Biogas Adoption Pathways for Clean Cooking Among Low-income Women in Sub-Saharan Africa

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Abstract. Household dependence on traditional biomass for cooking remains a major public health, gender, and environmental challenge in sub-Saharan Africa. In Nigeria, low-income women face exposure to indoor air pollution, time poverty, and climate vulnerability from firewood and charcoal use. This study investigates pathways to scale biogas as a clean cooking solution for low-income women in sub-Saharan Africa, drawing policy lessons from international energy transitions. A descriptive cross-sectional survey of 251 women was conducted using reliability and inter-item correlation analysis, thematic analysis of open-ended responses, and policy synthesis. Findings reveal inadequate government support (Mean = 3.73, SD = 1.34) as the most significant barrier, followed by lack of skilled technicians (Mean = 3.45) and low awareness (Mean = 3.36). Safety and reliability concerns were minimal. Respondents strongly endorsed youth technical training programmes (Mean = 3.65) and NGO-led awareness campaigns (Mean = 3.56). Regular training (Mean = 3.67) and community-level maintenance services (Mean = 3.36) were identified as key sustainability strategies. The paper proposes an integrated adoption pathway emphasising institutional coordination, targeted financing, and local capacity development. This study offers actionable policy guidance for governments, donors, and partners to accelerate gender-responsive clean cooking transitions.

1 Introduction

The global transition to sustainable clean cooking energy systems has become increasingly urgent as efforts to mitigate climate change and achieve the United Nations Sustainable Development Goals (SDGs), particularly SDG 7 on affordable and clean energy, intensify. Despite growing international commitments, access to clean cooking remains limited, with billions of people worldwide still relying on biomass, kerosene, and coal for household cooking [1] The challenge is particularly severe in Sub-Saharan Africa (SSA), where access to clean cooking remains the lowest globally and continues to undermine public health, environmental sustainability, and climate mitigation efforts [2].

Nigeria reflects this broader regional challenge. A large proportion of households continue to depend on firewood, charcoal, and kerosene for cooking, exposing communities to indoor air pollution, deforestation, and associated health risks, particularly among women and children [3]. While Liquefied Petroleum Gas (LPG) has emerged as a cleaner alternative, rising LPG prices in recent years have weakened its affordability and encouraged renewed dependence on traditional biomass fuels in many communities [4]. In Anambra State, this trend has intensified environmental degradation and health concerns. Previous studies report that emissions from firewood combustion in the state exceed recommended health thresholds, with prolonged exposure linked to respiratory and other health complications [5].

Biogas presents a viable renewable alternative within this context. Produced from organic waste through anaerobic digestion, biogas offers environmental, economic, and health benefits by reducing greenhouse gas emissions, improving indoor air quality, and providing locally available cooking fuel [6]. Its circular economy benefits also make it particularly relevant to low-income households and rural communities. However, adoption across SSA remains limited due to several barriers, including high upfront costs, inadequate financing, low public awareness, limited technical capacity, and weak institutional support [7].

Across SSA, the clean cooking deficit remains substantial. Recent estimates indicate that approximately four out of five households in the region still lack access to clean cooking solutions, while nearly 300 million people globally need to transition annually to remain on track with net-zero targets and SDG 7 [8].

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Household air pollution from biomass combustion continues to contribute significantly to disease burden and premature mortality across Africa [9]. Nigeria remains one of the countries most affected by this challenge.

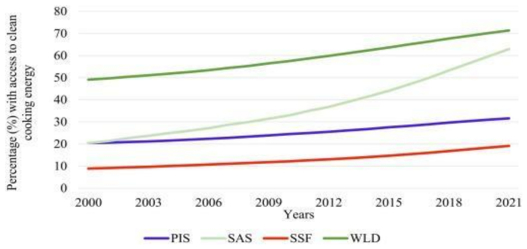

Fig. 1. Share of the population with access to clean cooking energy across selected regions.
Note: PIS = Pacific Island Small States;
SAS = South Asia
SSA = Sub-Saharan Africa;
WLD = World.
Source: *World Bank (2023).*

Among available clean cooking alternatives, biogas offers distinct advantages. Compared with improved biomass cookstoves and solar cookers, it produces significantly lower indoor emissions while generating fuel locally from waste. Although LPG generally provides higher thermal efficiency, affordability concerns and supply volatility increasingly constrain its use. In contrast, biogas offers long-term affordability and environmental sustainability despite higher initial installation costs [10]. These characteristics position it as a promising option for household energy transition in low-income SSA settings.

