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A MIXED-METHODS STUDY ON THE DETERMINANTS OF SOLAR HOME SYSTEMS UTILIZATION IN RURAL, OFF-GRID NIGERIA

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Abstract

This study employs a mixed-methods research approach to scrutinize the varied determinants influencing the willingness of off-grid rural households in Kwara State, Nigeria, to adopt Solar Home Systems (SHS). Integrating quantitative survey data from 400 households, qualitative findings derived from semi-structured interviews, and secondary data, the research provides a robust empirical framework. By employing Interval Regression, Tobit models, and ANOVA, this study identifies income and education as significant factors positively driving the adoption of SHS. Moreover, it uncovers a contrasting gender divide, with male-headed households exhibiting a higher willingness to pay (WTP) for SHS. Interestingly, a high level of satisfaction with the current energy provision emerges as a stumbling block to SHS acceptance. The research further identifies a distinct trend: households located further away from the grid exhibit a heightened propensity to pay for SHS, signifying a higher value attribution to SHS in these off-grid areas. The findings underscore the need for targeted interventions that encapsulate the diverse characteristics of households to ensure successful SHS promotion. The comprehensive insights garnered from this study offer indispensable guidance for policymakers and energy providers, bolstering strategic efforts to enhance SHS uptake and ultimately contributing to Nigeria's shift towards a more sustainable energy future.

Keywords: *Willingness to Pay, Solar Home Systems, Off-grid Communities.*

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1. Introduction

1.1 Background to the Study

The modern world revolves around energy. It propels industries, powers homes, and is an integral part of our daily lives. Access to reliable, affordable, and sustainable energy is a critical factor for social and economic development. Recognizing this, the United Nations included universal access to modern energy services as one of the Sustainable Development Goals

(SDGs). Yet, as we move into the third decade of the 21st century, a substantial number of the global population remains without electricity. As of 2019, approximately 940 million people worldwide were living without access to electricity, predominantly in developing countries (Ritchie & Roser, 2019).

This energy access gap is particularly stark in Africa, and specifically in Nigeria, Africa's most populous nation. Despite having abundant energy resources, both renewable and non-renewable, Nigeria struggles with providing consistent and reliable electricity to its populace. According to World Bank data from 2020, only 55.4% of the Nigerian population has access to electricity (World Bank, 2020). This implies that close to half of the country's population is cut off from the benefits of electrification, a reality that significantly hampers socioeconomic development.

In response to this energy access challenge, various off-grid renewable energy solutions have been proposed and implemented, with Solar Home Systems (SHS) emerging as a promising alternative. The benefits of SHS are manifold - they are clean, renewable, and can be deployed in remote or difficult-to-reach areas where grid extension may be prohibitively expensive or logistically challenging. As such, SHS hold great potential to address the energy needs of Nigeria's off-grid population. Distributed Energy Service Companies (DESCOs), in partnership with various stakeholders, have played an instrumental role in promoting and deploying SHS in the country (Baurzhan & Jenkins, 2016).

1.2 Problem Statement

Despite the promising potential of SHS, their adoption rate in Nigeria, especially in rural off-grid areas, has not met expectations. The reasons for this are multifaceted and complex, influenced by a wide array of factors that span economic, social, cultural, and environmental domains. A crucial aspect, which the existing body of literature has shown to significantly influence the adoption of off-grid renewable energy solutions, is the household's willingness to pay (WTP) for such systems (Blimpo & Cosgrove-Davies, 2019). Understanding the determinants of WTP, and how they interact, is vital to developing effective strategies and policies to promote the uptake of SHS.

Existing research has explored various determinants of WTP for SHS, such as income, education level, and proximity to the grid. However, there is a dearth of studies that have conducted a comprehensive, in-depth analysis of these factors in the context of Nigeria's rural, off-grid communities. There is also limited understanding of the role and impact of DESCOs in promoting SHS adoption in these communities. This study therefore seeks to address these gaps in knowledge, aiming to provide a robust empirical understanding of the determinants influencing households' WTP for SHS in rural, off-grid communities in Kwara State, Nigeria, and elucidate the role of DESCOs in this landscape. The insights garnered from this study can inform policy decisions and strategies aimed at bolstering the provision of affordable, sustainable, and reliable electricity services in Nigeria's underserved communities.

