An Analysis of Biomass Energy Consumption as an Alternative Energy Source in Jos

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Abstract

The need for cleaner, more sustainable energy systems has become a major priority in the twenty-first century. This is driven by growing concerns about energy insecurity, environmental degradation, and climate change linked to fossil fuel exploration and consumption, as well as the economic risks of overreliance on fossil fuels for energy. This prompted this study to carry out an analysis of biomass energy consumption as an alternative energy source in Jos. The objectives of this investigation are to examine the types of biomass resources available in Jos, consumption patterns, available technologies for converting waste to energy, the potential of biomass energy to replace fossil fuel energy sources, and the socio-economic and environmental implications for the people. Integrated primary data obtained through structured questionnaires and field measurements, along with secondary data from relevant literature, were used. A total of 374 valid responses were analyzed using both descriptive and inferential statistics to evaluate relationships among biomass availability, accessibility, and utilization. The study identified major categories of biomass resources used, including agricultural residues, animal dung and poultry waste, wood residues and sawdust, and market and household organic waste. The results showed that biomass energy consumption is predominantly moderate (41.7%), followed by low (34.5%) and high (23.8%), with primary uses in cooking, heating, and small-scale commercial activities. Traditional biomass combustion remains the dominant conversion technology due to its affordability and accessibility, while adoption of improved technologies such as briquettes, biogas, and gasification remains limited. The study further reveals that biomass energy contributes to improved household energy affordability, waste reduction, employment generation, and enhanced sanitation. It recommends promoting improved biomass technologies, strengthening policy interventions, and increasing public awareness to enhance efficiency and reduce environmental and health impacts.

Keywords: *Biomass energy, Alternative energy, Energy consumption, Biomass utilization, Sustainable energy, Jos, Plateau State, Nigeria.*

INTRODUCTION

The need for cleaner, more sustainable energy systems has become a major priority in the twenty-first century. This is due to increasing concerns about energy insecurity, environmental degradation, and climate change resulting from fossil fuel exploration and its consumption, coupled with the economic risk of over-depending on fossil fuels for energy (Sovacool, 2019). Conventional energy systems based on coal, oil, and natural gas are widely criticized for contributing to greenhouse gas emissions, ecosystem disruption, and unstable energy markets that disproportionately affect developing economies (Bridge, 2018). Consequently, the desire for renewable energy sources such as solar, wind, hydro, and biomass is increasingly becoming the pathway to low-carbon energy development, energy diversification, and sustainable energy supply in society (Cherni, 2020). Among these renewable sources of energy, biomass energy appears to play two important roles: waste management and generation of energy; it also supports rural livelihood when properly managed (Kemausuor, 2021).

Biomass refers to organic materials such as agricultural residues, forest waste, animal dung, and municipal solid waste that can be converted into energy through biochemical and thermo-chemical processes (Oladeji, 2023). It remains one of the most widely used renewable energy sources globally, especially in developing countries where access to modern energy is limited (IEA, 2022). Unlike some renewable sources, biomass is dispatchable, meaning it can provide energy when needed, making it more reliable for continuous supply (Batidzirai, 2020; Scarlat, 2019).

In many developing regions, biomass has traditionally served as the main household energy source in the form of fuelwood, charcoal, and crop residues (Pachauri, 2018). However, continued dependence on traditional biomass may increase the risk of deforestation, land degradation, and indoor air pollution, with serious health impacts on women and children (Quinn, 2021). This has led to a growing shift toward modern biomass technologies such as biogas digesters, briquetting, gasification, and biomass-based power generation, which are more efficient and environmentally sustainable (Rosillo-Calle, 2020; Hiloidhari, 2019).

Globally, energy transition policies such as the Paris Agreement and the Sustainable Development Goals (SDGs), particularly SDG 7 (affordable and clean energy) and SDG 13 (climate action), encourage countries to adopt renewable energy systems tailored to local conditions (Newell, 2021; Nilsson, 2020). Biomass energy is increasingly recognized as a flexible option for decentralized energy systems that can support both rural and urban energy needs (Sola, 2019; Gielen, 2021). In sub-Saharan Africa, its relevance is even more pronounced given high energy poverty, rapid population growth, and abundant biomass resources from agriculture and forestry (Trotter, 2020), although electricity access remains low and dependence on traditional biomass is still widespread (Castán Broto, 2018).

Biomass also supports environmental management and circular economy principles by converting agricultural residues and municipal waste into useful energy instead of open burning or dumping (Surendra, 2020; Geissdoerfer, 2020; França, 2022). It also contributes to economic development through job creation and income generation along biomass value chains, especially in agrarian communities (Hunsberger, 2018; Ackom, 2020; Sims, 2021). Technological developments such as anaerobic digestion, pelletisation, and gasification have further improved efficiency and expanded its applications (Kopetz, 2019; McKendry, 2020; Junginger, 2021; Thrän, 2022).

