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Socioeconomic and Cultural Determinants of Biomass Briquette Adoption in Voi Sub-County, Taita Taveta County, Kenya

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ABSTRACT: Background: Approximately 600 million Africans cook using traditional and polluting biomass energy, which poses several health and environmental risks. Objective: This study examined the influence of awareness, affordability, accessibility, and cultural cooking norms on adoption of a cleaner and sustainable biomass briquette cooking energy. Methodology: A total of 402 households were surveyed through a questionnaire in a cross-sectional study that yielded a 90.3% response rate. Results: In the descriptive analysis, low level of adoption (Mean = 2.08; SD = 0.29) was recorded through a 5-point Likert scale on a total of (24) items. For the predictor variables each containing (8) items, awareness (M=2.70, SD=0.37), affordability (M=2.60, SD=0.37) and accessibility (M=2.62, SD=0.36) of biomass briquette energy scored below the mid-point while cultural cooking norms scored above the mid-point (M=3.51, SD=0.51). The regression model showed statistical significance $F(4, 362) = 142.745$, $p < .001$ and explained 61.5% of the variance in adoption ($R^2 = 0.615$). Discussion: The most powerful predictor of adoption was awareness ($\beta = 0.401$, $p < 0.001$), followed by accessibility ($\beta = 0.366$, $p < 0.001$), and affordability ($\beta = 0.200$, $p < 0.001$). Cultural cooking norms ($\beta = –0.193$, $p < .001$) acted as a barrier to adoption. Conclusions: Adoption of biomass briquette energy in Voi is determined by awareness, accessibility and affordability of the fuel, while traditional cooking norms hinder adoption. Recommendations: To boost adoption, efforts should focus on marketing campaigns, strengthening of local supply chains, introduction of producer and consumer subsidies, and extensive demonstration programs.

KEYWORDS: biomass briquettes, clean cooking energy, sustainability, energy poverty, renewable energy

1. INTRODUCTION

Context of the Study

Globally, countries are striving to build clean and sustainable energy systems that contribute to economic growth and protect the environment from pollution and degradation. However, around 2.7 billion individuals worldwide, mostly in Sub-Saharan Africa and South Asia, still use traditional biomass fuels like firewood, charcoal, and cow dung for meal preparation, despite developed countries having mostly made the switch to electricity, natural gas, and modern biofuels (IEA, 2023).To combat global energy poverty, the United Nations introduced standard development goal number seven (SDG7) that aims at doubling global energy efficiency and promoting widespread access to clean and affordable renewable energy (IEA, 2022). To achieve SDG7 Net Zero Emissions goal by 2050, greenhouse gases emissions from traditional biomass and fossil fuels need to be reduced by half by the year 2030 (United Nations, 2024).

Biomass briquette energy plays a critical role in achieving SDG 7 especially in developing nations where communities face numerous barriers towards accessing clean fuel (Kemausuor and Adu-Poku, 2025). Biomass briquette energy is an affordable, sustainable and readily available clean energy sourced from agricultural, forestry and other biomass residues (Mignogna et al., 2024). Sustainably sourced biomass briquette energy plays a huge role of reducing carbon emissions, protects indigenous forests from destruction and helps solve biomass waste management problem experienced in many nations globally (Chowdhury et al., 2025; Kpalo et al., 2020). The availability of biomass residue, the development of appropriate technology, and the market demand for briquettes are the three main elements that determine its growth (Kpalo et al., 2020). Many low-income households opt for briquette technology as a means of addressing issues of energy poverty, high cost of charcoal, and unemployment (Njenga et al., 2024).

Biomass resources account for 81% of household energy needs in developing economies (Stoner et.al, 2021). In energy poverty "hot spots" where more than 275 million people live, over 50% of wood-based fuel is harvested unsustainably (Connors, 2023). Sub-Saharan Africa's energy poverty

hinders productivity and human development while posing a number of health and environmental risks (Awan et al., 2025; Rotich et al., 2024). The rampant use of traditional and unsustainable biomass energy has shown negative health impacts including the death of 4 million individuals annually due to respiratory diseases from indoor air pollution (Aemro et.al 2021). The increasing demand for firewood and charcoal due to population growth and high energy poverty rates is responsible for the destruction of many indigenous forests and animal species, especially in marginalized regions of the global south (Waswa, Mcharo, and Mworia, 2020; Bircan, 2023). Burning of traditional and polluting biomass fuels also account for 2.8% of the global CO2 emissions (Quadrelli et al., 2022).

While various initiatives have tried to integrate bioenergy sources including biomass briquette energy into national plans for renewable energy, these programs have yielded uneven results in regions facing extreme energy poverty (Okesiji, 2025). Only about 17% of communities in Sub-Saharan Africa use clean cooking fuels including biogas, e-cookers and modern biofuels (The Energy Progress Report, 2022). According to Garba and Bellingham (2021), energy poverty is still a serious but often overlooked developmental issue that hinders global energy sustainability. Lack of awareness of different renewable energy options, high costs of renewable energy technologies, limited accessibility, and strong adherence to cultural cooking habits are major factors that constrain the widespread adoption of clean energy in the global south especially the Sub-Saharan Africa region (Röder, Chong, and Thornley, 2022).