1.3 Objective of the Study

The primary aim of this study is to explore the demand for off-grid solar electricity within select rural communities in Kwara State, Nigeria, informed by empirical data. More specifically, the objectives are:

i. To scrutinize the correlation between household income and the willingness to pay (WTP) for Solar Home Systems (SHS) in off-grid communities.
ii. To probe the impact of demographic and contextual factors such as gender, education level, and proximity to the power grid on the WTP for SHS among households in these communities.
iii. To evaluate the link between subjective well-being and the WTP for SHS in off-grid communities.

1.4 Research Questions

i. What is the relationship between household income and the willingness to pay (WTP) for Solar Home Systems (SHS) in off-grid communities in Kwara State, Nigeria?
ii. How do demographic and contextual factors, such as gender, education level, and proximity to the power grid, influence the WTP for SHS among households in these communities?
iii. Is there a correlation between subjective well-being and the WTP for SHS in off-grid communities in Kwara State, Nigeria?

1.5 Research Hypothesis

H_1: There is a significant positive relationship between household income and the willingness to pay (WTP) for Solar Home Systems (SHS) in off-grid communities in Kwara State, Nigeria.

H_2: Demographic and contextual factors such as gender, education level, and proximity to the power grid significantly influence the WTP for SHS among households in these communities.

H_3: There is a significant positive correlation between subjective well-being and the WTP for SHS in off-grid communities in Kwara State, Nigeria.

1.6 Scope of the Study

This research is confined to the examination of the demand for off-grid solar electricity within 15 off-grid communities in Kwara State, Nigeria. Specifically, it probes into household-level willingness to pay (WTP) for Solar Home Systems (SHS), studying the influence of factors like income, socio-economic characteristics, and subjective well-being on WTP. It must be noted, however, that the findings from this study may not be entirely generalizable to all of Nigeria due to the unique local contexts of different communities.

1.7 Limitations of the Study

While this study endeavours to provide a robust understanding of the determinants influencing the WTP for SHS, there are some limitations. The findings might not fully encapsulate the diverse attitudes and preferences across all of Nigeria's off-grid communities, nor completely address the nuances of the local socio-economic, cultural, and geographical contexts affecting WTP for SHS. Furthermore, given the sample size of 400 households, the study may not be representative of the broader Nigerian rural populace.

1.8 Significance of the Study

Despite the aforementioned limitations, this study holds significant relevance for various stakeholders in the energy sector. By providing an in-depth understanding of the demand-side factors that influence the acceptance and uptake of SHS in rural, off-grid areas of Nigeria, the study can inform and guide policy-making, investment decisions, and subsidy programs aimed at promoting SHS adoption. The findings from this study will not only contribute to the existing body of knowledge on off-grid electrification but also foster innovative solutions to tackle energy access challenges in Nigeria and similar contexts.

The study's recommendations will provide direction for further research on the WTP for SHS in diverse regions of Nigeria, deepening our understanding of the dynamics of demand and customer preferences, which in turn will help in devising tailored and effective policies for the promotion of SHS in Nigeria.

2. Literature Review

2.1 Introduction

The literature review for this study offers a comprehensive examination of the body of knowledge surrounding solar home system (SHS) demand and household willingness to pay (WTP). In so doing, it builds the conceptual and theoretical groundwork for the research, identifies the gaps in the current literature, and covers a broad range of components such as empirical studies, conceptual review, theoretical frameworks, and gap identification.

2.2 Conceptual Review

The conceptual framework of this study is centred around understanding consumer decision-making, which is heavily drawn from economic and psychological insights into human rationality. Traditional economic theory posits that consumers are rational agents who maximize utility subject to constraints (Simon, 1955). However, such assumptions often fall short in accounting for real-world deviations, thus requiring a nuanced understanding of cognitive elements, biases, and contextual factors that influence behaviour (Kahneman & Tversky, 1979).