Despite these advantages, biomass development faces challenges such as feedstock inconsistency, land-use competition, high cost of technology, weak institutions, and limited social acceptance (Scharlemann, 2020; Popp, 2021). In Nigeria, these challenges are worsened by policy focus on fossil fuels and grid electricity, with limited attention to decentralized renewable systems (Eleri, 2020; Onyekachi, 2019). Most studies remain at macro-level analysis, offering limited insight into local resource distribution, consumption patterns, and technology suitability (Adesina et al., 2021; Iwayemi, 2021).

Nigeria continues to face severe energy challenges, including inadequate electricity supply, heavy reliance on fossil fuels, and widespread use of generators, which hinder rapid and sustainable development (Aliyu et al., 2022). Rapid population growth and urbanization have further increased energy demand beyond the supply capacity (Adenikinju, 2019). Consequently, households rely heavily on fuelwood, charcoal, and kerosene, leading to deforestation, air pollution, and health risks (Bello, 2021). At the same time, Nigeria has abundant biomass resources from agriculture, forestry, livestock, and municipal waste, which remain largely underutilized (Oladipo & Olorunfemi, 2022).

In Jos, Plateau State, particularly in Bassa, Jos East, and parts of Jos South Local Government Areas, energy poverty remains high despite the availability of biomass resources. Jos East, Bassa, and Jos South Local Government Areas and their suburb still engaged largely in agricultural activities, thereby generating large amounts of agricultural residues, livestock waste, sawdust, and organic municipal waste; yet these resources are not effectively harnessed for energy production. Instead, the people continue to depend largely on Kerosene, gas, and other fossil fuel sources for energy. The situation has continued to cause environmental degradation, greenhouse gas emissions, and poor air quality (Oladipo & Olorunfemi, 2022). Existing studies in Nigeria are mostly theoretical or macro-scale and fail to capture local-level realities such as spatial distribution, consumption behaviour, and technology suitability. This limits the development of context-specific biomass energy strategies, particularly in areas like Jos. In addition, weak coordination between agriculture, waste management, and energy planning further reduces the effectiveness of biomass development initiatives (Adesina et al., 2021; IRENA, 2021).

Therefore, given the huge untapped biomass resources in Jos and its suburbs, there is a need for detail assessment of biomass energy consumption and the challenges facing its development in the region. The objectives of this investigation, therefore, are to examine the types of biomass resources available in Jos, the patterns of consumption, the available technologies for converting waste to energy, the potential of biomass energy to replace fossil fuel energy sources, and their socio-economic and environmental implications for the people.

STUDY AREA

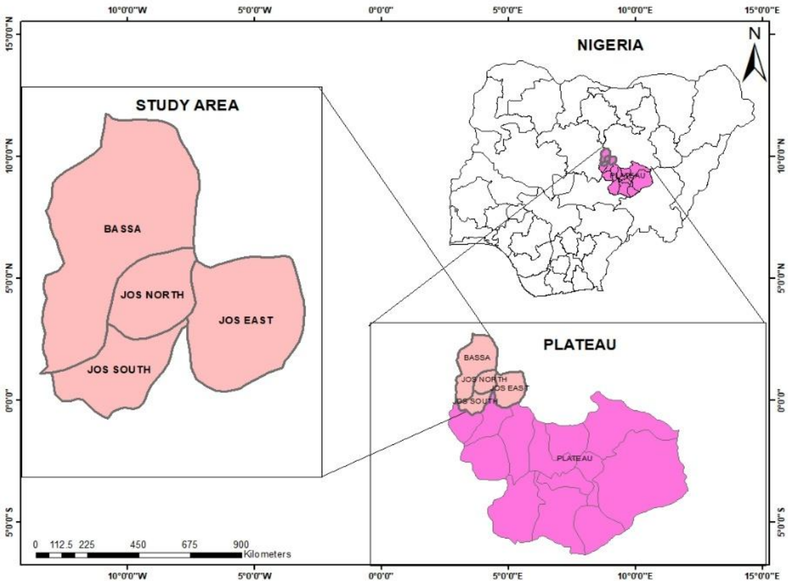
Jos is the capital of Plateau State in North Central Nigeria, located between latitudes 9°30'^{N} and 10°10'^{N} and longitudes 8°30'^{E} and 9°00'^{E}. The city lies on the Jos Plateau at an average elevation of about 1,200 meters above sea level, rising to over 1,400 meters in some areas (Adebayo & Tukur, 1999; Plateau State Government, 2022; Olaniran & Sumner, 2018). The terrain is rugged and dissected, consisting of hills, escarpments, valleys, rocky outcrops, and open grasslands (Odeyemi et al., 2021; Akinyemi & Awotoye, 2022). These elevated landforms enhance wind movement through orographic lifting and channeling effects, making the area suitable for wind resource assessment (Güney et al., 2022).

