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ASSESSMENT OF THE AWARENESS OF ENERGY VALORISATION OF RICE BY-PRODUCTS AMONG RICE FARMERS AND PROCESSORS IN NIGERIA.

MASTER'S THESIS

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Declaration

I hereby declare that I have done this thesis entitled "**Assessment of the awareness of energy valorisation of rice by-products among rice farmers and processors in Nigeria"** independently, all texts in this thesis are original, and all the sources have been quoted and acknowledged by means of complete references and according to citation rules of the FTA.

In Prague, April 2024

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Sylvia Ukamaka Echefu

Dedication

This research is dedicated to my loving Mother – Hon. Veronica Nmarurulo Echefu; you have been a great support system and my wonderful cheerleader. Thank you for all your prayers, inspiration and always believing I can do it!

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Abstract

The purpose of this study is to promote sustainable agricultural practices and resource management by examining the awareness, knowledge, and willingness of Nigerian rice farmers and processors to use rice by-products as an alternative energy source. The production of rice yields abundant by-products such as rice straw and husks, and they have the potential to serve as an alternative source of energy that is renewable. This would have advantages including effective waste management and a decreased dependency on fossil fuels. The main aim is to evaluate rice farmers' and processors' level of awareness and knowledge of the possibility of rice by-products energy valorization. Using questionnaires, 150 rice farmers and 50 processors were interviewed in-person, and Microsoft Excel was used to carried out descriptive statistics while Statistical Package of Social Science (SPSS) version 26.0 was used to analyse the respondent's attitudes, willingness, and the rate at which rice husk and straws are converted into energy by rice farmers' and processors. Additionally, one-way ANOVA was applied to compare the difference in the use of rice by-products among rice farmers and processors. Results indicate a lack of awareness among 81 % of rice farmers regarding the energy valorisation of rice by-products. Interestingly, 61.2 % expressed willingness to adopt energy valorisation from rice husks and straws. Conversely, the findings shown that 15 % of factories use the rice husks to produce electricity, whereas 55 % of rice processors burn them. The aforementioned results highlight the need for the rice producing industry to adopt more sustainable techniques and to raise awareness of them. This research adds to the body of knowledge on the waste management, renewable energy, and sustainable agriculture especially in developing countries such as Nigeria. Targeted awareness campaigns, educational programs, and policies measures in line with national energy policies and sustainability objectives are among the recommendations. Such actions can promote long-term sustainability and resource management by improving environmental practices and strengthening the Nigerian rice production industry's resilience.

Key words: Rice straw, Rice husk, Bioenergy, Sustainable waste management, Cooking fuel

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List of the abbreviations used in the thesis

ABP Anchor Borrowers Program

AD Anaerobic Digestion

ANOVA Analysis of Variance

CBN Central Bank of Nigeria

FAO Food and Agriculture Organisation

FCT Federal Capital Territory

FGN Federal Government of Nigeria

FMARD Federal Ministry of Agriculture and Rural Development

GACs Government Aggregation Centres

GDP Gross Domestic Product

IITA International Institute of Tropical Agriculture

IRM Integrated Rice Mill

NC North-Central

NCRI National Cereals Research Institute

NE North-East

NGOs Non-governmental Organisations

NRDS National Rice Development Strategy

NW North-West

PFI Presidential Fertilizer Initiative

PHL Post-Harvest Losses

R&D Research and Development

SE South-East

SPSS Statistical Package for the Social Sciences

SW South-West

WARDA West Africa Rice Development Association

1. INTRODUCTION

Rice holds significant importance in Nigeria as one of the primary dietary staples, making it a crucial crop because it plays a pivotal role in enhancing food security, generating income, and fostering employment opportunities. The nation has an important agricultural sector devoted to cultivating and processing rice (Ayansina & Maren, 2020). Nigeria stands out as Africa's top rice producer, with an estimated yearly production of more than 8.3 million metric tonnes (Sasu, 2023). Smallholder farmers who employ conventional agricultural techniques produce most of the rice and contribute to more than 85 % of domestic agricultural production in Nigeria (Sennuga et al., 2020; Mohammed et al., 2022).

With approximately 11,000 rice mills, the rice processing sector in the country is particularly crucial (Illankoon et al., 2023). However, the rice processing sector encounters poor infrastructure, low productivity, and waste management issues. Thus, by converting waste into valuable energy resources, the energy valorisation of rice by-products offers a chance to overcome these difficulties. Numerous by-products emerge during the rice harvesting and processing cycle, comprising rice bran, broken rice, rice straws, and rice husks. These residues offer potential for conversion into biofuels like biogas, biomass pellets, and briquettes, serving as a possible source of energy (Nguyen et al. 2019). Several advantages come from the energy valorisation of rice by-products, including waste reduction, the production of renewable energy, and an additional income to rice farmers and processors.

Nigeria faces several energy challenges, including insufficient electricity supply, high energy costs, poor access to electricity, and dependence on fossil fuels (unsustainable energy sources) (Adaramola & Oyewola, 2017). The country's dependence on wood fuel contributes to desertification in the arid region states and erosion in the southern region states. Consequently, its extensive reliance on fossil fuels, notably oil and gas, makes it vulnerable to price volatility, supply disruptions and has resulting to a significant rise in carbon dioxide emissions (Oyedepo, 2012; Adewale, 2020). According to Adeoti et al. (2021), to achieve the nation's sustainable development goal (SDG) 7 (affordable and clean energy) and SDG 12 (responsible consumption and production), it is necessary to search for a sustainable, renewable type of energy as an alternative source to fossil fuel. However, diversifying the energy mix and promoting sustainable energy sources (bioenergy) is crucial for achieving energy security, encouraging proper waste management, and addressing environmental concerns, particularly for developing nations like Nigeria (Ibikunle et al., 2021). Alternative and sustainable energy sources, such as the energy valorisation of rice by-products, present an opportunity to harness renewable energy sources, improve energy security, promote cheap and clean energy, contribute to the country's energy transition goals, and offer socioeconomic benefits.

Creating awareness and knowledge dissemination are essential for encouraging rice farmers and processors to adopt energy valorisation practices and techniques. However, studies have shown low awareness and understanding of energy valorisation among rice farmers and processors in Nigeria (Ohimain, 2013a; Okafor et al., 2022). Thus, the limited awareness and understanding of the potential benefits and technologies associated with energy valorisation, and misconceptions about high initial costs, may hinder its adoption in Nigeria (Olujobi et al., 2022; Olusola et al., 2023).

By evaluating existing states of awareness and identifying the factors influencing the adoption of energy valorisation practices, this study aims to shed light on the current state of knowledge and help to develop targeted strategies to promote sustainable energy practices and reduce waste within the rice industry. This study will serve as a support for further research into perspectives regarding the optimisation of agricultural by-products, with a specific focus on biomass. It will also delve into the barriers that impede the widespread adoption of biomass as a viable alternative energy source in Nigeria.

2. LITERATURE REVIEW

This section summarises the most relevant information on the potential of rice by-products for energy valorisation, the current state of rice production and processing in Nigeria, and the level of awareness among rice farmers and processors regarding the utilisation of rice by-products as a sustainable alternative to non-renewable fossil fuels for energy production.

2.1. Agricultural Production and Climatic Conditions

Nigeria has a varied geography, characterized by three distinct climate zones. The Sahelian region, in the north, experiences hot, and semi-arid weather. The climate changes to a tropical monsoon climate as one transition southward, while the central region predominantly has tropical savannah climates. These regions exhibit divers weather patterns, including two tropical climates with distinct rainy and dry seasons. In Nigeria, the average temperature is between 21 to 35 ^{0}C. Consequently, there is a gradual reduction in precipitation level from the southern to the northern regions (World Bank Group, 2022). The nation is Africa's top producer of gas and oil, has abundant natural gas reserves, and is home to the continent's greatest natural gas reserves (Kamer, 2023). Besides petroleum, agriculture is Nigeria's most significant economic sector that contributes more than 23 % of the country's GDP. In Nigeria 60 % of the population works in this industry, mostly at a subsistence level, including many rural women (Sasu, 2023). With an average contribution of 90 % to the overall output of the agricultural sector, its subsector, "Crop Production", is the main output driver. This subsector includes the production of staple foods like rice, maize, and cassava as well as cash crops like cocoa, rubber, among others (KPMG, 2019).

In Nigeria, the agricultural industry is of great economic importance, employing more than 70 % of the workforce, primarily in subsistence farming. But although with its pivotal role, the sector has numerous obstacles that prevent it from producing at its best (Isu & Chukwu, 2023). These difficulties include insufficient land tenure, antiquated technology, high production costs, ineffective resource management, restricted market access, scarce finance options, and large post-harvest losses.

Collectively, these obstacles limit agricultural productivity, thereby restraining the sector's contribution to the country’s GDP. Moreover, as the population grows, the country imports more food, which lowers the country’s food sufficiency levels (Eno & Eze, 2023). Nigeria has 70.8 million hectares of agricultural land, mostly used for the cultivation of rice, yam, millet, cassava, and guinea corn. Nigeria produced 3.7 million metric tonnes of rice in 2017, while 4.0 million metric tonnes were produced in 2018. Despite this increase, domestically produce supplies account for only 57 % of Nigeria’s annual rice consumption of 6-7 million metric tons. As a result, leaving a shortage of almost 3 million metric tons of rice, which is either smuggled or illegally imported into the country (Kamai et al., 2020; FAO, 2023). It is expected that the Nigerian government would persist to provide top priority to activities in the agriculture sector, with a particular emphasis on crop production, through policies to attract investments and end hunger. This is in line with the current administration's drive for diversification and fulfilling one of its fundamental pillars, which is food security (FMARD, 2020).

2.2. Overview of Rice Production and Processing in Nigeria

In Nigeria, rice is important for various reasons. It plays a significant role in both domestic and sub-regional trade. Furthermore, rice is a staple food that is consumed by people from all socioeconomic classes and is vital for food security of the six geopolitical zones of the country, which are North-East (NE), North-West (NW), North-Central (NC), South-South (SS), South-West (SW), and South-East (SE) (Obianefo et al., 2023). Consequently, its processing and production are crucial to Nigeria's agricultural sector and economy. Nonetheless, rice farming is the main occupation in few states of Nigeria’s NE, NW, NC, SW, and SE (Neezer, 2018).

In Nigeria, 90 % of all rice is produced on a small scale by low-input farmers and producers who use low input strategies that result in low output and minimal input requirements. The crop is grown in a variety of agroecological zones throughout the nation, with the major producing states being Kebbi, Ebonyi, Kano, Niger, Benue, Borno, and many others, each of which is suited to a different variety and cultivation technique (KPMG, 2019; Chukwu, 2024).

Nigeria is among the countries in Africa that consumes the most rice. The current annual consumption of rice is approximately 7.9 million metric tonnes, with an average Nigerian consuming 24.8 kg, representing 9 % of total annual calorie intake (Ibrahim et al., 2018; Farmcenta, 2020). Nigeria's rice processing capacity is approximately 8.34 million metric tonnes of paddy (FAO, 2023; Illankoon et al., 2023).

In recent years, the country has increased domestic paddy/rice production to reduce its reliance on rice importation and improve the quality of locally produced rice. The government and various stakeholders (private sector) continue to work towards further enhancing the local rice production and processing value chain to meet the country's rice consumption needs and potentially become a rice-exporting nation (Ekundayo, 2023). In so doing, the government has implemented various initiatives and intervention programs such as the Anchor Borrowers Program (ABP) of the Central Bank of Nigeria (CBN), which provides credit and support to small-scale farmers, the Presidential Fertilizer Initiative (PFI), and a new 10-year plan (2020 - 2030) National Rice Development Strategy II (NRDS II) (FMARD, 2020). These initiatives aim to enhance domestic rice production, reduce rice imports, promote resource use efficiency, stimulate economic growth in the agricultural sector, and ensure the sustainability of the overall output of Nigerian rice (Salihu et al., 2023). According to the Federal Ministry of Agriculture and Rural Development (FMARD, 2020), in order to achieve the government's goals of self-sufficiency in rice production, food and nutrition security, employment creation, and wealth generation, as well as to further double production and produce surplus for the West African markets, the National Rice Development Strategy II (2020–2023) aims to set the purpose and direction for the development of the rice sub-sector. However, fewer than 1 % of all rice value chain participants in Nigeria and less than 10 % of the country's 1.2 million rice farmers have access to programs.

Despite these advancements, the nation is presently unable to achieve self-sufficiency in the production of locally milled rice due to population growth, which continues to increase by 2.5–3.0 % annually; consumer preferences are largely influenced by the growth in urbanization and are partially caused by significant post-harvest losses (PHL) (Obianefo et al., 2023). Even though every geographic area faces unique challenges, the problems that are almost universally encountered are drought, pests and diseases, urbanisation, insufficient irrigation facilities, limited mechanization and technology, the impact of climate change, salinity of the soil, inadequate infrastructure (land availability), and inconsistent government policies. Support from these entities as well as NGOs and international organisations has additionally hindered the sector's expansion (IEA, 2019; Mohammed et al., 2019).