Gender also remains central to clean cooking transitions. Women are disproportionately affected because they bear primary responsibility for cooking and fuel collection. Energy justice literature highlights the importance of equitable access, recognition of gendered burdens, and inclusive participation in energy decisions [11]. Studies consistently show that women-focused interventions—including targeted subsidies, microfinance, and community-based cooperatives-improve clean energy adoption and long-term sustainability [9], [12]. This makes women's willingness and capacity to adopt biogas a critical policy concern.

Beyond SSA, policy experiences from industrialized countries offer transferable insights. The United Kingdom provides an instructive example of coordinated low-carbon transition through long-term financing mechanisms, workforce development, public awareness strategies, and institutional coordination [12]. While the UK context differs significantly from Nigeria, policy transfer theory suggests that adaptable principles, rather than direct replication, can inform energy transitions in institutionally constrained environments such as SSA [13].

The adoption of biogas in this study is further informed by multiple theoretical perspectives. The Theory of Planned Behaviour explains how awareness, affordability, and social acceptance influence adoption intentions [13]. Socio-technical transition theory emphasizes the interaction between technological systems, institutions, and social practices [14]. The Energy Justice framework highlights inclusive and gender-sensitive access, while Diffusion of Innovation theory explains how perceived benefits and social networks shape adoption behaviour [14]. These perspectives jointly provide a useful basis for understanding adoption decisions among low-income women.

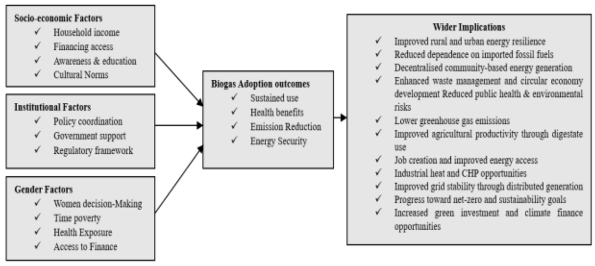

Fig. 2. Conceptual Framework Linking Institutional, Socioeconomic, and Gender Factors to Biogas Adoption in SSA

1.1 Theoretical framework for biogas adoption

Four theoretical views underpin this study. The theory of planned behaviour (TPB) explains how awareness, affordability, and cultural acceptance shape low-income women's adoption intentions. Socio-technical transition theory emphasizes integrated approaches addressing technical, socio-cultural, and institutional barriers. The Energy Justice Framework prioritizes inclusive, gender-sensitive access. Diffusion innovation theory identifies strategies that leverage biogas's cost-saving and environmental benefits, while policy transfer theory frames the adaptation of the UK financing and training model to Nigeria's socio-economic context [15].

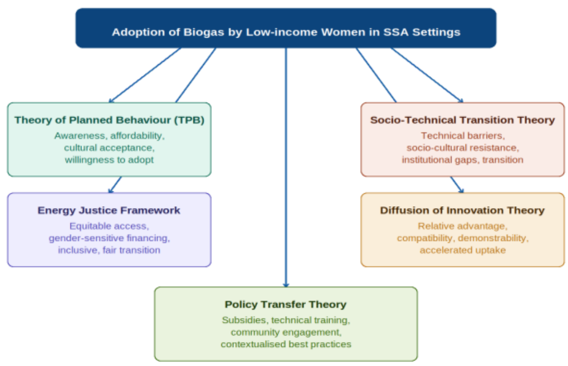

Fig. 3. Theoretical Framework for Biogas Adoption by Low-Income Women in SSA

Although clean cooking has been widely studied, important gaps remain. Existing literature has not sufficiently examined willingness among low-income women to adopt biogas in SSA through an integrated analysis of behavioural, institutional, and socio-economic determinants while simultaneously drawing policy lessons from industrialized clean energy transitions. This study addresses that gap through a case study of Anambra State, Nigeria, using a mixed-method design comprising cross-sectional survey analysis, logistic regression modelling, thematic analysis of qualitative responses, and policy synthesis. Although the empirical evidence is drawn from Nigeria, the study is framed within a broader SSA perspective given shared institutional, socio-economic, and gender-related dynamics that influence clean cooking transitions across the region. The findings therefore contribute both context-specific and transferable insights for advancing inclusive biogas adoption in SSA.