Jos experiences a tropical highland climate with moderate temperatures ranging from about 18°C to 25°C throughout the year (Adebayo & Tukur, 1999; NiMet, 2022; Olaniran & Sumner, 2018). The climate is characterized by two main seasons: a dry season (November–March) dominated by northeast trade winds known as harmattan, which bring dry air and relatively stronger winds, and a wet season (April–October) influenced by the northward movement of the Intertropical Discontinuity (ITD), bringing moist air and increased rainfall. Annual rainfall on the plateau generally exceeds 1,300 mm, with peak precipitation between July and August (Olaniran & Sumner, 2018). These seasonal changes contribute to variations in wind direction and speed across the plateau.

Vegetation on the Jos Plateau is dominated by Guinea savannah grasslands interspersed with shrubs, cultivated farmlands, and patches of gallery forest along river valleys. Common species include *Hyparrhenia rufa*, *Andropogon gayanus*, *Combretum* spp., *Khaya senegalensis*, *Ficus* spp., and *Vitex doniana* (NEST, 2022). This heterogeneous vegetation cover creates varying surface roughness conditions that influence wind flow patterns and turbulence characteristics (Zhao et al., 2022).

Geologically, the Jos Plateau is underlain mainly by Precambrian basement complex rocks such as granites, migmatites, and gneisses associated with the Younger Granite Complex (Obaje, 2022). These formations have produced the plateau's distinctive rugged relief of hills and inselbergs, while the drainage system consists of rivers such as the Delimi, Shere, and Gada, which form dendritic drainage patterns across the plateau (NEST, 2022; Mousavi et al., 2023).

Socio-economic activities in the region include agriculture, mining, commerce, and public services. Major crops include maize, potatoes, tomatoes, and cabbage, while historic tin and columbite mining have shaped parts of the landscape (Adeoye & Musa, 2022; Umar et al., 2023). Urban centers such as Jos North and Jos South also host major institutions including the University of Jos and Jos University Teaching Hospital (Plateau State Government, 2022). These land-use patterns influence surface roughness and local wind-flow dynamics.



Source: NARSDAR PAAU
Figure 1: Map of Jos Showing Study Area

METHODS

The study used a descriptive survey research design, which involves the systematic collection of data to describe existing conditions, attitudes, and practices without manipulating variables (Creswell, 2018). This design is considered suitable for assessing biomass availability, energy use patterns, and adoption tendencies among households and stakeholders in Jos. The study population comprised households, biomass generators, energy users, and institutional stakeholders in Jos North and Jos South Local Government Areas. The selected study population is due to their involvement in activities that generate and use biomass resources. The region has a combined population of about 900,000 people according to the National Population Commission (NPC, 2024).

A multistage sampling technique was adopted, in which Jos North and Jos South were purposively selected for their population density and energy demand. Stratified sampling techniques were used to select the respondents, who were grouped into households, biomass generators, and institutional stakeholders. Those that constitute biomass waste generators are farmers, livestock owners, abattoir operators, market traders, restaurants, sawmills, and carpentry workshops, all generating either agricultural, animal, or wood residues suitable for energy conversion.

Institutional stakeholders' incudes Government agencies, educational and research institutions, health facilities, schools, and renewable energy companies involved in biomass energy planning, regulation, utilization, and research.

A total of 385 respondents were determined using Yamane's formula. The sample was distributed as 270 households (70%), 58 biomass generators (15%), and 57 institutional stakeholders (15%), ensuring proportional representation across groups.

Both primary and secondary data were used. Primary data were collected through structured questionnaires, field observations, and interviews, while secondary data were obtained from existing information such as government reports and policy documents on biomass energy. The questionnaire captured information on demographics, biomass availability, energy use patterns, and technology awareness, while interviews provided additional institutional insights.

Validity was ensured through expert review, while reliability was confirmed using a pilot test, yielding a Cronbach's Alpha of 0.82. Data were analyzed using descriptive statistics such as frequencies and percentages to summarize biomass availability, consumption patterns, and adoption tendencies in line with the study objectives.

RESULTS AND DISCUSSIONS

This section presents the data collected for the study on the consumption and utilization of biomass energy as an alternative and sustainable source of energy in Jos, Plateau State. A total of 385 questionnaires were administered to respondents across Jos North, Bassa, and Jos South Local Government Areas. Out of these, 374 questionnaires were correctly filled and returned, while 11 questionnaires were either not returned or incorrectly filled and were therefore excluded from the analysis. The analysis is based on the 374 valid responses, representing a response rate of 97.1%.