Nigeria has two main rice cultivation seasons: the rainy season (main season) and the dry season (off-season). Rice cultivation in Nigeria is primarily rainfed, but there are efforts to expand irrigated rice farming to improve yields and reduce vulnerability to climate fluctuations (Chukwu & Anozie, 2023). However, both upland and lowland rice cultivation methods are employed, with variations in production practices and type of variety depending on the regional conditions and agroecological zone. Asian rice (*Oryza sativa*) and African rice (*Oryza glaberrima*) are the two types of rice that are mainly grown in Nigeria. Additionally, improved varieties like FARO 44, FARO 52, FARO 61, GAWAL R1, NERICA 1, and NERICA 2 have been developed in collaboration with NGOs, international organisations, and research institutions like the African Rice Centre-International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria, GoSeed, and the National Cereals Research Institute (NCRI) Badeggi, Nigeria, and African Rice Development Association (WARDA) Bouake are among the rice varieties that are primarily grown in Nigeria. Due to their high potential for yield and resilience to environmental stress, farmers are advised to plant these cultivars (Mohammed et al., 2019; KPMG, 2019).

After production and harvesting, rice undergoes various post-harvest processing, handling, and management processes, including threshing, parboiling, milling, and polishing. Traditional processing methods are still commonly used in Nigeria, but modern rice milling facilities have been established to improve the quality and quantity of processed rice (Adeola, 2020).

2.2.1. Post-harvest Processing Handling and Management:

In Nigeria, approximately 80–85 % of rice farmers lack access to post-harvest equipment and services, causing them to rely mostly on traditional harvesting methods. Due to the rice farmers' poor harvest and post-harvest practices, 15 % of the produce is lost on the farm (Obianefo et al., 2023). Additionally, inadequate pre-cleaning, drying, winnowing, and storage facilities, as well as a lack of technical know-how in the use of contemporary facilities like post-harvest machinery like rice threshers, basic combine harvesters, rice reapers, dryers, and winnowers in the rice processing industry, all contribute to the loss of produce (Xue et al., 2021). According to the FMARD (2020) report on National Rice Development Strategy II (2020-2023), the Nigerian government possesses a mere 25 rice aggregating centres (GACs) spread across 9 states, with just 17 of them being operational although inadequately equipped. Though few of the privately owned centres process rice based on demand, some of the privately held aggregation centres stopped processing rice due to inadequate power supplies and sharp rises in the price of gasoline, diesel, and other fuels.

2.2.2. Processing (Parboiling and Milling):

In rice processing, more mechanisation is required, and where it is present, it frequently uses outdated machinery or equipment with poor design. Post-harvest losses in rice are estimated to account for up to 40 % of total production and are largely caused by inadequate processing equipment (Ibrahim et al., 2018). In Nigeria, many rice processors use traditional methods, still, there is a growing shift towards modern rice mills and processing facilities. Currently, there is a low recovery rate of milling machines, with an average milling efficiency of 60 % for the IRM (Integrated Rice Mill) and 50 % for small and medium millers, leading to less than 50 % of the installed milling capacity being in use and limited availability of upgraded small-scale parboiling equipment (FMARD, 2020).

The parboiling and milling process usually requires rice species of similar quality or shape with minimal impurities. Parboiling, which involves partially boiling the rice paddy before milling, is a common practice in Nigeria. This process enhances the nutritional value of rice and makes it more marketable (Adeola, 2020). However, they produce substandard paddy (mixed-up varieties with high moisture content and impurities) as a result of mill operators' (processors') low knowledge and experience sharing. The parboiling and sorting process is usually suboptimal due to the high level of inconsistency in the rice species grown by various outgrowers, as well as the large amounts of impurities in the outputs. In addition, the seasonal availability of locally grown paddy could lead to long periods of underutilisation (KPMG, 2019).

The Federal Government of Nigeria (FGN) has projected that in response to the aforementioned challenges, by 2025, at least 20-30 % of farmers will receive training on improved post-harvest practices, and by 2030, 40-45 % of farmers will receive this training. This will increase the number of skilled technical labourers needed for mill operation and maintenance by 2030, and by that same year, 40-50 % of rice farmers will have access to modern post-harvest machinery and increased financing for mills (FMARD, 2020). Furthermore, they plan to create community warehouses in rice-producing communities, organize at least 40 % of small-scale millers into production clusters by 2025, provide at least one grain aggregation centre in each State and Local Government Area where rice is produced, and train small millers in food safety, standards, grading, and branding (Salihu et al., 2023). Other plans include, by 2023 decreasing post-harvest losses by 50 %, achieving 65 % milling efficiency for IRM and 60 % milling efficiency for small and medium millers, 75 % utilisation of the milling capacity, and effective use of rice by-products such bran, husk, and straw (FMARD, 2020).

In Nigeria, a large number of rice farmers and processors burn rice by-products in open fields or landfills because of the insufficient knowledge and awareness of the potential benefits of using them as an alternative renewable energy source. This can be problematic because rice husk ash results in low bulk density, which can have detrimental effects on the environment and public health (Ramchandra, 2016). Similarly, in some cases, the rice farmers and processors sell the rice by-product (rice husks) to poultry farmers, who use it in place of sawdust and wood shavings for litter and bedding in the poultry houses (Strausberg, 1995; Cothren, 2011) or rice bran to mix formula as feed for their birds, since it is recognized as a valuable source of energy and a feasible feed ingredient for broiler chickens, as well as a viable option for feeding other livestock (Amaefule et al., 2006; Ricke et al., 2013).

2.3. Energy Valorisation of Rice By-Products: Technologies and Applications

Most of the energy used in Nigerian households is used for cooking, and this energy is mostly obtained from biomass (65 % fuelwood, 6 % charcoal) and fossil fuels

(18 % coal and kerosene) (IEA, 2019). One of the main drawbacks of using fuel wood as a source of energy is the amount of harmful air pollutants that are released into the atmosphere, which can lead to health problems for women and children (Aondoyila et al., 2021) and also encourages desertification, and deforestation leading to erosion which has become an issue of great concern (Adewale, 2020).

Therefore, any fuel substitute for domestic utilisation in society that is both economical and beneficial to the environment would be appreciated (Hoang et al., 2021).

Thus, the energy valorisation of rice by-products is an important field of research and development, with the potential to support sustainable agriculture and the production of renewable energy generation. In a country where rice production is significant, such as Nigeria, utilising rice by-products (biomass) for energy seems to be the optimal solution for enhancing the country's energy security and can be particularly beneficial as it offers an opportunity for sustainable waste management, generates renewable energy sources, and contribute to sustainable agricultural practices (Benova et al., 2021).

Rice byproducts that are rich in organic matter and can be utilised for producing bioenergy include rice husk, rice straw, and rice bran. They have the potential to be transformed into many kinds of energy sources, including heat, electricity, and biofuels (Nguyen et al., 2019). Various technologies and applications are used for energy valorisation of rice by-products in Nigeria, including biomass combustion, biomass gasification, anaerobic digestion, biomass briquetting/pelleting, and pyrolysis. Still, there are many challenges in transforming rice by-product material into biofuel in Nigeria (Singh & Patel, 2022).

2.3.1. Biomass Combustion:

Combustion is the most used technique to produce heat or generate electricity on a large scale with steam turbines. When a substance quickly reacts with oxygen (O_2), a combustion reaction takes place. The process of burning is termed combustion, and the substance that burns are called fuel (James, 2020). Biomass combustion involves burning rice husks or other by-products to produce heat. In combustion, a large amount of oxygen in the form of air is mostly added to the system. Appropriate ratio of fuel and air is required for complete combustion of the biomass for energy generation. Biomass and waste are combusted at temperatures between 800-1,000 °C. Three chemical elements: carbon (C), hydrogen (H), and sulfur (S) that generate heat during burning are present in the fuel.

Their complete combustion occurs by subsequent chemical reactions as provided by Key & Ball (2014):

$$C + O_2 \rightarrow CO_2 + HEAT$$

$$2H_2 + O_2 \rightarrow 2H_2O + HEAT$$

$$S + O_2 \rightarrow SO_2 + HEAT$$

Although the combustion of sulfur produces heat, the presence of sulfur in fuels is considered extremely undesirable because of its negative environmental impact and risk of corrosion of heating surfaces. When a heat sink like a solid surface or flame trap quenches the combustion, incomplete combustion takes place because there isn't enough oxygen present for the hydrocarbons to react entirely with the oxygen to form carbon dioxide and water. Although nitrogen does not participate in combustion, some nitrogen will transform into nitrogen oxides (NO_X) at high temperatures (James, 2020).

$$CH_4 + O_2 + N_2 \rightarrow 2H_2O + N_2 + CO + NO_X + HEAT$$

2.3.2. Biomass Gasification

Gasification is a process that involves partially oxidising biomass exothermically. The process parameters are designed to produce large amounts of gaseous products, (Aristizabal-Alzate et al., 2023) such as producer gas or syngas, which are rich in carbon monoxide (CO), hydrogen (H_2), methane (CH_4), nitrogen (N_2), carbon dioxide (CO_2), and comparatively less hydrocarbons. It can be utilised for various applications, including electricity generation, heat production, and the synthesis of valuable chemicals (Demirbaş, 2005; Aristizabal-Alzate et al., 2023). Although gasification is one of the most effective ways of converting biomass into fuels, it comes at a significant cost of investment. Because it is exceedingly expensive to store or transport, the gas produced needs to be consumed promptly (El Bassam, 2020). In the process of gasification, biomass is directly transformed into syngas, or synthesis gas, in a gasifier with regulated airflow. Syngas can be utilised to generate both heat and electricity in a cogeneration system or in internal combustion (IC) engines (Jeng et al., 2012). Gasification can provide a wide range of co-products in addition to heat and power, which can increase a project's cost-effectiveness.

Biomass gasification is a transformative process that holds significant promise for sustainable energy production and waste management (Smith et al., 2019). In this method, biomass, such as agricultural residues, wood, or organic waste, are converted thermochemically in a regulated environment. As a result of this conversion, a gaseous fuel, called syngas is produced (Doherty et al., 2009).

One of the main benefits of biomass gasification, or the product gas, is its adaptability as a feedstock to produce hydrogen and liquid hydrocarbons like ethanol, diesel, and chemical feedstocks (Bridgwater, 2012). Gasification now has the possibility to be a carbon-neutral or carbon-negative energy source thanks to biochar, which has several potential markets (Carolyn, 2010).

Unlike some other renewable energy sources, biomass is abundantly available and diverse, making it a flexible and locally sourced material for gasification processes. This adaptability enables the utilisation of different biomass feedstock types based on regional availability and specific project requirements (Singh & Patel, 2022).

Moreover, biomass gasification contributes to environmental sustainability by providing an alternative to traditional fossil fuels (McKendry, 2002). When syngas generated from biomass is used instead of directly burning biomass or fossil fuels, less greenhouse gas and other pollutants are released into the atmosphere. The reduced environmental impact is in line with international initiatives to slow down climate change and switch to greener energy sources.

Additionally, soil enhancement and carbon sequestration can be achieved by the utilisation of biomass gasification byproducts like biochar (Lehmann, 2007). A stable carbon source, biochar can enhance soil fertility and contribute to long-term carbon storage in agricultural lands. This dual benefit of energy production and soil enrichment demonstrates the potential for biomass gasification to offer integrated solutions for sustainable agriculture and renewable energy generation (Bartoli et al., 2020).

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carbon source, biochar can enhance soil fertility and contribute to long-term carbon storage in agricultural lands.

2.3.3. Anaerobic Digestion

The innovative and sustainable process of anaerobic digestion (AD) has great potential for energy valorisation from rice by-products. In the absence of oxygen, this process breaks down organic molecules to produce biogas, a renewable energy source which is mostly composed of carbon dioxide and methane (Meegoda et al., 2018). Anaerobic digestion has been found to be an efficient means to achieve the effective use of low-value agricultural waste, improving the environment, reducing costs overall, enhancing economic sustainability, and creating a community network for sustainable energy generation in the context of rice by-products. It also presents a viable solution for waste management (Kaniapan et al., 2022).

Rice by-products, including rice straw, husks, and bran, are abundant agricultural residues in countries like Nigeria. Traditionally considered as waste, these by-products can be effectively utilised through anaerobic digestion, converting them into valuable resources. The process begins with the collection of rice residues, which are then fed into anaerobic digesters. These digesters create an oxygen-free environment, allowing naturally occurring microorganisms to decompose the organic material present in the by-products (Syafrudin et al., 2020).

The generation of biogas is one of the main benefits of anaerobic digestion. The main component of biogas, methane, is a clean, renewable energy source with a wide range of uses including cooking and electricity generation. Biogas derived from rice byproducts provides a sustainable substitute for traditional fossil fuels, helps in lowering greenhouse gas emissions and reducing environmental effects (Chen et al., 2008).

Furthermore, digestate, a byproduct of anaerobic digestion, serves as a nutrient-rich organic fertilizer and provides a long-term solution to enhance soil fertility and improve agricultural productivity, creating a closed-loop system that aligns with the principles of sustainable agriculture (Kaniapan et al., 2022).

The implementation of anaerobic digestion for rice by-products energy valorisation presents several economic and environmental advantages. This reduces the environmental impact of open-field burning and uncontrolled decomposition, addressing the problem of agricultural waste management by turning rice wastes into useful energy resources. This aligns with sustainable waste management practices, contributing to cleaner and healthier environments in rice-producing regions (Ahring, 2003).

2.3.4. Biomass Briquetting/Pelleting

Briquetting and pelleting of rice by-products represent innovative and sustainable methods for energy valorisation, providing an efficient means of converting agricultural residues into a valuable energy resource, thereby preventing deforestation (Voicea et al., 2016). This technology offers a transformative solution for the management of rice straw, husks, and other by-products, contributing to both environmental sustainability and energy security.

