating and cooking needs, among other benefits. However, some of the biowaste is sold out, perhaps to those who feed their livestock, and some portion of the waste ends up in waterways and drainage by the roadside. Statistical tests showed that the categories of biowaste and the frequency at which waste is is generated are significant to the adoption of biogas technology as an alternative fuel. However, a major constraint revealed that the generated biowaste had not been sorted before disposal. This is evidence that the Nigerian waste disposal system does not prioritize waste sorting at the point of disposal, which is very important for achieving a sustainable biowaste for bioenergy conversion. Therefore, this study concludes that biowastes are readily available among small- to medium-sized food vendors, which could be leveraged for bioresources by bio-entrepreneurs in the FCT.

Also, the study's research questions have clarified that Animal-based waste, plant-based waste and kitchen waste, which is the largest share, are the major categories of biowaste generated in the FCT across several sectors, while the majority of the waste ends up in the waste dump. More so, most of the waste generated is not effectively used, as most end up as solid and liquid waste as lead to environmental hazards. Finance, training and technical support are significant initiatives that best enhance the effective utilization of biowaste in the FCT, with financial support topping the list.

Therefore, the outcome of the study supports the following recommendations: i) there is a need to ensure a smart biowaste management approach (through the use of AI to sort waste), which could be achieved by providing different waste bins that are labelled and identify different waste such as plant and animal biowaste, plastic waste, etc.; ii) commercialize waste generated by providing a readily available market for biowaste that could otherwise be used to generate bioenergy, and iii) as most vendors belong to the youthful group and have a sufficiently educational background, the government and Non-Governmental Organization (NGO) should intensify advocacy and training on the importance and need for bioenergy.

**Data Availability Statement**

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

**Declarations**

**Ethical approval**

This study received ethical approval from the University of Venda Research Ethics Committee (Project Reference number: SES/16/GGIS/05/1511). All experimental procedures were carried out in accordance with the UNIVEN Research Ethics Policy and Guidelines, as well as relevant international ethical standards governing environmental fieldwork and laboratory-based experimental research. This research did not involve animal subjects.

**Consent to participate**

Informed consent was obtained from all individual participants included in the study

**Consent to publish**

Consent to publish was obtained from all individual participants included in the study

**Conflict of interest**

No potential competing interest was reported by the authors.

**Clinical trial number**

not applicable.

COMPETING INTERESTS DISCLAIMER:

Authors have declared that they have no known competing financial interests OR non-financial interests OR personal relationships that could have appeared to influence the work reported in this paper.

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