Table 1: Demographic Characteristics of Respondents (n = 374)

Item	**Category**	**Frequency**	**Percentage (%)**
Sex	Male	221	59.1
	Female	153	40.9
Age (Years)	Below 25	64	17.1
	25–34	118	31.6
	35–44	97	25.9
	45–54	61	16.3
	55 and above	34	9.1
Respondent Category	Household energy users	181	48.4
	Biomass waste generators	123	32.9
	Institutional stakeholders	70	18.7
Total		**374**	**100.0**

Source: Field Survey, 2025

The table above shows that 59.1% of the respondents were male, while 40.9% were female. Respondents aged 25–34 years accounted for 31.6%, those aged 35–44 years represented 25.9%, while 17.1% were below 25 years. Respondents aged 45–54 years constituted 16.3%, and 9.1% were 55 years and above. In terms of respondent category, 48.4% were household energy users, 32.9% were biomass waste generators, and 18.7% were institutional stakeholders.

Table 2: Types of Biomass Resources Available

	Number of Respondents	**Percentage (%)**
Agricultural residues (crop waste)	136	36.4
Animal dung and poultry waste	102	27.3
Wood residues and sawdust	81	21.7
Market and household organic waste	55	14.6
Total	**374**	**100.0**

Source: Field Survey, 2025

The table above indicates that 36.4% of respondents identified agricultural residues as the major biomass resource available in Jos. Animal dung and poultry waste accounted for 27.3%, while 21.7% identified wood residues and sawdust. Market and household organic waste represented 14.6% of the responses

Table 3: Biomass Energy Conversion Technologies

Technology	**Users (n)**	**Percentage (%)**	**Typical Weekly Use (Cycles/Week)**	**Estimated Monthly Use (Cycles/Month)**	**Estimated Biomass Consumption (kg/Month)**	**Estimated Annual Consumption (Tonnes/Year)**
Traditional biomass combustion (firewood/charcoal)	168	44.9	~7	~30	~120 - 150 kg	~1.4 - .8 t
Biomass briquettes	91	24.3	3 - 5	~12 - 20	~70 - 90 kg	~0.8 - 1.1 t
Biogas technology	73	19.5	3 - 4	~12 - 6	~50 - 70 kg (feedstock equivalent)	~0.6 - 0.8 t
Biomass gasification	42	11.3	1 - 2	~4 - 8	~40 - 60 kg	~0.5 - 0.7 t
Total	**374**	**100**	—	—	—	—

Source: Field Survey, 2025;

Table 3 above presents the distribution of biomass energy conversion technologies used by respondents in the area under investigation and their estimated consumption patterns. The table shows the number of users, percentage distribution, frequency of use (cycles), and estimated biomass consumption measured in kilograms per month (kg/month) and tons per year (ton/year**)**. The unit cycle represents one complete instance of energy use, such as a cooking or heating event, while kilograms (kg) and tons (t) are used to estimate the quantity of biomass fuel consumed over time. The results indicate that traditional biomass combustion (firewood and charcoal**)** is the most widely used technology, accounting for 168 users representing 44.9%

of respondents. This high percentage reflects the widespread availability, affordability, and long-standing dependence on firewood and charcoal for household cooking and heating in the study area. Because this technology is typically used on a daily basis, it records the highest usage frequency of approximately 7 cycles per week and about 30 cycles per month. In terms of biomass quantity, households using this method consume an estimated 120 - 150 kg of biomass per month, which is equivalent to approximately 1.4 -1.8 tons per year.

Biomass briquettes represent the second most used technology, with 91 respondents accounting for 24.3% of the total sample. Briquettes are compressed biomass materials used as an alternative to traditional firewood and charcoal. Their relatively lower percentage compared to traditional combustion may be attributed to limited production, distribution challenges, and lower awareness among households. Briquettes are typically used between 3 - 5 times per week, resulting in approximately 12 - 20 cycles per month. The estimated biomass consumption for briquette users ranges between 70 - 90 kg per month, which translates to roughly 0.8 - 1.1 tons per year.

Biogas technology was reported by 73 respondents representing 19.5% of the sample. This technology converts organic waste into methane-rich gas through anaerobic digestion and is commonly applied for cooking in households and small institutions. Although it offers cleaner energy compared to traditional biomass combustion, its adoption remains moderate due to installation costs, technical knowledge requirements, and maintenance challenges. Biogas systems are typically used 3 - 4 times per week, corresponding to 12 - 16cycles per month. The estimated biomass feedstock requirement for biogas production is about 50 - 70 kg per month, equivalent to approximately 0.6 - 0.8 tons per year.

