Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

Drivers of Household Willingness-to-Pay for Alternative Cooking Technologies in Urban Malawi

Betchani H. M. Tchereni

btchereni@mubas.ac.mw

Malawi University of Business and Applied Sciences

Admore Samuel Chiumia

Malawi University of Business and Applied Sciences

Hope Baxter Chamdimba

Malawi University of Science and Technology

Bertha Chipo Bangara

University of Malawi

Research Article

Keywords: Willingness to pay, clean cooking, household energy demand, LPG adoption, urban Malawi, energy transition

Posted Date: September 15th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-10645580/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License

Additional Declarations: No competing interests reported.

Drivers of Household Willingness-to-Pay for Alternative Cooking Technologies in Urban Malawi

Betchani H. M. Tchereni[1*], Admore Samuel Chiumia[1*] Hope Baxter Chamdimba[3] and Bertha Chipo Bangara[3]

[1] School of Business and Economic Sciences, Malawi University of Business and Applied Sciences, Private bag 303, Chichiri, Blantyre 3, Malawi; admoresc@gmail.com

[2] Ndata School of Climate and Earth Sciences, Malawi University of Science and Technology, P.O. Box 5196, Limbe, Malawi; hchamdimba@must.ac.mw,

[3]Department of Economics, University of Malawi, P. O. Box 280, Zomba, Malawi; bbchikadza@unima.ac.mw

*Corresponding author(s). E-mail(s): btchereni@mubas.ac.mw; admoresc@gmail.com

Abstract

Household demand for clean cooking technologies remains a critical barrier to energy transitions in developing countries. This study examines the determinants of willingness-to-pay (WTP) for alternative and clean cooking technologies in urban Malawi using survey data from 1,613 households across the cities of Lilongwe, Blantyre, Mzuzu, and Zomba. Using a stated preference approach, the study employs a logistic regression model to estimate the influence of economic, behavioural, technological, market, and socio-demographic factors on household willingness to pay for improved cooking technologies. To improve interpretation of the practical influence of explanatory variables, the analysis reports odds ratios and marginal effects derived from the logit model. The results indicate that behavioural factors are the strongest predictors of willingness to pay. Awareness increases the probability of willingness to pay by 14.5 percentage points, exposure to clean cooking campaigns by 12.1 percentage points, and prior experience with improved stoves by 16.8 percentage points. Technological perceptions also significantly influence willingness to pay, with convenience increasing the probability by 13.9 percentage points, efficiency by 13.2 percentage points, and safety by 9.1 percentage points. Household income and accessibility increase the probability of willingness to pay by 8.2 and 7.8 percentage points, respectively, while larger household size reduces the probability by 2.4 percentage points. Despite 88.6% of households expressing willingness to pay for improved cooking technologies, charcoal remains the dominant cooking fuel (82.8%), supporting the energy stacking model rather than the linear energy ladder framework. The findings suggest that demand for clean cooking technologies is shaped by interconnected economic, behavioural, technological, and market-related factors. Policy interventions should therefore focus on expanding affordability through targeted financing mechanisms,

strengthening supply chains and last-mile distribution systems, promoting experiential awareness campaigns, and supporting user-centered stove designs that prioritize efficiency, convenience, and safety. This study provides practical evidence to support clean cooking transitions in Malawi and across Sub-Saharan Africa, contributing to the achievement of Sustainable Development Goal 7

Keywords: Willingness to pay; clean cooking; household energy demand; LPG adoption; urban Malawi; energy transition

1. Introduction

Access to clean and modern cooking energy continues to represent one of the most persistent and multidimensional development challenges globally, with profound implications for environmental sustainability, human health, gender equity, and economic productivity. Despite sustained international efforts and policy commitments, approximately 2.3 billion people worldwide still rely on traditional biomass fuels, including firewood and charcoal, for their daily cooking needs, with Sub-Saharan Africa accounting for the largest proportion of this population (Nsamba et al., 2021). In Malawi, the situation is particularly critical, as over 90% of households depend on biomass fuels, with charcoal dominating urban energy consumption while firewood remains prevalent in rural areas (NSO, 2018). This continued reliance reflects entrenched structural energy poverty and highlights the limited progress achieved in transitioning toward modern and sustainable cooking solutions.

The environmental consequences of biomass dependence are substantial and well documented across the African continent. In Malawi, the production and consumption of charcoal constitute a primary driver of deforestation, forest degradation, and biodiversity loss, with the country experiencing one of the highest deforestation rates in Sub-Saharan Africa, estimated at approximately 2.8% per annum (AFREC, 2024; Pueyo, 2018). Urban demand for charcoal remains the dominant underlying factor, as expanding urban populations increase pressure on surrounding forest ecosystems. Comparable dynamics are observed in neighboring countries such as Zambia, Mozambique, and the Democratic Republic of Congo, where charcoal production forms a central component of urban energy systems and contributes significantly to forest depletion (Mukanema et al., 2026; Mulenga, 2019; Ng'ombe et al., 2026). Similarly, in East Africa, countries including Uganda, Kenya, and Rwanda are experiencing escalating deforestation pressures linked to growing charcoal markets and rapid urbanization (Kayima et al., 2026; Sekajja et al., 2026). Even in relatively advanced economies such as South Africa, biomass continues to play a significant role among low-income households, underscoring the persistence of traditional energy use despite broader economic development (Zulu, Djenontin, et al., 2026; Zulu, Kamoto, et al., 2026). These patterns collectively contribute to increased greenhouse gas emissions, exacerbate climate change, and undermine ecosystem resilience in regions already highly vulnerable to climatic shocks.

In addition to environmental degradation, reliance on traditional cooking fuels has severe public health implications. The use of biomass in inefficient stoves generates high levels of household air pollution (HAP), exposing users to harmful pollutants such as

fine particulate matter (PM2.5) and carbon monoxide. According to the World Health Organization, exposure to HAP is a leading contributor to respiratory infections, cardiovascular diseases, and premature mortality worldwide (Kwong et al., 2026a, 2026b; Vinci et al., 2026). Empirical studies across Sub-Saharan Africa have consistently demonstrated strong associations between biomass smoke exposure and adverse health outcomes, particularly among women and children, who are disproportionately exposed due to their primary roles in cooking (Gill-Wiehl & Ray, 2026; Pillarisetti et al., 2026). In Malawi, these health risks are further compounded by socio-economic conditions that limit access to healthcare and clean energy alternatives, reinforcing the cyclical nature of energy poverty and health vulnerability (Pei et al., 2026). Moreover, the time burden associated with fuel collection and preparation, especially in peri-urban and rural settings, reduces opportunities for income-generating activities and educational attainment, thereby perpetuating gender inequalities and limiting socio-economic mobility (Ololade et al., 2026; Sani et al., 2026; Scovronick et al., 2026).

From an economic perspective, dependence on traditional fuels imposes significant financial pressures on households, particularly in urban areas where charcoal is a fully monetized commodity. Rising charcoal prices, driven by supply constraints, transportation costs, and regulatory enforcement, have increased household energy expenditures over time (Ng'ombe et al., 2026). Similar trends have been observed in major urban centers such as Lusaka, Nairobi, and Kampala, where charcoal markets are characterized by high levels of commercialization and price volatility (Ng'ombe et al., 2026; Zulu, Kamoto, et al., 2026). For low-income households, energy expenditures can account for a substantial share of total income, limiting their ability to invest in cleaner alternatives. Furthermore, the inefficiency of traditional cooking technologies results in higher fuel consumption, further exacerbating cost burdens in the long term (Zulu, Kamoto, et al., 2026). Evidence from countries such as Rwanda and Mozambique indicates that, despite policy interventions promoting clean cooking, affordability constraints remain a major barrier to adoption (Adongo et al., 2026; Ahmed et al., 2026).

In response to these challenges, a range of clean cooking technologies, including liquefied petroleum gas (LPG), electricity, ethanol, biogas, and improved biomass stoves (Telukhunoana et al., 2026), have been promoted across Sub-Saharan Africa as viable alternatives. These technologies offer multiple co-benefits, including reduced emissions, improved energy efficiency, enhanced safety, and significant time savings (Chen & Wang, 2026; Murey & Mecha, 2026). Several countries have demonstrated notable progress through targeted policy interventions. For instance, Rwanda and Kenya have implemented fiscal incentives and infrastructure investments to expand LPG access, while South Africa has significantly increased electricity access through national electrification programs (Richardson et al., 2026). However, despite these advancements, adoption rates remain uneven and generally low across the region. In Malawi, as in many comparable contexts, charcoal continues to dominate urban energy use due to its perceived affordability, accessibility, and compatibility with local cooking practices (MacCarty et al., 2024; Mlowa et al., 2024; Wernecke et al., 2024a; Zulu et al., 2024). This persistence highlights the complex, multidimensional, and non-linear nature of household energy transitions.

Traditional theoretical perspectives, particularly the energy ladder model, posit that households shift from traditional to modern fuels as income increases (Koomson, 2024; Wernecke et al., 2024b). While this framework provides a useful starting point, it has been increasingly challenged by empirical evidence demonstrating that households tend to adopt a portfolio of fuels rather than fully transitioning to cleaner options. This phenomenon, commonly referred to as energy stacking, reflects a combination of economic constraints, risk management strategies, and socio-cultural preferences (Urgessa Ayana & Ferede Agaje, 2026). More recent analytical frameworks, such as the 4A framework encompassing affordability, accessibility, acceptability, and awareness, offer a more comprehensive understanding of the factors shaping energy choices (Li et al., 2025). These frameworks emphasize that clean cooking adoption is influenced not only by income but also by supply-side conditions, cultural norms, and information availability.

