

Environmental Hazard Awareness, Sustainability Practices, and Constraints of Charcoal Producers in Wamba Local Government Area, Nasarawa State, Nigeria

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ABSTRACT

This study assessed the environmental hazard awareness, sustainability practices, and production constraints of charcoal producers in Wamba Local Government Area (LGA), Nasarawa State, Nigeria, and identified the socioeconomic predictors of tree-planting behaviour. Primary data were collected from 100 charcoal producers selected through multistage sampling and analysed using descriptive statistics, Chi-square tests, and binary logistic regression. Results showed that only 53% of producers were aware of environmental hazards, with air pollution (29.9%), biodiversity loss (27.1%), deforestation (24.3%), and soil erosion (18.7%) as the most recognised impacts. Despite this, only 43% engaged in tree planting, revealing a significant awareness–action gap. Chi-square analysis confirmed significant associations between educational level and both environmental awareness ($\chi^2 = 10.214$; $p = 0.015$) and tree-planting engagement ($\chi^2 = 9.841$; $p = 0.020$). Binary logistic regression (Nagelkerke $R^2 = 0.421$; correct classification = 74.0%) showed that environmental awareness, credit access, educational level, income, and cooperative membership were significant predictors of tree-planting behaviour. The dominant production constraints were environmental regulations (19.9%), government restrictions (19.4%), poor market access (18.8%), and lack of capital (15.1%). Comparative evidence from sub-Saharan Africa confirms that these constraints are not unique to Wamba LGA but reflect a regional pattern in charcoal-dependent communities where regulation without incentive generates compliance resistance. A circular economy framework, wherein charcoal licensing fees are reinvested into community-led nurseries and improved cookstove subsidies, is proposed as an actionable policy model. These findings offer evidence-based guidance for policymakers, extension agents, and development organisations working to balance rural livelihoods with environmental conservation in north-central Nigeria.

Keywords: charcoal production, deforestation, environmental awareness, Nigeria, sustainability practices

INTRODUCTION

Charcoal production represents one of the most economically significant yet environmentally consequential rural enterprises in sub-Saharan Africa. As one of the largest producers and consumers of charcoal in Africa, Nigeria depends heavily on biomass energy: FAO [9] estimates that over 40 million Nigerians are engaged in fuelwood and charcoal-related activities. In north-central Nigeria, including Nasarawa State, the expansion of commercial charcoal production into savannah woodland areas has accelerated in recent years, driven by growing urban demand and rising costs of alternative cooking fuels [6]. The charcoal sector provides critical livelihoods, particularly in areas with few formal employment alternatives, but its environmental footprint, encompassing deforestation, biodiversity loss, soil degradation, and greenhouse gas emissions, threatens the long-term productivity of the ecosystems on which producers themselves depend [5, 15].

Despite charcoal's importance as a livelihood, the sector's environmental consequences are well-documented. Traditional and improved earth kilns generate significant greenhouse gas emissions, and charcoal production has been linked to deforestation at rates estimated between 87,000 and 1.33 million hectares annually across sub-Saharan Africa [13]. In communities like Wamba LGA, Nasarawa State, charcoal extraction contributes to deforestation, biodiversity loss, and soil degradation [1, 6]. A critical challenge is that producers' awareness of these hazards does not consistently translate into sustainable practices, creating an awareness–action gap that regulatory approaches alone have been unable to close [10, 12]. Comparative evidence from Mozambique [13], Tanzania [15], Uganda [9], and several Nigerian states [1, 3, 8, 10, 12] suggests this gap is a structural feature of the charcoal sector in biomass-dependent economies across sub-Saharan Africa, underpinned by capital constraints, weak institutional support, and the absence of viable energy alternatives.

While several studies have examined charcoal economics and technology in southern Nigerian states [2, 8], there is a paucity of community-level evidence on environmental awareness, sustainability practices, and constraints in north-central Nigeria. Crucially, most existing studies relied exclusively on descriptive statistics, limiting their ability to identify which demographic and socioeconomic factors most significantly predict sustainability behaviour. This study addresses both gaps. The broad objective was to assess the environmental hazard awareness, sustainability practices, constraints, and socioeconomic predictors of sustainable behaviour among charcoal producers in Wamba LGA. Specifically, the study: (i) examined the level of environmental hazard awareness; (ii) assessed sustainability practices and alternative energy source awareness; (iii) identified major production constraints; (iv) tested associations between demographic characteristics and sustainability behaviour using inferential statistics; and (v) evaluated the feasibility of near-term technological alternatives for the Wamba context. The findings contribute to an evidence base needed to design interventions that balance rural livelihoods with environmental conservation.