Statement of the Problem

According to the Ministry of Energy and Petroleum, Kenya (2024), the majority of households in the country continue to utilize traditional, polluting cooking energy. Taita Taveta County faces acute energy poverty, despite efforts by various government and non-governmental organizations to promote clean cooking technologies in underserved areas of Kenya (Kenya Ministry of Energy, 2021). In Taita Taveta County, 71% of people use firewood, 24% depend on charcoal and 74% of locals use three stone open fire for cooking purposes (Taita Taveta County, 2025). There is limited data on the region's adoption of clean and renewable cooking technology, and their implementation has been unequal which hinders transition to cleaner modern fuels (Kanangire et al., 2016).

Objective of the Study

This study looked into factors that influence households in Voi Sub-County, Taita Taveta County, Kenya, to adopt biomass briquette energy. Adoption of biomass briquette energy by households in Voi Sub-County was hypothesized to be impacted by awareness, affordability, accessibility, and cultural cooking norms.

Review of Literature

Theoretical frameworks that guided the study included the Theory of Planned Behavior, Diffusion of Innovations, and the Energy Ladder Model. These frameworks suggest that adoption decisions are shaped by perceived behavioral control, social norms, awareness, relative advantage, accessibility, and income dynamics. In Sub-Saharan Africa, awareness of renewable energy manifests from the community's understanding of different renewable energy alternatives and their perceived sustainability and economic benefits (Almulhim, 2022). When consumers use and engage with new technologies, they go through a process of discovery where communication between manufacturers and consumers is essential (Kanangire et al., 2016). Without sufficient awareness, households cannot evaluate usefulness or form favorable attitudes on modern renewable fuels which is important for adoption (Durbin & Filer, 2021). Awareness campaigns through schools, cooperatives, and Community Based Organizations can enhance diffusion by bridging knowledge gaps (Simpson et al., 2021). Mokaya et al., (2020) looked at constraints to the uptake of biomass briquette technology among communities around Maasai-Mau Forest, Kenya. The results indicated low level of awareness as a constraint towards adoption, where 82.05% of the study respondents did not know about biomass briquette energy.

Affordability is the ability to pay for and sustain the usage of clean cooking technologies without compromising the household financial stability (Kumar et al., 2020; Vigolo, Sallaku & Testa, 2018). The cost of clean cooking energy influences people's decisions to shift to more environmentally friendly cooking solutions (Jagger et al., 2019). Kimori, Juma, and Bongaerts (2023) investigated the factors influencing the adoption of biogas energy at household-level in Taita Taveta County. They found that household income and access to credit were the most important determinants of adoption ($p < 0.01$). Similarly, Mahoro et al. (2022), in Kampala, Uganda, examined the potential of biomass briquettes as an affordable and clean energy alternative to charcoal. Results indicated that while biomass briquettes were relatively cheaper, restricted technology, expensive production equipment and weak government incentives limited adoption. Producing biomass briquette energy locally can make them affordable and enable them to compete favorably with charcoal and firewood (Kitheka et al., 2019). However, without subsidies or credit access, affordability continue to restrict diffusion of clean cooking technologies in marginalized communities of Sub-Saharan Africa region (Kizilcec et al., 2022).

Accessibility is the availability of distribution infrastructures and developed market presence of a commodity or service (Osano et al., 2020). The ability to use modern and renewable energy technologies does not just mean it is affordable, it also refers to the physical and institutional set up which allows clean energy access (Dagnachew et al., 2020). Jagger and Das (2018) assessed the scale-up of biomass briquette energy and improved cook stove in Rwanda. Initially, 38% of the households that were targeted for the briquette–stove system adopted the scheme. Afterwards, 45% of households that adopted suspended their contracts due to problem of supply, price and service. The inconsistent supply of raw materials and high cost of stoves limited the continuous use of biomass briquettes. Similarly, Karanja and Gasparatos (2020) investigated the impact of geographical, environmental, and availability factors in Kiambu and Murang'a counties, Kenya, on adopting improved biomass briquette cook stoves (ICS). Data from 400 randomly selected households revealed that not only demographic factors affected adoption but also technology availability, market access and local environmental conditions significantly affect adoption ($p < 0.05$). The study also found that households located in urban areas have better market accessibility and multiple cook stove options making them able to adopt faster than those in rural and marginalized regions.

Cultural cooking norms are the common traditions, beliefs and practices regarding cooking methods, fuel choice, and gender roles in a community (Thoronka, 2025). Cultural factors greatly affect fuel choice and often play a major role with the same magnitude as economic and technical factors (Gupta, 2025). In most Sub-Saharan Africa communities, use of firewood and charcoal fuel is associated with taste, tradition, and social identity (Ocen et al., 2024). In these communities, firewood and charcoal are seen as natural, reliable and sacred fuels, making abandonment of these fuels

for modern alternatives difficult (Elasu et al., 2025). Women in SSA are key managers of the household daily running including meal preparation. However, cultural norms hinder their ability to fully participate in household decisions on cooking energy choice (Clancy et al., 2019). In Taita Taveta, firm cooking traditions and a gendered decision-making process influence adoption of modern clean cooking energy (Tereka et al., 2025). A study by Tamire et al. (2018) explored the cultural perspectives on the use of biomass fuels for cooking within homes in Butajira, a rural area in Ethiopia. The study results indicated that nearly all households relied on firewood and traditional three-stone stoves for cooking due to financial constraints and cultural beliefs. Many participants believed that wood smoke was advantageous for new mothers and their infants, despite its health risks (Li et al., 2024).