Within this evolving discourse, willingness to pay (WTP) has emerged as a critical metric for understanding consumer demand for clean cooking technologies. WTP captures the maximum amount households are willing to pay for a given technology, reflecting both economic capacity and perceived value (Strazzera et al., 2024; Yang et al., 2025). Unlike binary adoption measures, WTP provides deeper insights into price sensitivity, demand elasticity, and market potential, making it particularly relevant for informing subsidy design, pricing strategies, and financing mechanisms (Chukwuone et al., 2022; Das et al., 2022a, 2022b). However, empirical evidence on WTP for clean cooking technologies in Malawi remains limited, with existing studies primarily focusing on descriptive adoption patterns rather than quantifying demand intensity.

This study addresses this gap by providing a comprehensive analysis of the determinants of willingness to pay for clean cooking technologies in urban Malawi. The study adopts a multidimensional analytical framework that integrates economic factors (income, fuel expenditure, and charcoal prices), behavioral dimensions (awareness, exposure, and prior experience), technological perceptions (efficiency, safety, cleanliness, and convenience), market conditions (availability and access), and socio-demographic characteristics (education, gender, age, and household size). Using both ordinary least squares (OLS) and logistic regression models, the study provides robust empirical evidence on both the magnitude and likelihood of willingness to pay. The focus on urban Malawi is particularly significant, as urban households represent a critical segment for clean cooking transitions due to their reliance on purchased fuels and exposure to market dynamics. However, these households also face persistent barriers, including price volatility, supply chain limitations, and entrenched consumption behaviors. Understanding the determinants of willingness to pay in this context is therefore essential for designing effective and scalable policy and market interventions.

The study makes three key contributions to the literature. First, it provides empirical evidence on willingness to pay for clean cooking technologies in Malawi, addressing a notable gap in existing research. Second, it adopts a multidimensional analytical framework that integrates demand- and supply-side factors, offering a more holistic understanding of household energy decision-making. Third, it generates policy-relevant insights that can inform targeted interventions, including subsidies, financing mechanisms, behavioral change campaigns, and improvements in supply chain

infrastructure. From a policy perspective, the findings align with Malawi's National Energy Policy (2018) and National Charcoal Strategy (2017), both of which emphasize reducing dependence on biomass fuels and promoting sustainable alternatives. At the global level, the study contributes to the achievement of Sustainable Development Goal 7 (SDG 7), which seeks to ensure access to affordable, reliable, sustainable, and modern energy for all (Clean Cooking Alliance, n.d.; IEA, 2023; Pachauri & Rao, 2020). By identifying the key determinants of willingness to pay, this study provides actionable evidence to support more effective clean cooking interventions in Malawi and across Sub-Saharan Africa.

2. Conceptual Framework

The transition to clean cooking in Malawi is shaped by a combination of economic, behavioral, technological, and market-related factors that interact to influence household decision-making. While existing studies often examine these determinants independently, this study adopts an integrated approach to explain variations in willingness to pay (WTP) for clean cooking technologies within a unified analytical framework. The conceptual framework is grounded in the 4A framework (affordability, accessibility, acceptability, and awareness), which provides a comprehensive lens for understanding the structural and behavioral drivers of clean cooking adoption. Within this framework, WTP is conceptualized as a binary outcome reflecting a household's decision to invest in improved cooking technologies. Accordingly, WTP is modeled as a function of four key dimensions: affordability (proxied by income and expenditure variables), accessibility (captured through availability and access to suppliers), acceptability (measured through perceived efficiency, safety, and convenience), and awareness (captured through exposure and prior experience with clean cooking technologies). These dimensions are interrelated and jointly shape household decision-making. For example, affordability may be necessary but insufficient in the absence of reliable supply, while high awareness may not translate into adoption without technologies that are perceived as convenient and efficient. Similarly, improved accessibility may increase adoption only when households have sufficient purchasing capacity. This interaction reflects the multidimensional nature of clean cooking transitions in developing country contexts. Empirically, the framework is operationalized using a logistic regression model, which estimates the probability that a household is willing to pay for clean cooking technologies. This specification is appropriate given the binary nature of the dependent variable and enables the identification of key determinants influencing adoption decisions. By aligning the conceptual framework with the econometric model, the study ensures consistency between theory and empirical analysis.

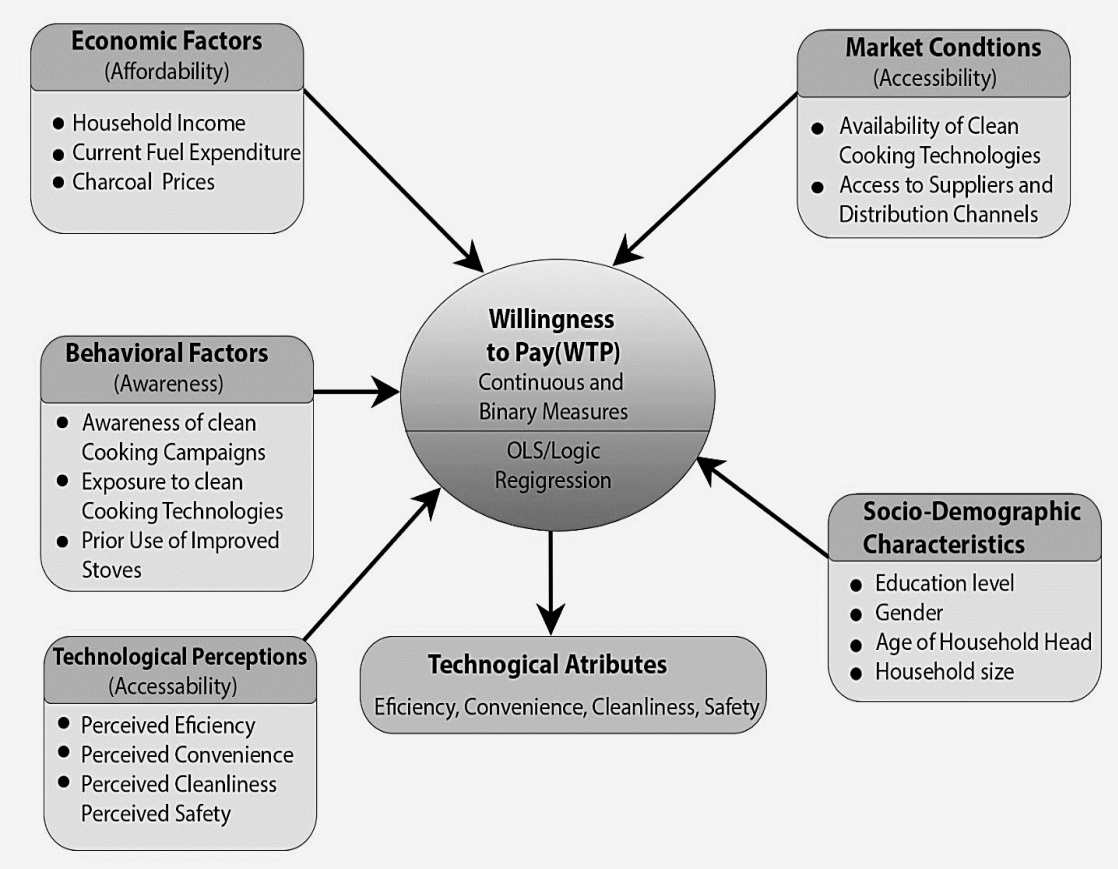


Figure 1: Conceptual framework developed from the authors' synthesis of existing literature (Adongo et al., 2026; Ahmed et al., 2026; Chen & Wang, 2026; Murey & Mecha, 2026; Yan, 2026).

3. Methodology

3.1. Study Area.

The study focuses on urban Malawi, covering the four major cities of Lilongwe, Blantyre, Mzuzu, and Zomba. These cities are characterized by high dependence on charcoal as the primary cooking fuel, alongside increasing availability of alternative technologies such as electricity and liquefied petroleum gas (LPG). The dataset comprises 1,613 households and is representative of urban cooking energy users. The survey targeted respondents primarily responsible for cooking decisions, ensuring that the data accurately reflect household-level energy choices and preferences. Figure 1 shows study locations In Malawi.