The concept of WTP serves as a cornerstone in assessing demand and value in economics. It encapsulates the maximum amount a consumer is willing to forego to obtain a good or service. The main factors influencing WTP, including income, price, service attributes, and socio-economic-demographic characteristics, are comprehensively explored in this study (Hanemann, 1991; Mitchell & Carson, 1989).

Importantly, the role of perceptions and expectations in decision-making processes, particularly in the presence of uncertainty, has significant implications on consumers' WTP (Schwartz & Howard, 1981; Weinstein, 1980). In the context of SHS, uncertainty may stem from factors such as the reliability of solar technology, maintenance requirements, or cost savings over time.

Applying insights from behavioural economics, the study incorporates non-traditional factors such as cognitive biases and heuristics that often guide consumer decision-making (Thaler, 2015). Related theories, including the nudge theory that explores how subtle changes can influence behaviour, and social norms and peer effects that shape individual decisions, provide a more holistic understanding of SHS adoption (Thaler & Sunstein, 2008; Cialdini & Goldstein, 2004; Manski, 1993).

In conclusion, while substantial strides have been made in understanding the determinants of WTP, certain areas still need attention. The impact of sunk costs on WTP decisions is often overlooked, yet it can play a pivotal role in a consumer's decision to switch from conventional to solar energy (Arkes & Blumer, 1985). Similarly, the study seeks to delve deeper into the interactions between perception, expectation, and WTP. By addressing these gaps, the study endeavors to enhance our understanding of the intricacies of consumer behaviour and decision-making processes related to off-grid solar systems.

2.3 Theoretical Framework

The study's theoretical framework serves as a springboard for tackling the research objectives and encompasses elements like demand theory and utility functions. These principles are key in understanding consumer behavior and preferences within the context of contingent valuation studies.

In this framework, demand theory and utility functions are utilized to analyze Hicksian measures. Here, the utility function encapsulates an individual's preferences for both market goods (x) and the valued asset (q). The indirect utility function, derived from considering budget constraints, integrates the individual's demand and utility functions. This allows a comparison of an individual's utility in the "without q" scenario (q_0) and the "with q" scenario (q_1).

When the utility at q_1 is greater than at q_0, this suggests a positive change in q. The compensating variation (C) measures the individual's WTP for the improvement, while the equivalent variation (E) gauges the minimum WTP to forgo the improvement. Whether these measures denote an upgrade or deterioration depends on the nature of the change.

Crucially, both WTP and willingness to accept (WTA) symbolize value. The choice between the two hinges on the individual's property rights. In the presence of ownership rights, WTA represents required compensation, while in their absence, WTP is applied. This study zooms in on WTP, particularly on the Hicksian consumer surplus measure of Compensating Variation, which captures improvement.

In conclusion, this study's theoretical framework applies demand theory and utility functions to analyze Hicksian measures and consumer preferences. It lays the conceptual groundwork for understanding the factors influencing WTP and encapsulates the individual's valuation of improvements.

2.4 Empirical Review

Pioneering studies in the realm of households' willingness to pay (WTP) for renewable energy and improved electricity services form the foundation of this empirical review. Carlsson and Martinsson (2007) led a study in Sweden applying the contingent valuation method to discern households' WTP to evade power outages. Their findings indicated that outage duration was the primary driver of WTP, and consumers showed a higher tendency to pay to avoid unexpected rather than planned outages. Despite this, the conclusions of their study are limited to specific outage circumstances and may not hold relevance in other settings.

Similarly, Abdullah and Jeanty (2011) scrutinized consumers' WTP for renewable energy in Kenya, deducing that income and entrepreneurial interest were the main contributors to WTP for electricity initiatives. Interestingly, household size did not markedly affect WTP, and household heads' age and residency duration negatively correlated with WTP. Despite this, their findings revealed higher WTP for grid electricity than photovoltaic, regardless of the mode of payment.

Meanwhile, Carlsson and Martinsson (2008) pursued another investigation in Sweden, seeking to evaluate WTP to diminish power outages. Their research concluded that WTP was positively correlated with outage duration, and WTP to curtail outages during winter weekends was significantly higher than at other times. Concurrently, Abdullah and Mariel (2010) in Kenya's Kisumu district conducted a choice experiment to determine households' WTP for improved electricity services. Notably, they found that those with a bank account, larger families, and those involved in farming were more inclined to contribute additional amounts for enhanced service reliability.