Biomass briquetting involves compressing rice residues into dense, compact, and energy-dense briquettes. Due to its superior compressive strength over alternative techniques, briquetting is a viable process that has gained broad notice in recent years. In order to improve its compressive strength, briquetting employs an extra binder, such as sawdust, molasses, starch, asphalt, or cow dung (Sanchez, 2022). Rice husk has a low bulk density, which makes its transportation and handling difficult. However, production of briquettes manages these problems because they are simple to use in the subsequent phases of valorisation. In the field of heat production, briquettes are commonly utilised as an alternative to wood or coal for the generation of power (Kaniapan et al., 2022).

Since they generate fewer particles than rich husk combustion, briquettes are thought to be more economical and environmentally beneficial. Briquettes have various advantages over pellets, such as requiring less pressure during densification, being less expensive, and they can be manufactured closer to industrial locations, like palm mills, which promotes decentralization of production (Kaniapan et al., 2021). However, rice husk-based briquettes' low bulk density and moisture content lead to their inadequate mechanical strength and durability. Therefore, to create a better briquette, more binder, raw material mixing ratios, final pressure, temperature adjustment, and forms are required (Saeed et al., 2021).

Similarly, biomass pelleting entails the formation of small cylindrical pellets using a pellet mill. In comparison with raw rice wastes, the combustion performance of rice pellets has been greatly enhanced through chemical degradation (Nielsen et al., 2020). However, compressing rice residues requires higher production pressure and temperature in order to produce a better pellet with a higher compressibility strength and to avoid the unneeded addition of a binding agent (Canabal et al., 2023).

The majority of raw biomass applications, particularly straw, that are utilized as solid fuels in biomass boilers result in a greater ash concentration. This leads to clinker and corrosion, which over time may require routine maintenance. The ash level of any solid biomass fuel meant for boiler fuel needs to be reduced (Kaniapan et al., 2022). Furthermore, rice straw pellets are more durable than rice husk pellets, and both kinds of pellets get more durable as the compression temperature rises (Yang et al., 2016).

Both briquetting and pelleting processes aim to increase the energy density of rice by-products, making them more suitable for combustion and energy production. These briquettes and pellets can be utilised for various applications, ranging from household cooking to industrial processes and electricity generation (Okwu et al., 2023). The ease of handling and transportation is one of the main benefits of biomass briquetting and pelleting. The densification process results in a reduction of volume, making it more cost-effective to transport and store these energy-dense materials. This characteristic is particularly beneficial for rural areas where the collection and transport of loose biomass can be logistically challenging and economically impractical (Voicea et al., 2016).

In addition, biomass briquettes and pellets provide a more sustainable and cleaner substitute for conventional fuels like wood or charcoal. The combustion of rice by-products in the form of briquettes or pellets produces fewer emissions, contributing to air quality improvement and mitigating the environmental impact associated with open field burning of agricultural residues (Tumuluru et al., 2010). The mitigation of greenhouse gas emissions is consistent with worldwide endeavours to tackle climate change and fosters a more sustainable energy environment.

The utilisation of rice by-products through biomass briquetting and pelleting also address the problem of management waste in rice-producing regions. Rather than allowing residues to decompose in the fields, contributing to methane emissions and soil degradation, these technologies transform the by-products into a valuable energy resource. This not only enhances waste management practices but also provides an additional revenue stream for farmers or entrepreneurs engaged in the production and sale of biomass briquettes or pellets (Voicea et al., 2016).

Furthermore, biomass briquetting and pelleting contribute to decentralized energy production. Small-scale enterprises, local cooperatives, or individual farmers can adopt these technologies to produce energy-dense fuel for their own use or for sale to local communities. This decentralized approach promotes energy independence, reduces reliance on centralized energy sources, and stimulates economic development at the community level.

While biomass briquetting and pelleting offer numerous benefits, challenges such as the availability of briquetting or pelleting equipment and the need for standardized quality control should be considered. Government support, in the form of incentives and subsidies, can play a crucial role in overcoming the challenges and promoting the widespread adoption of these technologies (Yang et al., 2013).

2.3.5. Pyrolysis

In the processes of gasification and combustion, pyrolysis is always the initial stage. For thousands of years, this process has been used to produce chemicals and charcoal. Biomass (such as rice by-products) can be pyrolyzed by heating it to a certain temperature (pyrolysis temperature) in an inert atmosphere and maintaining it there for a set amount of time (Yaning et al., 2019).

Pyrolysis is the process of breaking down carbonaceous biomass materials without the presence of oxygen. Depending on the kind of pyrolysis (rapid, slow, or ultra-quick/flash pyrolysis), heating rate, residence period, and desired products, the temperature for this process can range from 350 to 1,300 °C (Yaning et al., 2019). For downdraft fixed-bed gasifiers, it produces solid, liquid, and gaseous fractions, which normally consist of roughly 20–25 wt% solids, 1 wt% liquids, and 70–90 wt% gaseous fractions (Emdadul et al., 2021).

Biofuels such as bio-oil, biochar, and non-condensable gasses (pyrolytic gas) are produced when biomass is pyrolyzed. Nonetheless, variables including biomass content, pyrolysis temperature, heating rate, nitrogen sweeping rate, and residence time affect their final product's relative yield and quality (Yaashikaa et al., 2020). Extreme pyrolysis is known as carbonisation, in which most carbon the carbon remains in the solid residue (Jeng et al., 2012).

2.4. Rice By-Products and their Potential for Energy Valorisation

The cultivation of rice yields numerous byproducts. The milling process can result in up to 40 % yield loss because by-products are discarded, which varies depending on the strain (variety) of rice and techniques utilised for production. Broken rice, husks, straw, and layers of bran are examples of rice by-products (Syafrudin et al., 2020). Following rice cultivation and processing, 1 kg of harvested paddy rice can yield approximately 0.41 to 3.96 of the residue-to-product ratios using a standard milling process (Esa et al., 2013). Based on the variety of harvested paddy rice, 78 % of the rice's weight decomposition is made up of rice, broken rice, and bran, and 22 % is made up of the husk that is obtained during rice milling. In addition, the maximum yield of rice to grain ratio is also influenced by the harvesting technique, soil fertility, the amount of light, and the availability of water (Kaniapan et al., 2022).

However, the milling procedure is crucial since it enhances the rice's sensory qualities, cooking time, and nutritional value (Dhankar, 2014). The yield and sustainability of rice production would therefore be enhanced if these by-products could be used in other industries, such as the renewable energy sector among others (Sanchez et al., 2018).

The most common agricultural wastes from the rice industry, rice husk and straw, have a significant role to play in helping to reduce the world's reliance on fossil fuels. These factors, along with the ongoing advancements in biomass energy conversion technologies, have also made rice by-products an essential source of renewable energy (Awoyale & Lokhat, 2019).

However, cogeneration systems could provide both power and heat to address the local energy needs. For this reason, the food supply is not endangered by rice's byproducts, as it is a staple food in most countries and its byproducts do not pose a threat to the world's food supply. Their qualities make them acceptable as feedstocks for biochemical conversion to fuel, such as ethanol, and therefore are not the cause of the "food or fuel" dilemma (Jeng et al., 2012). As a result, the by-products are widely available to provide an alternative energy source and lessen growing worries about waste management and environmental protection (Ezeligo et al., 2021).

Due to their widespread availability at rice mills, rice husk and straw have been used extensively to produce heat and electricity in various countries (Jeng et al., 2012). Nevertheless, they have not been sufficiently utilised in some areas, mostly in underdeveloped nations. Because of widespread air pollution, which includes smoke and greenhouse gas emissions, burning rice straw and husk is becoming socially unacceptable (Bernard, 2020).

2.5. Existing Awareness and Practices among Rice Farmers and Processors

In many rice-producing regions in Nigeria, prevalent practices among farmers and processors involve traditional methods of rice by-product disposal, such as open-field burning or leaving residues to decompose. These practices, deeply entrenched in traditional farming approaches, contribute to environmental degradation and air pollution, underscoring the need for a shift toward more sustainable practices (Oyedepo, 2012). The challenge lies in such practices being deeply ingrained, making it difficult for stakeholders to transition to more sustainable and energy-efficient methods.

Adopting alternative practices, such as utilising rice straw for animal bedding or thatching, remains limited in Nigeria. Studies indicate that despite the potential economic gains and sustainable resource management opportunities associated with energy valorisation, these practices need to be widely embraced by Nigerian rice farmers (Adekoya et al., 2016). The lack of awareness regarding alternative uses and energy valorisation technologies limits the exploration of new avenues for economic and environmental benefits.

Challenges faced by rice farmers and processors in Nigeria include financial constraints, a lack of technical expertise, and the absence of supportive policies. The initial investment required for adopting energy valorisation technologies, such as anaerobic digestion or biomass briquetting, poses a significant obstacle, particularly for small-scale farmers in Nigeria (Isu & Chukwu, 2023). The absence of clear and supportive government policies further compounds these challenges, creating a disincentive for stakeholders to transition from traditional practices to more sustainable and efficient methods (Ogedengbe et al., 2017).

Despite these challenges, opportunities for improvement exist within the Nigerian context. Targeted educational campaigns emerge as a key strategy to enhance awareness and promote better practices among rice farmers and processors in Nigeria. These campaigns should emphasise the economic benefits, environmental impact, and long-term sustainability associated with energy valorisation from rice by-products, considering Nigerian farmers' specific cultural and socio-economic contexts (Adeoti et al., 2019). To effectively bridge the knowledge gap and empower stakeholders to make informed decisions, training programs, workshops, and on-field demonstrations that are specifically designed to meet the needs of Nigerian farmers should be implemented.

Government intervention is critical in Nigeria to support stakeholders to overcome challenges and embrace sustainable practices. The agriculture industry in Nigeria may undergo significant change if policies are implemented to support and incentivize the adoption of energy valorisation technologies (Ekundayo, 2023). Financial assistance, subsidies, and tax incentives can encourage Nigerian farmers and processors to invest in more sustainable practices, benefiting the agricultural industry as well as the environment.

2.6. Factors Influencing Awareness and Adoption of Energy Valorisation among Farmers and Processors

A crucial factor impacting awareness is the level of education among farmers and processors. Studies indicate that more knowledge of innovative practice such as energy valorisation is positively correlated with greater levels of education (Ajiboye et al., 2019). Educated individuals are more likely to access and understand information about the benefits of energy valorisation, enabling them to make informed decisions regarding its adoption.

Access to information plays a pivotal role in shaping awareness among farmers and processors in Nigeria including an access to extension services and information channels, which contributes to a need for more awareness regarding the potential benefits of energy valorisation technologies (Ogedengbe et al., 2017). Insufficient outreach programs and communication channels hinder the dissemination of knowledge, creating a barrier to adopting sustainable practices.

The economic context within which farmers and processors operate is a critical determinant of their willingness to adopt energy valorisation technologies. Financial constraints pose a significant challenge, particularly for small-scale farmers who may perceive the initial investment in technologies such as anaerobic digestion or biomass briquetting as prohibitive (Adekoya et al., 2016). Therefore, the economic viability of adopting energy valorisation practices becomes a crucial consideration for stakeholders.

Government policies and support mechanisms are pivotal in influencing awareness and adoption. A study conducted in Nigeria highlighted that the absence of clear and supportive government policies hinders progress in sustainable practices within the agricultural sector (Adeoti et al., 2019). Policies that provide incentives, subsidies, and financial assistance can encourage farmers and processors to invest in energy valorisation technologies, fostering a supportive environment for adoption.

Technological literacy is another determinant of adoption, with farmers and processors needing the knowledge and skills to operate and maintain energy valorisation systems. A lack of technical expertise can act as a barrier, preventing stakeholders from embracing innovative technologies. Capacity-building initiatives and targeted training programs are essential in addressing this gap and empowering individuals to adopt and effectively use these technologies (Singh et al., 2020).

Cultural factors also influence the adoption of energy valorisation among farmers and processors. Deeply rooted cultural practices and beliefs may shape attitudes towards new technologies (Ajiboye et al., 2019). Aligning awareness campaigns with cultural values and practices can facilitate a smoother integration of sustainable practices into existing systems.

Environmental awareness and concerns contribute positively to the adoption of energy valorisation technologies. As global awareness of environmental issues grows, farmers and processors in Nigeria are increasingly recognising the ecological impact of traditional energy sources. Aligning awareness campaigns with narratives of environmental conservation is crucial for effective communication and resonating with the population's concerns (Akpan-Obong et al., 2023).

2.7. Knowledge Gaps and Research Needs

One of the prominent knowledge gaps is the need for stakeholders to understand the available energy valorisation options and their specific applicability to diverse agricultural contexts in Nigeria. Research is needed to comprehensively catalogue the existing technologies, evaluate their performance under varying conditions, and disseminate this information to farmers and processors (Moraes et al., 2014). Bridging this knowledge gap will empower stakeholders to make informed decisions regarding the most suitable energy valorisation methods for their agricultural practices.

Furthermore, there is a need for in-depth studies focusing on the socio-economic and cultural factors influencing the adoption of energy valorisation technologies. Understanding the unique challenges and opportunities within different regions and communities will aid in tailoring awareness campaigns and interventions effectively. Research should delve into the cultural dynamics that shape perceptions of new technologies, and the economic feasibility of adopting these innovations, especially for small-scale farmers (Singh et al., 2023).