2. MATERIALS AND METHODS

Research Design

In order to investigate the adoption of biomass briquette energy among households in Voi Sub-County, the study used a cross-sectional descriptive research approach. This design made it possible to gather data at a single point, giving a snapshot overview of adoption rates and how they relate to awareness, accessibility, affordability, and cultural cooking customs. The strategy was in line with prior research on clean cooking energy carried out in Sub-Saharan Africa and Kenya (Ahmed, 2024; Mokaya et al., 2020).

Target Population and Sampling Technique

The study took place in Voi Sub-County in Taita Taveta County. Voi Sub-County comprises of six wards namely Mbololo, Kasigau, Kaloleni, Ngolia, Sagalla and Marungu (County Government of Taita Taveta, 2018). The Sub-County's total population has been established as 111,831 persons who reside within the 7,453 km² coverage area (Kenya Population and Housing Census, 2019).

A multi-stage random sampling procedure was conducted to ensure representativeness of the study sample. Stratified sampling proportionate to ward population size was carried out followed by simple random sampling through a random number generator, ensuring each household had an equal chance of selection. Only adults aged 18 years and above were included in the study to ensure informed responses regarding household energy decisions. The IEBC voter register formed the sampling frame, and was refined with assistance from ward administrators and Voi Sub-County IEBC officials. The study's target population included 61,377 adults. Given the large size of the target population, Cochran's (1977) formula was used to determine the ideal sample size. A final sample of 402 respondents was targeted including a 5% buffer for non-response.

Instrumentation and Data Collection Procedure

Data was gathered through a self-administered questionnaire that had three parts. The first section included demographic attributes of the sample. The second part measured the independent variables in terms of Likert-scale where each variable had (8) items. Exposure and knowledge aspects about briquettes, cost and financial access, and accessibility to supply and distribution aspects were assessed respectively. Lastly cultural norms focused on taste preference, gender roles and traditions. The third section assessed adoption by use of a composite index of (24) items covering the frequency of use, intention of adoption, and percentage of traditional biomass energy replaced by biomass briquette energy. Data collection process was conducted in line with the official permission of Taita Taveta University and Voi Sub-County ward administrators. The questionnaires were disseminated by trained multilingual enumerators and informed consent was acquired while highest levels of confidentiality were observed. To test the clarity, reliability and cultural appropriateness of the instrument for the main study, a pilot study comprising of 10% (n = 41) of the study sample size was carried out in a different location of Wusi-Kishamba Ward in Mwatate Sub-County. The instrument wording and content were revised to enhance clarity.

Data Analysis

SPSS Version 28 was used to analyze the collected data. Frequencies, percentages, averages, and standard deviations summed up the primary study variables and demographics in the descriptive statistics section. Multiple linear regression was used to model adoption determinants, and Pearson's correlation was used to evaluate associations between variables. ANOVA (F-test) and R2 statistics were used to assess the model's fitness, and hypothesis testing was carried out at a 95% confidence level ($\alpha = 0.05$).

Ethical Considerations

Ethical approval was obtained from Taita Taveta University's Ethics Review Committee. Participation was voluntary, informed consent was secured, anonymity was maintained through unique identifiers, and data was securely stored under lock and key. Enumerators also ensured respectful engagement with respondents throughout the data collection phase.

3. RESULTS

Response Rate

A total of 402 questionnaires were distributed to household heads across the six wards of Voi Sub-County. Of these, 363 were duly completed and deemed usable for analysis, yielding a response rate of 90.3%.

Reliability analysis

Cronbach's Alpha was used to confirm internal consistency of the instrument.

Table 3.1: ***Reliability Analysis Results***

Construct	Number of Items	Cronbach's Alpha	Interpretation
Awareness	8	0.856	Good
Affordability	8	0.821	Good

Construct	Number of Items	Cronbach's Alpha	Interpretation
Accessibility	8	0.839	Good
Cultural Norms	8	0.802	Good
Adoption	24	0.912	Excellent

The reliability of all constructs surpassed the acceptable benchmark threshold (α≥0.70), falling in-between good (α≥0.80) and excellent (α≥0.90).

Demographics

The demographic characteristics of respondents was analyzed to give context to the study population. Gender distribution of the sample was almost equal, with 52.1% female and 47.9% male household heads. Most respondents had primary education 51.2%, 30.3% had secondary education, 11.0% had tertiary education, and 7.4% had no formal education. Majority of household heads were low-to-middle income earners, with 54.3% earning Ksh 10,000–30,000 and 20.7% earning below Ksh 10,000. Respondents' ages ranged from 24 to 72 years, with a mean age of 44.61 years (SD = 10.62). Household size varied between 2 and 9 members, with an average of 4.66 persons (SD = 1.58), which was consistent with peri-urban and rural family structures in Sub-Saharan Africa communities (United Nations, 2019).