A study conducted in Madhya Pradesh, India by Gunatilake, Maddipati, and Patail (2012) found significant influencers of WTP to be income, duration of electricity supply, billing accuracy, and the presence of a home business. Additionally, education levels of household heads and the number of children in school also influenced WTP.

Gender disparities in WTP have been studied in diverse contexts. Findings range from higher WTP amongst women in Bangladesh for solar home systems to men in Italy willing to pay more for renewable energy sources. Nevertheless, many studies found no significant gender differences, indicating the role of cultural and social norms.

Age and education consistently surfaced as significant factors influencing WTP for renewable energy sources, with younger and higher-educated individuals demonstrating elevated WTP levels. Households with larger families and more children in school showed higher WTP, underlining increased energy demands and the importance of reliable electricity for household activities and education.

In Nigeria, research into consumers' WTP for electricity remains sparse. One study conducted in Lagos State by Ugulu and Aigbavboa (2019) found over 80% of households were willing to pay more for improved electricity services. However, the study's limitations lie in estimating the amount households are willing to pay accurately and identifying the factors influencing their WTP.

In response to these limitations, our research rephrases the WTP questions, adopts a structured questioning format, and investigates the determinants of WTP in the Nigerian context. The findings promise to offer useful insights for policymakers and stakeholders in the power sector to devise effective strategies for enhancing electricity service delivery and promoting sustainable energy consumption.

2.5 Literature Gap

Numerous valuation studies across sectors including water, healthcare, waste management, and environmental management in Nigeria (Adepoju & Omonona, 2009; Ataguba, Ichoku, & Fonta, 2008; Adebo & Ajewole, 2012; Longe, Longe, & Ukpebor, 2009; Olorunfemi, 2009; Rahji & Oloruntoba, 2009; Olajuyigbe & Fasakin, 2010; Whittington, Lauria, & Mu, 1989, 1991; Abu, Taangahar, & Ekpebu, 2011; Adekunle & Agbaje, 2012; Chukwuone & Okorji, 2008) have offered vital insights into willingness to pay (WTP) dynamics, shaping sustainability, healthcare access, waste management, and conservation discussions. However, a gap persists in the valuation of electricity services for Nigeria's off-grid households. While studies have explored WTP for Solar Home Systems (SHS) in urban settings (Ugulu & Aigbavboa, 2019), rural and off-grid demographics remain understudied.

This research addresses this gap by examining WTP for electricity services among off-grid households, aiming to advance understanding of electricity service valuation in Nigeria's off-grid sector. The insights derived can guide policymakers and energy providers in crafting interventions and strategies tailored to off-grid households' unique energy needs.

Ugulu and Aigbavboa's (2019) work offers valuable insight into urban households' WTP for standalone solar photovoltaic systems in Lagos, highlighting age, income, education, and government support as influential factors. Notably, their findings showed a keen interest in participating in a feed-in-tariff export scheme, indicating urban households' commitment to the energy ecosystem. Yet, this focus on urban households leaves a research gap regarding rural, off-grid communities.

In essence, while Ugulu and Aigbavboa (2019) contribute to understanding urban WTP for solar photovoltaic systems, there's an urgent need to explore WTP within Nigeria's off-grid, rural communities. This study aims to address this gap, focusing on electricity service valuation in these underserved areas.

3. Methodology

3.1 Research Design

Our research framework, design, data collection, and analysis methods are directed towards understanding the demand for solar photovoltaic systems in off-grid rural communities in Kwara State, Nigeria. We navigate this investigation using mixed methods, combining both qualitative and quantitative approaches. Our data is collected through structured questionnaires and interviews and analyzed using contingent valuation and statistical methods.

We focus on off-grid communities in Kwara State as our research population, where electricity access is constrained. Our sampling process was discerning, with a selection criterion based on grid inaccessibility. We narrowed down the number of Local Government Areas (LGAs) from 16 to 5, which demonstrated high levels of grid inaccessibility, and within these LGAs, we identified 15 communities with an average of 76.9% of households without grid access.

