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Investigating Gender Inclusion and Sustainable Biomass Value Chain Development: Evidence from Bauchi State, Nigeria

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Abstract

The global transition toward sustainable energy systems has underscored the critical role of gender inclusion in fostering equitable, resilient, and economically viable biomass value chains, particularly in developing economies where women play central roles in household energy management and biomass utilization. Despite their substantial contributions, women continue to encounter institutional, financial, and socio-cultural constraints that limit their participation in higher-value biomass enterprises and broader renewable energy development initiatives. This study investigated gender inclusion and sustainable biomass value chain development in selected Local Government Areas (LGAs) of Bauchi State, Nigeria, with a focus on assessing women's participation, access to financial services, institutional challenges, and socio-cultural barriers influencing biomass sector development. A mixed-methods research design was employed, integrating quantitative and qualitative approaches through structured questionnaires, key informant interviews, focus group discussions, and field observations involving 1,144 biomass stakeholders across Bauchi, Jama'are, Misau, and Tafawa Balewa LGAs. Descriptive and comparative analyses were used to evaluate gender disparities and participation patterns across the study locations. The findings revealed pronounced gender imbalances within the biomass value chain, with women constituting only 24.7% of stakeholders compared to 75.3% for men, although female participation reached 43.0% in Misau LGA. The results further indicated persistently low access to formal financial services among women, reflecting limited financial inclusion and constrained investment capacity within biomass-related enterprises. Institutional inadequacies, restricted access to productive resources, and entrenched socio-cultural norms emerged as significant barriers to women's engagement and advancement within the sector. The study highlights the necessity for gender-responsive policies, targeted financial inclusion mechanisms, and institutional reforms to enhance women's participation and strengthen the sustainability, productivity, and socio-economic impact of biomass value chains in Nigeria.

Keywords
Gender inclusion;
Biomass value chain;
Renewable energy;
Financial inclusion;
Sustainable livelihoods;
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1. INTRODUCTION

The global transition towards renewable and low-carbon energy systems has intensified efforts to develop sustainable energy solutions capable of addressing climate change, energy insecurity, and socio-economic inequality. Within this transition, biomass energy has emerged as a strategic renewable resource because of its potential to simultaneously promote environmental sustainability, rural livelihoods, and inclusive economic development (Razmjoo et al., 2024; Obileke & Mukumba, 2025). The concept of a sustainable energy transition extends beyond technological innovation to encompass issues of social justice, equitable resource distribution, and inclusive participation among vulnerable populations. Consequently, achieving the Sustainable Development Goals (SDGs), particularly SDG 5 (Gender Equality), SDG 7 (Affordable and Clean Energy), and SDG 13 (Climate Action), requires energy systems that are socially inclusive as well as environmentally sustainable (United Nations, 2023).

In many developing countries, particularly across sub-Saharan Africa, biomass remains the dominant source of household energy despite the increasing adoption of modern renewable energy technologies. Nigeria continues to depend heavily on traditional biomass resources such as firewood, charcoal, agricultural residues, and organic wastes, especially within rural communities where access to electricity and clean cooking fuels remains inadequate (Ebisi, 2024; Jekayinfa et al., 2020). Although biomass provides an essential source of household energy and income generation, its continued dependence on traditional production and utilization methods contributes to deforestation, biodiversity loss, environmental degradation, and adverse public health outcomes associated with indoor air pollution (Odediran, 2024; World Health Organization [WHO], 2023). Consequently, the modernization of biomass value chains through improved technologies and sustainable management practices presents an important opportunity for enhancing energy security while promoting climate change mitigation and rural economic transformation.

Bauchi State, located in northeastern Nigeria, possesses abundant biomass resources derived from agricultural production, forestry activities, and organic municipal wastes, providing considerable opportunities for sustainable bioenergy production and rural enterprise development. Nevertheless, biomass utilization within the state remains largely informal, fragmented, and characterized by inefficient collection systems, inadequate processing technologies, poor storage infrastructure, and weak market coordination (Ogunrewo & Nwulu, 2024; Okoro et al., 2024). These structural deficiencies constrain the economic performance of the biomass sector and limit its contribution to sustainable development. More importantly, participation within the biomass value chain is unevenly distributed, with women and other vulnerable groups facing significant institutional, financial, and socio-cultural barriers that restrict their access to productive resources and economic opportunities.