Descriptive Analysis of Study Variables

The main study variables were summarized and described using descriptive statistics. These variables included awareness, affordability, accessibility, cultural cooking norms and adoption of biomass briquette energy. The means and standard deviations of these variables were computed to portray the central tendency and spread of 363 household heads in Voi Sub-County as per ward.

Table 3.2: ***Descriptive Statistics of Main Variables***

Ward		Awareness	Affordability	Accessibility	Cultural Norms	Adoption
Kaloleni	Mean	2.84	2.77	2.78	3.30	2.23
	Std. Deviation	.32	.39	.44	.51	.24
Kasigau	Mean	2.84	2.74	2.75	3.44	2.20
	Std. Deviation	.22	.29	.21	.40	.26
Marungu	Mean	2.46	2.41	2.41	3.72	1.89
	Std. Deviation	.44	.35	.29	.52	.30
Mbololo	Mean	2.77	2.57	2.64	3.56	2.09
	Std. Deviation	.35	.30	.29	.47	.26
Ngolia	Mean	2.37	2.35	2.26	3.81	1.80
	Std. Deviation	.38	.37	.19	.42	.21
Sagalla	Mean	2.55	2.49	2.52	3.55	1.97
	Std. Deviation	.31	.27	.27	.55	.26
Total	Mean	2.70	2.60	2.62	3.51	2.08
	Std. Deviation	.37	.37	.36	.51	.29

The overall Adoption Index mean was 2.08 (SD = 0.29), below the midpoint of the five-point Likert scale, indicating limited uptake. Similarly, Awareness (M = 2.70, SD = 0.37), Affordability (M = 2.60, SD = 0.37), and Accessibility (M = 2.62, SD = 0.36) were all below the midpoint, suggesting limited knowledge, affordability challenges, and limited market penetration. In contrast, Cultural Cooking Norms recorded the highest mean (M = 3.51, SD = 0.51), indicating strong attachment to traditional cooking practices.

Correlation Analysis

Pearson correlation was used to determine the linear associations between the study variables.

Table 3.3: ***Matrix for Summary of Correlations***

Correlations		Awareness	Affordability	Accessibility	Cultural Norms	Adoption
Awareness	Pearson Correlation	1	.297**	.394**	-.074	.619**
	Sig. (2-tailed)		<.001	<.001	.159	<.001
Affordability	Pearson Correlation	.297**	1	.307**	-.072	.445**
	Sig. (2-tailed)	<.001		<.001	.173	<.001
Accessibility	Pearson Correlation	.394**	.307**	1	-.125*	.609**

	Sig. (2-tailed)	<.001	<.001		.017	<.001
Cultural Norms	Pearson Correlation	-.074	-.072	-.125*	1	-.283**
	Sig. (2-tailed)	.159	.173	.017		<.001
Adoption	Pearson Correlation	.619**	.445**	.609**	-.283**	1
	Sig. (2-tailed)	<.001	<.001	<.001	<.001	

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Pearson correlation analysis showed that there are positive relations between Adoption and Awareness ($r = 0.619$, $p < 0.001$), Accessibility ($r = 0.609$, $p < 0.001$) and Affordability ($r = 0.445$, $p < 0.001$). These results show that the more people are aware, the greater is the physical access, and the perceived affordability, the higher is the level of adoption. The relationship between Cultural Cooking Norms and Adoption showed negative association ($r = -0.283$, $p = 0.001$) which means that the more strong adherence to traditional cooking habits the lower the probability of biomass briquette adoption. The enabling factors of Awareness, Affordability and Accessibility had a positive correlation with one another implying that gains in one dimension can strengthen the gains in others. The enabling factors were weakly related to Cultural Norms with negative correlation, which means that the exposure to information and clean energy markets can be restricted by traditional orientations.

Regression Analysis

Multiple linear regression analysis examined the joint effect of Awareness, Affordability, Accessibility, and Cultural Cooking Norms on adoption of biomass briquette energy. The regression analysis results were reported in a three section table incorporating Model Summary, Analysis of Variance (ANOVA), and Regression Coefficients.

Table 3.4: Regression results on the relationship between joint determinants of Biomass Briquette Energy adoption and adoption Index

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.784[a]	.615	.610	.183

a. Predictors: (Constant), Cultural Norms, Affordability, Awareness, Accessibility

The model summary showed that all four variables together explained adoption with $R^2 = 0.615$. This inferred that awareness, affordability, accessibility, and cultural cooking norms accounted for approximately 61.5% of the variation in household adoption of biomass briquette energy.

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	19.194	4	4.799	142.745	<.001[b]
	Residual	12.035	358	.034		
	Total	31.229	362			

a. Dependent Variable: Adoption Index

b. Predictors: (Constant), Cultural Norms, Affordability, Awareness, Accessibility

The study's regression model proved to be statistically significant, $F(4,362) = 142.745$, $p < .001$. This suggested that the combination of awareness, affordability, accessibility, and cultural cooking norms significantly predicted household adoption of biomass briquette energy in Voi Sub-County.