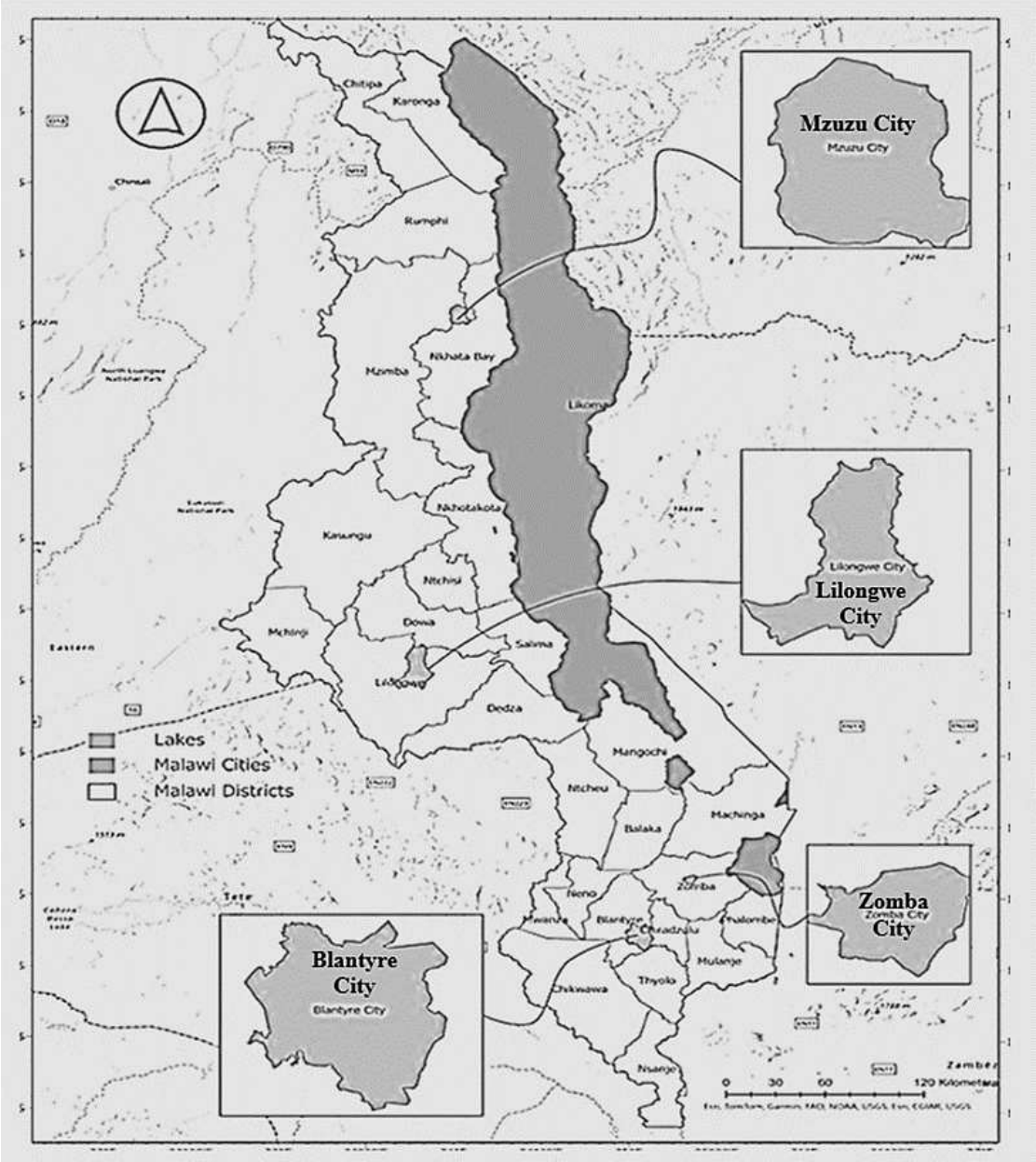


Figure 1: Map showing study locations in Malawi.

3.2 Research Design and Analytical Framework

This study adopts a quantitative cross-sectional research design to examine the determinants of willingness to pay (WTP) for clean cooking technologies in urban Malawi. The analysis is based on household-level data collected through the Modern Cooking for Healthy Forests (MCHF) Consumer Market Research (CMR) 2024 survey, which provides detailed information on cooking energy use, socio-economic characteristics, and perceptions of alternative cooking technologies. The analytical approach is grounded in an integrated conceptual framework combining the 4A framework (Affordability, Accessibility, Acceptability, and Awareness) and the Diffusion of Innovations (DOI) theory (van den Wall Bake et al., 2025). The 4A framework captures structural and market-related constraints affecting access to clean cooking solutions, while DOI explains adoption behavior based on perceived attributes of

technologies, including efficiency, safety, and convenience. This integrated framework is particularly relevant in urban African contexts, where households typically engage in fuel stacking rather than linear transitions from traditional to modern fuels.

3.3 Sampling Design

A multi-stage stratified sampling approach was employed to ensure representativeness across urban contexts. Urban centers were selected purposively based on their relevance to clean cooking markets. Within each city, administrative areas were selected using Probability Proportional to Size (PPS) to reflect population distribution. Households were then selected using systematic random sampling within geographically defined zones. This sampling strategy ensures adequate representation of variations in socio-economic characteristics, market access, and energy use patterns across urban Malawi.

Table 1. Sample distribution

City	Number of households	Percentage (%)
Lilongwe	394	**24.4**
Blantyre	407	**25.2**
Mzuzu	407	**25.2**
Zomba	405	**25.1**
Total	**1,613**	**100**

3.4 Variable Construction and Measurement

3.4.1. Dependent Variable

The dependent variable is willingness to pay (WTP) for clean cooking technologies, operationalized as a binary variable derived from the survey question on whether a household is willing to purchase an improved cookstove (d2k_buy_ics). The variable is coded as:

$$WTP_i = \begin{cases} 1 & \text{if household is willing to buy an improved cookstove} \\ 0 & \text{if household is not willing} \end{cases}$$

Responses such as "don't know" or missing values were excluded from the analysis. This binary specification is consistent with empirical studies on technology adoption, where stated willingness to purchase is used as a proxy for demand.

3.4.2. Independent Variables

The explanatory variables were selected based on theoretical relevance and data availability and are grouped into key dimensions of the conceptual framework. Perception variables were derived from survey responses indicating reasons for stove preference and are consistent with constructs from Diffusion of Innovations theory.

Table 2. Variable definition and theoretical linkage

Category	Variable	Description	Theoretical basis
Economic (Affordability)	Income source	Proxy for household purchasing capacity	4A
Behavioral (Awareness)	Awareness	Knowledge of alternative cooking technologies	DOI
	Previous use	Experience with improved stoves	Learning effects
Technological (Acceptability)	Efficiency	Perceived efficiency of technologies	DOI
	Safety	Perceived safety of technologies	Risk perception
	Convenience	Ease of use and practicality	Compatibility
Market (Accessibility)	Availability	Availability of technologies	4A
	Access	Proximity and access to suppliers	Market structure
Socio-demographic	Education	Level of education	Human capital
	Gender	Respondent gender	Social norms
	Age	Respondent age	Experience
	Household size	Number of household members	Budget constraints

3.5 Econometric Model Specification

Given the binary nature of the dependent variable, the study employs a logistic regression model to estimate the probability that a household is willing to pay for clean cooking technologies. Logistic regression is appropriate for modeling discrete choice behaviour where the dependent variable assumes only two outcomes, namely willingness to pay ($WTP_i = 1$)or unwillingness to pay ($WTP_i = 0$). Following Gujarati's formulation of qualitative response or choice models, the logistic model expresses the probability of willingness to pay as a nonlinear function bounded between 0 and 1 (Gujarati, 2004).

The estimable logit model is specified as:

$$\ln\left(\frac{P_i}{1-P_i}\right) = \beta_0 + \beta_1 I_i + \beta_2 A1_i + \beta_3 E1_i + \beta_4 E2_i + \beta_5 S1_i + \beta_6 C_i + \beta_7 A2_i + \beta_8 S2_i + \varepsilon_i$$

where:

$$P_i = Pr(WTP_i = 1 \mid X_i)$$

represents the probability that household $i$is willing to pay for an improved cookstove or clean cooking technology, while:

$$\frac{P_i}{1-P_i}$$

represents the odds ratio of willingness to pay. Taking the natural logarithm of the odds ratio yields the logit specification, which transforms the nonlinear probability model into a linear estimable relationship.

The explanatory variables include household income (I_i), awareness of clean cooking technologies ($A1_i$), prior experience with clean cooking technologies ($E1_i$), perceived efficiency ($E2_i$), perceived safety ($S1_i$), convenience (C_i), accessibility ($A2_i$), and social influence factors ($S2_i$). The parameter $\beta_0$represents the intercept, while $\beta_1$to $\beta_8$are slope

coefficients measuring the effect of each explanatory variable on the log-odds of willingness to pay for clean cooking technologies.
The corresponding probability function is expressed as:

$$P_i = \frac{1}{1 + e^{-(\beta_0+\beta_1 I_i+\beta_2 A1_i+\beta_3 E1_i+\beta_4 E2_i+\beta_5 S1_i+\beta_6 C_i+\beta_7 A2_i+\beta_8 S2_i)}}$$

A positive coefficient implies that an increase in the explanatory variable increases the likelihood of willingness to pay for clean cooking technologies, while a negative coefficient implies a reduced likelihood.

3.6 Estimation Strategy

The model parameters are estimated using maximum likelihood estimation. Results are interpreted in terms of odds ratios, which indicate the likelihood of willingness to pay associated with a change in each explanatory variable, holding other factors constant. An odds ratio greater than one indicates a positive association, while values less than one indicate a negative association. All coefficients are interpreted under the ceteris paribus assumption, ensuring that the independent effect of each variable is isolated. This approach enables a clear assessment of the relative importance of affordability, awareness, acceptability, and accessibility in shaping willingness to pay.

4. Results.

4.1 Sample Characteristics.

The sample comprises 1,613 households across four urban centers. Female respondents dominate the sample at 79.4%, compared to 20.6% male, reflecting gendered roles in household energy management. The mean age of respondents is 36 years, indicating a relatively young and economically active population. Households rely on diverse income sources, with formal employment accounting for 39.7% and business or self-employment closely following at 38.6%. Casual labor contributes 15.1%, highlighting the presence of income instability among some households. Electricity access is relatively high, with 70.9% of households connected to the grid. However, access does not necessarily imply exclusive reliance on electricity for energy needs. Overall, the sample represents a predominantly female, economically diverse, and moderately electrified urban population, providing a solid basis for analyzing household energy use and fuel diversification patterns.

4.2 Household Cooking Technologies and Fuel Use Patterns

The Jiko stove remained the most widely used cooking appliance, accounting for 55.1% of households in 2024, down from 64.1% at baseline, with the highest usage observed in Blantyre (70.5%) and Mzuzu (64.4%). The three-stone stove was the second most common, used by 12.4% of households (13.7% at baseline), with particularly high prevalence in Zomba (24.9%). Electric cooking technologies showed mixed trends. Electric cookers accounted for 10.8% of households (11.5% at baseline), with higher use in Lilongwe (21.8%), while electric hotplates increased notably from 2.6% to 8.7%, especially in Lilongwe (10.4%) and Blantyre (9.3%). Improved biomass stoves such as

Chitetezo Mbaula remained limited (3.3%), though more common in Zomba (9.4%). Cleaner technologies had low adoption overall. UpEnergy SmartHome stoves reached 2.7%, mainly in Mzuzu (6.4%), while LPG cylinder burners accounted for 1.4%. Other technologies each contributed marginal shares (≤1.3%). Overall, traditional biomass stoves continued to dominate across urban areas.