Gender inclusion has increasingly become a central component of sustainable energy policy because women play indispensable roles in biomass collection, processing, transportation, marketing, and household energy management across rural communities. Despite their significant contributions, women remain underrepresented in higher-value segments of biomass enterprises due to limited access to land ownership, financial services, modern technologies, extension support, and decision-making structures (Amadi et al., 2024; UNDP, 2024). Cultural norms and traditional gender roles further constrain women's participation in commercial biomass activities, thereby reducing their capacity to benefit from renewable energy investments and limiting the overall efficiency of biomass value chains. These inequalities reinforce existing socio-economic disparities and undermine

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efforts toward inclusive and sustainable energy development.

Financial inclusion represents another important dimension of sustainable biomass development. The adoption of improved biomass technologies, including biomass briquetting, efficient cookstoves, and decentralized bioenergy systems, requires access to affordable credit and investment opportunities. However, women entrepreneurs and small-scale biomass producers in northern Nigeria often experience significant barriers in accessing formal financial institutions due to collateral requirements, limited financial literacy, and institutional lending constraints (Adegbite & Machethe, 2020). Expanding financial inclusion through cooperative financing systems, green investment initiatives, and digital financial services could significantly strengthen women's participation while improving the productivity and sustainability of biomass enterprises.

Environmental sustainability is equally fundamental to the long-term viability of biomass value chains. Increasing dependence on fuelwood and charcoal has accelerated forest degradation and biodiversity loss across many parts of northern Nigeria, threatening ecosystem services and rural livelihoods (Odediran, 2024). Sustainable biomass development therefore requires integrated approaches that combine renewable energy promotion with forest conservation, sustainable land management, and community participation in natural resource governance. Such integrated strategies can simultaneously enhance environmental resilience, reduce carbon emissions, and generate inclusive employment opportunities for women and youth within rural communities.

Despite growing international attention to gender-responsive renewable energy development, empirical evidence on gender inclusion within biomass value chains remains limited in northern Nigeria, particularly in Bauchi State. Existing studies have largely concentrated on biomass resource assessment, energy potential, and technological innovations, with relatively limited attention devoted to the institutional, financial, and socio-cultural factors shaping women's participation and social inclusion in biomass markets (Okoro et al., 2024; Ogunrewo & Nwulu, 2024). This knowledge gap constrains the formulation of evidence-based policies capable of promoting equitable biomass sector development. Therefore, investigating gender inclusion and sustainable biomass value chain development in Bauchi State is essential for identifying barriers, strengthening women's participation, and providing practical policy recommendations that integrate renewable energy development with gender equality, poverty reduction, and climate resilience objectives.

2. LITERATURE REVIEW

2.1 Gender and Sustainable Energy Transition

The global transition towards sustainable energy systems has increasingly recognized that renewable energy development must address not only environmental sustainability but also social equity and inclusive participation. Contemporary energy transition frameworks argue that access to clean energy should be accompanied by equitable opportunities for all segments of society, particularly women and other marginalized populations who are disproportionately affected by energy poverty (Razmjoo et al., 2024). Consequently, the concept of a Just Energy Transition has emerged as an important policy framework that integrates gender equality, social justice, and environmental sustainability into renewable energy planning and implementation (Amadi et al., 2024). Rather than viewing women as passive beneficiaries of energy interventions, recent studies emphasize their roles as entrepreneurs, producers, consumers, and decision-makers capable of driving sustainable energy transitions within local communities (UNDP, 2024).

In sub-Saharan Africa, biomass continues to account for the largest share of household energy consumption despite growing investments in modern renewable energy technologies. Nigeria remains heavily dependent on traditional biomass resources, particularly in rural communities where limited access to electricity and clean cooking fuels reinforces reliance on fuelwood, charcoal, and agricultural residues (Ebisi, 2024; Jekayinfa et al., 2020).

Although biomass provides an important source of energy and livelihood, traditional production and utilization practices are associated with deforestation, environmental degradation, and severe health consequences arising from indoor air pollution. These challenges are particularly pronounced among rural women who bear the primary responsibility for fuel collection and household energy management, making gender-responsive biomass policies essential for achieving sustainable energy transitions.