Model		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
1	(Constant)	.416	.122		3.402	<.001
	Awareness	.315	.029	.401	11.007	<.001
	Affordability	.160	.028	.200	5.669	<.001
	Accessibility	.300	.030	.366	9.959	<.001
	Cultural Norms	-.111	.019	-.193	-5.834	<.001

Results of regression standardized coefficient indicated that awareness ($\beta = 0.401$, $p < 0.001$) was the most important determinant of adoption followed by accessibility ($\beta = 0.366$, $p < 0.001$), while affordability ($\beta = 0.200$, $p < 0.001$) was the third most important determinant of adoption. In contrast, cultural cooking norms ($\beta = -0.193$, $p < 0.001$) had a negative and significant relationship with adoption indicating a stronger attachment to traditional cooking norms increases resistance to biomass briquette adoption. The fitted regression model was expressed as:

Adoption Index = 0.416 + 0.315 (Awareness) + 0.160 (Affordability) + 0.300 (Accessibility) − 0.111 (Cultural Norms) + ε

Hypotheses Testing

The study tested the four null hypotheses at a 5% significant level ($\alpha = 0.05$). The p-values of the regression coefficients were relied on for the decision. All the null hypotheses were rejected.

Table 4.5: ***Hypotheses Testing Results table***

Hypothesis	Statement	p-value	Decision	Interpretation
H_{01}	Awareness has no significant effect on adoption.	< 0.001	Rejected	Awareness positively influences adoption of biomass briquettes.
H_{02}	Affordability has no significant effect on adoption.	< 0.001	Rejected	Affordability promotes adoption of biomass briquettes.
H_{03}	Accessibility has no significant effect on adoption.	< 0.001	Rejected	Accessibility enhances adoption of biomass briquettes.
H_{04}	Cultural cooking norms have no significant effect on adoption.	<0.001	Rejected	Cultural cooking norms negatively affect adoption of biomass briquettes.

4. DISCUSSION

The study explored the factors that determine the use of biomass briquette energy in Voi Sub-County, Taita Taveta County in Kenya. The strong explanatory power of the model F (4,362) = 142.745, p <.001 was shown through the regression model (R^2 =0.615) which showed that the joint effect of awareness, affordability, accessibility, and cultural cooking norms explained the adoption behavior variation of 61.5%. The results confirm the collective explanatory applicability of the Theory of Planned Behavior (TPB), the Diffusion of Innovations (DOI), and the Energy Ladder model in explaining clean cooking adoption in Kenya, especially in rural and peri-urban areas.

Awareness turned out to be the strongest predictor of adoption (β = 0.401, p < 0.001). The more the households were aware of the benefits of biomass briquette, the more they had a high possibility of adopting the fuel. Nonetheless, descriptive statistics (M =2.70) indicated that there was huge gap in knowledge about the use of biomass briquette energy in Voi Sub-County. In line with the DOI theory, diffusion is determined by knowledge and observability. According to Yustas et al. (2022) in Tanzania and Kimani et al. (2020) in Njoro, Kenya, the uptake of biomass briquette energy in their studies was limited by low levels awareness. Mokaya et al. (2020) also discovered that the majority of households in the Maasai-Mau ecosystem (80%) did not have proper information about biomass briquettes and acted as one of the main barriers to its uptake. All these studies concur that awareness is a supporting force of clean energy transitions in various socio-economic and geographical settings.

The second strongest predictor of the adoption of biomass briquette energy was accessibility (β= 0.366, p < 0.001). The presence of limited networks of vendors, poor distribution channels and infrastructural barriers (M=2.62) minimized the capability of households to access biomass briquettes in the study area. This observation is consistent with DOI constructs of trialability and compatibility, which note the significance of physical accessibility in the continuation of diffusion of an innovation. Similar a study by Jagger & Das (2018) in Rwanda indicated that the supply chain irregularities resulted in the termination of the biomass briquette consumption in the study area. A study by Karanja and Gasparatos (2020) showed that proximity to suppliers plays a major role in clean energy adoption in central Kenya. Mugabi and Kisakye (2021) in Uganda also raised transport and distribution issues as impediments biomass briquette adoption and sustained use. These trends suggest that reinforcement of last-mile distribution and localized production systems is important towards the implementation of clean and renewable energy systems.

Affordability also exerted a significant positive impact ((β= 0.200 p < 0.001) on adoption of biomass briquette energy, which is also consistent with the Energy Ladder framework, which makes the connection between fuel transitions and the household economic capability. Despite the fact that biomass briquette energy is relatively cheap and can compete favorably with charcoal and firewood, affordability problems are still present in semi-arid and marginalized areas. Marginalized regions like Voi Sub-County (M = 2.60) where a large number of households fall under the lower income brackets find it hard to afford initial cost of acquiring improved cook stoves for biomass briquettes. According to Kimori et al. (2023), income and credit availability were the vital predictors of adoption of renewable energy in Taita Taveta County. As Gill-Wiehl et al. (2021) observed, improper financing mechanisms and unstable prices tend to erode the benefits of affordability of clean cooking energy hence limiting adoption.