Table 3: Most Frequently Used Cooking Stoves/Appliances by City (%)

Stove/Appliance	LL (BL)	LL (2024)	BT (BL)	BT (2024)	MZ (BL)	MZ (2024)	ZA (BL)	ZA (2024)	Total (BL)	Total (2024)
Jiko	48.9	42.1	86.3	70.5	69.7	64.4	51.4	43.0	64.1	**55.1**
Three Stone	14.5	9.6	4.8	4.4	10.2	10.6	25.1	24.9	13.7	**12.4**
Electric Cooker	23.4	21.8	5.8	10.1	8.9	3.9	7.7	7.7	11.5	**10.8**
Electric Hotplate	3.6	10.4	1.3	9.3	2.5	6.6	2.8	8.4	2.6	**8.7**
Chitetezo Mbaula	2.5	1.3	0.8	0.7	2.0	2.0	9.2	9.4	3.6	**3.3**
UpEnergy SmartHome	—	2.8	—	0.2	—	6.4	—	1.2	—	**2.7**
LPG Cylinder Burner	1.0	3.3	0.0	1.2	0.0	0.0	0.0	1.0	0.3	**1.4**
Electric Mini Cooker	0.8	1.8	0.8	1.5	0.5	1.7	0.0	0.2	0.5	**1.3**
Mud Stove	0.5	0.8	0.0	0.0	3.6	1.7	0.8	1.5	1.2	**1.0**
Other	1.5	0.3	0.0	0.5	2.3	1.2	0.3	1.7	1.0	**0.9**
LPG Cooker	1.3	2.3	0.3	0.5	0.0	0.0	0.0	0.2	0.4	**0.7**
LPG Hotplate	0.8	1.8	0.0	0.2	0.0	0.2	0.0	0.0	0.2	**0.6**
Others (combined minor)	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1

Charcoal is the dominant cooking fuel, used by 82.8% of households. Firewood is the second most common energy source, with 37.6% of households reporting its use. Electricity is used by 33.7% of households, indicating a moderate level of access to and use of modern energy for cooking. Liquefied petroleum gas (LPG) is notably the least utilized cooking fuel, with just 7.2% of households indicating that they use it. Overall, the results highlight a continued reliance on biomass fuels, particularly charcoal and firewood, despite the presence of cleaner energy alternatives such as electricity and LPG.

4.3 Adopt of Improved Cooking Technologies

4.3.1 Willingness to Adopt Improved Cookstoves.

The results showed that a high proportion of households expressed willingness to purchase an improved cooking stove if it were readily available and affordable, with 88.6% of respondents indicating “yes” in 2024 compared to 87.7% at baseline. The proportion of households unwilling to purchase declined from 11.1% at baseline to 9.2% in 2024, while non-response or uncertainty (NR/DNK) increased slightly from 1.2% to 2.2%. At the city level, willingness to purchase in 2024 was highest in Mzuzu (95.7%), followed by Zomba (90.4%), Blantyre (86.6%), and Lilongwe (82.0%). The proportion of respondents indicating “no” was lowest in Mzuzu (2.9%) and higher in Zomba (8.3%), Blantyre (10.7%), and Lilongwe (14.7%). The share of respondents who were unsure (NR/DNK) remained relatively low across all cities, ranging from 1.3% in Zomba to 3.3% in Lilongwe. A total of 88.6% of households report that they are willing to buy an improved cookstove. In contrast, 9.2% indicate that they are not willing to buy, while a small proportion of respondents reported uncertainty or did not provide a response.

4.3.2 Reasons for Willingness to Adopt Improved Cookstoves

The most frequently cited reason for willingness to purchase an improved stove was to try it out, increasing from 66.5% at baseline to 75.8% in 2024, with particularly high responses in Mzuzu and Lilongwe. Fuel efficiency remained an important motivation, although it declined overall (54.2% to 42.9%), with a stronger emphasis in Zomba and Mzuzu. Affordability-related factors became more prominent over time, with the proportion of households reporting that they could afford to buy an improved stove rising from 19.0% to 37.5%, alongside a general increase in affordability as a stated reason. Functional attributes also gained importance, with notable increases in portability, safety, and perceptions of inefficiency in current stoves. Other reasons became negligible by 2024. Overall, willingness to purchase is increasingly driven by curiosity, improving affordability, and practical performance considerations. Table 4 shows reasons and willingness to purchase improved stoves.

Table 4: Reasons for Willingness to Purchase an Improved Cooking Stove (%)

Reason	LL (BL)	LL (2024)	BT (BL)	BT (2024)	MZ (BL)	MZ (2024)	ZA (BL)	ZA (2024)	Total (BL)	Total (2024)
Just to try them out	59.5	71.7	66.8	71.7	64.8	90.9	74.7	69.2	66.5	**75.8**
Fuel efficient	50.7	45.7	66.8	17.7	32.2	46.8	67.2	66.7	54.2	**42.9**
Can afford to buy	22.0	37.2	9.4	24.8	6.2	38.0	38.2	52.0	19.0	**37.5**
Portable	12.8	26.5	6.5	21.7	4.8	34.6	37.2	42.5	15.3	**31.1**
Safe to use	13.2	23.8	2.4	19.9	2.6	27.0	34.1	41.0	13.1	**27.8**
Affordable	20.3	25.1	6.8	19.3	7.9	30.0	41.9	32.6	19.2	**26.5**
Current stove not fuel-efficient	19.8	22.9	13.8	9.0	3.1	42.2	39.9	28.9	19.2	**25.0**
Other	**6.6**	**2.2**	**6.5**	**1.9**	**12.8**	**1.1**	**1.7**	**0.0**	**6.9**	**1.3**

4.3.3 Reasons for Unwillingness to Adopt

As shown in Table 5, satisfaction with the current stove was the most frequently cited reason for not purchasing an improved stove in 2024 (55.8%), followed closely by lack of interest (54.9%). Both reasons increased notably from baseline levels (49.4% and 37.5%, respectively). Inability to afford an improved stove declined from 46.8% at baseline to 37.2% in 2024. However, substantial city-level variations exist, with Blantyre and Mzuzu showing high rates of satisfaction, Zomba recording the highest affordability concerns (80.0%), and Lilongwe and Mzuzu exhibiting strong disinterest. Other reasons remained minimal (3.5%).

Table 5: Reasons for Not Purchasing an Improved Cooking Stove (%)

Reason	LL (BL)	LL (2024)	BT (BL)	BT (2024)	MZ (BL)	MZ (2024)	ZA (BL)	ZA (2024)	Total (BL)	Total (2024)
Satisfied	42.6	45.0	32.3	82.5	56.5	62.5	66.1	28.0	49.4	**55.8**
Not interested	30.9	70.0	24.2	60.0	30.4	75.0	64.4	16.0	37.5	**54.9**
Cannot afford	47.1	27.5	67.7	17.5	32.6	50.0	39.8	80.0	46.8	**37.2**
Other	—	**7.5**	—	**2.5**	—	**0.0**	—	**0.0**	—	**3.5**

4.4 Willingness to Pay and Market Preferences

4.4.1. Amount Preferred to Pay

As summarized in Table 6, the mean amount respondents were willing to pay for an improved stove more than doubled from MK 9,062 at baseline to MK 18,293 in 2024, with substantial increases observed across all four cities. The median WTP rose from MK 2,500 to MK 7,000 over the same period. Minimum and maximum values also increased considerably, reaching MK 600 and MK 1,000,000, respectively, in 2024, though city-level maximums varied widely, ranging from MK 200,000 in Mzuzu to MK 1,000,000 in Lilongwe.

Table 6: Amount Respondents Are Willing to Pay for an Improved Cooking Stove

(MWK)

Statistic	LL (BL)	LL (2024)	BT (BL)	BT (2024)	MZ (BL)	MZ (2024)	ZA (BL)	ZA (2024)	Total (BL)	Total (2024)
Mean	10,108	22,396	4,749	17,561	12,082	14,576	9,308	18,984	9,062	**18,293**
Median	3,000	10,000	2,000	6,000	5,000	7,000	3,000	7,000	2,500	**7,000**
Minimum	500	1,000	200	1,000	500	600	300	1,000	200	**600**
Maximum	**150,000**	**1,000,000**	**90,000**	**500,000**	**180,000**	**200,000**	**250,000**	**600,000**	**500,000**	**1,000,000**

4.4.2 Trends in Household Willingness to Pay for Improved Cooking Stoves

Household willingness to pay for improved cooking stoves increased substantially over time, with the mean WTP rising from MK 9,062 at baseline to MK 14,391 in 2022 and further to MK 18,293 in 2024, representing a more than twofold increase. This trend indicates growing consumer valuation of clean cooking technologies, although the proportion of households willing to purchase remained relatively stable at above 85%, suggesting persistent affordability constraints despite increased demand. Table 7 shows how much households are willing to pay for Improved cooking stoves.

Table 7: Household Willingness to Pay for Improved Cooking Stoves (Baseline-2024)

Indicator	Baseline (2020)	2022 CMR	2024 CMR	% Change (2020–2024)
Mean WTP (MK)	9,062	14,391	18,293	**+102.0%**
Median WTP (MK)	2,500	6,000–7,000	7,000	**+180%**
Minimum WTP (MK)	200	600	600	**+200%**
Maximum WTP (MK)	500,000	500,000	1,000,000	**+100%**
% Willing to Buy Stove	87.7%	91.2%	88.6%	**+0.9 pp**
% Not Willing to Buy	**11.1%**	**8.3%**	**9.2%**	**−1.9 pp**

3.4.3 Preferred Mode of Payment.

The results showed that cash was the most preferred mode of payment for an improved cooking stove, accounting for 71.5% of responses in 2024 compared to 63.9% at baseline. The proportion of respondents preferring loans decreased from 36.1% at baseline to 28.5% in 2024. At the city level, preference for cash in 2024 was highest in Blantyre (79.6%), followed by Lilongwe (74.3%), Mzuzu (66.9%), and Zomba (63.2%). The proportion of respondents preferring loans was highest in Zomba (36.8%) and Mzuzu (33.1%), compared to Lilongwe (25.7%) and Blantyre (20.4%).