2.2 Women's Participation in Biomass Value Chains

Biomass value chains across developing countries exhibit strong gender dimensions that shape access to resources, market participation, and economic benefits. Women are extensively involved in biomass collection, transportation, processing, marketing, and household utilization, yet their participation is largely concentrated within informal and low-income segments of the value chain (Aliyu, 2023). Limited ownership of productive assets, inadequate access to technology, and socio-cultural restrictions continue to constrain women's participation in higher-value biomass enterprises, reducing both household income opportunities and the overall productivity of the biomass sector.

Recent empirical studies suggest that strengthening women's participation can significantly improve the sustainability and commercial performance of biomass value chains through enhanced resource management, entrepreneurship, and community-level innovation (ResearchGate, 2024). Interventions involving improved cookstoves, biomass briquettes, and clean cooking technologies have demonstrated considerable potential for increasing women's economic empowerment while simultaneously reducing environmental degradation and health risks (MEDA, 2024). However, inadequate institutional support, limited technical training, and the predominance of informal biomass markets continue to restrict women's ability to fully participate in emerging bioenergy opportunities across northern Nigeria.

2.3 Financial Inclusion and Renewable Energy Entrepreneurship

Financial inclusion represents one of the most important determinants of women's participation in renewable energy value chains. Access to affordable credit, savings mechanisms, insurance products, and digital financial services enables entrepreneurs to adopt modern technologies, expand production capacity, and improve market competitiveness. Nevertheless, women operating within biomass markets frequently encounter financial exclusion arising from limited collateral, insecure land tenure systems, and institutional lending practices that disadvantage female entrepreneurs (Adegbite & Machethe, 2020). Such constraints perpetuate low productivity and reinforce dependence on informal financing mechanisms that rarely support long-term business expansion.

Recent developments in green finance and digital financial technologies provide new opportunities for addressing these challenges by extending affordable financial services to rural women engaged in renewable energy enterprises. Innovative financing models, including mobile banking platforms, digital credit systems, and cooperative financing arrangements, have demonstrated considerable potential for improving women's access to productive assets and clean energy technologies (Women's World Banking, 2024). However, their effectiveness depends on complementary investments in financial literacy, digital skills development, and institutional reforms capable of addressing structural gender inequalities within financial markets.

2.4 Sustainable Livelihoods Theory

The Sustainable Livelihoods Theory (SLT) provides an appropriate theoretical framework for understanding the interrelationships between biomass resources, gender inclusion, and rural development. The theory argues that sustainable livelihoods depend on households' ability to access and effectively utilize five forms of capital: natural, human, social, physical, and financial capital (Scoones, 2015). Within biomass-dependent communities, natural capital in the form of agricultural residues and forest resources constitutes

the foundation upon which household energy security and income generation depend. However, unsustainable biomass extraction and environmental degradation gradually weaken these livelihood assets, reducing household resilience and increasing vulnerability to poverty and climate change.

From a gender perspective, women often experience unequal access to these livelihood capitals due to socio-cultural constraints, institutional barriers, and discriminatory resource allocation systems. Strengthening women's access to education, technology, financial services, and community networks can therefore improve biomass resource utilization while simultaneously enhancing household welfare and environmental sustainability. The Sustainable Livelihoods Theory thus provides a useful analytical lens for examining how gender-inclusive biomass value chains can contribute to poverty reduction, renewable energy development, and sustainable rural livelihoods.

2.5 Social Inclusion and Institutional Perspectives

Social inclusion has become an increasingly important dimension of sustainable energy policy because renewable energy transitions should benefit all members of society irrespective of gender, age, disability, or socio-economic status. Inclusive energy systems require institutional arrangements that facilitate equal access to energy resources, markets, technologies, and decision-making processes while addressing historical inequalities that limit participation among marginalized populations (Idrus et al., 2025). In Nigeria, however, institutional fragmentation and weak coordination among agencies responsible for energy, environment, agriculture, and gender affairs continue to constrain the implementation of integrated renewable energy policies. Moreover, the absence of gender-responsive institutional frameworks further limits women's participation within biomass value chains by restricting access to extension services, financing opportunities, and market information. Developing inclusive biomass policies therefore requires stronger institutional coordination, gender-sensitive planning, and evidence-based interventions that incorporate social inclusion principles into renewable energy programmes. Such institutional reforms will not only improve women's participation but also strengthen the sustainability, resilience, and socio-economic impact of biomass energy systems within Bauchi State and similar rural contexts across Nigeria.