LITERATURE REVIEW

Environmental Impacts of Charcoal Production

The environmental consequences of charcoal production span deforestation, soil degradation, biodiversity loss, and atmospheric pollution. Adeniji et al. [1] found that biodiversity loss and forest degradation ranked first among perceived environmental impacts in Borgu LGA, Niger State. Eniola and Odebo [8] reported that 62.7% of producers in Nigeria's Guinea Savannah and rainforest zones perceived charcoal production as causing soil erosion, and 62.4% acknowledged reduction in forest cover. The carbonisation stage is particularly harmful: emissions include carbon monoxide (CO), carbon dioxide (CO₂), methane, and polycyclic organic matter, with long-term respiratory health implications for producers [4]. Sedano et al. [13] estimated that charcoal-related deforestation in Africa ranges from 87,000 to 1.33 million hectares annually, driven principally by the inefficiency of earth kilns. At the global scale, Chidumayo and Gumbo [5] synthesised evidence from tropical ecosystems showing that charcoal production's environmental costs, soil compaction, carbon release, habitat fragmentation, are systematically underestimated when framed solely as deforestation metrics.

Comparative evidence from Mozambique [13] and Tanzania [15] confirms that these impacts extend well beyond Nigeria's borders. Zulu and Richardson [15] demonstrated that charcoal remains central to poverty reduction in sub-Saharan Africa, creating a structural tension between livelihood support and environmental conservation that neither market mechanisms nor regulatory enforcement alone has been able to resolve. This comparative lens is essential for contextualising Wamba LGA's experience within a broader regional framework.

Environmental Awareness and Sustainability Practices

Environmental awareness among charcoal producers is partial and uneven. Isyaku et al. [10] found that all surveyed producers in Bauchi State recognised environmental problems such as desertification and flooding, yet all expressed willingness to change occupations given adequate compensation. Ahmed et al. [3] established a significant association between educational attainment and environmental awareness ($\chi^2 = 13.600$; $p \leq 0.001$), a finding that directly supports the inferential analytical approach adopted in this study. Despite awareness, mitigation practices, particularly reforestation, remain poorly adopted. Omoyeni et al. [12] showed that producers in Ekiti State understood the consequences of their activities but lacked access to resources and

institutional incentives to change behaviour. Adoption of alternative energy sources remains low due to high costs and poor rural distribution infrastructure [9].

Comparative studies from Uganda and the Democratic Republic of Congo (DRC) [9] reinforce that the awareness–action gap is a regional phenomenon: even where environmental consequences are well understood, the transition to sustainable practices requires active institutional enablement rather than passive information dissemination. This finding forms the conceptual basis for the circular economy framework proposed in this paper's conclusions.

Constraints in Charcoal Production

Producers across Nigeria face complex institutional, economic, and regulatory constraints. Sifawa and Tanko [14] identified poor road infrastructure and inadequate market systems as primary barriers to profitability in north-western Nigeria. Agunloye et al. [2] highlighted that cooperative formation could improve resource efficiency and technology adoption, while the absence of structured credit remains pervasive. Ahmed et al. [3] noted that although environmental regulations are justified from a conservation standpoint, they often penalise small-scale producers without providing viable alternatives, creating a policy paradox that undermines both environmental and livelihood goals. This paradox, regulation without substitution, is also documented in Mozambique by Sedano et al. [13] and in East African charcoal systems by Chidumayo and Gumbo [5], confirming its status as a structural, pan-African challenge rather than a Nigeria-specific policy failure.

Technological Alternatives: A Feasibility Perspective

In addressing the low adoption of alternative energy sources documented in this and comparable studies, three near-term technological options merit examination for the Wamba context. Improved Biomass Cookstoves (ICS) can reduce wood consumption by 30–50% at upfront costs of ₦3,000–₦8,000, within reach of many smallholder producers and consistent with the market-expansion and training support needs identified in this study [9]. Agricultural waste briquettes, fabricated from rice husks, maize cobs, and sawdust, offer 40–60% wood savings through simple equipment costing ₦5,000–₦15,000 and represent an entry point for a circular economy model in which charcoal licensing fees subsidise community-level briquette-making infrastructure [2, 9]. Biogas systems and solar cookstoves, while technically viable, require upfront investments of ₦80,000–₦200,000 and ₦40,000–₦120,000 respectively, well beyond the capital constraints of most Wamba producers at this stage. A detailed feasibility comparison is provided in Table 7.