Technical literacy poses another critical knowledge gap, especially among rural farmers. Research efforts should focus on developing user-friendly technologies and providing training programs that enhance the technical skills of farmers and processors. Additionally, studies should explore innovative approaches, such as community-based learning initiatives, to bridge the gap between technological advancements and the practical knowledge required for successful implementation at the grassroots level (Singh et al., 2020).

The landscape of adoption of energy valorisation is significantly shaped by government policy. Research is needed to evaluate existing policies' effectiveness and propose new frameworks that incentivize and support the integration of sustainable practices within the agricultural sector (Al-Mansour et al., 2019). Building an environment that is conducive to the widespread adoption of energy valorisation technology will involve identifying policy gaps and opportunities for improvement.

3. AIMS OF THE THESIS

The overall purpose of this master's thesis was to examine the level of knowledge and awareness among rice farmers and processors concerning the potential for energy valorization of rice by-products.

3.1. Specific Objectives:

1. Assess the awareness level of energy valorisation of rice by-products among rice farmers and processors in Nigeria.
2. Assess the sources of energy used by Nigerian's rice farmers and processors for cooking and heating.
3. Evaluation of the willingness of the rice farmers in Nigeria to adopt rice by-products as an alternative energy source for their household use (cooking and heating).
4. Examine the factors and barriers that influence the adoption of these technologies among rice farmers in Nigeria.

3.2. Research Questions

This study's research question is important because it directs every step of the study, from data collection and study design to analysis and reporting. These steps include:

1. What level of awareness do Nigerian rice farmers and processors have regarding the potential for energy valorisation offered by rice by-products such as husks and straws?
2. What are the sources of energy Nigerian‘s rice farmers and processors used for cooking and heating?
3. How can the willingness and adoption of energy valorisation practices for rice by-products be increased among rice farmers in Nigeria?
4. What challenges and barriers do Nigerian rice farmers face in adopting energy valorisation practices and techniques for rice by-products?

3.3. Limitation of the Study

Outlining the study's goals and limitations will provide a clear framework for the study and make it easier for readers to understand the investigation boundaries.

1. The findings may be uniformly applicable to only some of the countries as there are different regions within Nigeria with varying levels of awareness and access to technologies.
2. Participants provided information based on their perceptions, which could be subjected to reporting bias; despite efforts to minimise bias, the study may be subjected to some degree of bias or subjectivity in responses and interpretation.
3. As a diverse country, cultural differences, language barriers, and Insurgencies all could have an impact on how precise and comprehensible the data is collected, the use of language interpreter and data collection assistant in the location with language barriers and insurgencies was employed respectively.
4. Time limits, sample size, and participant representativeness may limit the study's findings and affect the depth and breadth of data collection and analysis.

4. MATERIAL AND METHODS

4.1. Study Area Description

Nigeria is a nation officially known as the Federal Republic of Nigeria. It is a country in West Africa that has a coastline which runs along both the Atlantic Ocean and the Gulf of Guinea, and it shares borders with Benin to the west, Niger to the north, the Gulf of Guinea to the south, Chad, and Cameroon to the east (The World Bank, 2023).

Nigeria is the most populous country in Africa, constituting approximately one-fourth of the population in sub-Saharan Africa. Its most distinctive feature is the size of its population, with more than 230 million people, distributed over a total area of 923,777 square kilometres (356,669 square miles) (The World Bank, 2022).

Nigeria is a multiethnic state with about 250 ethnic groups that speak almost 500 different indigenous languages, exhibiting a vast diversity of identities and cultures (Ethnicity in Nigeria, 2007). In Nigeria the three main ethnic groups are the Igbo in the east, the Hausa in the north, and the Yoruba in the west. These groups make up over 60 % of the total population and collectively play a substantial role in shaping the country's cultural landscape and societal dynamics. Other ethnic groups are frequently referred to as minor ethnic groups. To foster linguistic unity linguistic unity across the country the country, English has been designated as the official language (Gbolaha et al., 2019).

The Federal Republic of Nigeria comprises 36 independent states, alongside the Federal Capital Territory, which houses the country's capital, Abuja. Each state showcases its own unique diversity in terms of ethnicity and culture, contributing to the rich tapestry of Nigerian society. The most significant metropolitan areas are Kaduna, Kano, Ibadan, and Lagos (Nigeria's largest city, one of the largest metropolitan areas globally, and the largest in Africa) (Yusuf et al., 2023). Nigeria is subdivided into six geopolitical zones: North-East (NE), North-West (NW), North-Central (NC), South-South (SS), South-East (SE), and South-West (SW). Its topography comprises southern lowlands merging with central hills and plateaus, mountains in the southeast, and plains in the north. The country experiences tropical monsoon climate in the south, tropical savanna in the centre, and Sahelian and semi-arid in the north. Nigeria is rich in natural resources, including coal, limestone, iron ore, oil, tin, natural gas, and other minerals (Library of Congress, 2011).

The study comprises a selected sample of small- and large-scale rice stakeholders, as well as rice farmers and processors from different states of the geopolitical zones in Nigeria that are recognised for their rice production. The state includes Nasawara (North-Central), Ogun (South-West), Niger (North-Central), Kano, Kebbi (North-West), Gombe (North-East) and Taraba (North-East). The population consists of rice farmers and processors in these states that are known for rice production. According to NBS (2021-2022), 32 % of rice is produced in the NW, 25 % in the NE, 17 % in the NC, 16 % in SW, 9 % in the SE and 1 % in the SS geopolitical zones.

4.2. Research Design and Approach

In the Gwagwalada area council of Nigeria, five structured questionnaires were distributed to rice farmers and processors, respectively, as a pilot test to evaluate the level of farmers/processors using rice by-products as an alternative energy source. The pilot testing from 5 respondents each from rice farmer and processor, was done to know if the questionnaire captured what was to be evaluated and if there was a need to amend the questionnaire prior to the data collection.

After the pilot testing, structured questionnaires with some open-ended questions were designed for the rice farmers and processors. Approximately 200 questionnaires were administered to the rice farmers and 60 to the processors in the sampling locations (Geopolitical Zones) known for rice production in Nigeria as shown in Table 1.

Using the structured questionnaire, data were collected from the states in the geopolitical zones known for rice production in Nigeria; Nasawara (NC), Ogun (SW) and Niger (NC) around August-September 2022 and with the assistance of extension officers' data was collected from Kano (NW), Gombe (NE) and Taraba (NE) in November-December 2022 due to some security challenges.

Table 1: Number of Questionnaires Administered and Retrieved from each Zones

Zone	**Rice Farmers**		**Rice Processors**	
	Distributed	Retrieved	Distributed	Retrieved
NW	50	45	15	12
NE	50	36	15	11
SW	50	38	15	13
NC	50	31	15	14
Total	200	150	60	50

4.3. Sampling Techniques

A survey of 200 rice farmers and 60 processors respondents across major states of the geopolitical zones in Nigeria's known rice-producing was conducted. Using purposive sampling techniques, data were collected from August 2022 to September 2022. In areas with insurgency, data were conveniently selected with the help of extension officers from November 2022 to January 2023. Finally, in some instances, snowballing (farmers/processors referring to other farmers/processors) was also used to collect data.

Out of the administered questionnaire amongst the rice farmers and processors, 150 respondents of the rice farmers and 50 respondents of the processors were fully completed and retrieved for analysis. Out of the 200 questionnaires administered among rice farmers, 75 % response rate were retrieved, and 83 % of rice processors' responses were received out of the 60 distributed questionnaires.

4.4. Data Collection Method

For the data collection, we conducted interview with key informants who gave the necessary information to necessitate our study; some of the informants were district heads, administrators (chiefs, sub chiefs, and village elders), and small-scale farmers of varying ages from 18 years to 50 and above, and representatives of rice processing companies. Interviewing the study respondents was carried out through a face-to-face approach with pen and paper, on a door-to-door basis, of the rice farmers and processors in Nigeria. The sampled rice farmers and processors depended mainly on the willingness to provide information on their views of using rice by-products for energy production.

The study data were collected using three main methods (respondent's one-on-one interviews, questionnaires, and field observation). Data collected included general information such as socio-demographic information, knowledge and awareness level of rice farmers and processors about energy production from the valorisation of rice by-products, the willingness of rice farmers and processors to adopt energy production from the valorisation of rice by-products, barriers to energy production from the valorisation of rice by-product, and information on the techniques used for harvesting rice. Depending on the method of harvesting, the amount of rice straws and rice husks differs.

4.4.1. Questionnaires

The questionnaire designs includes both closed-ended and open-ended questions to gather a comprehensive range of responses from the participants. The purpose of the questions was to collect data on socioeconomic factors, the respondents' awareness of the ability to generate energy from rice byproducts, their attitudes and perceptions regarding the valorisation of energy from rice husks, their willingness to convert rice byproducts into an alternative energy source, and the barriers related to the production of energy from rice byproducts. The data obtained from the respondents were examined regularly to ensure their reliability and completeness. There were four sections and 27 questions on the questionnaire for rice farmers. The first section comprised the following topics: years of agricultural experience, total land area (hectares), land under cultivation, land ownership, and the demography of the household (HH), which included farmers and processor contact information for potential follow-up. The second section covered the rice production system, method of harvest, and usage of rice straw and husk. The perception, knowledge, willingness, and barriers to using straw and husk for energy valorisation were covered in sections three and four. Figure 1 represents the rice farmers responding to the questionnaires. Figure 2 shows the interviewer with the rice farmer and language interpreter, while Figure 3 and 4 shows the interviewer with the rice farmer responding to the questions.

On the other hand, there were two sections and 15 questions on the rice processors' questionnaire. The demographics of the processors, their position within the processing facility, their years of work experience, the types of rice they process, and the energy source they utilize for processing were all covered in these sections. The Figure 5 shows the interviewer with the Rice Processor at the Milling Facility.

Figure 1: Rice Farmers Responding to the Questionnaires


Figure 2: Interview with Rice Farmer and the Interpreter


Figure 3: Interview with Young Female Rice Farmer/Processor

Figure 4: Interview with Young Male Rice Farmer

Figure 5: Interview with the Rice Processor at the Milling Facility


Figure 6: Interview with Rice Processor at the Local Fabricated Rice Milling Facility

4.4.2. Field Observation

Collecting some of the vital data for our analysis required an in-person field observation. For instance, to assess the effectiveness of rice harvesting techniques and gather data on rice farming techniques (irrigation, paddy production, and lowland rainfed systems), several rice farms were visited for observation and data recording. During field observation data was gathered on the usage of rice by-product (livestock feeding, selling, burning, and throwing away) by the rice farmers. Figure 7, and 8 shows field observations of the rice husks and straw dumping and burning site, while Figure 9 shows the observation of what Farmers/Processors used mostly for heating and cooking in Nigeria.

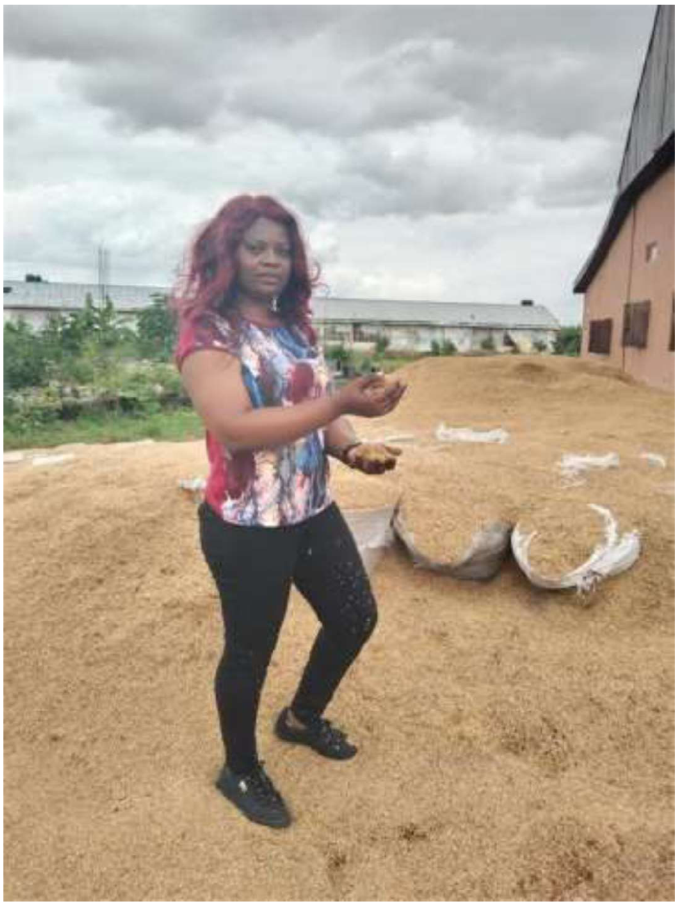

Figure 7: Field Observation at the Dumping Site of Rice Husks and Straw

Figure 8: Field Observation at the Burning Site of Rice Husks and Straw

Figure 9: Field Observation of what Farmers/Processors used mostly for Heating and Cooking (wood fuel as source of energy)

4.5. Data analysis

Following data cleaning, 150 respondents from farmers and 50 from rice processors were utilised for analysis. Quantitative data collected from completed questionnaires was coded, recorded, grouped, and analysed using Microsoft Excel. They were transcribed and properly categorised to guarantee the completeness and meaningfulness of the quantitative data. Microsoft Excel carried out descriptive statistics, including frequency, percentage, mean, and standard deviation. Furthermore, using Statistical Package of Social Science (SPSS) version 26.0, the respondent's attitudes, willingness, and the rate at which rice husks and straw are converted into energy by rice farmers and processors were measured. Cross tabulation was used to give a clear picture of the data association, and chi-square analysis was employed to determine how significant the research variables were. The summary of the data analysis is presented in Table 2 below.