3.0 METHODOLOGY

This study adopted a mixed-methods research design to investigate gender inclusion and sustainable biomass value chain development across selected Local Government Areas (LGAs) in Bauchi State, Nigeria. The study was conducted in Bauchi, Jama'are, Misau, and Tafawa Balewa LGAs, which were selected due to their significant biomass resource base and active participation in biomass-related activities. A cross-sectional survey approach was employed to collect both quantitative and qualitative data from stakeholders involved in biomass production, collection, processing, transportation, marketing, and utilization. Primary data were obtained from 1,144 respondents through structured questionnaires, key informant interviews, focus group discussions, and field observations.

Particular attention was given to capturing gender-disaggregated information on participation levels, access to resources, financial inclusion, decision-making opportunities, and constraints affecting women's involvement in the biomass value chain. Quantitative data were analysed using descriptive statistical techniques, including frequencies, percentages, means, and comparative analyses, while qualitative responses were subjected to thematic analysis to identify recurring patterns and gender-related challenges. The integration of quantitative and qualitative findings enabled a comprehensive assessment of the socio-economic, institutional, and gender dimensions of biomass value chain development and provided evidence for recommending strategies to enhance women's participation and promote inclusive renewable energy development in Bauchi State.

4.0 RESULTS

4.1 Gender Participation across the Study LGAs

Table 1: Gender Distribution of Respondents by LGA

LGA	Male	Female	Total	Percentage
Bauchi	230	4	234	1.8%
Jama'are	357	99	456	21.6%
Misau	190	143	333	43.0%
Tafawa Balewa	84	37	121	30.6%
TOTAL	**861**	**283**	**1,144**	**24.7%**

The analysis of gender participation demonstrates substantial disparities in women's involvement across the biomass value chain within the four study Local Government Areas (LGAs). The findings indicate that women constituted only **24.7% (283 respondents)** of the total study population, while men accounted for **75.3% (861 respondents)**, reflecting a significant gender imbalance within biomass-related activities.

More importantly, considerable spatial variation exists among the study areas. Women's participation was extremely low in **Bauchi LGA (1.8%)**, moderate in **Jama'are (21.6%)** and **Tafawa Balewa (30.6%)**, but relatively high in **Misau (43.0%)**, suggesting that local socio-economic and cultural contexts strongly influence women's engagement in biomass activities. These variations indicate that gender participation in biomass value chains cannot be generalized across regions but is highly dependent on local institutional arrangements, livelihood systems, and prevailing cultural norms. The relatively higher participation observed in Misau further demonstrates that increasing women's involvement in biomass enterprises is achievable when enabling socio-economic conditions exist.

4.2 Women's Roles in Biomass Value Chain Activities

The study findings reveal that women play significant but largely informal roles within the biomass value chain. Qualitative evidence obtained from focus group discussions indicates that women are predominantly involved in biomass collection, residue sorting, market waste handling, animal feed preparation, household biomass utilization, and small-scale trading activities.

However, their participation remains concentrated within low-income and labour-intensive segments of the value chain, while men dominate transportation, aggregation, processing, and commercial marketing activities that generate higher economic returns. The findings further suggest that women's contributions remain largely unrecognized despite their central role in household energy management and agricultural residue utilization. This unequal distribution of responsibilities and economic opportunities limits women's capacity to benefit from biomass commercialization and constrains the overall productivity and inclusiveness of the biomass sector in Bauchi State.