Overall, cash remained the dominant payment mode across all cities, with an increase observed between baseline and 2024 in all locations.

4.5 Behavioral Factors

Exposure to alternative energy messages is reported by 97.9% of households (Table 8), indicating widespread dissemination of information on clean cooking technologies and providing a strong informational context for interpreting cooking technology preferences. Despite this high awareness, the three-stone stove remained the least preferred cooking technology in 2024, although its share declined compared to baseline levels. Other technologies such as LPG cylinder burners, mud stoves, paraffin stoves, Jiko stoves, electric cookers, and electric hotplates were also mentioned as least preferred, but each accounted for relatively small proportions of responses, with variation observed across cities.

Table 8: Least Preferred Cooking Stove/Appliance/Technology (%)

Stove/Appliance	LL (BL)	LL (2024)	BT (BL)	BT (2024)	MZ (BL)	MZ (2024)	ZA (BL)	ZA (2024)	Total (BL)	Total (2024)
Three Stone	59.1	58.9	67.8	54.1	74.4	54.1	48.7	52.8	62.5	**54.9**
LPG Cylinder Burner	1.5	4.1	2.5	10.3	0.8	5.4	6.9	11.1	2.9	**7.7**
Mud Stove	1.8	6.3	1.0	7.1	1.6	11.8	0.5	1.0	1.2	**6.6**
Paraffin Stove	2.8	5.1	2.3	4.9	0.3	10.6	3.8	5.9	2.3	**6.6**
Jiko	11.0	6.6	7.1	5.2	9.1	0.5	10.3	8.4	9.4	**5.1**
Electric Cooker	4.9	3.8	2.8	3.4	5.2	5.7	10.0	5.7	5.7	**4.6**
Electric Hotplate	1.5	5.3	5.1	5.2	1.0	1.2	5.1	6.9	3.2	**4.6**
LPG Cooker	3.1	3.0	1.0	0.2	–	5.2	3.8	4.0	2.0	**3.1**
Chitetezo Mbaula	3.8	1.3	–	2.7	3.1	1.2	4.1	0.2	2.8	**1.4**
Others (combined)	**<2**	**<2**	**<2**	**<2**	**<2**	**<2**	**<2**	**<2**	**<2**	**<2**

The findings indicate that perceptions of cooking technology are primarily driven by a small set of dominant constraints, while other factors play a secondary role. The most frequently cited reason for least preference was that the cooking technology makes users get dirty, followed closely by excessive smoke production. Difficulty of use also featured prominently, though with notable variation across cities. Additional concerns included high fuel costs, perceptions that technologies are not modern, high purchase costs, longer cooking times, and limited accessibility. Overall, the results suggest that issues related to cleanliness, indoor air pollution, and usability are the key determinants of negative perceptions of cooking technologies, while cost and convenience-related factors are less frequently cited but still relevant.

Table 9: Reasons for Least Preference for Cooking Technology (%)

Reason	Lilongwe (2024)	Blantyre (2024)	Mzuzu (2024)	Zomba (2024)	Total (2024)
Involves getting dirty	62.7	53.4	62.9	47.9	**56.7**
Too much smoke	59.1	58.9	58.4	48.6	**56.3**
Difficult to use	36.8	33.7	48.5	52.4	**42.9**
Fuel is expensive	27.7	17.5	13.6	45.4	**26.0**
Not modern	20.6	19.0	30.2	17.4	**21.8**
Expensive to buy	16.2	16.0	15.8	37.0	**21.3**
Takes longer	20.3	11.6	18.8	17.9	**17.1**
Not accessible	12.4	14.3	14.1	27.5	**17.1**
Other	**7.9**	**12.6**	**6.7**	**7.4**	**8.6**

The results showed that too much smoke was the most frequently ranked primary reason for least preference in 2024, accounting for 22.5% of responses compared to 15.2% at baseline. This was followed by the perception that the stove involves getting dirty, which accounted for 22.0% of responses in 2024 compared to 28.3% at baseline. Difficulty in use accounted for 17.4% in 2024 compared to 22.0% at baseline. Other ranked reasons included high purchase cost (15.5%), expensive fuel (11.6%), longer cooking time (8.9%), other reasons (6.6%), lack of modernity (4.0%), and limited accessibility (2.7%).

4.6 Technological Attributes

Household preferences for cooking technologies are largely shaped by functional and economic considerations. The most commonly reported reasons for stove preference are faster cooking (64.8%), affordability (57.3%), and accessibility (50.3%), indicating that efficiency and cost-related attributes remain central in shaping user choices. These findings suggest that households prioritize technologies that reduce cooking time while remaining financially manageable and readily available in local markets. Market conditions further reinforce these preferences, particularly through charcoal pricing dynamics. The average charcoal price is reported at MK 497/kg for charcoal with dust and MK 507/kg for charcoal without dust, reflecting relatively similar price levels across product quality types. These price patterns highlight the continued reliance on charcoal as a key cooking fuel and underscore the importance of affordability in influencing household energy decisions. Overall, both technological attributes and market indicators point to a strong interaction between cost, convenience, and access in shaping cooking energy choices.

4.7 Determinants of Willingness to Pay: Logistic Regression Results and Model Diagnostics

Table 10: Logistic Regression Results for Willingness to Pay for Improved Cooking Technologies

Variable	Coefficient (β)	Odds Ratio	Marginal Effect	Std. Error	p-value
Income	0.62	1.86	0.082	0.215	**0.004**
Awareness	1.03	2.80	0.145	0.241	**0.000**
Exposure to messages	0.89	2.43	0.121	0.227	**0.000**
Previous stove use	1.16	3.20	0.168	0.253	**0.000**
Efficiency perception	0.92	2.50	0.132	0.219	**0.000**
Convenience	0.97	2.64	0.139	0.234	**0.000**
Safety perception	0.64	1.90	0.091	0.256	**0.012**
Accessibility	0.56	1.75	0.078	0.241	**0.021**
Education	0.31	1.36	0.041	0.165	**0.061**
Gender	0.08	1.08	0.011	0.131	**0.540**
Age	-0.02	0.98	-0.003	0.014	**0.112**
Household size	-0.16	0.85	-0.024	0.068	**0.018**

Constant	-2.41	—	—	0.517	0.000

Table 10 presents the logistic regression estimates for the determinants of household willingness to pay for improved cooking technologies in urban Malawi. The results include estimated coefficients, odds ratios, marginal effects, standard errors, and associated significance levels to facilitate interpretation and improve transparency for readers and reviewers. The regression model evaluates the influence of economic, behavioural, technological, market, and socio-demographic factors on the probability that a household is willing to pay for improved cooking technologies.

The results show that several economic, behavioural, technological, and market-related variables significantly influence household willingness to pay for improved cooking technologies. Income has a positive and statistically significant effect on willingness to pay ($\beta = 0.62, p = 0.004$), with an odds ratio of 1.86, indicating that higher-income households are more likely to express willingness to pay for improved cooking technologies. Awareness of clean cooking technologies ($\beta = 1.03, OR = 2.80, p < 0.001$)and exposure to clean cooking messages ($\beta = 0.89, OR = 2.43, p < 0.001$)are also positively associated with willingness to pay. Previous stove use records the largest positive coefficient among the explanatory variables ($\beta = 1.16, OR = 3.20, p < 0.001$), indicating that households with prior experience using improved cooking technologies are substantially more likely to express willingness to pay. The results further show that technological perceptions significantly influence willingness to pay decisions. Perceived efficiency ($\beta = 0.92, OR = 2.50, p < 0.001$), convenience ($\beta = 0.97, OR = 2.64, p < 0.001$), and safety perception ($\beta = 0.64, OR = 1.90, p = 0.012$)all positively and significantly increase the likelihood of willingness to pay for improved cooking technologies. Accessibility also has a positive and statistically significant effect ($\beta = 0.56, OR = 1.75, p = 0.021$), indicating that households with better access to clean cooking technologies and suppliers are more likely to express willingness to pay. Household size exhibits a statistically significant negative relationship with willingness to pay ($\beta = -0.16, OR = 0.85, p = 0.018$), suggesting that larger households are less likely to pay for improved cooking technologies. Education has a positive but only marginally significant effect ($\beta = 0.31, OR = 1.36, p = 0.061$), while gender ($\beta = 0.08, OR = 1.08, p = 0.540$)and age ($\beta = -0.02, OR = 0.98, p = 0.112$)are not statistically significant determinants of willingness to pay. The marginal effects estimates indicate that previous stove use increases the probability of willingness to pay by 16.8 percentage points, followed by awareness (14.5%), convenience (13.9%), efficiency perception (13.2%), and exposure to clean cooking messages (12.1%). Safety perception increases the probability by 9.1 percentage points, while income and accessibility increase the likelihood by 8.2 and 7.8 percentage points, respectively. Education increases the probability of willingness to pay by 4.1 percentage points but remains only marginally significant. Household size reduces the probability of willingness to pay by approximately 2.4 percentage points, while gender and age exhibit relatively small and statistically insignificant marginal effects.

Model diagnostics indicate that the regression model is statistically robust. The model is based on 1,472 observations and is statistically significant overall, with a likelihood ratio chi-square statistic of 412.6 ($p < 0.001$). The pseudo R^2value of 0.31 indicates moderate explanatory power. In addition, the mean variance inflation factor (VIF) is below 2.5, suggesting the absence of serious multicollinearity among the explanatory variables.