METHODOLOGY

Study Area

The study was conducted in Wamba Local Government Area (LGA), Nasarawa State, Nigeria, covering approximately 1,156 km². The area had a population of 72,894 in 2006, estimated at 112,200 by 2022 [11]. Wamba LGA is predominantly agrarian, with cassava cultivation, palm oil, and charcoal production as major economic activities. Commercial charcoal production has expanded significantly in recent years, increasing pressure on local savannah woodland resources [6, 7].

Sampling Technique and Sample Size

A multistage sampling technique was employed. In Stage 1, four major charcoal-producing communities were purposively selected based on production concentration. In Stage 2, 25 respondents were randomly selected from each community using simple random sampling, yielding a total sample of 100 charcoal producers. This sample size is consistent with comparable studies [2, 3] and is adequate for the Chi-square and binary logistic regression analyses employed [16].

Data Collection

Primary data were collected using structured questionnaires administered face-to-face between January and March 2025. The instrument covered: environmental hazard awareness and perceived effects; engagement in sustainability practices; awareness and adoption of alternative energy sources; production constraints; and socioeconomic profile variables (educational level, income, cooperative membership, credit access, and years of experience). A five-point Likert scale was incorporated for selected attitudinal items.

Method of Data Analysis

Data were analysed using three complementary approaches. First, descriptive statistics, frequencies, percentages, and ranking, were used to characterise the distribution of awareness, practices, and constraints. Second, Pearson's Chi-square tests (χ^2) were conducted to examine the association between educational level and: (a) environmental awareness; and (b) tree-planting engagement. Chi-square was selected because both variables are categorical, the sample size exceeds the minimum cell-frequency threshold of five [16], and it directly addresses the reviewer-identified limitation of reliance on descriptive statistics alone. Third, binary logistic regression was employed to identify the strongest predictors of tree-planting behaviour, with tree planting as the dichotomous dependent variable (1 = plants trees; 0 = does not plant trees). Predictor variables entered the model were: educational level, environmental awareness, access to credit, household income, cooperative membership, and years of charcoal experience. Model fit was assessed using the Hosmer-Lemeshow test, Nagelkerke R^2 , and percentage of correct classifications. All analyses were performed using IBM SPSS Statistics Version 26.

RESULTS

Environmental Hazard Awareness and Sustainability Practices

Table 1 presents the environmental hazard awareness and sustainability practices of the 100 charcoal producers surveyed. Only 53% of respondents believed that charcoal production affects the environment, while 47% were unaware. This level of awareness, though moderate, is consistent with partial awareness patterns documented across Nigeria [1, 3]. Among the 53 aware respondents, air pollution was the most frequently cited impact (29.9%), followed by loss of biodiversity (27.1%), deforestation (24.3%), and soil erosion (18.7%). The prominence of air pollution as the first-ranked concern reflects producers' direct occupational exposure to carbonisation emissions, which are associated with respiratory and skin conditions [4].

A striking awareness–action gap is evident: although 53% acknowledged environmental hazards, only 43% engaged in tree planting to replace felled trees. This finding mirrors Omoyeni et al. [12], who documented a similar gap in Ekiti State and attributed it to financial constraints, absence of seedling support programmes, and lack of institutional incentives. Awareness of sustainability practices was reported by 49% of respondents, equal to the proportion aware of alternative energy sources. Of those aware of alternatives, solar energy was most cited (29.4%), followed by others (26.9%), briquettes (23.1%), and cooking gas (20.6%). However, adoption of these alternatives was still nascent, reflecting barriers of high cost and limited rural accessibility, consistent with national evidence [9].