Table 2: Summary of Key Findings by LGA

Findings	Bauchi	Jama'are	Misau	Tafawa Balewa
Farmers as primary stakeholders	42.7%	73.2%	31.8%	60.3%
Women's participation	1.8%	21.6%	43.0%	30.6%
Primary biomass sources	All types	All types	All types	All types
Estimated annual generation (tonnes)	355-442	355-442	315-402	215-256
Seasonal availability variation	(40-50% dry)	71% consistent	95% consistent	70% dry
Wasted biomass	Yes	Yes	Yes	Yes
Dominant transport mode	Motorcycle/Truck	Motorcycle	Motorcycle/Truck	Tricycle/Bicycle
Transport cost per km (₦)	583.33	1,570.53	87.57	1,300.00
Covered storage	No data	No data	58%	52.1%
Manual handling	88.9%	>50%	89.2%	15.7%
Price gap analysis	+1.28%	-24.84%	-1.21%	+20.02%
Cash payment preference	100%	93.4%	99.1%	93%
Top challenge	Multiple	Multiple	Poor roads	Poor roads

4.3 Financial Inclusion among Biomass Stakeholders

Financial inclusion among biomass stakeholders remains critically low across all study LGAs. The results show that access to formal banking services ranged from **12% in Jama'are to 18% in Misau**, while access to mobile money services remained below **10%** in most locations. More importantly, access to formal credit facilities was extremely limited, varying between **4% and 7%** across the study area. These findings indicate that the majority of biomass stakeholders operate outside formal financial systems, thereby limiting their ability to invest in improved storage infrastructure, transportation equipment, biomass processing technologies, and enterprise expansion. The limited financial inclusion observed among respondents further constrains women's participation because inadequate access to credit and financial services reduces opportunities for entrepreneurship and value addition within the biomass sector.

Table 3: Access to Formal Financial Services

LGA	Bank Account (%)	Mobile Money (%)	Access to Credit (%)
Bauchi	15%	8%	5%
Jama'are	12%	6%	4%
Misau	18%	10%	7%
Tafawa Balewa	14%	7%	5%

4.4 Payment Systems within the Biomass Market

The biomass market in Bauchi State remains overwhelmingly cash-based, reflecting the informal structure of biomass trading systems. Across the four LGAs, between **93% and 100%** of respondents preferred immediate cash payments, with only a very small proportion accepting instalment or alternative payment arrangements. Bauchi recorded complete dependence on cash transactions (100%), while Jama'are and Tafawa Balewa exhibited slightly higher acceptance of instalment payments at **6.6% and 7.0%**, respectively. The dominance of cash transactions limits financial transparency, reduces access to formal credit systems, and weakens opportunities for digital financial inclusion and market formalization. Consequently, informal payment practices continue to constrain investment, business expansion, and efficient market coordination throughout the biomass value chain.

Table 4: Preferred Payment Terms by LGA

LGA	Cash Preferred	Other Payment Terms
Bauchi	100%	0%
Jama'are	93.4%	6.6% (installment)
Misau	99.1%	0.9%
Tafawa Balewa	93%	7%

4.5 Institutional Barriers Affecting Gender Inclusion

Institutional barriers emerged as significant constraints affecting women's effective participation in biomass value chain activities. Respondents consistently identified inadequate storage infrastructure, poor road accessibility, limited processing facilities, weak institutional coordination, and insufficient market support as major challenges limiting sector development. The absence of adequate drying facilities across most LGAs further restricts biomass quality preservation and commercialization opportunities. Qualitative evidence indicates that women experience additional institutional barriers related to limited access to land ownership, production equipment, extension services, and formal market networks. These institutional deficiencies reinforce existing gender inequalities and reduce opportunities for women to transition from informal biomass collection activities into higher-value biomass enterprises.

Top Challenges by LGA

LGA	Most Frequently Reported Challenges	Percentage
Bauchi	Poor road access, Storage limitations, Competition, Cultural resistance, Labor shortages, Gender barriers	-
Jama'are	Storage limitations, Competition, Cultural resistance, Gender barriers	100%
Misau	Poor Road access, Storage limitations	84.6% / 38.5%
Tafawa Balewa	Poor road access	84.6%

Access to Drying Facilities by LGA

LGA	No Access	Limited Access	Basic Access	Adequate Access
Bauchi	Majority	-	Small fraction	-
Jama'are	Significant gap	-	-	-
Misau	Significant gap	-	-	-
Tafawa Balewa	Many respondents	-	-	-