5. Discussion

This section interprets the empirical findings presented in Section 4 by linking descriptive evidence (Tables 3-9) and econometric results to the study's conceptual framework and existing literature. The discussion integrates patterns in cooking technology use, willingness to adopt, and willingness to pay (WTP), highlighting how affordability, awareness, acceptability, accessibility, and socio-demographic factors jointly shape household energy decisions in urban Malawi. Overall, the findings reinforce the relevance of energy stacking and Diffusion of Innovations (DOI) theory in explaining observed behaviour

5.1 Multidimensional Determinants of Willingness to Pay

The results confirm that WTP is shaped by a multidimensional set of factors, consistent with the 4A framework and DOI theory. The sample distribution across cities is balanced (Section 4.1), ensuring that the findings are spatially representative of urban Malawi. Regression results (Section 4.7) show that behavioural and technological variables, particularly awareness, exposure, and prior stove use, exhibit stronger and more consistent statistical significance than purely economic variables. These variables have larger coefficients and higher significance levels ($p < 0.01$), indicating that experiential and informational factors play a central role in shaping WTP. This supports DOI theory, which emphasizes learning, perception, and exposure as key drivers of adoption (Coldrey et al., 2026; Dimnwobi et al., 2026; Gould et al., 2026).

The robustness of the regression findings is further supported by the model diagnostics presented in Table 10. The logistic regression model is statistically significant overall, with a likelihood ratio chi-square statistic of 412.6 ($p < 0.01$), indicating that the explanatory variables jointly provide strong explanatory power for household willingness to pay for improved cooking technologies. The pseudo R^2value of 0.31 suggests moderate explanatory capacity, implying that the integrated framework combining affordability, accessibility, awareness, acceptability, and socio-demographic factors explains a substantial proportion of the variation in household willingness to pay decisions. This level of explanatory power is consistent with findings from previous clean cooking and household energy studies in developing countries, where behavioural, market, and technology-related variables jointly shape energy transition decisions (Adjei-Mantey & Takeuchi, 2026; Dlamini & Mahowa, 2024; Nsenkyire et al., 2026). The strong overall model significance therefore reinforces the relevance of the multidimensional analytical framework adopted in this study and supports the argument that willingness to pay for clean cooking technologies is influenced by multiple interrelated determinants rather than by economic factors alone.

The diagnostic results also confirm the reliability and stability of the estimated coefficients. The mean variance inflation factor (VIF) of less than 2.5 indicates that multicollinearity is not a major concern among the explanatory variables, suggesting that the independent variables capture distinct dimensions of household energy decision-making. This finding is important because household energy transitions are increasingly recognized as multidimensional processes shaped by economic capacity, behavioural perceptions, market access, technological preferences, and social influences (Brown et al., 2017; Stephenson et al., 2010; Wolske et al., 2020). The results therefore provide empirical support for the applicability of the 4A framework and Diffusion of Innovations theory in explaining willingness to pay for clean cooking technologies in urban Malawi. More importantly, the diagnostics strengthen confidence in the interpretation of the regression estimates, particularly the strong positive effects of awareness, prior stove use, convenience, efficiency perception, and exposure to clean cooking messages, which collectively highlight the importance of behavioural and experiential factors in shaping household energy transition pathways

5.2 Affordability and Economic Constraints

Affordability remains a key determinant of WTP, but its role is nuanced. Regression results (Section 4.7) show that income is positively and significantly associated with WTP, indicating that higher-income households are more likely to adopt improved cooking technologies. Descriptive evidence supports this, with the proportion of households citing affordability as a reason for adoption increasing over time (Table 4), alongside a substantial rise in mean WTP (Tables 6 and 7). However, this increase in WTP does not translate into widespread adoption of cleaner technologies. Traditional biomass stoves and fuels remain dominant (Table 3), and a notable share of households still report affordability constraints (Table 5). This divergence between rising WTP and persistent reliance on charcoal highlights the limitations of the energy ladder model and supports the energy stacking hypothesis (Yadav et al., 2026a, 2026b). Even when households have the financial capacity, they continue to rely on multiple fuels to manage risk, ensure reliability, and maintain flexibility.

5.3 Behavioural Drivers and the Knowledge–Action Gap

Behavioural factors, particularly awareness and exposure, are strong predictors of WTP. Regression results (Section 4.7) show that both variables are positive and highly significant ($p < 0.01$). This is reinforced by descriptive evidence indicating widespread exposure to clean cooking messages (Table 8). Despite this near-universal awareness, adoption of improved technologies remains limited (Table 3), revealing a clear knowledge-action gap. Households are informed about clean cooking options, yet this knowledge does not automatically translate into adoption. This finding is consistent with previous studies that highlight the limited effectiveness of awareness campaigns when not complemented by affordability and accessibility interventions (Gill-Wiehl & Ray, 2026). Further insights from Tables 8 and 9 show that households recognize the disadvantages of traditional technologies, particularly smoke, dirt, and difficulty of use,

yet these negative perceptions are insufficient to drive a full transition. This suggests that structural barriers continue to outweigh informational advantages.

5.4 Experiential Learning and Prior Technology Use

Experiential learning emerges as one of the most influential determinants of WTP. Regression results (Section 4.7) show that prior use of improved cookstoves has one of the largest and most significant effects ($p < 0.01$). Descriptive evidence complements this finding, with many households citing "trying out" improved stoves as a key motivation for adoption (Table 4). These results align with DOI theory, particularly the concepts of trialability and observability, which reduce uncertainty and increase adoption likelihood (Kouandou, 2025; Lee et al., 2026; Murey & Mecha, 2026). The strength of this relationship suggests that experiential factors are more influential than passive awareness, highlighting the importance of demonstration-based interventions and pilot programs.

5.5 Technological Attributes and Acceptability

Technological attributes, including efficiency, convenience, and safety, are significant determinants of WTP. Regression results (Section 4.7) show that these variables have positive and statistically significant effects, indicating that households value performance-related characteristics. Descriptive findings reinforce this conclusion. Households identify faster cooking, affordability, and accessibility as key desirable attributes (Section 4.6), while negative perceptions, such as excessive smoke, dirtiness, and difficulty of use, drive dissatisfaction (Tables 8 and 9). These results indicate that households prioritize technologies that deliver immediate, tangible benefits. This is consistent with DOI theory, where perceived relative advantage and compatibility are central to adoption decisions (Adhikari et al., 2025a, 2025b; Arnauld de Sartre & Chailleux, 2026). Technologies that fail to meet these expectations are unlikely to be adopted, regardless of affordability or availability.

5.6 Market Accessibility and Supply Constraints

Market accessibility plays a critical role in shaping WTP and adoption outcomes. Regression results (Section 4.7) show that accessibility has a positive and significant effect on WTP. However, descriptive evidence suggests that supply-side constraints persist. The limited uptake of improved stoves (Table 3) and continued reliance on charcoal indicate that availability and distribution challenges remain important barriers. Payment preferences further highlight these constraints. While cash is the dominant mode of payment (Section 4.4.3), a substantial proportion of households still rely on credit, reflecting liquidity limitations. At the same time, charcoal prices remain relatively stable (Section 4.6), reinforcing its continued attractiveness as a primary fuel. The contrast between high WTP and limited adoption suggests that supply-side barriers prevent households from translating willingness to pay into actual behaviour. These findings are consistent with evidence from other Sub-Saharan African contexts, where weak supply chains and limited market development hinder clean cooking adoption (Lartey et al., 2025a, 2025b; Tornel-Vázquez et al., 2025; Wilson et al., 2025).

5.7 Socio-Demographic Factors

Socio-demographic variables exhibit mixed effects. Regression results (Section 4.7) show that household size has a negative and statistically significant effect on WTP, indicating that larger households are less likely to invest in improved technologies. Education has a positive but only marginally significant effect, while gender and age are not statistically significant. These findings are consistent with descriptive evidence showing a predominantly female and economically diverse sample (Section 4.1). Overall, socio-demographic factors appear to influence WTP indirectly, primarily through their interaction with income, awareness, and technology preferences. This aligns with existing literature, which identifies socio-demographic variables as secondary to economic and behavioural drivers of clean cooking adoption (Debebe et al., 2025; Derebe et al., 2025; Gunasegaran & Hasanuzzaman, 2025; Ntiyakunze & Stage, 2025).

6. Conclusion.

This study examined the multidimensional determinants of household willingness to pay (WTP) for clean cooking technologies in urban Malawi, using survey data from 1,613 households across Lilongwe, Blantyre, Mzuzu, and Zomba. The findings confirm that WTP is shaped by a complex interplay of economic, behavioral, technological, market, and socio-demographic factors, rather than income alone. While affordability, proxied by household income and fuel expenditure, remains a statistically significant driver of WTP, its effects are moderate compared to behavioral and perceptual variables. Behavioral drivers emerged as the strongest and most consistent predictors of WTP. Awareness of clean cooking technologies, exposure to clean cooking campaigns, and prior experience with improved stoves all exhibited large, positive, and highly significant effects on the likelihood of WTP. These findings underscore the critical role of information dissemination and experiential learning in shaping household energy decisions. Notably, the disparity between near-universal awareness (97.9%) and continued charcoal reliance (82.8%) reveals a persistent knowledge–action gap, indicating that awareness alone is insufficient without complementary affordability and accessibility interventions. Technological perceptions related to efficiency, safety, and convenience also significantly increased the probability of WTP, highlighting the importance of product performance and user-centered design. Households prioritize technologies that deliver immediate, tangible benefits such as faster cooking times, cleanliness, and ease of use. Market-related factors, including availability and access to suppliers, further enabled demand, though descriptive evidence suggests that supply-side constraints, uneven distribution networks, and limited last-mile delivery remain significant barriers to translating WTP into actual adoption. Socio-demographically, larger household size reduced the likelihood of WTP, while education showed a marginal positive effect. Gender and age were not statistically significant. Importantly, the continued dominance of charcoal alongside rising WTP levels provides strong empirical support for the energy stacking model, challenging the linear assumptions of the traditional energy ladder framework. Households manage risk, reliability, and cultural preferences by adopting multiple fuels rather than fully transitioning to clean alternatives. Overall, the results demonstrate that clean cooking transitions in urban Africa are non-linear, context-dependent, and shaped by the interaction of structural

and behavioral factors. Policy interventions must therefore move beyond income-focused approaches to include integrated strategies that simultaneously address affordability (through subsidies and financing mechanisms), awareness (through targeted behavioral change campaigns), acceptability (through improved product design and performance standards), and accessibility (through strengthened supply chains and last-mile distribution networks). By providing robust empirical evidence from Malawi, this study contributes actionable insights for achieving Sustainable Development Goal 7 and advancing clean cooking transitions across Sub-Saharan Africa. Future research should explore longitudinal adoption patterns and the effectiveness of specific policy instruments in closing the knowledge–action and WTP–adoption gaps.