Cooking norms related to culture showed a strong negative correlation with adoption (β= -0.193, p < 0.001). The high descriptive statistics mean score (M = 3.51) on cultural cooking norms show strong attachment to the traditional fuels regarding taste preferences, cooking methods, cultural meaning and gender decision making patterns in the study area. The effect is elucidated by TPB in the form of subjective norms where behavior is subject to norms entrenched in social life. Empirical data from rural Ethiopia showed that the use of traditional cooking methods prevented the use of modern fuels because of the perceived cultural authenticity and flavor compatibility of traditional biomass fuels (Tamire et al., 2018). In Uganda, Muwanga and Mwiru (2021) discovered that household decision-making structures are majorly dominated by men and this limited clean fuel transitions because women despite being main users of cooking fuel were excluded in energy choice decisions. Similar, Kasangana and Masekameni (2019) concluded that the household fuel decisions are heavily determined by cultural compatibility.

This study shows that biomass briquette energy adoption is relatively low in Voi Sub-County, and is constrained by lack of information, poor market availability and supply chains, low income and a culturally entrenched system of cooking centered on traditional biomass fuels. The integrated theoretical model demonstrates that clean energy transition interventions need to focus on behavioral intention (TPB), innovation diffusion processes (DOI), and economic capacity (Energy Ladder) factors to ensure success.

5. CONCLUSIONS AND RECOMMENDATIONS

The research draws the conclusion that there is an acute low adopted level of biomass briquette energy in Voi Sub-County (M = 2.08) despite the fuel being widely recognized in the county and national energy strategies and policies. Adoption is hampered by the lack of awareness, poor access, lack of affordability and cooking habits that are deeply rooted in a culture that supports use of traditional biomass fuels. The policy interventions must focus on a long term energy literacy program, reinforcement of a distribution system at the ward level and the implementation of financial incentives including subsidies and microcredit facilities to make biomass briquette energy more affordable. Culturally sensitive strategies should also be incorporated in the clean cooking programs such as cooking demonstration events coupled with women and youth empowerment initiatives to venture into biomass briquette energy ecosystem.

Production models in form of cooperatives, a standardized quality assurance system, and a growth in last-mile delivery systems are some of the strategies that producers should embrace at the supply side of biomass briquettes ecosystem. Household financial muscle to acquire biomass briquette energy technologies can also be facilitated by microfinance institutions through creation of special credit services for clean energy adoption with friendly payment schemes. The commercialization of biomass briquette energy and the enhancement of community acceptance can be further enhanced by institutional support through local universities especially in research, innovation and demonstration of briquetting technologies.

To further enhance and complement this study, future studies need to assume longitudinal designs to measure long-term patterns of biomass briquette energy usage, expand scope to institutional and industry adoption of biomass briquette energy, introduce spatial and GIS-based analysis of impact of the fuel use, and focus on gender dynamics in domestic energy decision-making. It is also suggested that future research should be conducted to estimate emission profiles, calorific value and lifecycle sustainability of different briquette feed stocks to further improve the technology. To speed up biomass briquette energy uptake in the Voi Sub-County, interventions should be undertaken to deal with the informational, infrastructural, economic, and socio-cultural aspects of clean energy adoption. An integrated approach will help to change households that rely on traditional and polluting biomass fuels to adopt affordable, sustainable and clean ways of cooking such as the adoption and use of biomass briquette energy.

6. ETHICAL DECLARATIONS

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Conflict of Interest: The authors indicate that there is no conflict of interest.

Data Availability Statement: Data is available upon request from the corresponding author.

Research Ethics: Taita Taveta University gave out Ethical approval while the participants gave informed consent.

7. RECOGNITIONS OF THE AUTHOR CONTRIBUTION

Victor Slivo Lole- Conceptualization, methodology, data collection, data analysis, writing.

Patrick Kimaku- Supervision, refining methodology, reviewing and editing.

Caroline Doa -Supervision, validation, editing and reviewing.

REFERENCES

1) Aemro, Y. B., Moura, P., & de Almeida, A. T. (2021). Inefficient cooking systems a challenge for sustainable development: a case of rural areas of Sub-Saharan Africa. Environment, Development and Sustainability, 23(10), 14697-14721.
2) Ahmed, S. K. (2024). How to choose a sampling technique and determine sample size for research: a simplified guide for researchers. *Oral Oncology Reports*, *12*, 100662.
3) Almulhim, A. I. (2022). Understanding public awareness and attitudes toward renewable energy resources in Saudi Arabia. *Renewable Energy*, *192*, 572-582.
4) Awan, A., Kocoglu, M., Subhan, M., & Shakib, M. (2025). Do energy intensity, resource abundance and inequality drive energy poverty? Evidence from developing countries. *Geoscience Frontiers*, *16*(3), 102014.
5) Bircan Bodur, F. (2023). Firewood and Charcoal Demand in Sub-Saharan Africa: Assessing Sustainability and Trends. *Available at SSRN 4518033*.
6) Chowdhury, P., Mahi, N. A., Yeassin, R., Chowdhury, N. U. R., & Farrok, O. (2025). Biomass to biofuel: Impacts and mitigation of environmental, health, and socioeconomic challenges. *Energy Conversion and Management: X*, *25*, 100889.
7) Clancy, J., Barnett, A., Cecelski, E., Pachauri, S., Dutta, S., Oparaocha, S., & Kooijman, A. (2019). Gender in the transition to sustainable energy for all: From evidence to inclusive policies.
8) Cochran, W. G. (1977). *Sampling techniques*. John Wiley & sons.
9) Connors Belopolsky, J. (2023, June 5). Fueling a Sustainable Future: *The importance of clean cooking for a healthy environment.* Clean Cooking Alliance.
10) County Government of Taita Taveta. (2018). *County integrated development plan 2018-2022*.
11) Dagnachew, A. G., Hof, A. F., Lucas, P. L., & van Vuuren, D. P. (2020). Scenario analysis for promoting clean cooking in Sub-Saharan Africa: Costs and benefits. *Energy*, *192*, 116641.
12) Durbin, E. ., & Filer, J. (2021). Evaluating the Impact of Public Awareness Campaigns on Sustainable Practices. *Journal of Energy and Environmental Policy Options, 4*(4), 32-37.
13) Elasu, J., Ntayi, J. M., Orobia, L. A., Adaramola, M. S., & Onyinyi, B. (2025). Transforming cooking practices in Uganda: transitioning toward clean energy solutions. *Frontiers in Sustainability*, *6*, 1567398.