Figure 1 Top Challenges by LGA

4.6 Social Constraints to Women's Participation

The findings indicate that socio-cultural constraints continue to significantly influence women's participation in biomass value chains. Focus group discussions revealed that traditional gender norms, household responsibilities, limited mobility, and community perceptions regarding biomass-related occupations restrict women's involvement in commercial biomass activities. Respondents reported that biomass transportation, residue collection, and

market aggregation are frequently perceived as male occupations, discouraging female participation. Time constraints associated with childcare, domestic responsibilities, and agricultural labour further reduce women's capacity to engage in income-generating biomass enterprises. These socio-cultural barriers partly explain the substantial differences in women's participation observed across the study LGAs and highlight the need for context-specific interventions that address underlying gender inequalities within rural communities.

5.0 Discussion

5.1 Comparison with Previous African Studies

The findings of this study corroborate previous evidence from sub-Saharan Africa indicating that women constitute the backbone of household biomass utilization while remaining underrepresented in commercial biomass enterprises. Similar studies conducted in Kenya, Uganda, and Ghana have demonstrated that women's participation is largely concentrated within low-income segments of biomass value chains due to unequal access to productive resources, finance, and technology. The relatively higher participation observed in Misau suggests that local socio-economic conditions can significantly influence gender outcomes and supports previous assertions that context-specific interventions are more effective than generalized national policies.

5.2 Implications for Sustainable Development Goals

The observed gender disparities have important implications for achieving the Sustainable Development Goals, particularly **SDG 5 (Gender Equality)**, **SDG 7 (Affordable and Clean Energy)**, **SDG 8 (Decent Work and Economic Growth)**, and **SDG 13 (Climate Action)**. Improving women's participation within biomass value chains would simultaneously enhance household livelihoods, increase renewable energy production, stimulate rural entrepreneurship, and promote environmentally sustainable biomass utilization practices. Consequently, gender-inclusive biomass policies should be considered an integral component of sustainable energy transition strategies in Nigeria.

5.3 Gender Equity and Inclusive Biomass Development

The limited participation of women in commercial biomass enterprises represents both a social inequality and an economic inefficiency. Greater inclusion of women through improved access to finance, technical training, leadership opportunities, and market participation would strengthen biomass value chains while improving resource utilization efficiency and enterprise productivity. The findings therefore reinforce growing international recognition that gender equality constitutes a critical determinant of successful renewable energy transitions rather than merely a social welfare objective.

5.4 Implications for Rural Livelihood Improvement

The biomass sector presents substantial opportunities for improving rural livelihoods through employment generation, entrepreneurship development, and income diversification. However, these opportunities cannot be fully realized unless barriers to women's participation are systematically addressed. Expanding financial inclusion, strengthening institutional support systems, promoting women-led biomass cooperatives, and investing in biomass processing technologies could significantly enhance household incomes while contributing to sustainable rural development. Integrating gender-responsive interventions into biomass development programmes will therefore strengthen both social inclusion and renewable energy outcomes in Bauchi State and similar agrarian regions across Nigeria.

6. Conclusion

This study examined gender inclusion within the biomass value chain in Bauchi State and demonstrated that although women play indispensable roles in biomass collection, processing, utilization, and small-scale trading, their participation remains largely confined to low-value segments of the value chain. The findings revealed significant disparities in access to financial services, productive resources, market opportunities, and decision-making structures, which collectively limit women's ability to benefit from the growing biomass economy. Institutional deficiencies, socio-cultural norms, and inadequate infrastructure

further reinforce gender inequalities and constrain the development of an inclusive and sustainable biomass sector. Nevertheless, the relatively higher levels of women's participation observed in some locations indicate that these barriers are neither inevitable nor insurmountable. The study therefore concludes that achieving a sustainable biomass value chain requires more than improving biomass resource utilization; it demands deliberate efforts to mainstream gender inclusion, strengthen financial and institutional support systems, and expand economic opportunities for women. By positioning women as active participants and beneficiaries of biomass development, policymakers and development practitioners can simultaneously advance renewable energy adoption, rural livelihood enhancement, social equity, and sustainable development outcomes in Bauchi State and across similar contexts in Nigeria.

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