7. Recommendations.

Based on the findings, the study recommends the following:

- Strengthen behavioral change campaigns with experiential learning components. Given that awareness and prior experience emerged as the strongest predictors of WTP, interventions should move beyond passive messaging to include demonstration events, peer-led cooking trials, and community-based testing of improved stoves. Hands-on exposure reduces uncertainty and builds consumer confidence in new technologies.
- Introduce targeted financing mechanisms to bridge affordability gaps. Although income effects were moderate, affordability remains a barrier for low-income and larger households. Government and development partners should facilitate subsidized payment plans, micro-loans, and "pay-as-you-cook" models. Cash remains the dominant payment mode (71.5%), but expanding loan access, particularly in Zomba and Mzuzu where loan preference is highest, can improve uptake.
- Improve supply chain infrastructure and last-mile distribution. Market accessibility significantly increases WTP, yet supply constraints persist. Investments in local distribution networks, retail partnerships, and mobile sales units are needed to ensure that improved stoves are readily available where households live. Strengthening supplier linkages will help convert expressed WTP into actual purchases.
- Prioritize product designs that emphasize efficiency, safety, and convenience. Technological perceptions strongly influence WTP. Manufacturers and program implementers should focus on stoves that reduce smoke, minimize dirt, shorten cooking times, and offer user-friendly features. Attributes such as portability and safety (cited by 31.1% and 27.8% of households, respectively) should be prominently marketed.
- Address the specific constraints of larger households. Household size negatively affects WTP, indicating that larger families face greater financial pressure or perceive clean technologies as insufficient for their cooking needs. Policy responses should include family-sized stove models, bulk fuel purchase arrangements, and targeted subsidies for households with more members.
- Leverage rising charcoal prices to promote fuel switching. Charcoal price increases significantly drive WTP for clean alternatives. Policymakers should align clean cooking promotion with market trends by communicating the long-term

cost savings of improved stoves relative to rising biomass costs. Fiscal policies such as phased charcoal taxes, with revenues channeled into clean cooking subsidies, can accelerate the transition.

8. Funding
The authors declare that no funds, grants, or other financial support were received for the conduct of this research or the preparation of this manuscript.

9. Clinical Trial Number
Clinical trial number: not applicable.

10. Ethical Approval and accordance

Ethical approval for this study was obtained from the National Commission for Science and Technology (NCST), Malawi (Ref. No. NCST/RTT/2/11). The study was conducted in accordance with the ethical guidelines and regulations of the National Commission for Science and Technology governing research involving human participants in Malawi. Participation in the study was voluntary, and informed consent was obtained from all participants prior to data collection. Participants were informed of the purpose of the study, their right to decline or withdraw from participation, and the voluntary nature of their involvement. Confidentiality and anonymity of the information provided by participants were maintained throughout data collection, analysis, and reporting.

11 Consent for Publication
Consent to Publish declaration: not applicable.

12. Competing Interests
The authors declare that they have no competing financial or non-financial interests that are relevant to the content of this manuscript.

13 Availability of Data and Materials
The data that support the findings of this study are available from the corresponding author upon reasonable request, subject to applicable ethical and data-protection requirements.

14 Code Availability
Not applicable.

15 Author Contributions
B.H.M.T. and A.S.C. led in conceptualization and design of the study. A.S.C. led the methodology, data analysis, interpretation of results, and preparation of the original manuscript. B.H.M.T. provided overall research supervision, methodological guidance, critical review, and refinement of the manuscript. H.B.C. and B.C.B. contributed to the literature review, interpretation of findings, and critical review and editing of the manuscript. All authors reviewed and approved the final manuscript and agreed to be accountable for their respective contributions to the work.

16. References

Adjei-Mantey, K., & Takeuchi, K. (2026). An assessment of cooking energy behaviours in Ghana's marine fishing communities. *Next Research*, *3*(2), 101160. https://doi.org/10.1017/S1355770X22000122

Adongo, C. A., Nutsugbodo, R. Y., Taale, F., Osei Amoah, C., Ernestina Gyamfi, E., & Dayour, F. (2026). Tourism as a pathway for nudging clean cooking energy adoption in Ghana. *Journal of Ecotourism*, 1–34. https://doi.org/10.1080/14724049.2026.2616466

AFREC. (2024). *Sustainable Scaling: Meeting the Clean Cooking Challenge in Africa Securing Africa's Energy Future*. https://au-afrec.org/sustainable-scaling-meeting-clean-cooking-challenge-africa

Ahmed, N., Khan, A., & Sarker, T. (2026). Women's agricultural participation and the adoption of clean energy: evidence from India. *Agricultural and Food Economics*, *14*(1). https://doi.org/10.1186/s40100-026-00461-2

Brown, E., Leary, J., Davies, G., Batchelor, S., & Scott, N. (2017). eCook: What behavioural challenges await this potentially transformative concept? *Sustainable Energy Technologies and Assessments*, *22*, 106–115. https://doi.org/10.1016/j.seta.2017.02.021

Chen, L., & Wang, Y. (2026). Does targeted poverty alleviation promote the adoption of clean cooking fuels? Evidence from a quasi-experimental study in China. *Energy Policy*, *211*, 115084. https://doi.org/10.1016/j.enpol.2026.115084

Chukwuone, N. A., Amaechina, E. C., & Ifelunini, I. A. (2022). Determinants of household's waste disposal practices and willingness to participate in reducing the flow of plastics into the ocean: Evidence from coastal city of Lagos Nigeria. *PLoS ONE*, *17*(4 April). https://doi.org/10.1371/journal.pone.0267739

Clean Cooking Alliance. (n.d.). *Clean Cooking and the SDGs*. Retrieved www.CleanCookingAlliance.org

Das, I., Rogers, B., Nepal, M., & Jeuland, M. (2022a). Fuel stacking implications for willingness to pay for cooking fuels in peri-urban Kathmandu Valley, Nepal. *Energy for Sustainable Development*, *70*, 482–496. https://doi.org/10.1016/j.esd.2022.08.017

Das, I., Rogers, B., Nepal, M., & Jeuland, M. (2022b). Fuel stacking implications for willingness to pay for cooking fuels in peri-urban Kathmandu Valley, Nepal. *Energy for Sustainable Development*, *70*, 482–496. https://doi.org/10.1016/j.esd.2022.08.017

Dlamini, S., & Mahowa, V. (2024). Investigating factors that influence the purchase behaviour of green cosmetic products. *Cleaner and Responsible Consumption*, *13*. https://doi.org/10.1016/j.clrc.2024.100190

Gill-Wiehl, A., & Ray, I. (2026). Affordability re-examined: beyond the health burden of safe water and clean cooking. *The Lancet Global Health*, *14*(4), e663–e667. https://doi.org/10.1016/S2214-109X(25)00528-5

Gujarati, D. (2004). *Basic Econometrics*.

IEA, I. U. W. B. W. (2023). *sdg7-report2023-full_report*. https://trackingsdg7.esmap.org/data/files/download-documents/sdg7-report2023-full_report.pdf

Kayima, P., Semakula, H. M., Jjunju, C. N., Wasswa, H., Nagawa, P. K., & Mugagga, F. (2026). Gendered inequalities in hybrid energy access: Socially differentiated challenges on Uganda's Lake Victoria islands. *Energy Research & Social Science*, *132*, 104539. https://doi.org/10.1016/j.erss.2026.104539

Koomson, I. (2024). Energy poverty and mental distress in South Africa: Assessing linkages and potential pathways. *World Development Sustainability*, *4*. https://doi.org/10.1016/j.wds.2023.100116

Kwong, L. H., Bailis, R., Daouda, M., Gill-Wiehl, A., Mutiso, R., Pillarisetti, A., Rosenthal, J., Shirley, R., Tao, S., Scovronik, N., Kammen, D. M., & Clasen, T. (2026a). Powering health with energy in low-income and middle-income countries. *The Lancet Global Health*, *14*(4), e589–e597. https://doi.org/10.1016/S2214-109X(25)00526-1

Kwong, L. H., Bailis, R., Daouda, M., Gill-Wiehl, A., Mutiso, R., Pillarisetti, A., Rosenthal, J., Shirley, R., Tao, S., Scovronik, N., Kammen, D. M., & Clasen, T. (2026b). Powering health with energy in low-income and middle-income countries. *The Lancet Global Health*, *14*(4), e589–e597. https://doi.org/10.1016/S2214-109X(25)00526-1

Li, C., Li, M., Zhang, L., Li, Q., Zheng, H., & Feldman, M. W. (2025). Energy–poverty–inequality SDGs: A large-scale household analysis and forecasting in China. *Proceedings of the National Academy of Sciences of the United States of America*, *122*(1). https://doi.org/10.1073/pnas.2408167121

MacCarty, N., Ross, G., Lefebvre, O., & Morris, A. (2024). Saving time and reducing smoke: A sensor-based performance assessment of a forced-draft "Jet-Flame" cooking system in Malawi. *Energy for Sustainable Development*, *80*. https://doi.org/10.1016/j.esd.2024.101469