2 System model

2.1 Study design and area

This study was conducted in selected rural and peri-urban communities in Anambra State, Nigeria, with emphasis on areas where household dependence on traditional cooking fuels remains high. The study focused on low-income women because they are primarily responsible for household cooking and often make decisions related to domestic energy use.
A descriptive cross-sectional survey design was adopted to examine perceptions, barriers, and willingness to adopt biogas for household cooking at a single point in time. To complement the quantitative findings, open-ended responses and short interviews were included to capture contextual experiences and provide deeper insight into household energy decisions.
The target population comprised women aged 18 years and above with primary responsibility for cooking and household energy management. Ethical standards were maintained throughout the study. Participation was voluntary; informed consent was obtained before data collection; confidentiality was protected; and respondents were assured that participation would not expose them to harm or disadvantage.

2.2 Sampling procedure and data collection

A multistage sampling approach was adopted. Three Local Government Areas in Anambra State, Aguata, Anaocha, and Njikoka, were purposively selected based on their rural and peri-urban characteristics and relevance to household clean cooking practices. Two communities were then randomly selected from each area, followed by systematic random sampling of every nth household. Eligible participants were women aged 18 years and above, primarily responsible for cooking, with monthly household income not exceeding ₦70,000. Of 260 questionnaires administered, 251 valid responses were analysed. Data covered socio-demographics, cooking practices, biogas awareness, adoption barriers, and proposed interventions, supplemented by interviews

Table 1. Demographic Information of Respondents

Variable	Responses	Frequency (F)	Percentage (%)
Age	18 – 24 Years	51	20.3
	25 – 34 Years	26	10.4
	35 – 44 Years	88	35.1
	45 – 54 Years	71	28.3
	55 – 64 Years	13	5.2
	65 Years and Above	2	0.8
	Total	**251**	**100**
Marital Status	Single	67	26.7
	Married	148	59
	Divorced	16	6.4
	Widowed	20	8
	Total	**251**	**100**
Educational qualification	No formal education	13	5.2
	Primary education	20	8
	Secondary education	105	41.8
	Tertiary education	111	42.2
	Vocational/technical education	2	0.8
	Total	**251**	**100**

Note: Since 84% of respondents attained secondary or tertiary education, compared with the rural Anambra average of 62% (DHS, 2018), the findings may underrepresent less educated and marginalized women.

2.3 Socio-demographic profile of respondents

The demographic profile supports assessment of biogas adoption among low-income women in Anambra State. Most respondents were married adults aged 35–54 and had completed secondary or tertiary education, indicating strong awareness potential. However, the low level of vocational or technical training suggests a significant skills gap in biogas installation and maintenance.

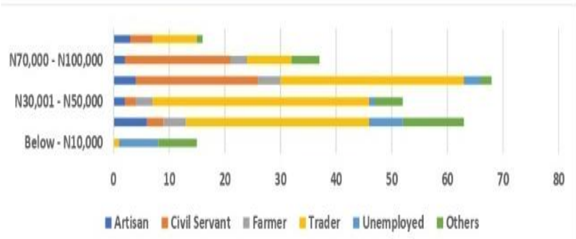

Fig. 4. Employment Status and Monthly Household Income

Figure 4 shows employment status and monthly household income. Trading dominated the ₦10,000–₦70,000 income range, highlighting informal commerce as a key livelihood source. Civil servants were concentrated in higher-income groups, while unemployed respondents were mostly in lower-income brackets. These patterns influence household purchasing power and the ability to adopt biogas.