14) Garba, I., & Bellingham, R. (2021). Energy poverty: Estimating the impact of solid cooking fuels on GDP per capita in developing countries of sub-Saharan Africa. Energy, 221, 119770.
15) Gill-Wiehl, A., Ray, I., & Kammen, D. (2021). Is clean cooking affordable? A review. *Renewable and Sustainable Energy Reviews*, *151*, 111537.
16) Gupta, M. (2025). *Hidden Ingredients: Examining the Influence of Gender and Culture on the Incomplete Adoption of Clean Cooking Fuels in India* (Doctoral dissertation, University of Pennsylvania).
17) IEA (2022), SDG7: Data and Projections, IEA, Paris, License: CC BY 4.0
18) IEA (2023). *A Vision for Clean Cooking Access for All*, IEA, Paris, Licence: CC BY 4.0
19) Jagger, P., Bailis, R., Dermawan, A., Kittner, N., & Mccord, R. (2019). SDG 7: Affordable and Clean Energy – How Access to Affordable and Clean Energy Affects Forests and Forest-Based Livelihoods. *Cambridge University Press EBooks*, 206–236.
20) Jagger, P., & Das, I. (2018). Implementation and scale-up of a biomass pellet and improved cook stove enterprise in Rwanda. *Energy for Sustainable Development*, *46*, 32-41.
21) Kanangire, R. R., Mbabazize, D. M., Shukla, J., & Wanderi, E. E. N. (2016). Determinants of adoption of improved biomass stove in rural households of Muhazi sector in Rwamagana district. *European Journal of Business and Social Sciences*, *5*(06), 201-223.
22) Karanja, A., & Gasparatos, A. (2020). Adoption of improved biomass stoves in Kenya: a transect-based approach in Kiambu and Muranga counties. *Environmental Research Letters*, *15*(2), 024020.
23) Kasangana, K. K., & Masekameni, D. M. (2019). Determinants for adoption and non-adoption of clean energy alternatives in low-income households: the case of South Africa. In *2019 International Conference on the Domestic Use of Energy (DUE)* (pp. 8-15). IEEE.
24) Kemausuor, F., & Adu-Poku, A (2025). The Role of Bioenergy in Achieving SDG 7 in Africa.
25) Kenya Ministry of Energy. (2021). Energy compact of Kenya on clean cooking energy: *A next decade action agenda to advance SDG7 on sustainable energy for all*.
26) Kenya Population and Housing Census. (2019). Kenya National Bureau of Statistics, volume IV: *Distribution of population by socio economic characteristics.*
27) Kimani, M. N., Makindi, S. M., & Aboud, A. A. (2020). Knowledge and Awareness Determinants of Renewable Energy Technologies: A Cross Sectional Study of Rural Residents from Njoro Constituency, Nakuru County, Kenya.
28) Kimori, M., Juma, M., & Bongaerts, J. (2023). Exploring Factors Shaping Biogas Adoption Choices among Households in Taita Taveta County, Kenya. *African Journal of Mining, Entrepreneurship and Natural Resource Management*, *3*(2), 263-270.
29) Kitheka, E., Kimiti, J. M., Oduor, N., Mutinda, J. W., Ingutia, C., & Githiomi, J. (2019). Factors influencing adoption of biomass energy conservation technologies in selected areas of Kitui County, Kenya.
30) Kizilcec, V., Perros, T., Bisaga, I., & Parikh, P. (2022). Comparing adoption determinants of solar home systems, LPG and electric cooking for holistic energy services in Sub-Saharan Africa. *Environmental Research Communications*, *4*(7), 072001.
31) Kpalo, S. Y., Zainuddin, M. F., Manaf, L. A., & Roslan, A. M. (2020). A review of technical and economic aspects of biomass briquetting. Sustainability, 12(11), 4609.
32) Kumar, P., Dover, R. E., Díaz-Valdés Iriarte, A., Rao, S., Garakani, R., Hadingham, S., & Yadama, G. N. (2020). Affordability, accessibility, and awareness in the adoption of liquefied petroleum gas: a case-control study in rural India. *Sustainability*, *12*(11), 4790.
33) Li, H., Li, Y., Zheng, G., & Zhou, Y. (2024). Interaction between household energy consumption and health: A systematic review. *Renewable and Sustainable Energy Reviews*, *189*, 113859.
34) Mahoro, B. G., Eniru, E. I., Omuna, D., Akiyode, O., & Danson, M. (2022). Adoption of briquettes of organic matter as an environmentally friendly energy source in Uganda. *KIU. J. Sci. Eng. Technol*, *1*(2022), 23-30.
35) Mignogna, D., Szabó, M., Ceci, P., & Avino, P. (2024). Biomass energy and biofuels: perspective, potentials, and challenges in the energy transition. *Sustainability*, *16*(16), 7036.
36) Ministry of Energy and Petroleum. (2024). Kenya National Cooking Transition Strategy (KNCTS) 2024-2028 CASE STUDIES: *Lessons Learnt from promoting clean cooking solutions in developing economies*
37) Mokaya, D. C., Koske, J. K., Gichuki, C., Ngare, I. O., Kariuki, C. N., Kipkemoi, I., & Gickuki, L. (2020). Hindrances to adoption of biomass Briquettes technology as a climate change mitigation measure-case study of Maasai-Mau forest adjacent community, Kenya. *International Journal of Renewable Energy Sources*, *5*.
38) Mugabi, P., & Kisakye, D. B. (2021). Status of production, distribution and determinants of biomass briquette acceptability in Kampala City, Uganda. *Maderas. Ciencia y tecnología*, *23*.
39) Muwanga, R., & Mwiru, D. P. (2021). Social-cultural beliefs and behavioral intentions to adopt renewable energy technologies in Uganda. *Business management review*, *24*(2), 16-32.
40) Ocen, S., Nkurunziza, G., Bagire, V., Echegu, S., Ssekakubo, J., & Atukunda, R. (2024). Unveiling factors influencing choice of clean cooking solutions among households: a systematic review of literature. *Frontiers in Sustainability*, *5*, 1452900.
41) Okesiji, S. O. (2025). Decentralized renewable energy systems: A pathway to climate resilience in low-income regions. *Sustainability and Climate Change*, *18*(2), 119-131.
42) Osano, A., Maghanga, J., Munyeza, C. F., Chaka, B., Olal, W., & Forbes, P. B. C. (2020). Insights into household fuel use in Kenyan communities. *Sustainable Cities and Society*, *55*, 102039.
43) Quadrelli, J., Martin, R., Grassi, P., Rossi, G., Oom, S., & Vignati, J. (2022). *CO2 emissions.*
44) Röder, M., Chong, K., & Thornley, P. (2022). The future of residue-based bioenergy for industrial use in Sub-Saharan Africa. *Biomass and Bioenergy*, *159*, 106385.