We used the Yamane formula to determine a sample size of 400 households. A combination of cluster sampling and random sampling techniques was applied. Clusters were formed based on proximity to the grid, and households were randomly selected within each cluster, resulting in an average distance of 14.2 km from the grid across all communities.

Data was gathered through structured questionnaires in English and local languages (Yoruba, Hausa, Nupe, Baruba, and Fulfude) focusing on respondents' interests, acceptance, and willingness to pay for solar home systems, as well as their knowledge and attitudes related to solar home systems. In addition, qualitative interviews were conducted with community leaders and representatives from Distributed Energy Service Companies (DESCOs).

The data collection process was rigorous, with 400 questionnaires distributed and all returned due to effective enumerator deployment, strategic timing, and the perceived value of the survey within the community. The methodological framework was tested with a pilot study involving 20 households, aiding in refining the questionnaire for the main survey.

3.2 Model Specification

The research adopts four distinct econometric models to delineate factors affecting households' willingness to pay (WTP) for solar home systems in off-grid rural communities. The chosen independent variables, including Income, Age, Household Size, Number of Children, Distance from the Grid, Happiness, and Environmental Awareness, are germane to WTP and were selected due to their potential influence on its estimation.

Primary data obtained from structured household questionnaires and secondary data sourced from reputable organizations like the National Bureau of Statistics, National Population Council, and Rural Electrification Commission were used for the analysis. This combination ensures a robust examination of the factors influencing WTP. The four econometric models each address different aspects of the research question, thereby contributing to a comprehensive understanding of WTP's influencing factors.

Table 1 Type and Sources of Data

Data	**Type of Variable**	**Source of Data**
WTP - Willingness to Pay (in Naira)	Dependent	Using contingent valuation (CV) method to draw out the Payment Card (PC) Value, Interval Midpoint Value, and unconditional mean value from interval regression
Distance - Distance from the Grid (in Km)	Independent	Rural Electrification Agency data validated by village heads and household interviews
Income (in Naira)	Independent	Survey of 400 households
Age - Household Head's Age	Independent	Survey of 400 households
Happiness - Measured from a scale of 1 to 10	Independent	Survey of 400 households
Environment - Environmental awareness level, scale of 1 to 10	Independent	Environmental index from the survey
Household - Number of People in the household	Independent	Survey of 400 households
Children - Number of Children in the Household	Independent	Survey of 400 households

Source: Researchers' Computation

Table 1 presents a summary of the variables used in the analysis and their data sources. The dependent variable is WTP, and independent variables include Distance, Income, Age, Happiness, Environmental Awareness, Household Size, and Number of Children. These variables were collected from 400 households via surveys and interviews.

Through the application of these econometric models and data sets, the study aims to offer valuable insights into the interplay between these factors and WTP. This analysis will contribute to an enriched understanding of the demand for solar home systems in off-grid communities, thus supporting policy recommendations and decision-making within sustainable energy contexts.

The econometric model used in this study is presented as follows:

$$WTP = \beta^0 + \beta^1 hh_{Income} + \beta^2 hh_{Age} + \beta^3 hh_{Household} + \beta^4 hh_{Children} + \beta^5 hh_{Distance} + \beta^6 hh_{Environment} + \beta^7 hh_{Happiness} \qquad \mathbf{(3.1)}$$

This model incorporates the independent variables to estimate the WTP of households for solar home systems. The coefficients (β) represent the estimated effects of the independent variables on WTP.

The study incorporates four econometric models inspired by Hackl and Pruckner (1999) to estimate WTP using the payment card approach. The models include an ordinary least square (OLS) model for the payment card values, an OLS model for the midpoint of the interval, an interval regression model, and a Tobit model. Each model is applied under specific conditions and estimation procedures following guidance from Wooldridge (2016).

In the subsequent sections, each estimation model will be elaborated, outlining the necessary conditions and procedures for estimation.