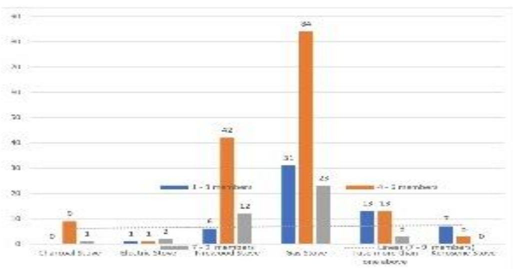

Fig. 5. Household size and cooking equipment

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Figure 5 shows the relationship between household size and cooking equipment used. Gas stoves were the most used across all household sizes, with the highest concentration among medium-sized households. Firewood remained the second most common option, while charcoal and combined fuel use appeared less frequently.

Smaller households demonstrated greater flexibility in combining multiple cooking fuels. In contrast, larger households showed stronger dependence on firewood and gas, likely due to higher cooking demand and cost considerations. These patterns suggest that household size remains an important factor influencing cooking fuel decisions and may affect willingness to transition to biogas.

2.4 Data Analysis

Quantitative data were analyzed using descriptive statistics, Cronbach's alpha, Pearson correlation, and logistic regression techniques. Descriptive statistics summarized respondents' demographic characteristics and key study variables, while Cronbach's alpha evaluated the internal consistency and reliability of the questionnaire items. Pearson correlation analysis examined relationships among variables, and logistic regression identified socio-economic, behavioral, institutional, and awareness factors influencing willingness to adopt biogas technology.

A five-point Likert scale was employed to assess perceptions, barriers, and intervention strategies, with a mean score of 3.0 used as the decision threshold for acceptance or agreement. Qualitative data obtained from interviews and open-ended responses were analyzed thematically and integrated with the quantitative findings to provide a comprehensive understanding of biogas adoption among low-income women in Anambra State.

$$\alpha = (k / (k-1)) \times (1 - \Sigma\sigma^2_i / \sigma^2_t) \quad (1)$$

where k is the number of items, σ^2_i is the variance of each item, and σ^2_t is the total variance of the composite score

For the inter-item correlation matrix, the Pearson correlation coefficient formula is presented:

$$r = \Sigma[(x_i - \bar{x})(y_i - \bar{y})] / \sqrt{[\Sigma(x_i - \bar{x})^2 \times \Sigma(y_i - \bar{y})^2]} \quad (2)$$

The mean cut-off scoring approach (using a 5-point Likert scale with a mid-point of 3.0 as the decision threshold) is also explicitly defined.

3 Results and discussion

3.1 Implementation Challenges to Biogas Adoption

The reliability analysis for the six constructs measuring implementation challenges produced a Cronbach's Alpha of 0.851, indicating strong internal consistency and confirming that the items reliably measure barriers to biogas adoption among low-income women.

Table 2. Reliability statistics for implementation challenges

Cronbach's Alpha	Cronbach's Alpha Based on Standardised Items	No of Items
0.851	0.7913	6

The mean scores indicate that inadequate government support is the most significant barrier to biogas adoption (Mean = 3.73; SD = 1.34). This is followed by lack of skilled technicians (Mean = 3.45; SD = 1.23) and low awareness (Mean = 3.36; SD = 1.32). These findings suggest that institutional support, technical capacity, and public awareness are the primary constraints affecting adoption.

High setup cost also recorded a mean above the decision threshold (Mean = 3.29), indicating that affordability remains a practical concern for many households. In contrast, limited financing options (Mean = 2.72) and cultural resistance (Mean = 3.01) were perceived as relatively less significant, although both remain relevant to adoption decisions.

The relatively wide standard deviations across the items indicate variation in respondent perceptions, likely reflecting differences in education, income, and household experience across the study communities. Overall, the results show that barriers to biogas adoption are multidimensional and require coordinated responses, including government support, technical training, awareness-raising, and access to finance.