Table 2: The Summary of Data Analysis

Thematic areas	Research questions	Variables	Analysis method
Knowledge and awareness of rice by-products in energy valorisation	Are rice farmers aware they can use rice husks and straw to generate energy?	i) Yes ii) No	1. Descriptive statistics
	What are the uses of rice by-products among the rice farmers?	i) Feeding livestock ii) Selling of rice by-products iii) Burning of rice by-products iv) Throwing away of rice by-products	1. Descriptive statistics (mean percentages, and frequency distribution tables)
Knowledge of rice processors about rice by-products' valorisation	Were rice processors aware that they can convert rice by-products to a source of energy for cooking and heating?	1. Yes 2. No	Descriptive statistics One-way ANOVA
The willingness of rice farmers to adopt rice by-products' valorisation	Are rice farmers willing to adopt the conversion of rice husks and straw as a source of energy?	1. Yes 2. No	The chi-square test. ANOVA analysis Descriptive statistics
Barriers to rice by-products valorisation	What are the barriers preventing the conversion of rice by-products to energy?	1. Lack of technology 2. Lack of knowledge	Descriptive statistics

5. RESULTS AND DISCUSSION

5.1. Descriptive Analysis

The categorical variables among rice farmers are classified in Table 3.

Table 3: Rice Farmers Descriptive Statistics of Categorical Variables (n = 150)

Variable	Description	Frequency	%
Source of Energy for Heating			
Firewood		86	57.3
Charcoal		84	56.0
Rice Husks	Yes (= 1)	33	22.0
Rice Straw		10	6.7
Paraffin Stoves		19	12.7
LPG Gas		17	11.3
Electricity		14	9.3
Biogas		8	5.3
Rice Harvesting Techniques			
Hand	(Yes = 1)	142	95.0
Machinery	(Yes = 2)	8	5.0
Household Head Characteristics			
Gender	Gender of HH (Male = 1)	144	96.0
	Female = 2	6	4.0
Marital Status	Single = 1	60	40.0
	Married = 2	90	60.0
	Divorced = 3	0	0
	Widowed = 4	0	0
	Separated = 5	0	0
Level of Education	Illiterate = 0	8	5.3
	Primary = 1	29	19.3
	Informal Education = 2	18	12.0
	Secondary Education = 3	69	46.0
	College/University Degree = 4	26	17.4
Farm Characteristics			
Rice Variety	African Rice (Yes = 1)	146	97.3
	Asian Rice (Yes = 2)	4	2.7
Land Ownership	Gift Tenure System (= 1)	11	7.3
	Inherited Tenure System (= 2)	97	65.0
	Leasehold Tenure System (= 3)	4	2.5
	Tenants at Government Will (= 4)	3	1.6
	Purchased (= 5)	8	5.7
	Rent Tenure System (= 6)	27	17.9

HH = Household Head

Note: *A categorical variable comprises data grouped into a set of categories, which can be either nominal or ordinal, thereby having a measurement scale (Sinharay, 2010).*

The study sample 150 rice farmers chosen from Nigerian geographical zones that are well-known for their rice production. As it can be seen from Table 3, in terms of sources of energy used for heating, respondents had multiple choice response to their energy source. Majority chose to use firewood and charcoal as their primary energy sources, probably because the area's electricity cost may be high. However, some people get their energy from rice husks and straw; and, interestingly, husks are used more than three times more frequent. Another interesting finding is that most of these respondents who mentioned rice by-products were from the SW and NC zones. This finding could be attributed to their level of awareness and training received on alternative sources of energy. It was discovered that most farmers who use machinery to harvest their rice, amounting to 3 % (out of the total 5 %), are from the SW and NC zones; and the remaining 2 % from the NE and NW zones. Notably, a mere 4 % of surveyed respondents were female, while 96 % were male, highlighting a predominance of male participants. This might be because of the traditional customs of the Nigerians, where the land is mostly inherited by the male gender and the farming process is tedious. Nonetheless, since most of the female population is involved in cooking, which requires energy, they should be involved in providing and finding alternative ways to generate energy used in their household. In terms of marital status, the majority of survey respondents, accounting for 60 %, reported being married, while 40 % said they were single, and none of the respondents indicated they were widowed, separated, or divorced. In terms of educational attainment, the largest percentage (46.0 %) of the respondents reported they had completed secondary school, while 19.3 % reported having completed primary school. Moreover, 17.4 % of respondents held a college or university degree, whilst a mere 5.3% were considered illiterate, meaning they had never received any formal education. Additionally, 12.0 % of respondents also indicated they had received informal schooling. With respect to land tenure systems, a large percentage of rice farmers reported cultivating on land inherited from parents and grandparents, constituting 65.0 % of the total respondents. In contrast, 7.3% of farmers farm under gift tenure, 17.9 % farm under a lease tenure, and 5.7 %. Furthermore, 1.6 % reported cultivating land leased from the government for state-funded food production initiatives.

The respondents interviewed indicated that the availability of land lease is becoming a problem due to the cost required and the population increase. Further, the respondents reported that catchment areas and forests are rapidly being depleted due to the need to claim land for farming and the constant need for charcoal and firewood for cooking and heating. Therefore, using rice by-products could become essential to reduce the level of forest destruction (deforestation) in search of firewood for energy usage. Notably, 95 % of respondents reported harvesting rice manually, while only 5 % utilised machinery for the purpose of harvesting.

Table 4: Rice Farmers Descriptive Statistics of Continuous Variables (n = 150)

Variables	Description	Mean	SD	Min	Max
Farmer's Characteristics					
Age	Years	38.75	10.55	18.0	70.0
Education	Years of Schooling	13.28	3.57	0.0	18.0
Household size	Individuals in House	10.48	9.80	1.0	47.0
Farming experience	Years in Farming	14.71	9.75	3.0	50.0
Farming Characteristics					
Land size	Hectares	3.91	3.97	5	30.0
Land under cultivation	Hectares	2.92	2.34	0.25	15.0

Note: *Continuous variables consist of measurements with decimal precision, such as distance and time, and can have an infinite number of values between the lowest and highest measurement points (McCue, 2007).*

Table 4 presents the continuous variables' categorization among rice farmers in the surveyed study locations. It was calculated that the average age of rice farmers was 38.75 years, with the youngest farmer being 18 years old and the oldest 70 years old. The average length of time respondents had attended school was 13.28 years, with a maximum of 18 years, in terms of educational attainment. The farmers that participated in the study reported an average household size of 10.48 individuals, notably with the largest household comprising 47 people. The average farmer was found to have 14.71 years of farming experience, while the most experienced farmer boasted 50 years of experience, and the least farmer had only 3 years of farming. The average land area owned by rice farmers was 3.91 hectares, with the greatest land area being 30 hectares and 5 hectares being the least. Additionally, the study also investigated the extent of land cultivated by each respondent, revealing a range from 0.25 as the least land area under cultivation and the highest 15.0 hectares, with an average of 2.92 hectares under cultivation.

Beside rice farmers, rice processors category variable classification is shown in Table 5.

Table 5: Rice Processor's Descriptive Statistics of Categorical Variables (n = 50)

Variable	Description	Frequency	%
Source of Energy for Milling			
Firewood		0	0.0
Charcoal	(Yes =1)	0	0.0
Rice Husk		5	10.0
Rice Straw		0	0.0
Diesel		48	96.0
LPG Gas		2	4.0
Electricity		0	0.0
Biogas		0	0.0
Processor's Characteristics			
Gender	Gender of HH (Male = 1)	39	78.0
	Female = 2	11	22.0
Marital Status	Single = 1	14	28.0
	Married = 2	34	68.0
	Divorced = 3	1	2.0
	Widowed = 4	1	2.0
	Separated = 5	0	0.0
Level of Education	Illiterate = 0	0	0.0
	Primary = 1	4	4.0
	Informal Education = 2	19	38.0
	Secondary Education = 3	24	48.0
	College/University Degree = 4	5	10.00
Processing Characteristics			
Rice Variety	African Rice (Yes = 1)	49	98.0
	Asian Rice (Yes = 2)	1	2.0
Position at the Processing Plant	Manager (= 1)	21	42.0
	Operator (= 2)	2	4.0
	Processor (= 3)	13	26.0
	Assistant (= 4)	9	10.0
	Staff (= 5)	5	18.0

Table 5 shows that there were 50 respondents in total, with a significantly skewed distribution of 78 % being male and 22.0 % female making up the processors. This gender disparity raises the questions about the factors influencing women's participation in rice-producing activities and calls for further research into potential barriers and inclusion-promoting opportunities. Understanding and addressing gender dynamics in the rice processor sector are crucial for promoting diversity and gender equality. The majority of rice processors accounting for 48 % have at least completed secondary education, with 10 % having a college or university degree and 4 % with only primary education.

Additionally, a substantial proportion of 35 % have obtained informal education. The diversity of education among rice processors highlights the varied skill sets within the sector and suggests the possibility of developing skill development initiatives tailored to the requirements of various educational backgrounds. The majority of the processors (68 %) were married, 28 % were single, whereas less than 5 % were either divorced, separated, or widowed/widower. The predominance of married individuals suggests that family units may play a significant role in rice processing activities, and considerations related to family dynamics could influence participation in the sector.

Table 6: Rice Processor's Descriptive Statistics of Continuous Variables (n = 50)

Variables	Description	Mean	SD	Min	Max
Farmer's Characteristics					
Age	Years	33.7	7.61	21.0	45.0
Education	Years of Schooling	12.4	3.50	5.0	20.0
Household size	Individuals in House	7.1	2.4	1.0	15.0
Processing experience	Years in Processing	9.74	3.67	3.0	15.0
Processing Characteristics					
Amount of Polished Rice Obtained	%	46.04	-	40	50.0
Price for Processing 50 kg bag	Naira *	1,667	-	800	3000

**1$ is 422.92 (Central Bank of Nigeria (CBN), 2022)*

The continuous variable of rice processors in the surveyed study locations was highlighted in Table 6. The demographic characteristics of rice processors in Nigerian provide valuable insights into the composition of this vital sector. The oldest rice processor was 45 years old, and the youngest was 21. The average age of rice processors was 33.7 years. Remarkably, the age range of the diversified workforce is 21–45 years old. Notably, no rice processors were reported to be age 50 and above, indicating that the workforce in this sector is predominantly younger, with potential implications for sustainability and succession planning within the industry. Regarding work experience at the processing facility, the average year is 9.74, with a minimum of 3 years and a maximum of 15 years' experience. An average 46.04 % of polished rice can be obtained from 50 kg of unprocessed rice, at a minimum price of 800 naira and a maximum price of 3,000 naira. This might be explained by the many geopolitical zones in Nigeria, where there are differences in living standards and cultural norms. This is consistent with the results of Afees et al. (2023), who emphasised the noteworthy correlation between the geopolitical zones and the volatility of the Nigerian stock and currency markets.

5.2. Specific Objective 1: Assess the Awareness Level of Energy Valorisation of Rice By-products among Rice Farmers and Processors in Nigeria.

The respondent's awareness and knowledge of energy valorisation of rice products were examined and assessed using various thematic as follows:

5.2.1. Disposal/Use of Rice Straw by Rice Farmers

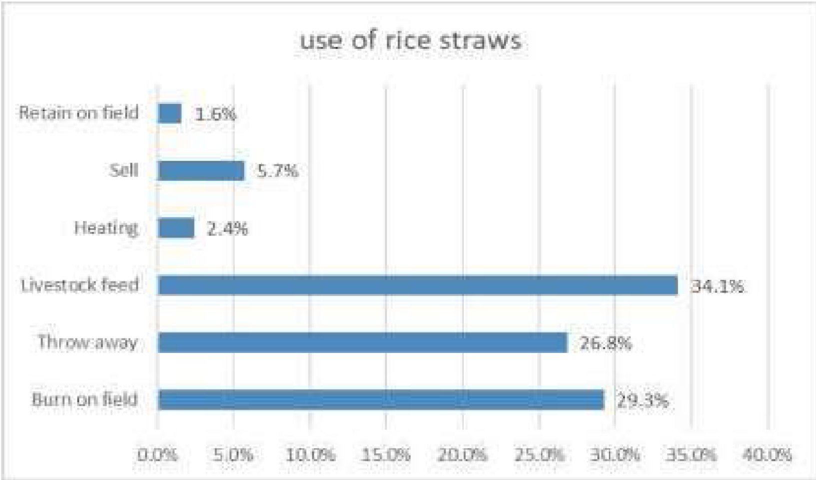

Figure 10: The Use of Rice Straw

One notable finding as shown in Figure 10, is that a significant portion of rice farmers, accounting for 29.3 %, reported the practice of burning rice straw on the field. This method, while common raises environmental concerns because it releases greenhouse gases and the potential for solid degradation. This aligns with the study of Hoang et al. (2021), that reveals the significance of finding fuel alternatives that that are not only cost-effective but also environmentally friendly for domestic use within society. Addressing sustainable alternatives becomes crucial to mitigate the environmental impact associated with this practice. The second most prevalent method identified is throwing away rice straw, with 26.8 % of respondents admitting to this practice. This practices, although less environmentally damaging than burning, contributes to waste and missed opportunities for resource utilisation (Nader, 2023). Understanding the reasons behind this practice, whether due to a lack of awareness or limited alternatives, is essential for developing effective interventions. Interestingly, a considerable % of farmers, constituting 34.1 %, reported using rice straw as livestock feed. This agrees with the study of Osti (2020), which states that rice straw serves as the primary feed source for ruminant animals during the dry season, particularly in semi-intensive and extensive farming systems. This practice showcases a positive trend toward resource maximisation and sustainability. Utilising rice straw as livestock feed not only reduces waste but also contributes to the circular economy within the farming system (Kumar, et al., 2022).