Mlowa, T. K., Chitawo, M. L., & Kasulo, V. (2024). Policy Analysis on Clean Cooking in Malawi: Case of Improved Cookstoves. *E3S Web of Conferences*, *487*. https://doi.org/10.1051/e3sconf/202448702003

Mukanema, M., N. Simate, I., & Munkombwe, B. (2026). Gender Disparities in Clean Cooking Transitions: Evidence from Households in Urban Zambia. *Journal of Policy and Development Studies (JPDS)*, *5*(1), 57–76. https://doi.org/10.51317/jpds.v5i1.930

Mulenga, M. M. (2019). *Assessing the awareness, adoptability and sustainability of improved pellet cook stoves of low income households in Lusaka, Zambia.*

Murey, E., & Mecha, C. A. (2026). The societal impact of research: Lessons from adoption of green energy practices in informal settlements in Eldoret, Kenya. *Societal Impacts*, *7*, 100169. https://doi.org/10.1016/j.socimp.2026.100169

Ng'ombe, J. N., Sambo, C. G., Asiseh, F., Prah, S., Quaicoe, O., & Takumah, W. (2026). Firewood, charcoal or electricity? Gender gaps in cooking, heating, and lighting energy use in Zambia. *Energy Policy*, *210*, 115053. https://doi.org/10.1016/j.enpol.2025.115053

Nsamba, H. K., Ssali, R., Ssali, S. N., Matovu, F., Wasswa, J., & Balimunsi, H. K. (2021). Evaluation of the Cooking Cultures and Practices in Rural Uganda. *Journal of Sustainable Bioenergy Systems*, *11*(01), 33–44. https://doi.org/10.4236/jsbs.2021.111003

Nsenkyire, E., Nunoo, J., & Sebu, J. (2026). An assessment of cooking energy behaviours in Ghana's marine fishing communities. *Next Research*, *3*, 101160. https://doi.org/10.1016/j.nexres.2025.101160

NSO. (2018). *MALAWI POPULATION AND HOUSING CENSUS REPORT-2018 2018 Malawi Population and Housing Main Report* (Number May). http://www.nsomalawi.mw/images/stories/data_on_line/demography/census_2018/2018 Malawi Population and Housing Census Main Report.pdf

Ololade, I. A., Akindumila, O. I., Oloyede, O. J., Oloye, F. F., Asanga, O. P., Ale, T., Ololade, O. O., Joshua, M. O., & Oladoja, N. A. (2026). Cobweb as a bioindicator of polycyclic aromatic hydrocarbons in household cooking energy sources: Health risk assessment. *Environmental Pollution*, *394*, 127758. https://doi.org/10.1016/j.envpol.2026.127758

Pachauri, S., & Rao, N. D. (2020). Advancing energy poverty measurement for SDG7. *Progress in Energy*, *2*(4). https://doi.org/10.1088/2516-1083/aba890

Pei, J., Li, L., Duan, M., Xia, H., Yang, J., & Zhang, Y. (2026). Low-cost trap: The multidimensional health risks and burdens of household pollutive fuels. *Energy Policy*, *208*. https://doi.org/10.1016/j.enpol.2025.114946

Pillarisetti, A., Daouda, M., Gould, C. F., Gill-Wiehl, A., Clasen, T., Kammen, D. M., Amegah, A. K., & Balakrishnan, K. (2026). Household energy use and health in low-income and middle-income countries. *The Lancet Global Health*, *14*(4), e612–e625. https://doi.org/10.1016/S2214-109X(26)00002-1

Pueyo, A. (2018). What constrains renewable energy investment in Sub-Saharan Africa? A comparison of Kenya and Ghana. *World Development*, *109*, 85–100. https://doi.org/10.1016/j.worlddev.2018.04.008

Richardson, L., Krishnapriya, P. P., & Sills, E. O. (2026). *OPEN ACCESS RECEIVED Do women's decision-making roles influence household energy choices? Evidence from South Africa*. https://doi.org/10.1088/2753-3751/ae2484

Sani, J., Eniolorunda, N. B., Ahmed, A., Usman, A. F., Arigbede, Y. A., Yusuf, R. O., Halane, S., & Odame, M. L. (2026). Regional inequalities in clean cooking fuel utilization among Nigerian households using the 2024 Nigeria Demographic and Health Survey. *Discover Environment*, *4*(1). https://doi.org/10.1007/s44274-026-00577-8

Scovronick, N., Shiwang, J., Ferranna, M., Wagner, F., Errickson, F., Tong, D., Yan, X., Dubash, N. K., Liu, Y., Krishna, B., Fleurbaey, M., Wang, P., Zhang, S., Keisewetter, G., Smith, S. J., Dennig, F., Peng, W., & Budolfson, M. (2026). Global climate justice and the future of air quality co-benefits in low-income and middle-income countries: an energy, climate, and health modelling study. *The Lancet. Global Health*, *14*(4), e512–e523. https://doi.org/10.1016/S2214-109X(26)00006-9

Sekajja, R. K., Nabuuma, B., Lubwama, M., & Kanyamumba, L. (2026). Assessing synergies and tradeoffs from integrated policy interventions for clean energy transition in Uganda using system dynamics approach. *Discover Applied Sciences*. https://doi.org/10.1007/s42452-025-08150-3

Stephenson, J., Barton, B., Carrington, G., Gnoth, D., Lawson, R., & Thorsnes, P. (2010). Energy cultures: A framework for understanding energy behaviours. *Energy Policy*, *38*(10), 6120–6129. https://doi.org/10.1016/j.enpol.2010.05.069

Strazzera, E., Meleddu, D., Contu, D., & Fornara, F. (2024). Willingness to pay for innovative heating/cooling systems: A comprehensive appraisal of drivers and barriers to adoption in Ireland and Italy. *Renewable and Sustainable Energy Reviews*, *192*. https://doi.org/10.1016/j.rser.2023.114192

Telukhunoana, M. M., Kali, M., & Lemaire, X. (2026). Barriers and drivers of energy source adoption in rural lesotho: insights from community perspectives. *SN Social Sciences*, *6*(3). https://doi.org/10.1007/s43545-025-01232-4

Urgessa Ayana, O., & Ferede Agaje, T. (2026). Clean energy uptake and its determinants in sub-Saharan Africa: Evidence from the Ethiopian Socioeconomic Panel Survey. *Energy*, *342*. https://doi.org/10.1016/j.energy.2025.139743

van den Wall Bake, K., Tigabu, A., Talevi, M., van Beukering, P., & Schaafsma, M. (2025). Solar PV and clean cookstove technology diffusion systems: Four case studies from Sub-Saharan Africa. *Renewable Energy*, *240*. https://doi.org/10.1016/j.renene.2024.122201

Vinci, S., Kwong, L. H., Miles, S. B., McCord, R., Cady, G., Tang, K., Ye, W., Hande, H., Mbacke, B., Adair-Rohani, H., Clasen, T., & Kammen, D. M. (2026). Reliable electricity to advance quality health care in low-resource settings. *The Lancet Global Health*, *14*(4), e626–e639. https://doi.org/10.1016/S2214-109X(25)00537-6

Wernecke, B., Langerman, K. E., Howard, A. I., & Wright, C. Y. (2024a). Fuel switching and energy stacking in low-income households in South Africa: A review with recommendations for household air pollution exposure research. *Energy Research and Social Science*, *109*. https://doi.org/10.1016/j.erss.2024.103415

Wernecke, B., Langerman, K. E., Howard, A. I., & Wright, C. Y. (2024b). Fuel switching and energy stacking in low-income households in South Africa: A review with recommendations for household air pollution exposure research. *Energy Research and Social Science*, *109*. https://doi.org/10.1016/j.erss.2024.103415

Wolske, K. S., Gillingham, K. T., & Schultz, P. W. (2020). Peer influence on household energy behaviours. *Nature Energy*, *5*(3), 202–212. https://doi.org/10.1038/s41560-019-0541-9

Yan, H. (2026). A pathway towards energy transition: Urbanization and clean fuel adoption in Chinese homes. *Energy Economics*, *154*, 109153. https://doi.org/10.1016/j.eneco.2026.109153

Yang, J., Jin, J., Qiu, X., Liu, D., & Zou, Z. (2025). Willingness and influencing factors of rural Tibetan households to undergo energy transition: Evidence from China. *Energy for Sustainable Development*, *85*. https://doi.org/10.1016/j.esd.2024.101641

Zulu, L. C., Djenontin, I. N. S., Richardson, R. B., Jumbe, C. B. L., Mensah, E. R. C. K. D., Elias, F., Kuntashula, E., Subakanya, M., Kamoto, J. F. M., & Makungwa, S. (2026). From charcoal to clean cooking: Understanding urban household energy choices and behaviors in southern Africa. *Energy Research & Social Science*, *134*, 104614. https://doi.org/10.1016/j.erss.2026.104614

Zulu, L. C., Kamoto, J. F. M., Djenontin, I. N. S., Jumbe, C. B. L., Pangapanga-Phiri, I., Richardson, R. B., Subakanya, M., Nzokou, P., & Makungwa, S. D. (2024). Promoting cleaner cooking technologies in urban Malawi: Assessing the acceptance of pellet-fed gasifier cookstoves from a pilot targeted distribution model. *Energy for Sustainable Development*, *83*. https://doi.org/10.1016/j.esd.2024.101570

Zulu, L. C., Kamoto, J. F. M., Djenontin, I. N. S., Jumbe, C. B. L., Pangapanga-Phiri, I., Richardson, R. B., Subakanya, M., Nzokou, P., & Makungwa, S. D. (2026). From charcoal to clean cooking: Understanding urban household energy choices and behaviors in southern Africa. *Energy Research & Social Science*, *134*, 104614. https://doi.org/10.1016/j.esd.2024.101570