Table 3. Mean scores for implementation challenges

Implementation Challenges	Mean	Std. Dev.
High Setup Cost	3.291	1.329
Low Awareness	3.363	1.318
Lack of Skilled Technicians	3.447	1.233
Cultural Resistance	3.008	1.121
Limited Financing Options	2.721	1.309
Inadequate Government Support	3.733	1.340

3.2 Inter-item correlations

The inter-item correlation matrix provides additional insight into the relationships among implementation challenges.

Table 4. Correlation matrix for implementation challenges

Implementation Challenges	High Setup Cost	Low Awareness	Lack of Skilled Technicians	Cultural Resistance	Limited Financing Options	Inadequate Government Support
High Setup Cost	1					
Low Awareness	-0.34	1				
Lack of Skilled Technicians	-0.27	-0.085	1			
Cultural Resistance	-0.224	-0.067	-0.011	1		
Limited Financing Option	-0.08	-0.059	-0.054	0.127	1	
Inadequate Government Support	-0.118	-0.156	0.111	0.06	-0.314	1

A moderate negative relationship exists between high setup cost and low awareness (r = -0.340), indicating that respondents who perceived cost as a major barrier were less likely to identify awareness as a major challenge. High setup cost also shows weak negative associations with lack of skilled technicians (r = -0.270) and cultural resistance (r = -0.224).

Limited financing options show a moderate negative relationship with inadequate government support (r = -0.314), suggesting that respondents may distinguish between household-level financial access and broader institutional support.

Most correlations remain weak, indicating that the barriers are related but largely independent dimensions of the adoption process. This reinforces the need for integrated interventions that address institutional, technical, financial, and behavioural constraints simultaneously.

3.3 Solutions to biogas adoption challenges

The reliability analysis for the five solution-related constructs produced a Cronbach's Alpha of 0.770, indicating acceptable internal consistency.

Table 5. Reliability statistics for perceived solutions

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	No of Items
0.77	0.79	5

The mean scores show strong support for youth technical training programs (Mean = 3.65), awareness campaigns led by NGOs (Mean = 3.56), and government subsidies (Mean = 3.53). These findings indicate that respondents prioritize practical training, awareness-raising, and financial support as the most effective pathways to improving adoption.

Women-targeted financial support received a moderate rating (Mean = 2.92), while promoting local manufacturing had the lowest mean (Mean = 2.52), suggesting weaker immediate support than training- and subsidy-based interventions.

Together, the results indicate that respondents favor interventions with direct and visible effects on affordability, knowledge, and technical readiness.

Table 6. Mean Cut-off Score for Possible Solutions to Challenges of Biogas Adoption Among Low-Income Women in Anambra State

Suggested Solutions	Mean	Std. Deviation
Government Subsidies	3.526	1.278
Promoting Local Manufacturing	2.518	0.997
Women Targeted Financial Support	2.920	1.025
Youth Training Programs	3.653	1.427

3.4 Inter-item correlations of matrix solution

The inter-item correlation matrix highlights the relationship among proposed solutions.

Table 7. Inter-item correlation matrix solution

Solutions	GS	AC	PLM	WTFS	YTP
GS	1				
AC	0.037	1			
PLM	-0.036	-0.036	1		
WTFS	0.090	0.090	0.169	1	
YTP	-0.209	-0.031	0.343	-0.15	1

Note: GS= Government Subsidies; AC=Awareness Campaigns by NGOs; PLM=Promoting Local Manufacturing; WTFS=Women Targeted Financial Support; YTP=Youth Training Programs

The strongest positive relationship appears between promoting local manufacturing and youth training programs (r = 0.343), indicating that respondents who support local production also tend to support technical capacity-building.

Most other correlations are weak, suggesting that the proposed interventions address different dimensions of adoption. For example, awareness campaigns show a small positive relationship with women-targeted financial support, while government subsidies show a limited association with the other measures.

This pattern suggests that respondents do not view a single intervention as sufficient; rather, they support a combination of awareness, training, and financial mechanisms to improve adoption.

3.5 Deployment sustainability strategies

The reliability analysis for the five-deployment sustainability strategy (DSS) constructs produced Cronbach's Alpha of **0.858**, indicating strong internal consistency and confirming that the measures reliably assess long-term biogas sustainability.