A small fraction of respondents, representing 2.4 %, reported using rice straw for heating. Interestingly, these respondents are from the South-West (SW) geopolitical zone. This highlights a potential avenue for exploring alternative uses of rice straw beyond traditional agricultural practices. The relatively low fraction of the respondents could be as a result of lack of awareness and technological know-how. This resonates with the literature highlighting the factors influencing awareness, including the scale of the processing facility, technological infrastructure, and access to information and training programs (Douthwaite, 2007). Further research and development in this area could lead to innovative solutions for addressing energy needs in rural communities. The survey also revealed that a minority of farmers, 5.7 %, sell rice straw, suggesting potential economic opportunities associated with this by-product. Understanding the market dynamics of selling rice straws and identifying strategies for enhancing the economic value of rice straw can contribute to the financial well-being of farmers. In contrast, a mere 1.6 % of respondents indicated retaining rice straw on the field. Although not common, this practice may have ecological benefits such as soil enrichment and erosion prevention. Thus, a comprehensive quantitative analysis of both the environmental and economic aspects of sustainable straw management is provided, compared to the complex issues associated with straw burning. This aligns with the findings of Bhattacharyya et al. (2021), which underscore the advantages of sustainable rice straw management practices over field burning, considering both environmental and economic perspectives. Exploring the reasons behind this low percentage can provide insight into farmers' challenges in adopting more sustainable practices.

Generally, the survey results indicate that Nigerian rice farmers use a diverse range of post-harvest practices. While some practices, such as burning and disposing of rice straws, raise environmental concerns, others, like using rice straw for livestock feed or exploring alternative uses, demonstrate a positive shift towards sustainability. Addressing the challenges associated with less sustainable practices and promoting viable alternatives will be essential for improving the overall sustainability and resilience of rice farming in Nigeria.

5.2.2. Rice Farmer's Knowledge of Energy Valorisation of Rice Straws

The respondents were required to respond to whether they were aware that the by-product (straws) could be used in generating energy for household usage. Among the 150 respondents who filled out the questionnaires, 19 % indicated that they knew using straws for cooking. Out of these respondents, 7 % were from the South-West, 7 % from the North-Central zone and 5 % from the other zones, while 81 % of the respondents were not aware of the valorisation of rice straws for cooking. The study also reveals that 28.6 % responded that they were aware of using rice straws for heating in their homes, while 71.4 % indicated that they were unaware of these facts. Among the 28.6 % of respondents that were aware, 12.4 % are recorded to be from the South-West, while 9 % from the North-Central and the rest from the North-East and North-West zones. The data collected from the respondents on the using rice straws as source of energy is shown in Table 7.

Table 7: The Frequency of using Rice Straw for Cooking and Heating

Variables	Frequency	Percentage
Rice straws for cooking		
Yes	28	19.0 %
No	122	81.0 %
Rice straws for heating		
Yes	43	28.6 %
No	107	71.4 %

5.2.3. Rice Farmer's Knowledge of Energy Valorisation of Rice Husks

As represented in Table 8, of the 150 participants in the study, 25 respondents indicated that they had experience using rice husks as a source of cooking, which represented 16.5 % of the total respondents; 83.5 % of them were completely unaware of the rice husk valorisation for cooking. This stark lack of awareness aligns with previous research emphasising the importance of knowledge dissemination for adopting sustainable practices (Meegoda et al., 2018). As indicated by the survey, the lack of awareness suggests a missed opportunity for rice farmers to adopt eco-friendly practices and reduce the environmental impact of agricultural activities. Inadequate awareness can hinder the integration of eco-friendly energy solutions, emphasising the need for educational campaigns to promote understanding among rice farmers. Research from Adekoya et al. (2016) emphasises the challenges associated with disseminating information and promoting awareness among farmers in developing countries.

Further, 26 % of them indicated that they had knowledge of using rice husks for home heating, while 74 % of them did not know its usage. This finding underscores the multifaceted nature of awareness gaps within the surveyed population. Research by Patel & Singh (2021) corroborates the idea that varying levels of awareness exist among farmers, with some being more informed about specific applications of agricultural by-products than others. Such discrepancies highlight the need for nuanced educational strategies adapted to farmers' diverse needs and contexts. However, regarding renewable energy, awareness is a key precursor to behavioural change and targeted educational campaigns have been advocated as effective strategies (Singh & Patel, 2022). The findings underscore the urgency of addressing the knowledge gap through widespread campaigns, government intervention, and financial support.

Table 8: The Respondents' Knowledge of Energy Valorisation using Rice Husk

Variables	Frequency	Percentage
Rice husks for cooking		
Yes	25	16.5 %
No	125	83.5 %
Rice husks for heating		
Yes	39	26.0 %
No	111	74.0 %

The survey findings on the knowledge of energy valorisation of rice husk among rice farmers in Nigeria underscore critical challenges in awareness and utilisation of sustainable practices within the agricultural sector. The results highlight the need for targeted interventions to bridge the identified gaps.

The study emphasises that 83.5 % of small-scale rice farmers are ignorant of techniques to ensure that by-products of rice farming are not wasted but used for generating sustainable and eco-friendly energy. The dearth of knowledge among farmers about the energy valorisation of rice husks and straws implies that a substantial portion of by-products, which could be harnessed for sustainable energy, is currently going to waste. Efficient utilisation of these by-products could have the potential to improve rice production's overall sustainability and efficiency while also promoting energy sustainability. Addressing this awareness gap is crucial for fostering a more environmentally conscious approach to rice production, aligning with global efforts to promote sustainable agriculture. However, effective communication strategies, considering local contexts, cultural nuances, and the accessibility of information, are imperative for addressing these challenges.

5.2.4. Assessment of Awareness among Rice Processors Regarding Energy Valorisation of Rice Husks.

The study also sought to determine the awareness of rice processors as the possibility of rice by-products being converted into energy, which can be used in the factory while processing the rice. Therefore, rice processors were asked to provide details regarding the utilisation of rice husks after processing phase. The result presented in Figure 11, reveals that 30 % of the rice processors who were interviewed reported that the rice by-products are sold to different companies, and 15 % indicated that the rice husks were used to produce energy in the factory. The majority of the rice processors amounted to 55 %, which reportedly burns the rice husks to ashes. This practice is recognized to produce a significant amount of air pollutants, which affects the public's health, causes climate change, and seriously deteriorates ambient air quality (Eze et al., 2022). This also aligns with the recent studies and surveys in various regions of Nigeria carried out by Adewale et al. (2022), which have sought to evaluate the awareness levels among rice processors concerning energy valorisation. Preliminary findings suggest a diverse landscape, with some processors displaying a good understanding of energy valorisation practices while others may lack comprehensive knowledge on the subject. However, the identified lack of knowledge on the use of rice husks may be attributed to deficiency in technology for energy valorisation from rice husks. This resonates with existing literature highlighting the contribution of technological infrastructure to the adoption of practices that are environmentally friendly (Fu et al., 2018). Research and development efforts are crucial in this context to identify and promote user-friendly technologies that align with the needs and capabilities of the farming community (Douthwaite, 2007).

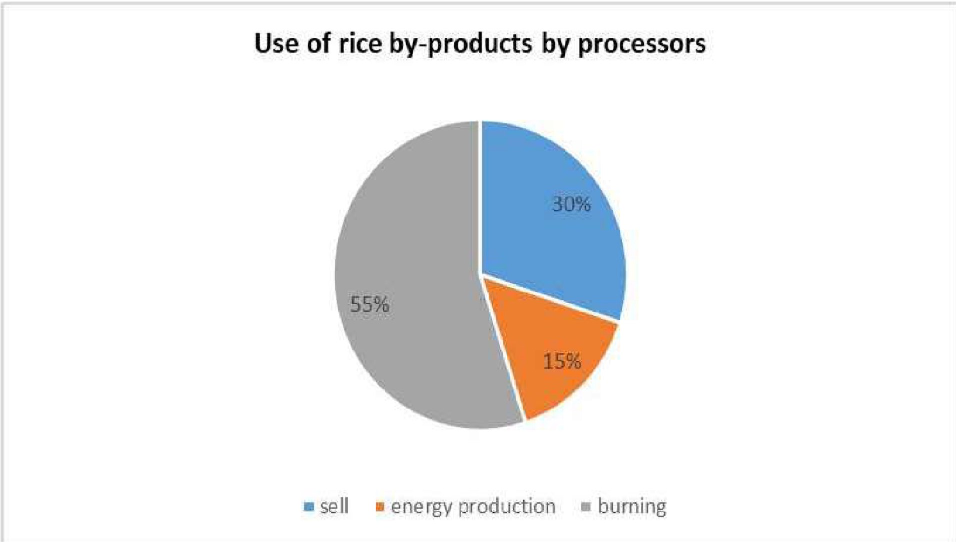

Figure 11: The Usage of Rice Husks by Rice Processors

5.3. Specific Objective 2: Assess the Sources of Energy used by Nigerian's Rice Farmers and Processors for Cooking and Heating.

5.3.1. Sources of Energy used by Farmers and Processors

To fully understand the attitudes of rice farmers in Nigeria towards energy valorisation technologies, it is important first to examine the historical source of energy for the people. This aligns with existing literature emphasising considering the role of local context and available resources in shaping energy practices (Matarira et al., 2007). Despite the fact that Nigeria as a nation has vast natural resources, most of its people are suffering from energy shortages, which leads to economic drags and poor living standards. Traditionally, the people, especially the farmers, have relied heavily on energy from firewood, charcoal, biomass, and fossil fuels. This reliance on natural growths and forests for energy has resulted heavily in the depletion of natural resources, deforestation, and environmental degradation. This corresponds to the study of Adewale (2020), which highlights that using fuel woods as a source of energy encourages deforestation and desertification leading to erosion which has become a great environmental concern. While this may provide short-term solutions for energy needs, the long-term sustainability of such practice may need to be revised. It is essential to balance short-term energy solutions with long-term environmental considerations to ensure the sustainability of energy practices in the agricultural sectors. However, understanding local alternatives and preferences is crucial for designing interventions that align with existing practises and address the community's specific needs.

5.3.2. Source of Energy for Rice Farmer in Nigeria

With the aim of understanding the perception and attitudes towards production of energy from rice by-products, the respondents were required to provide information on the source of energy they are using at home while heating and cooking as presented in Table 3 and Figure 12, respectively. The respondents recorded that the main source of home heating is firewood (57.3 %), which are obtained from the natural forests; the use of charcoal as a source of heat was reported by 56 % of the respondents, 5.3 % use biogas, 22 % use rice husks, straw 6.7 %, while 9.3 % and 11.3 % use electricity and LPG respectively. As observed, the main heating energy is extracted from traditional resources, leading to serious environmental degradation due to the growing population and the constant need for heating energy.

As indicated in Figure 12, 40.8 % of the respondents use charcoal as primary energy source for cooking, while 25.8 % of them indicated that they cook with firewood, 13.3 % use biogas, 5.0 % and 5.8 % use rice husks and rice straw consecutively. This indicates that people rely heavily on natural resources (trees) for cooking. Due to the global awareness of environmental concerns and the need to provide sustainable energy for home cooking and heating, some of the rice farmers have shifted from environmentally unfriendly sources of energy to more sustainable ones.

The technologies that have been applied to realise the objective of sustainable source of energy include biogas usage and rice husk and straws for home energy. Therefore, a substantial percentage of rice farmers, as observed from Figure 12, have adopted these methods. The usage of these technologies is not only sustainable and environmentally friendly but also affordable since the waste product that would have been otherwise destroyed is used to produce this energy.