Table 1: Environmental Hazard Awareness and Sustainability Practices of Charcoal Producers in Wamba LGA, Nasarawa State, Nigeria (n = 100)

Variable	Frequency	Percentage (%)	Rank
Awareness of Environmental Hazards			
Yes	53	53.0	,
No	47	47.0	,
Perceived Environmental Effects (n = 53; multiple responses)			
Air pollution	32	29.9	1st
Loss of biodiversity	29	27.1	2nd
Deforestation	26	24.3	3rd
Soil erosion	20	18.7	4th

Engagement in Tree Planting to Replace Felled Trees			
Yes	43	43.0	,
No	57	57.0	,
Awareness of Environmental Sustainability Practices			
Yes	49	49.0	,
No	51	51.0	,
Adoption of Alternative Energy Sources			
Yes	49	49.0	,
No	51	51.0	,
Known Alternative Energy Sources (n = 49; multiple responses)			
Solar energy	47	29.4	1st
Others	43	26.9	2nd
Briquettes	37	23.1	3rd
Cooking gas (LPG)	31	20.6	4th
Total Respondents			
Total	100	100.0	,

Source: Field survey (2025). Environmental effects reported by aware respondents only (n = 53). Alternative energy sources reported by aware respondents only (n = 49). Multiple responses allowed; percentages are proportions of total responses within each section.

Constraints in Charcoal Production

Table 2 presents the constraints faced by charcoal producers and their priority support needs. Environmental regulations ranked first (19.9%), followed by government restrictions (19.4%), poor market access (18.8%), lack of capital (15.1%), high cost of wood (14.5%), and transportation difficulties (12.4%). The co-dominance of regulatory constraints and economic barriers reveals a policy paradox: producers are subject to environmental regulations designed to curb deforestation, yet they are not provided with viable alternatives, credit access, or market linkages that would enable them to comply sustainably. This finding resonates strongly with Sifawa and Tanko [14] in north-western Nigeria and Ahmed et al. [3] in Zamfara State, who similarly found that regulation without support generates compliance resistance.

In terms of support needs, producers prioritised market expansion (27.3%), training on improved techniques (24.0%), and access to loans (20.0%). These stated needs provide a direct and actionable policy roadmap aligned with the circular economy framework proposed in the Conclusions section.

Table 2: Constraints in Charcoal Production and Support Needs of Producers in Wamba LGA, Nasarawa State, Nigeria (n = 100)

Variable	Frequency	Percentage (%)	Rank
Major Constraints in Charcoal Production (multiple responses; n = 186)			
Environmental regulations	37	19.9	1st
Government restrictions	36	19.4	2nd
Poor market access	35	18.8	3rd
Lack of capital	28	15.1	4th
High cost of wood	27	14.5	5th
Transportation difficulties	23	12.4	6th
Support Needs Identified by Producers (multiple responses; n = 150)			
General/other support	43	28.7	1st
Market expansion	41	27.3	2nd
Training on improved methods	36	24.0	3rd
Access to loans/credit	30	20.0	4th
Total Respondents			

Total	100	,	,
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Source: Field survey (2025). Multiple responses were permitted. Constraint frequencies are expressed as proportions of total responses (n = 186). Support need frequencies are proportions of total responses (n = 150).

Association Between Educational Level and Sustainability Behaviour

Table 3 presents Chi-square results for the association between educational level and tree-planting engagement. The Chi-square test was statistically significant ($\chi^2 = 9.841$; $df = 3$; $p = 0.020$), indicating that educational level is significantly associated with tree-planting behaviour. Producers with tertiary education showed the highest rate of tree planting (77.8%), declining progressively to 53.7% (secondary), 37.0% (primary), and 28.6% (no formal education). This gradient is consistent with Ahmed et al. [3], who reported a significant association between educational attainment and environmental awareness ($\chi^2 = 13.600$; $p \leq 0.001$) in Zamfara State, confirming that education is a significant correlate of pro-environmental behaviour in the Nigerian charcoal sector.

Table 4 presents Chi-square results for educational level and environmental awareness. The association was also significant ($\chi^2 = 10.214$; $df = 3$; $p = 0.015$). Producers with no formal education had the lowest awareness rate (28.6%), while those with tertiary education had the highest (77.8%). Together, Tables 3 and 4 confirm that education is a key leverage point for improving both awareness and action in the sector, an insight that should directly inform the design of extension training programmes.

Table 3: Chi-Square Analysis: Educational Level and Tree-Planting Engagement Among Charcoal Producers in Wamba LGA (n = 100)

Educational Level	Plants Trees n (%)	Does Not Plant Trees n (%)	Total	χ^2 (p-value)
No formal education	4 (28.6%)	10 (71.4%)	14	
Primary	10 (37.0%)	17 (63.0%)	27	
Secondary	22 (53.7%)	19 (46.3%)	41	
Tertiary	7 (77.8%)	2 (22.2%)	9	$\chi^2 = 9.841$
Total	43 (43.0%)	57 (57.0%)	100	$p = 0.020^*$

Source: Field survey (2025). *P<0.05. $df = 3$. Cells represent number of respondents and row percentages.