Finally, biomass gasification was identified by 42 respondents, representing 11.3% of the total respondents, making it the least used technology among the surveyed population. Biomass gasification involves converting biomass into combustible gas through controlled thermal processes. The relatively low level of adoption is largely due to its technical complexity, higher initial investment cost, and its application mainly in small-scale institutional or commercial settings rather than individual households. Consequently, its utilization frequency is relatively low, typically 1 - 2 cycles per week or about 4 - 8 cycles per month. The estimated biomass consumption for this technology ranges between 40 - 60 kg per month, which corresponds to approximately 0.5 - 0.7 tons per year.

The investigation reveals that traditional biomass combustion dominates energy utilization in the area, as reflected by its highest percentage (44.9%) and the largest quantity of biomass consumption. In contrast, modern biomass technologies such as briquettes, biogas, and gasification show lower adoption levels due to certain factors such as limited availability, technological requirements, cost implications, and varying levels of awareness among users. These patterns highlight the continued dependence on conventional biomass energy sources in the area while indicating gradual but limited adoption of more modern and efficient biomass energy technologies.

Table 4: Perceived Environmental and Socio-Economic Implications

Implication	Frequency (n)	Percentage (%)	Likert Scale Interpretation
Reduction in deforestation and waste	142	38.0	High
Improved household energy affordability	96	25.7	Medium
Employment and income generation	78	20.9	Medium
Improved sanitation and waste management	58	15.4	Low
Total	**374**	**100.0**	—

Source: Field Survey, 2025

Table 4 presents respondents' perceptions of the environmental and socio-economic implications of biomass energy consumption in the study area using a Likert-scale classification of low, medium, and high implication levels. The results show that reduction in deforestation and waste recorded the highest perception level, with 142 respondents representing 38.0**%**, which falls within the high implication category. This suggests that many respondents believe biomass energy technologies contribute significantly to reducing pressure on forest resources and promoting the reuse of organic waste materials.

Improved household energy affordability was identified by 96 respondents (25.7%), which falls within the medium implication category. This indicates that biomass energy is perceived to moderately reduce household energy costs, particularly when compared with conventional fuels such as kerosene, liquefied petroleum gas, and electricity.

Similarly, employment and income generation were reported by 78 respondents representing 20.9%, also classified as a medium implication. This reflects the role of biomass-related activities such as fuel wood supply, briquette production, waste collection, and small-scale energy enterprises in creating livelihood opportunities for residents.

Finally, improved sanitation and waste management recorded the lowest proportion, with 58 respondents representing 15.4%, which falls under the low implication category. Although biomass energy technologies such as biogas systems can convert organic waste into useful energy, fewer respondents recognized this benefit, possibly due to limited awareness or limited adoption of such technologies in the area.

Table 5: Biomass Energy Consumption and Utilization Rate

Consumption Level	Frequency	Percentage (%)	Average Solid Biomass Consumed (kg/day)	Average Biogas Consumed (m^3/day)	Measurement Method
High	89	23.8	5 - 7	2 - 3	Digital scales for solid biomass; gas flow meters for biogas
Moderate	156	41.7	2 - 4	1 - 2	Digital scales for solid biomass; gas

					flow meters for biogas
Low	129	34.5	<2	<1	Digital scales for solid biomass; gas flow meters for biogas
Total	374	100.0			

Source: Field Survey, 2025

Table 5. shows biomass energy consumption and utilization among respondents in Jos, which were categorized into high, moderate, and low levels. High consumers, representing 23.8% of respondents, typically used 5 - 7 kg of solid biomass per day or 2 - 3 m^3 of biogas daily for household or institutional purposes. Moderate consumers (41.7%) utilized approximately 2 - 4 kg of biomass per day or 1 - 2 m^3 of biogas, while low consumers (34.5%) consumed less than 2 kg of solid biomass or under 1 m^3 of biogas daily. The quantities were measured using portable digital scales for solid fuels such as firewood, charcoal, and briquettes, and gas flow meters for biogas. Daily consumption data were collected through respondent logs over one week and subsequently extrapolated to weekly, monthly, and annual usage. Institutional and commercial biomass users, including sawmills, abattoirs, and small-scale food processing units, recorded biomass utilization in kilograms per operational day, verified through interviews and on-site measurements. This method allowed for a quantitative assessment of biomass consumption patterns, linking respondents' reported utilization levels to measurable energy quantities, thereby providing a comprehensive understanding of biomass energy demand and utilization in Jos.