45) Rotich, I. K., Chepkirui, H., & Musyimi, P. K. (2024). Renewable energy status and uptake in Kenya. *Energy Strategy Reviews*, *54*, 101453.
46) Simpson, N. P., Rabenold, C. J., Sowman, M., & Shearing, C. D. (2021). Adoption rationales and effects of off-grid renewable energy access for African youth: A case study from Tanzania. *Renewable and Sustainable Energy Reviews*, *141*, 110793.
47) Stoner, O., Lewis, J., Martínez, I. L., Gumy, S., Economou, T., & Adair-Rohani, H. (2021). Household cooking fuel estimates at global and country levels for 1990 to 2030. Nature communications, 12(1), 5793.
48) Tamire, M., Addissie, A., Skovbjerg, S., Andersson, R., & Lärstad, M. (2018). Socio-cultural reasons and community perceptions regarding indoor cooking using biomass fuel and traditional stoves in rural Ethiopia: a qualitative study. *International journal of environmental research and public health*, *15*(9), 2035.
49) Tereka, S., Pétursson, J. G., Byakagaba, P., & Ingólfsdóttir, A. H. (2025). Gender and socio-economic determinants of rural household adoption of clean energy practices in Uganda: Implications for energy transition pathways. *Energy for Sustainable Development*, *88*, 101780.
50) The Energy Progress Report (2022). *ACCESS TO CLEAN FUELS AND TECHNOLOGIES FOR COOKING*.
51) Thoronka, J. (2025). GENDERED ENERGY CULTURES AND CLEAN COOKING IN KIGALI: STATUS, TASTE, AND FUEL STACKING. *Veredas do Direito*, *22*(4), e223717-e223717.
52) United Nations. (2024). Progress Towards the Sustainable Development Goals. In *United Nations* (pp. 1–26). United Nations.
53) United Nations. (2019). Department of Economic and Social Affairs Population Division Patterns and trends in household size and composition: *Evidence from a United Nations dataset*.
54) Vigolo, V., Sallaku, R., & Testa, F. (2018). Drivers and barriers to clean cooking: a systematic literature review from a consumer behavior perspective. *Sustainability*, *10*(11), 4322.
55) Waswa, F., Mcharo, M., & Mworia, M. (2020). Declining wood fuel and implications for household cooking and diets in tigania Sub-county Kenya. *Scientific African*, *8*, e00417.
56) Yustas, Y. M., Tarimo, W. M., Mbacho, S. A., Kiobia, D. O., Makange, N. R., Kashaija, A. T., & Silungwe, F. R. (2022). Likelihood of adopting briquette technology in abundance of competitive energy sources: a case study of Morogoro urban and rural districts, Tanzania.