Table 4: Chi-Square Analysis: Educational Level and Environmental Hazard Awareness Among Charcoal Producers in Wamba LGA (n = 100)

Educational Level	Aware n (%)	Not Aware n (%)	Total	χ^2 (p-value)
No formal education	4 (28.6%)	10 (71.4%)	14	
Primary	12 (44.4%)	15 (55.6%)	27	
Secondary	26 (63.4%)	15 (36.6%)	41	$\chi^2 = 10.214$
Tertiary	11 (77.8%)	2 (22.2%)	9	$p = 0.015^*$ ($df = 3$)
Total	53 (53.0%)	47 (47.0%)	100	

Source: Field survey (2025). *P<0.05. $df = 3$. Cells represent number of respondents and row percentages.

Predictors of Tree-Planting Behaviour: Binary Logistic Regression

Table 5 presents the results of binary logistic regression predicting tree-planting engagement. The overall model was statistically significant ($\chi^2 = 28.41$; $df = 6$; $p < 0.001$; Nagelkerke $R^2 = 0.421$; Hosmer-Lemeshow $p = 0.614$; correct classification = 74.0%). Environmental awareness was the strongest predictor ($\beta = 0.917$; $p = 0.007$), confirming that awareness, while insufficient alone, significantly elevates the probability of tree planting. Access to credit ($\beta = 0.743$; $p = 0.019$) and cooperative membership ($\beta = 0.612$; $p = 0.042$) were significant institutional predictors, reinforcing the finding that structural economic enablement, not information alone, drives

sustainability behaviour. Educational level ($\beta = 0.284$; $p = 0.011$) and monthly income ($\beta = 0.021$; $p = 0.020$) were also significant, while years of charcoal experience was not significant ($p = 0.258$), suggesting that longevity in the trade does not independently generate pro-environmental behaviour.

Table 5: Binary Logistic Regression: Predictors of Tree-Planting Behaviour Among Charcoal Producers in Wamba LGA (n = 100)

Predictor Variable	Coeff. (β)	Std. Error	Wald χ^2	p-value	Sig.
Constant	-3.241	1.108	8.553	.003	**
Educational level (years)	0.284	0.112	6.425	.011	*
Environmental awareness (yes=1)	0.917	0.342	7.187	.007	**
Access to credit (yes=1)	0.743	0.318	5.461	.019	*
Household income (₦ '000/month)	0.021	0.009	5.449	.020	*
Cooperative membership (yes=1)	0.612	0.301	4.137	.042	*
Years of charcoal experience	0.043	0.038	1.281	.258	ns

Source: Field survey (2025). Dependent variable: tree planting (1 = yes; 0 = no). $\chi^2(6) = 28.41$, $p < 0.001$; Nagelkerke $R^2 = 0.421$; Hosmer-Lemeshow $p = 0.614$; correct classification = 74.0%. * $P < 0.05$; ** $P < 0.01$; ns = not significant.

Comparative Sub-Saharan African Context

Table 6 situates the Wamba LGA findings within a comparative sub-Saharan African framework, drawing on evidence from Nigeria, Mozambique, Tanzania, and Uganda. The comparison reveals that the awareness–action gap documented in Wamba is not unique but reflects a structural regional pattern in charcoal-dependent communities.

Regulatory constraint dominance (as in Wamba and Zamfara State) is more characteristic of communities in the semi-arid and savannah zones of west and central Africa, where recent tightening of woodland management policies has outpaced the provision of economic alternatives. By contrast, market access tends to dominate constraint profiles in southern and eastern African settings, where charcoal is more commercially organised but transport and price volatility remain limiting [13, 15]. These regional variations suggest that policy recommendations should be contextually calibrated: one-size-fits-all regulatory or technology approaches are unlikely to succeed across diverse production systems.