Table 8. Reliability statistics for DSS

Cronbach's Alpha	Cronbach's Alpha Based on Standardised Items	N of Items
0.858	0.848	5

Among the strategies assessed**,** regular training recorded the highest means (Mean = 3.67; SD = 1.06**),** indicating strong agreement on its importance for sustained biogas adoption. This was followed by community-level maintenance services (Mean = 3.36) and monitoring systems (Mean = 3.06).

By contrast, tax incentives (Mean = 2.61) and women's group-led project management (Mean = 2.68) received lower ratings, indicating weaker perceived effectiveness or lower familiarity among respondents.

These findings suggest that respondents place greater emphasis on practical technical support and maintenance structures than on policy-based incentives or community-led management arrangements.

Table 9. Reliability statistics for DSS

DSS	Mean	Std. Deviation
RT	3.665	1.062
CLMS	3.359	1.408

ILTB	2.614	1.189
MS	3.064	1.295
WGM Local Project	2.681	1.249

3.6 Inter-Item Correlations

The correlation matrix provides further insight into how sustainability strategies relate to one another.

Table 10. Correlation matrix for DSS

DSS	RT	CLMS	ILTB	MS	WGM
RT	1				
CLMS	0.134	1			
ILTB	0.151	0.045	1		
MS	0.245	0.525	0.029	1	
WGM	0.169	0.006	0.735	0.013	1

Note : DSS= Deployment and Sustainability Strategies; RT = Regular Training ; CLMS = Community-Level Maintenance Services ; ILTB = Incentives Like Tax Breaks ; MS = Monitoring Systems ; WGM =Women's Group Managing Local Projects

The strongest positive relationship is between tax incentives and women's group-led project management **(**r = 0.735**)**, suggesting that economic incentives may be viewed as important for supporting women-led implementation efforts.

A moderate positive relationship is also observed between monitoring systems and community-level maintenance services **(**r = 0.525**),** indicating that respondents associate long-term maintenance with effective oversight.

Other relationships are relatively weak, suggesting that sustainability depends on multiple complementary strategies rather than a single dominant intervention. Overall, the findings indicate that long-term biogas adoption is most likely to be sustained through a combination of technical training, accessible maintenance support, and institutional reinforcement.

4 Discussion

This study integrates empirical evidence from Nigeria with comparative insights from Sub-Saharan Africa (SSA) and the United Kingdom, demonstrating that biogas adoption among low-income women is shaped less by technological or safety concerns than by institutional, socio-economic, and gender-related constraints. This reinforces the view that clean cooking transitions are systemic and governance-dependent rather than simple technological substitutions. The finding that inadequate government support (Mean = 3.73) represents the most significant barrier is consistent with earlier studies that identified policy and institutional gaps as dominant constraints to biogas adoption in developing economies. By contrast, safety concerns were comparatively minimal, in contrast to findings in Ethiopia and South Africa, where perceived safety risks were more pronounced. This variation may reflect the relatively higher educational attainment of respondents in the present study. The strong support for youth technical training (Mean = 3.65) further confirms the importance of capacity-building for long-term adoption sustainability. In addition, the high inter-item correlation between tax incentives and women-led project management (r = 0.735) extends existing scholarship by empirically linking fiscal support mechanisms with gender-responsive governance in clean energy transitions.

4.1 Interacting drivers of biogas adoption in sub-saharan african settings

The conceptual framework in Figure 1 shows how institutional, socio-economic, and gender-related factors interact to shape biogas adoption. Inadequate government support, limited technical capacity, and low awareness emerged as the main barriers, while safety and reliability concerns were less significant, indicating unmet demand for clean cooking solutions. From a socio-technical perspective, adoption is constrained by fragmented governance and weak policy coordination. Similar conditions are common across Sub-Saharan Africa, where clean cooking programs are often short-term or donor-driven rather than integrated into long-term energy and climate strategies, making the findings relevant beyond Nigeria.