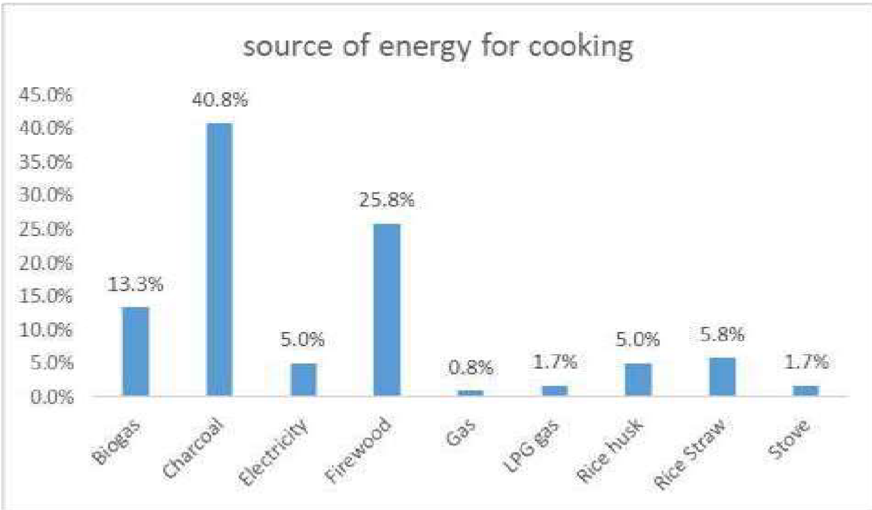

Figure 12: The Source of Energy for Cooking in Nigeria

5.3.3. Source of Energy for Rice Processors in Nigeria

As indicated in Table 5, conversely from rice farmers, the main sources of energy for rice processors in processing facilities are diesel (96 %), followed by rice husks (10 %), and LPG gas (4 %). This again highlights the predominance of fossil resources and the need for clean alternative fuels.

5.4. Specific Objective 3: Evaluation of the Willingness of the Rice Farmers in Nigeria to Adopt Rice By-products as an Alternative Energy Source for their Household Use (Cooking and Heating).

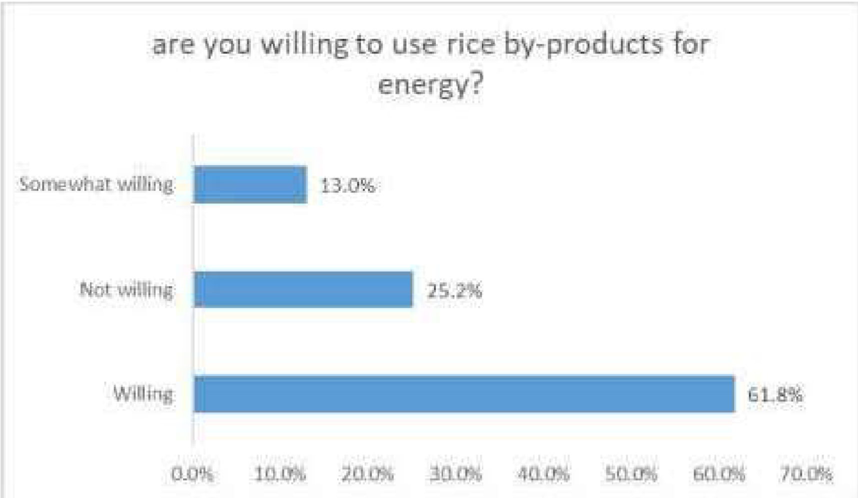

Figure 13: The Willingness of Farmers to Use Rice By-products for Energy

The data on the willingness of rice farmers in Nigeria to adopt energy valorisation from rice by-products provides valuable insights into the attitudes and preferences within this agricultural community. The findings, based on the responses collected underscores the importance of awareness and access to information in shaping farmers' attitudes towards adoption of energy valorisation practices.

As depicted in Figure 13, a significant majority of the surveyed rice farmers, comprising 61.8 %, demonstrated a strong willingness to adopt energy valorisation from rice by-products. Out of which 24 % of the respondents are from the South-West zone, while 19.5 % from the North-Central and the remaining 8.6 % and 9.7 % respondents from the North-East and North-West zone, respectively. The observed willingness of surveyed farmers to adopt energy valorisation reflects a positive inclination towards embracing innovative and sustainable approaches in their farming operations. This robust percentage highlights a significant openness among farmers towards embracing sustainable and innovative practices in their agricultural operations. This aligns with the global trend of increasing awareness of environmental issues and the growing emphasis placed on sustainable agricultural methods (Ajibade et al., 2023). The willingness to explore new technologies indicates an openness among farmers to contribute to environmental conservation and adopt practices that align with broader sustainability goals. This study suggests that a considerable portion of the rice farming community is receptive to transformative changes that can contribute to the overall sustainability of agricultural operations. The positive willingness observed among most rice farmers can be attributed to several factors. Economic considerations emerge as a key motivator, as energy valorisation from rice by-products presents an opportunity for additional income generation (Sharma & Malaviya, 2023). Farmers may see the adoption of this technology as a means to not only manage rice by-products more sustainably but also to tap into new revenue streams. The identified economic considerations as key motivators for the positive willingness observed among the majority of rice farmers resonates with economic motivation theories in agricultural adoption literature (Nawaz et al., 2022), which posit financial incentives as significant drivers for the adoption of new technologies in agriculture. The potential for additional income generation through energy valorisation serves not only as an economic incentive for farmers but also as a pathway towards sustainable resource management. This finding underscores the interconnectedness of economic viability and environmental sustainability, emphasising the capacity of energy valorisation to address both aspects simultaneously.

On the other hand, 25.2 % of respondents indicated that they were not willing to adopt energy valorisation. This segment represents a notable proportion of farmers who may have reservations or concerns about the technology or may perceive barriers to its implementation. Understanding the specific reasons behind this reluctance is crucial for developing targeted interventions and strategies to overcome potential barriers to adoption. Factors such as perceived risks, uncertainties about the technology, or concerns about implementation costs may influence this segment's resistance (Fu et al., 2018). Addressing these concerns through targeted communication and support mechanisms is essential to encourage a more widespread acceptance of energy valorisation among rice farmers. Policymakers and stakeholders must engage with this group to address their reservations and collaboratively work towards creating an environment conducive to the adoption of energy valorisation technologies.

Interestingly, 13.0 % of the farmers expressed a somewhat willing attitude towards adopting energy valorisation. This intermediate category adds complexity to the overall landscape and suggests a nuanced perspective among a subset of respondents, possibly may be influenced by various factors such as perceived benefits, awareness, or access to information. Exploring the factors that contribute to this moderate willingness may offer significant details about the nuances of farmer decision-making in the context of adopting new technologies. Understanding the nuances of this subgroup can guide the development of tailored strategies to further enhance their openness to energy valorisation, contributing to a more comprehensive and inclusive adoption landscape.

5.5. Specific Objective 4: Examine the Factors and Barriers that Influence the Adoption of these Technologies among Rice Farmers in Nigeria.

5.5.1. Factors Influencing Rice Farmers Awareness and Adoption of Energy Valorisation and its Technologies

It is a fact that creating a sustainable and environmentally friendly energy source will significantly address and improve the energy challenges experienced by rice farmers in Nigeria. However, to fully implement energy valorisation of rice by-products, it is important to fully understand the challenges that hinder it, hence develop strategies and solutions to overcome these challenges. In our study, with the aim of establishing the exact barriers to the usage of rice by-products to produce energy, we asked the respondents to provide their views as to what these challenges were.

The most prominent challenge to the energy valorisation of rice by-products is the lack of knowledge by the rice farmers which is presented in Table 9, with 69.9 % of the respondents indicating that they had no knowledge of how to convert rice by-products to energy and the general valorisation technologies. The lack of knowledge might be due to lack of technology to ensure valorisation from rice by-products.

Table 9: Barriers to using Straw for Energy by Rice Farmers

Variable	Frequency	Percentage
Lack of knowledge	105	69.9 %
Lack of technology	37	25.2 %
Never considered	3	1.6 %
Insufficient quantities	5	3.3 %
Total	150	100.0 %

The participants of the survey also highlighted the fact that they were not conversant with the technology used in the energy valorisation of rice straws. The result reported that 25.2 % of the respondents lack the appropriate technology to carry out energy valorisation of rice by-products. This echoes literature highlighting the importance of technological infrastructure in facilitating the adoption of sustainable practices (Schelly et al., 2010). Farmer' restricted access to appropriate technology presents a major obstacle to effectively utilising rice by-products for energy production. Additionally, the study suggests that the lack of technical know-how may contribute to the insufficient knowledge among respondents. This resonates with the broader literature emphasising the importance of capacity-building and skill development in the successful adoption of new practices (Filho et al., 2019). Technology awareness and literacy levels are identified as crucial influencers of attitudes towards energy valorisation. Therefore, enhancing technological literacy is crucial for creating an informed and receptive audience capable of embracing energy valorisation technologies.

These results also correspond with studies by Oyedepo (2012), which highlight that a lack of understanding of these technologies and their benefits contributes to low awareness. The lack of technology to carry out the process highlights a crucial gap in the infrastructure needed for the valorisation of rice by-products. To address this issue, there is a need to invest in research and development to find an efficient technology that will allow even those with no or informal education to perform energy valorisation of rice by-products in their homes. Furthermore, technology transfer initiatives and capacity-building programs can empower local communities to embrace and utilise this advancement. Therefore, targeted educational campaigns addressing different demographic groups are essential to enhance technological literacy and create an informed and receptive audience.

Some respondents indicated that the reason they have not implemented energy valorisation from rice by-products is because there are not enough rice straws to carry out this process; the barrier was identified by 3.3 % of the respondents. While this percentage is relatively small, it is crucial to address concerns related to the steady supply of raw materials for energy valorisation. Conversely, 1.6 % of the respondents have never considered the fact that rice by-products could be used in the generation of energy for cooking and heating. This result indicates that there have been unexplored opportunities to bring about a sustainable energy generation process. The fact that respondents have never considered the matter could be due to low level of awareness of the energy valorisation of rice by-products. This lack of consideration aligns with literature suggesting unexplored opportunities in the realm of sustainable energy generation (Filho et al., 2019). The findings indicate unawareness of the energy valorisation of rice by-products, emphasising the need for education and awareness initiatives. Literature suggests that showcasing success stories and practical applications can be effective in changing perceptions and promoting adoption and how cultural practices impact the acceptance of new technologies (Carley & Lawrence, 2013).

As per the responses from the participants, a substantial number of them who were unaware had never heard of or even considered the use of rice husks and straws to generate energy for cooking and heating in their homes could also be attributed to cultural and traditional practices. The cultural fabric of Nigeria plays a pivotal role in influences perspectives towards innovative solutions like energy valorisation. According to Ajiboye et al. (2019), cultural practices deeply rooted in waste disposal and energy use impact the acceptance of new technologies. Traditional beliefs often influence the perception of waste materials, and incorporating cultural sensitivity into educational campaigns is essential to bridge the gap between customary practices and modern energy solutions. As such, efforts must be made to create awareness among the people that rice by-products are beneficial and should not be thrown away or burned in the field. Through proper education and showcasing success stories, the perception of the people can be changed in order to adopt energy valorisation from rice straws and husks. The study emphasises the necessity of incorporating cultural sensitivity into educational campaigns, a strategy supported by existing literature advocating for context-specific interventions (Singh & Patel, 2022). Efforts to create awareness among individuals rooted in cultural and traditional practices align with literature emphasising the importance of aligning interventions with local beliefs and values (Nawaz et al., 2022)

However, the government should intervene to provide education and financial support for the people to ensure that the process of converting rice by-products to energy is successful. Addressing this challenge to the production of energy through rice by-products will cultivate more informed farmers who will, in time, be able to generate a fully sustainable source of energy that will benefit them and the nation at large.

5.6. Rice Production Systems in Nigeria

The findings and results from the data on rice production systems in Nigeria as shown in Figure 14 reveal a diverse landscape of agricultural practices, each with its unique characteristics and implications for rice cultivation. Among the surveyed production systems, flooded Fadamas emerged as the predominant method, constituting 48.0 % of the responses. This indicates the widespread use of lowland areas with natural water sources, highlighting the preference for environments conducive to flooded conditions. Flooded Fadamas are known for their exceptional water retention capacity, making them well-suited for rice cultivation. This characteristic creates an optimal environment for the growth and development of rice crops.

Basin irrigation systems, while less prevalent at 8.1 %, showcase a noteworthy presence in the agricultural landscape. This finding suggests a diversification in irrigation practices, emphasising the importance of efficient water management for rice cultivation. The adoption of basin irrigation reflects a deliberate effort to control water distribution and optimise resource utilisation in rice fields.

Rainfed lowland systems, accounting for 25.2 % of responses, indicating a significant reliance on natural rainfall for rice cultivation. This practice aligns with the geographic distribution of regions with consistent rainfall patterns, underlining the importance of environmental conditions in shaping rice production systems. The prevalence of rainfed lowland systems underscores the adaptability of rice cultivation to varied agroecological zones in Nigeria.

Rainfed upland and paddy rice systems contribute 13.0 % and 1.6 %, respectively, to the overall distribution. These findings highlight the diversity in topography and land use for rice cultivation. Rainfed upland systems, relying on rainwater without flooding, showcase the adaptability of rice cultivation to varying altitudes. The presence of paddy rice systems, while relatively low, signifies specialised cultivation practices, often involving standing water to enhance yields.