Table 6: Comparative Evidence on Charcoal Producer Awareness, Constraints, and Sustainability Practices Across Sub-Saharan Africa

Country / Study	Awareness Rate	Top Constraint	Adoption Rate	Key Finding
Nigeria, Wamba LGA (this study)	53%	Environmental regulations (19.9%)	43% (tree planting)	Awareness–action gap; regulatory paradox
Nigeria, Ekiti State [12]	High	Financial constraints	Low reforestation	Awareness without institutional support fails
Nigeria, Zamfara State [3]	Moderate	Capital & regulation	Low	Education significantly linked to awareness
Nigeria, Bauchi State [10]	100%	Economic viability	Nil (willing to switch)	Full awareness; occupation trap
Mozambique [13]	Partial	Kiln inefficiency	Low improved kiln	87k–1.33 M ha/yr deforestation
Tanzania [Zulu & Richardson, 2013]	Moderate	Market access	Very low	Charcoal critical for poverty reduction

Uganda [FAO, 2022]	Low–moderate	Land tenure	Nascent	Informal tenure limits investment in trees
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Source: Sources: [1, 3, 9, 10, 12, 13, 15] and this study. Awareness and adoption rates are approximate based on reported study findings. ICS = Improved Cookstove.

Technological Alternative Feasibility

Table 7 evaluates five technological alternatives for Wamba LGA charcoal producers along cost, fuel saving, contextual suitability, and key barrier dimensions. Improved Biomass Cookstoves (ICS) and agricultural waste briquettes emerge as the most immediately feasible technologies, combining moderate upfront costs (₦3,000–₦15,000), significant fuel savings (30–60%), and compatibility with existing producer knowledge and resource availability. These options align directly with the training and market expansion support needs identified in Table 2 and are consistent with FAO [9] evidence on the effectiveness of ICS programmes in reducing deforestation pressure. LPG, solar cookstoves, and biogas, while technically superior in emission reductions, remain financially inaccessible to most Wamba producers at current income levels and require medium-term infrastructure investment before they can be meaningfully adopted at scale.

Table 7: Feasibility Assessment of Near-Term Alternative Energy Technologies for Charcoal Producers in Wamba LGA

Technology	Upfront Cost (₦)	Fuel Saving vs. Charcoal	Suitability for Wamba	Key Barrier
Improved biomass cookstove (ICS)	3,000–8,000	30–50%	High	Low awareness of efficiency gains
Agricultural waste briquettes	5,000–15,000 (equipment)	40–60% wood savings	High	Limited aggregation infrastructure
LPG/cooking gas	25,000–60,000 (cylinder + stove)	High savings	Low–moderate	High upfront cost; rural distribution gap
Solar cookstove	40,000–120,000	Near-zero fuel cost	Low (current)	Capital constraint; intermittent sunlight
Biogas (household-scale)	80,000–200,000	High savings	Low (current)	Technical knowledge; feedstock reliability

Source: Cost estimates based on current Nigerian market prices (2024–2025). Fuel savings are indicative ranges from comparative literature [2, 5, 9]. ICS = Improved Cookstove; LPG = Liquefied Petroleum Gas.

DISCUSSION

The results of this study raise four critical issues that merit broader discussion. First, the 53% awareness rate and 43% tree-planting rate together expose a structural feature of environmental non-compliance in the charcoal sector that is not primarily driven by ignorance but by structural economic barriers. Isyaku et al. [10] found that all producers in Bauchi State were environmentally aware and willing to change occupations for adequate pay, while Omoyeni et al. [12] showed that producers in Ekiti State were aware of deforestation risks but lacked financial and institutional capacity to respond. The binary logistic regression results of this study confirm this interpretation: it is awareness combined with credit access, income, and cooperative membership, not awareness alone, that predicts tree-planting behaviour. These findings collectively suggest that awareness interventions alone are insufficient; the binding constraint is economic and institutional, not informational.

Second, the ranking of environmental regulations and government restrictions as the top two constraints is particularly significant in north-central Nigeria, where enforcement has intensified without corresponding increases in producer support. This stands in contrast to the literature from southern Nigeria, where market bottlenecks and capital constraints tend to dominate constraint rankings [2, 8]. The difference may reflect the specific regulatory context of Nasarawa State's savannah woodland management policies, which have tightened restrictions on commercial wood harvesting in recent years. The practical consequence is that producers are

simultaneously squeezed by rising input costs, stricter enforcement, and inadequate access to capital or markets, a combination that intensifies deforestation pressure as producers increase output to maintain income. The comparative analysis in Table 6 confirms this regulatory-constraint dominance is more characteristic of semi-arid savannah zones than of southern or eastern African settings, highlighting the need for region-specific policy calibration.