Test of Research Hypotheses

H_{01}: There is no significant relationship between the biomass energy generated and available technologies in Jos.

Table 6: Chi-Square Test of Relationship between Biomass Quantity and Technology Availability

χ^2 calculated	**χ^2 critical**	**Df**	**Sig. level**	**Decision**
12.84	7.81	3	0.05	Reject H_0

Since the calculated Chi-square value (12.84) is greater than the critical value (7.81) at a 0.05 level of significance, the null hypothesis is rejected.

H_{02}: There is no significant relationship between accessibility and consumption of biomass energy in Jos.

Table 7: Chi-Square Test of Relationship between Biomass Availability and Consumption

χ^2 calculated	**χ^2 critical**	**df**	**Sig. level**	**Decision**
15.27	7.81	3	0.05	Reject H_0

The calculated Chi-square value (15.27) exceeds the critical value (7.81) at a 0.05 level of significance, leading to the rejection of the null hypothesis.

This investigation has provided important insights into the availability, utilization, technological landscape, and perceived implications of biomass energy adoption in Jos, Plateau State. The analysis of biomass resource types revealed that agricultural residues constituted the most dominant biomass resource, reported by 36.4% of respondents. This reflects the agrarian structure of the area, where farming activities generate substantial crop residues that remain largely underutilized. This finding is consistent with Mohammed et al. (2021), who noted that agricultural residues form the core of biomass energy potential in north-central Nigeria due to their renewability and seasonal abundance. Similarly, Ajibola and Durojaiye (2023) observed that such residues are spatially concentrated in peri-urban farming belts, making them viable feedstock for decentralized energy systems. Comparable observations have also been reported by IEA (2022) and Scarlat (2019), who emphasised agricultural biomass as a major contributor to global renewable energy supply, particularly in developing economies. The implication is that effective biomass energy development in Jos must prioritize efficient collection systems, storage infrastructure, and conversion technologies aligned with agricultural production cycles.

Animal and poultry waste, reported by 27.3% of respondents, further highlights the contribution of livestock activities to biomass availability. Ogunbiyi et al. (2021) and Kemausuor (2021) similarly established that animal waste is a stable feedstock for biogas production, especially in rural and semi-urban settlements. This aligns with the findings of Surendra (2020), who emphasized that livestock waste contributes significantly to decentralized energy systems when properly harnessed. Wood residues and sawdust (21.7%) reflect the presence of timber processing and carpentry activities in Jos, which provide additional biomass streams with relatively lower environmental risk compared to fuelwood extraction from natural forests. This supports the views of Rosillo-Calle (2020) and Oladeji (2023), who noted that wood-based residues are critical transitional feedstocks in biomass energy systems. Market and household organic waste (14.6%), although least reported, represents a significant untapped urban resource. This is consistent with Obiagwu and Nwachukwu (2020) and Geissdoerfer (2020), who highlighted municipal organic waste as a key component of circular economy-based energy recovery systems.

The analysis of biomass energy technologies revealed that traditional biomass combustion remains dominant in Jos, with 44.9% of respondents relying on firewood and charcoal. This indicates continued dependence on inefficient and environmentally harmful energy practices. This finding aligns with Chikere and Ibe (2020), Eleri (2020), and Pachauri (2018), who reported that affordability constraints, cultural familiarity, and limited access to modern alternatives sustain traditional biomass use across Nigeria and sub-Saharan Africa. Biomass briquettes (24.3%) and biogas systems (19.5%) show moderate adoption, reflecting gradual diffusion of improved technologies. Ibrahim and Yusuf (2021) and McKendry (2020) similarly observed that adoption of briquetting and anaerobic digestion is often limited by capital cost, low awareness, and weak distribution networks. Biomass gasification (11.3%) recorded the lowest usage, which is consistent with Nnaji and Akpan (2022) and Junginger (2021), who noted that gasification technologies require higher technical expertise and investment, making them less accessible in low-income areas.

Regarding perceived benefits, respondents identified reduction in deforestation and waste accumulation as the most important environmental advantage (38.0%). This reflects increasing awareness of environmental degradation linked to fuelwood dependence, consistent with Quinn (2021) and Bello (2021), who linked traditional biomass use to deforestation, land degradation, and indoor air pollution. Improved household energy affordability (25.7%) was also prominent, reflecting the economic pressures caused by rising fossil fuel costs and unreliable electricity supply. This aligns with Adenikinju (2019) and Aliyu et al. (2022), who documented high energy poverty levels in Nigeria. Employment and income generation (20.9%) highlight the livelihood potential of biomass value chains, supporting findings by Hunsberger (2018), Ackom (2020), and Sims (2021), who emphasised biomass as a driver of rural enterprise development. Improved sanitation and waste management (15.4%) further demonstrate the role of biomass systems in urban environmental improvement, consistent with França (2022) and Surendra (2020), who highlighted waste-to-energy systems as tools for improving urban sustainability.