4.2 Socio-economic constraints and suppressed demand

Socio-economic factors, particularly low household income and limited access to finance, remain major barriers to biogas adoption despite positive perceptions of its benefits. Respondents strongly supported subsidies, awareness campaigns, and technical training, highlighting the importance of demand-side interventions in advancing clean cooking transitions. These findings confirm that affordability and access often shape household energy decisions more than preference alone. Without targeted financing options such as microcredit, results-based subsidies, or pay-as-you-go systems, biogas is likely to remain inaccessible to many households affected by energy poverty. Similar barriers have been reported across Ethiopia, Kenya, and South Africa. Gender-related factors also strongly influence adoption. Women's exposure to household air pollution, time spent collecting fuel, and limited financial access affect both willingness to adopt and long-term use. At the same time, providing financial support, technical training, and decision-making opportunities can strengthen adoption and generate broader social and development benefits, reinforcing the need for gender-responsive clean cooking policies across SSA.

4.3 Comparative Insights: cautionary lessons from high-income contexts

Lessons from high-income clean energy policies, such as the United Kingdom's Boiler Upgrade Scheme, should be applied with caution in low-income settings due to differences in institutional capacity, financial systems, infrastructure, and household incomes. Conditions assumed in the UK- strong regulation, established training systems, and greater ability to meet upfront costs- are often absent in rural Nigeria. A more practical approach is to adapt broad policy principles to local realities. These include policy coordination, long-term funding, and linking skills development with technology deployment. In this context, community-based technician training and microfinance are more suitable than formal certification systems or commercial loans.

4.4 Contribution to literature and originality

This study contributes to research on clean cooking and the renewable energy transition in three ways. It provides household-level evidence on biogas adoption among low-income women in Nigeria, links women's health, time poverty, and financial constraints to adoption outcomes, and integrates behavioural, socio-technical, and energy justice perspectives to propose a context-sensitive biogas adoption pathway for SSA.

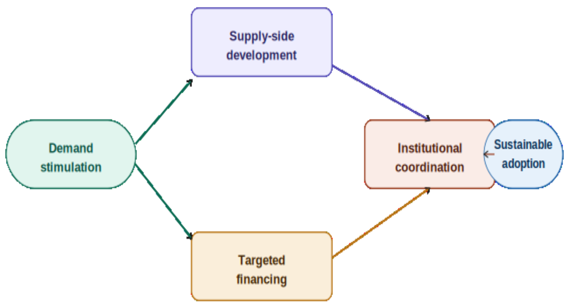

Fig. 6. Integrated Biogas Adoption Pathway for clean cooking in a sub-Saharan African setting.

4.5 Sub-Saharan Africa generalisation statement

The proposed pathway may apply across SSA countries with similar institutional and socio-economic conditions. However, local validation and country-specific adaptation remain essential. It offers transferable policy guidance while allowing flexibility for national and community-level differences.

4.6 Policy, climate and research implications

The study shows that clean cooking transitions in SSA require coordinated policy systems rather than stand-alone technology interventions. Policymakers should integrate biogas into renewable energy, climate, gender, and industrial development strategies, while development partners prioritize long-term financing and capacity-building over short-term project cycles. For practitioners, technical training, installer certification, and after-sales support remain essential for sustainable adoption. Biogas adoption also supports multiple Sustainable Development Goals by improving access to clean energy, reducing household air pollution, easing women's health burdens and time constraints, and contributing to climate mitigation. However, the findings should be interpreted with caution due to regional diversity, sampling limitations, and a focus on adoption intentions. Future studies should adopt longitudinal and comparative approaches across different SSA contexts.

5 Conclusion

This study provides empirical and policy-relevant evidence on biogas adoption for clean cooking in SSA using household data from Nigeria and comparative insights from UK low-carbon transition strategies. Major barriers included inadequate government support, limited technical capacity, and low awareness, while safety concerns were minimal. Respondents strongly supported youth training, awareness campaigns, and community maintenance services. The proposed integrated pathway highlights practical conditions for scaling clean cooking transitions and positions biogas as a viable pathway for an inclusive renewable energy transition in similar SSA contexts.

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5.1 Declaration of competing interest

The authors declare no competing financial or personal interests that could have influenced the work reported in this paper.

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