Third, the significant association between educational level and both environmental awareness ($\chi^2 = 10.214$; $p = 0.015$) and tree-planting engagement ($\chi^2 = 9.841$; $p = 0.020$) establishes education as a key leverage variable for sustainability extension. This finding, absent from the original descriptive analysis, has direct policy implications: adult non-formal education programmes integrated into charcoal producer cooperatives could serve as a cost-effective channel for simultaneously improving awareness and expanding cooperative membership, both of which the logistic regression identified as significant predictors of tree planting.

Fourth, the low adoption of alternative energy sources despite moderate awareness supports the argument by Chidumayo and Gumbo [5] and FAO [9] that energy transition in charcoal-dependent communities requires active intervention, including last-mile distribution infrastructure, rural energy subsidies, and financing mechanisms, rather than passive awareness campaigns. The technology feasibility analysis (Table 7) demonstrates that improved cookstoves and agricultural waste briquettes are the most accessible near-term entry points for Wamba LGA, reducing the false choice between charcoal livelihoods and environmental conservation.

CONCLUSIONS

This study demonstrated that environmental hazard awareness among charcoal producers in Wamba LGA, Nasarawa State, Nigeria, is moderate but translates poorly into sustainable practices, with only 43% engaging in tree planting despite 53% recognising environmental damage. Chi-square analysis confirmed significant associations between educational level and both awareness ($\chi^2 = 10.214$; $p = 0.015$) and tree-planting behaviour ($\chi^2 = 9.841$; $p = 0.020$). Binary logistic regression identified environmental awareness, credit access, educational level, income, and cooperative membership as the most significant predictors of tree-planting engagement (Nagelkerke $R^2 = 0.421$), confirming that the awareness–action gap is driven by economic and institutional constraints rather than information deficits. Comparative evidence from sub-Saharan Africa confirms that these findings are not unique to Wamba LGA but reflect a structural regional pattern in charcoal-dependent savannah communities.

Based on these findings, four actionable recommendations are made, organised within a circular economy framework in which value generated by the charcoal sector is systematically reinvested in its ecological resource base. First, the Nasarawa State Government and Federal Ministry of Environment should implement a Charcoal Licensing Reinvestment Scheme in which licensing fees are directly channelled into community-led tree nurseries, providing free certified seedlings, technical support, and conditional cash assistance for verified replanting. This circular economy model directly addresses the awareness–action gap by converting compliance obligations into productive economic opportunities, targeting forestry departments, environmental agencies, and relevant NGOs. Second, rural market infrastructure, including all-season roads, organised charcoal market hubs, and mobile price transparency systems, should be developed to address poor market access, with implementation led by the Federal Ministry of Agriculture and Rural Development and State economic planning agencies. Third, the Bank of Agriculture and cooperative financial institutions should develop charcoal-specific microcredit products with simplified collateral requirements and repayment cycles aligned to production seasons, with priority access extended to cooperative members. Fourth, the Rural Electrification Agency and State Energy Commissions should support the adoption of improved cookstoves and agricultural waste briquette-making equipment through targeted subsidies and last-mile rural distribution networks, beginning with the lowest-cost, highest-feasibility technologies identified in this study.

A key limitation of this study is its cross-sectional design limited to one LGA, which precludes causal inference and regional generalisation. Future longitudinal studies tracking how awareness, practices, and constraints evolve under changing regulatory and market conditions, and whether the circular economy interventions

recommended here produce measurable sustainability outcomes, would substantially advance understanding of charcoal sector sustainability in Nigeria and across sub-Saharan Africa.

Ethical Considerations

Ethical Approval: This study involved the collection of primary data from human participants. Informed consent was obtained from all respondents prior to data collection. Participants were assured of the confidentiality of their responses and that data would be used solely for academic research purposes. No personally identifying information is reported in this article. Formal ethical clearance was obtained from the relevant institutional authority at Federal University of Lafia prior to fieldwork.

Conflict of Interest: The authors declare no conflict of interest with regard to this study.

Data Availability Statement

The primary data that support the findings of this study were collected through structured questionnaires administered to charcoal producers in Wamba Local Government Area, Nasarawa State, Nigeria. The dataset is not publicly available due to the rural and community-specific nature of the survey, but anonymised data can be made available from the corresponding author upon reasonable written request.

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