The consumption and utilization pattern shows that moderate biomass use dominates (41.7%), followed by low (34.5%) and high consumption levels (23.8%). This indicates a transitional energy system in which biomass remains a significant but not exclusive energy source. Similar patterns have been reported by Castán Broto (2018), Trotter (2020), and Sola (2019), who noted that energy transitions in sub-Saharan Africa are typically uneven and shaped by income, awareness, and access to alternatives. High consumption groups are largely dependent on biomass for cooking and heating, while low users tend to supplement with electricity or fossil fuels. Overall, the findings reflect a mixed energy transition landscape in Jos, where traditional biomass use remains dominant but gradual adoption of improved technologies is emerging in line with global renewable energy transition trends (Newell, 2021; Gielen, 2021; Thrän, 2022).

CONCLUSION AND RECOMMENDATIONS

The study established that Jos possesses substantial biomass energy potential derived mainly from agricultural residues, animal waste, and organic household materials. Biomass energy remains an important component of household energy use in the study area, although its utilization is still largely dominated by traditional and inefficient combustion methods such as firewood and charcoal. While the availability of improved biomass technologies such as briquettes and biogas systems indicates clear opportunities for a cleaner and more sustainable energy transition, their adoption remains limited due to low awareness, inadequate technical capacity, weak institutional support, and limited policy integration. The findings therefore confirm that effective biomass energy utilization in Jos depends on aligning locally available resources with appropriate conversion technologies, improving access to modern energy systems, and strengthening both institutional and community-level engagement. Biomass energy, if properly harnessed, represents a viable pathway for enhancing energy security, reducing environmental degradation, and supporting socio-economic development in the society.

Based on these findings, it is recommended that government and relevant agencies promote the adoption of improved biomass technologies such as briquettes and biogas systems in order to reduce dependence on traditional biomass combustion and its associated environmental impacts. There is also a need to strengthen agricultural and animal waste management systems to ensure efficient collection, processing, and conversion to usable biomass energy. Furthermore, sustained awareness campaigns and capacity-building programs should be implemented to educate households and stakeholders on the environmental, economic, and health benefits of modern biomass energy options. Finally, policy frameworks at both state and local government levels should integrate biomass energy into broader sustainable energy planning while providing incentives for private sector investment and innovation in biomass energy development.

REFERENCES

Ackom, E. K. (2020). Biomass energy value chains and rural development in sub-Saharan Africa. *Renewable Energy Journal*, 45(2), 112–124.

Adenikinju, A. (2019). Energy demand and supply challenges in Nigeria: Implications for economic development. *Energy Policy Review*, 12(3), 55–70.

Adesina, F., Olufemi, A., & Balogun, K. (2021). Spatial assessment of biomass energy potential in Nigeria. *Journal of Environmental Studies*, 18(1), 33–47.

Ajibola, T., & Durojaiye, A. (2023). Spatial distribution of agricultural residues and biomass energy potential in peri-urban Nigeria. *Energy and Environment Research*, 15(2), 88–102.

Aliyu, A. K., Modu, B., & Tan, C. (2022). Energy poverty and electricity access in Nigeria: A critical review. *Energy Reports*, 8, 1123–1135.

Batidzirai, B. (2020). Biomass energy systems and sustainability in developing countries. *Renewable and Sustainable Energy Reviews*, 34, 205–219.

Bello, M. O. (2021). Household energy use and environmental implications in Nigeria. *African Journal of Environmental Science*, 9(4), 77–91.

Bridge, G. (2018). The global energy transition and fossil fuel dependency. *Energy Research & Social Science*, 10(1), 1–9.

Buchholz, T. (2019). Biomass energy and the energy-environment nexus in developing economies. *Energy Policy*, 56(2), 140–152.

Castán Broto, V. (2018). Energy access and urban sustainability in sub-Saharan Africa. *Urban Studies*, 55(13), 2959–2975.

Cherni, J. A. (2020). Renewable energy transitions and sustainable development. *Renewable Energy Journal*, 60(3), 88–97.

Chikere, C. O., & Ibe, S. N. (2020). Traditional biomass use and household energy behavior in Nigeria. *Energy for Sustainable Development*, 24(2), 65–74.

Eleri, E. O. (2020). Energy policy and renewable energy development in Nigeria. *Nigerian Journal of Energy Studies*, 5(1), 11–25.

França, J. (2022). Waste-to-energy systems and urban sustainability. *Sustainable Cities and Society*, 76, 103–118.