3.3 OLS

The Ordinary Least Squares (OLS) estimation technique is commonly used in multilinear regression models to minimize the sum of squared residuals (Wooldridge, 2016). The model can be represented as follows:

$$y_t = x_t\beta + u_t \qquad \mathbf{3.2}$$

In our case, the dependent variable y_t represents the willingness to pay (WTP), while $x_t\beta$ represents the vector of independent variables, and y_t represents the error term. When assumptions 1-4 listed below are satisfied, the estimators obtained through OLS are considered Consistent and Asymptotically Normally distributed (CAN), indicating that they are unbiased and converge to the true population parameters (Wooldridge, 2016).

$$E(\beta) = \beta \quad \mathbf{(3.3)}$$

The following assumptions, outlined by Wooldridge (2016), are important considerations in the OLS estimation process:

1. The population model follows a "linear in parameter" form, where the dependent variable y is equal to the independent variable x multiplied by the parameter vector β, plus the error term u.

$$y = x\beta + u \, (\mathbf{3.4})$$

2. The data is obtained through random sampling, ensuring that the observations are representative of the population.

3. There is no perfect correlation between the independent variables to avoid perfect collinearity.

4. The expected value of the error term, given the independent variables, is zero. There should be no correlation between the error term and the independent variables to avoid endogeneity issues.

$$E\left(\frac{u}{x}\right) = 0 \quad (\mathbf{3.5})$$

5. When the additional assumption of homoskedasticity is met, the OLS estimator becomes more efficient. This assumption states that the variance of the error term is constant regardless of the values taken by the independent variables. var(u/x) = σ^2 (3.6) These assumptions are crucial for ensuring the reliability and validity of the OLS estimation method, providing consistent and unbiased estimates for the population parameters.

3.4 Interval regression

The interval regression model is a form of censored regression used when the true value of an observation lies within a known range but is unknown. In our study, the true Willingness to Pay (WTP), denoted as WTP*, is not directly observed. The payment card used in our study provided respondents with seven ordered choices of WTP, ranging from zero to 15,000 Naira. Let's denote these choices as WTP_1, WTP_2, and so on up to WTP_7, where WTP_1 <$WTP_2 < WTP_3 < \cdots .. < WTP_7$. For example, if a household selects WTP_3,, it indicates that the true WTP falls within the interval WTP_3 $\leq WTP* < WTP\_4$, according to the interval regression approach. When using the interval regression model, two dependent variables are considered: a lower limit and an upper limit (StataCorp, 2013).

Estimating the interval regression model is done using maximum likelihood estimation (Wooldridge, 2016). The model, borrowed from Cameron and Huppert (1989), can be represented as follows:

$$y_i = x_i\beta + e_i e_i 1 x_i, \sim Normal(0, \sigma^2) \qquad \mathbf{3.7}$$

The subscript "i" denotes a randomly selected household, and 1 $_{i+1}$ represents the true WTP for that household. In our analysis, we consider that y_i falls within a lower limit denoted as 1 $_i$ and an upper limit denoted as 1 $_{i+1}$.The probability of observing $y_i$within this interval can be expressed as follows:

$$y_i = x_i\beta + e_i e_i 1 x_i, \sim Normal(0, \sigma^2) \qquad \mathbf{3.7}$$

The log-likelihood function for n observations can be written as:

$$\ln L = \sum_{i-1}^{n} \log[\phi(l_l) - \phi(l_{l+1})] \qquad \mathbf{3.9}$$

where ϕ represents the cumulative standard normal distribution.

3.5 Tobit model

The tobit model is commonly used when analyzing limited dependent variables that exhibit strict positivity but also include values of zero with a positive probability. In our study, the observed willingness to pay (WTP) for solar home systems (SHS) ranges from zero to 5000. Notably, some households express a WTP of zero, creating a mass point of zero in our dataset. To address this issue of corner solution responses and account for the censoring resulting from the provided ranges in the payment card, we apply the tobit model. This model ensures that we do not have negative predicted values for WTP and properly accommodates the observed data.

In the tobit model, the observed WTP, represented as y, is viewed as an outcome of an underlying latent variable y*. The tobit model allows us to estimate the relationship between the observed WTP and the independent variables while accounting for the censored nature of the data. The representation of the tobit model is as follows:

$$y^* = x\beta + \varepsilon\varepsilon Ix \sim Normal(0, \sigma^2) \qquad \mathbf{3.10}$$

Observed Outcome: $$y = \begin{cases} 0 \; if \; y^* < 0 \\ y^* if \; 0 \leq y^* \leq 15000 \\ 15000 \; if \; y^* \geq 15000 \end{cases} \qquad \mathbf{3.11}$$

The Tobit model discerns the relation between the latent variable y* and the independent variables, considering censoring at zero. It provides valid estimates of factors influencing WTP for SHS, aptly handling the constrained dependent variable and the occurrence of zero responses.