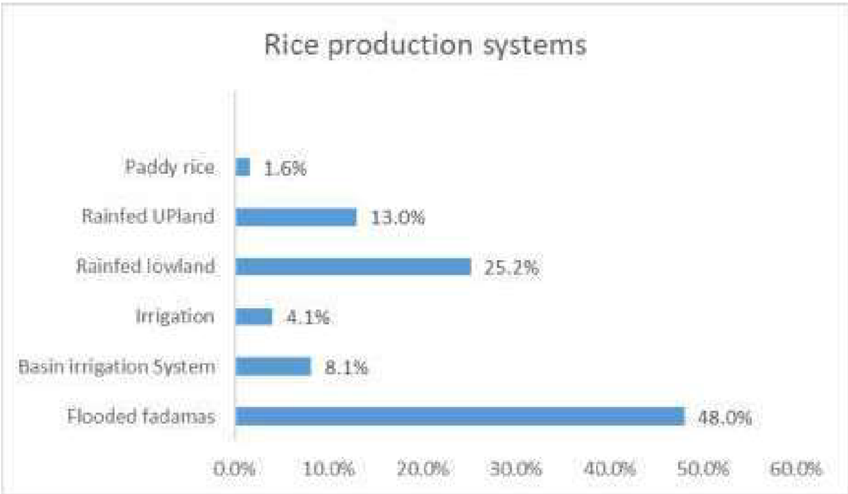

Figure 14: The Rice Production Systems in Nigeria

5.6.1. Rice Processing

Rice processing involves a series of post-harvest activities aimed at transforming raw rice into edible, marketable products. The literature on rice processing examines diverse techniques, from traditional methods to modern industrial processes. Key stages include parboiling, milling, and polishing, each influencing the quality and market value of the final product. Studies emphasise the impact of processing on nutritional content, shelf life, and consumer preferences. Sustainable processing practices, technological advancements, and the influence of government policies in optimizing the efficiency and environmental sustainability of rice processing are central themes in this body of research.

In the study, rice processors were required to provide a series of information on rice processing: their demographic information, the use of rice by-products, the type of energy they use in the factory, and information on the actual cost and amount of rice produced from 50 kg of unprocessed rice.

5.7. By-products usage between the Farmers and Processors

We carried out a single factor ANOVA analysis to determine if there is a difference between the use of rice by-products by the farmers and the processors. The analysis in Table 10 below indicates the results of the one-way ANOVA. The result showed that the significance level of the usage of rice by-products by the farmers and the processors is slightly $p = 0.0527$ which is insignificant at $p<0.05$. This indicates that rice farmers and processors in Nigeria have nearly identical responses to the usage of rice by-products.

The analysis was carried out between the rice farmers and processors to determine the difference in their disposal methods of the rice by-products. As indicated in the one-way ANOVA, there is a slight difference.

Table 10: Summary of the usage of Rice By-products (Husks) among the Rice Farmers and Processors

Groups	*Count*	*Sum*	*Average*	*Variance*
Farmers	6	10	25	294.4
Processors	6	50	8.333333	51.06667

Table 11: The One-way ANOVA Analysis for the usage of Rice By-products (Husks) among the Rice Farmers and Processors

Source of Variation	***SS***	***Df***	***MS***	***F***	***P-value***	***F crit***
Between Groups	833.3333	1	833.3333	4.824392	0.052757	4.964603
Within Groups	1727.333	10	172.7333			
Total	2560.667	11				

There is notable variability between the two groups "farmers and processors", as indicated by the between groups analysis in Table 11. This suggests that there are differences in the average values of the dependent variable between these two groups. Additionally, within each group, there is considerable variability among individual observations, as evidenced by the within-groups analysis. This reflects how individual data points within each group deviate from their respective group means. Together, these findings highlight the presence of both between-groups and within-group variability, contributing to the overall variability observed in the dataset.

Generally, the analysis indicates that the use of rice by-product within Nigeria by the farmers and processors are slightly different. The processors sell a slightly larger percentage of their by-products than the farmers. As such it is a general concern that there is lack of conversion of the rice by-products to energy production towards heating or cooking purposes.

6. CONCLUSION AND RECOMMENDATION

6.1. CONCLUSION

The assessment of awareness regarding the energy valorisation of rice by-products among rice farmers and processors in Nigeria has provided valuable insights into the challenges and opportunities for sustainable practices within the agricultural sector. The findings highlight a critical lack of awareness among farmers regarding possible utilization of rice husks and straw, which creates barriers to the adoption of environmentally friendly energy sources. Addressing these challenges requires a multifaceted approach involving comprehensive educational campaigns, technological advancements, and capacity-building initiatives tailored to the diverse needs of small-scale rice farmers.

The study's revelation that only 16.5 % of respondents (farmers) are aware of using rice husk as a source of cooking emphasises the urgent need for knowledge dissemination. Inadequate awareness can impede the adoption of sustainable practices, necessitating targeted educational campaigns to promote understanding among rice farmers. The study aligns with existing literature emphasising the intricate relationship between awareness, technology, and local context. Efforts should be directed toward developing effective communication strategies that account for local contexts, cultural nuances, and the accessibility of information.

Further analysis indicating that 26 % of respondents (farmers) have knowledge of using rice husks for home heating underscores the multifaceted nature of awareness gaps within the surveyed population. Nuanced educational strategies tailored to the diverse needs and contexts of farmers are essential to bridge these gaps. The study aligns with research emphasising varying levels of awareness among farmers, highlighting the need for tailored interventions. Effective communication strategies, grounded in the local context, are imperative for addressing these challenges and fostering awareness among small-scale rice farmers in Nigeria.

The identified lack of knowledge about rice by-products may be attributed to a deficiency in technology for energy valorisation from rice husks and rice straws. Moreover, addressing the lack of technical know-how requires technical training programs and capacity-building initiatives, empowering farmers with the skills required for effective energy valorisation.

The indication that respondents have alternative sources of heating and cooking aligns with existing literature emphasising the role of local context and available resources in shaping energy practices. While this may provide short-term solutions, the long-term sustainability of such practices might be questionable. Balancing short-term energy solutions with long-term environmental considerations is essential to ensure the sustainability of energy practices in the agricultural sector. Understanding local alternatives and preferences is crucial for designing interventions that align with existing practices and address the specific needs of the community.

Generally, the survey findings underscore the pressing need for transformative changes in the agricultural and energy sectors in Nigeria. Bridging the knowledge gap, addressing technological barriers, understanding farmer attitudes, and leveraging economic motivators are key components of a comprehensive strategy. Absolutely, collaboration among policymakers, researchers, and stakeholders is essential for developing and implementing initiatives that empower farmers, promote sustainable practices, and align with the broader goals of environmental conservation and energy sustainability within Nigeria's agricultural sector. By working together, innovative solutions can be identified and implemented to address the challenges facing farmers while ensuring the long-term health of the environment and the sustainable use of energy resources.

Moving forward, there is potential to enhance awareness, foster technology adoption, and promote sustainable, eco-friendly energy practices in rice farming in Nigeria. Policymakers should play a proactive role in disseminating information, providing education, and offering financial support to farmers. In crafting a comprehensive policy framework, it's crucial to incorporate initiatives that support research and development, facilitate technology transfer, and promote capacity-building programs. These efforts can foster innovation, enhance productivity, and ensure sustainable development across various sectors of the economy. The substantial positive inclination (61.2 %) among surveyed farmers toward adopting energy valorisation holds promising prospects for the integration of sustainable and innovative practices within the agricultural landscape.

However, challenges persist, as highlighted by the 25.6 % of farmers expressing unwillingness to adopt energy valorisation. Understanding the specific reasons behind this resistance is crucial for developing targeted interventions and strategies. Policymakers and stakeholders must engage with this group to address reservations and collaboratively work towards creating an environment conducive to the adoption of energy valorisation technologies.

The nuanced perspective exhibited by the 13.2 % of somewhat willing farmers adds complexity to the adoption landscape. Factors such as perceived benefits, awareness, or access to information influence this subgroup's attitudes. Tailoring strategies to address the specific considerations of these farmers may further enhance their willingness to adopt energy valorisation, contributing to a more comprehensive and inclusive adoption landscape.

The finding also reveals that the main sources for heating as well for cooking among the rice farmers are firewood and charcoal, while the processors for milling in their facilities use mainly diesel as their primary source of energy. In terms of residual disposal or usage, over 56 % rice farmers throw the straw away or burn it on a field, 34.1 % use the straw for their livestock feed, 5.7 % sell and only 2.4 % use it for heating; and the rice husks are mainly also openly burned. Compared to the rice processors, majority of them purposely burn the husks (55 %), 30 % sell and 15 % utilise it in their milling facilities as sources of energy.

The economic considerations identified as key motivators for the positive willingness of the majority align with established economic motivation theories in agriculture. Policymakers can leverage these economic motivators to design incentive structures that make the adoption of energy valorisation more attractive and feasible for a broader spectrum of farmers.

The emphasis on awareness and access to information as crucial factors influencing farmers' attitudes reinforces the need for robust educational initiatives and extension services. Investments in educational and outreach programs are key elements for any strategy aiming at promoting the widespread adoption for energy valorisation in the rice farming community. Creating targeted programs to disseminate information about the technology and its benefits can empower more farmers with the knowledge they need in making appropriate decisions.

In summary, addressing the identified challenges requires a coordinated effort from various stakeholders. By aligning interventions with existing literature and considering the specific circumstances of the farming community, there is potential to foster a paradigm shift towards sustainable and eco-friendly energy practices in rice farming in Nigeria. The study's implications extend beyond individual awareness levels, reaching into the realms of technology adoption, economic considerations, and cultural factors. The success of future initiatives will depend on the collaborative efforts of policymakers, researchers, farmers, and other stakeholders committed to sustainable development in the agricultural sector of Nigeria.

6.2. RECOMMENDATIONS

Increasing awareness and adoption of energy valorisation practices for rice by-products among rice farmers and processors in Nigeria is essential for promoting sustainable agricultural practices, enhancing economic viability, and contributing to environmental conservation. To achieve this, a comprehensive approach that addresses the multifaceted challenges faced by rice farmers and processors is required. By considering technological, educational, communication strategies, government policies, perceived benefits, and barriers, and understanding the impact on sustainability and profitability, the following recommendations were made.

Localised Communication Strategies:

Targeted communication strategies are crucial to increase awareness and adoption. Communication strategies should be adapted to local contexts, considering the diverse demographics and cultural nuances of farming community. Utilising a combination of traditional and modern channels can effectively disseminate information to the diverse demographic of rice farmers and processors. Local language community radio broadcasts, community meetings, and workshops can serve as effective platforms for engaging directly with farmers. Information dissemination should be accessible and relevant, ensuring that farmers and processors can easily understand and relate to the messages conveyed. Simultaneously, leveraging digital media, such as social networks and mobile applications, can reach a wider audience, especially among the younger generation.

Tailored Educational Initiatives:

Campaigns to raise awareness should be adapted to the specific demands and contexts of rice farmers and processors. Educational programs should focus not only on the benefits of energy valorisation but also on practical aspects such as technological know-how and operational skills. Workshops, training sessions, and demonstration projects can provide hands-on experience, empowering stakeholders with the knowledge required for effective adoption.

Government Support Policies and Incentives:

Government intervention is pivotal in promoting the adoption of energy valorisation practices. Policymakers ought to formulate and enact supportive policies that include financial incentives such as subsidies, grants, or tax breaks. These measures can encourage investment and stimulate growth in critical sectors of the economy. These incentives can help offset initial investment costs, making the adoption of energy valorisation technologies more attractive to rice farmers and processors. Additionally, streamlined regulatory processes can facilitate the integration of these practices into existing farming and processing operations. A coordinated effort across relevant government departments is crucial for policy coherence and effective implementation.

Perceived Benefits and Barriers:

Understanding the perceived benefits and barriers is essential for tailoring interventions. Communicating the economic advantages, such as additional income generation and potential savings on energy costs, can positively influence farmers and processors. Highlighting the environmental benefits, including reduced waste and minimised ecological impact, contributes to a positive perception. Simultaneously, addressing perceived barriers, such as initial investment costs and technical know-how, requires targeted support mechanisms, including training programs and access to affordable technology.

Impact on Sustainability and Profitability:

The level of awareness of energy valorisation practices significantly impacts the sustainability and profitability of rice farming and processing. Increased awareness ensures the efficient utilisation of rice by-products, reducing waste and promoting sustainable resource management. Consequently, this enhances the general sustainability of agricultural activities. Moreover, the adoption of energy valorisation practices positively influences profitability by offering an additional revenue stream and reducing dependency on conventional energy sources.

Barriers and Challenges:

Several barriers and challenges hinder the adoption of energy valorisation practices among rice farmers and processors in Nigeria. Inadequate technological infrastructure poses a significant obstacle, limiting access to appropriate technology. Moreover, the deficiency in technical know-how necessitates comprehensive capacity-building initiatives, including skill development and training programs. Addressing this challenge requires substantial investments in research and development (R&D) to identify user-friendly technologies. Governmental organizations, research institutions, and private sector companies collaborating can produce innovations that are aligned with the needs and capabilities of rice farmers. R&D initiatives should focus on developing affordable, scalable, and easy-to-implement solutions that address the technological barriers hindering widespread adoption. However, partnerships can facilitate pooling resources, expertise, and knowledge, creating a synergistic approach to addressing the challenges associated with energy valorisation adoption. Joint initiatives can leverage diverse perspectives and resources to implement holistic solutions.

In conclusion, increasing awareness and adopting energy valorisation practices for rice by-products in Nigeria necessitates a multifaceted approach. The integration of traditional and digital communication channels, coupled with government support through policies and incentives, can create an enabling environment. Emphasising the perceived benefits, addressing barriers, and understanding the impact on sustainability and profitability are integral components of a successful strategy. By addressing technological challenges, providing capacity-building initiatives, and fostering a supportive policy environment, Nigeria can harness the full potential of energy valorisation, ensuring a sustainable and economically viable future for rice farming and processing. Also, empowering individuals with the necessary skills could fosters self-sufficiency and sustainability in the adoption process.

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