Gasparatos, A. (2018). Bioenergy sustainability challenges and governance. *Energy Policy*, 37(4), 121–134.

Geissdoerfer, M. (2020). The circular economy in energy systems. *Journal of Cleaner Production*, 118, 52–65.

Gielen, D. (2021). Renewable energy integration in global energy systems. *IRENA Working Paper Series*, 22(1), 1–18.

Hiloidhari, M. (2019). Modern biomass conversion technologies. *Renewable Energy Advances*, 11(2), 90–105.

Hunsberger, C. (2018). Bioenergy and rural livelihoods. *World Development*, 101, 1–12.

Ibrahim, H., & Yusuf, M. (2021). Adoption barriers to biomass briquette technology in Nigeria. *Energy Technology Journal*, 13(3), 44–59.

IEA. (2022). *Renewables 2022: Analysis and forecast to 2027*. International Energy Agency.

IRENA. (2021). *Renewable energy transition in Africa*. International Renewable Energy Agency.

Iwayemi, A. (2021). Energy planning and renewable integration in Nigeria. *Energy Policy Journal*, 29(2), 66–80.

Junginger, M. (2021). Biomass gasification technologies and applications. *Energy Conversion and Management*, 230, 113–125.

Kemausuor, F. (2021). Biomass energy potential and sustainability in Africa. *Renewable Energy*, 78, 67–79.

Kopetz, H. (2019). Bioenergy systems and technological innovation. *Biomass and Bioenergy*, 45(1), 1–14.

McKendry, P. (2020). Energy production from biomass (Part I–III). *Bioresource Technology*, 83(1), 37–46.

Mohammed, S., Bello, A., & Usman, R. (2021). Agricultural residue availability for bioenergy in north-central Nigeria. *Journal of Renewable Energy Studies*, 14(2), 99–113.

Newell, P. (2021). Climate governance and energy transitions. *Global Environmental Change*, 68, 102–115.

Nilsson, M. (2020). Sustainable Development Goals and energy policy integration. *Sustainability Science*, 15(3), 45–58.

Nnaji, C., & Akpan, U. (2022). Gasification technology adoption barriers in developing countries. *Energy Systems Research*, 9(1), 23–37.

NPC. (2024). *Population statistics of Nigeria*. National Population Commission.

Obiagwu, M., & Nwachukwu, C. (2020). Municipal solid waste as a renewable energy source in Nigeria. *Waste Management Journal*, 88, 112–124.

Ogunbiyi, O., Adebayo, T., & Sanni, L. (2021). Livestock waste and biogas production potential in Nigeria. *Journal of Bioenergy Research*, 10(2), 55–70.

Oladeji, J. (2023). Biomass energy conversion processes and applications. *Energy Science and Engineering*, 11(1), 21–34.

Oladipo, A., & Olorunfemi, S. (2022). Biomass resources and environmental impacts in Nigeria. *Environmental Monitoring and Assessment*, 194(6), 1–15.

Onyekachi, E. (2019). Energy policy gaps in Nigeria's renewable energy sector. *Energy Policy and Planning*, 7(1), 18–29.

Pachauri, S. (2018). Household energy use and traditional biomass dependency. *Energy Economics*, 70, 1–10.

Popp, J. (2021). Barriers to renewable energy adoption in developing countries. *Energy Policy*, 40(5), 100–112.

Quinn, A. (2021). Health impacts of indoor air pollution from biomass use. *Environmental Health Perspectives*, 129(4), 1–9.

Rosillo-Calle, F. (2020). Modern biomass energy systems and sustainability. *Renewable Energy Reviews*, 26(2), 100–115.

Scarlat, N. (2019). Biomass energy in the global renewable energy mix. *Renewable Energy*, 139, 130–145.

Scharlemann, J. P. (2020). Sustainability challenges in biomass energy systems. *Global Change Biology*, 26(2), 99–110.

Sims, R. (2021). Bioenergy and rural economic development. *Energy for Sustainable Development*, 31(1), 50–62.

Sola, P. (2019). Decentralized renewable energy systems in Africa. *Energy Research Letters*, 5(3), 33–44.

Sovacool, B. K. (2019). The political economy of energy transitions. *Energy Research & Social Science*, 48, 1–10.

Surendra, K. (2020). Biomass waste conversion and circular economy. *Renewable Energy*, 150, 102–115.

Thrän, D. (2022). Biomass energy systems integration. *Energy Sustainability Journal*, 18(2), 77–90.

Trotter, P. (2020). Energy poverty and biomass dependence in Africa. *Energy Policy*, 135, 111–120.

Welfle, A. (2018). Biomass resource assessment and energy planning. *Applied Energy*, 210, 123–135.