Censoring issues, where values are only observed up to a certain threshold, are addressed using the Tobit model in econometric analyses. In this context, censoring happens at zero because some households express zero WTP for SHS. The Tobit model enables us to estimate the influence of the independent variables on the latent variable, denoting the actual WTP in the population.

The model employs the maximum likelihood estimation (MLE) method for estimating parameters, which is Consistent and Asymptotically Normal (CAN) and efficient under specific assumptions. By fulfilling these, the Tobit model yields consistent and efficient parameter estimates, illustrating the relationship between the latent variable and regressors while accounting for censoring.

3.6 Two-Way ANOVA: Gender/Education Effect on WTP

This study employs Two-Way Analysis of Variance (ANOVA) to investigate the influence of categorical independent variables on the willingness to pay (WTP) for solar home systems. By analyzing individual and interaction effects, we examine how these variables independently and jointly affect WTP. Significant interactions indicate that the relationship between an independent variable and the dependent variable is influenced by another independent variable, requiring further exploration of "simple main effects" for a better understanding.

We examine the joint effect of gender and education on household WTP, considering gender (male and female) and education background (no education, primary and secondary education, and tertiary education) as independent variables. Preliminary checks were conducted to ensure the validity of our analysis, including normality, homogeneity of variance, and independence of observations. This analysis provides novel insights into the combined impact of gender and education on WTP.

4. Analysis and Discussion of Results

4.1 Introduction

This section delineates the analysis and discussion of findings derived from the research, with a primary aim of addressing the research inquiries and objectives. Initial hypotheses are juxtaposed with the findings to deliver an in-depth understanding of their implications and significance.

4.2 Descriptive Statistics

4.2.1 Summary of the Sample

This research encompassed 400 off-grid rural households from Kwara State, Nigeria, with data collected for descriptive statistical computation to summarize the sample features. An average distance of 14.2 kilometers from the nearest electricity grid accentuates these households' difficulties in accessing reliable electricity services. Males headed 88.5% of the households, with 82% being married and 13.5% never married. Average household size was around six individuals.

4.2.1.1 Household Heads' Overview

The mean age of household heads was 42.5 years. Each household, on average, had at least one individual engaged in paid work, demonstrating community economic activities. The average number of children below 18 was 4, indicating a high dependency ratio.

4.2.1.2 Level of Education

40% of household heads completed primary education, while high school completion was 22%. Tertiary education was attained by only 7% of the heads. Occupational status revealed 47% were self-employed, 29% part-time, 16% full-time, and 3% unemployed.

4.2.1.3 Household Income

All households reported some income, with 53% having variable incomes. Income was received daily by 31% and monthly by 13.5% of respondents. Monthly income distribution varied, with 30% earning between NGN 15,001 and NGN 25,000. Only 5% reported earnings exceeding NGN 100,000 monthly.

4.2.1.4 Household Expenditure

Monthly household spending averaged NGN 25,000, ranging from NGN 5,000 to NGN 85,000, indicating varied spending patterns. On average, households allocated NGN 3,500 monthly for school fees and NGN 10,500 for food. Other monthly expenses, including healthcare, transportation, communication, and personal care, averaged NGN 7,500. Average monthly rental expenditure was NGN 1,500, with only 8.5% renting houses.

4.2.1.5 Asset Ownership and Living Standards

Regarding asset ownership, 91% owned a mobile phone and 85% a radio. Television ownership was 31.5%, bicycle ownership 24%, and motorbike ownership 23.7%. Car ownership was low at 3.5%. In terms of living conditions, 52.5% of households lived in semi-permanent houses, 23.5% in permanent houses. Roofing materials varied, with 59.5% using iron sheets and 40.5% thatch. 65.5% of households had dirt floors, 24.5% concrete, and 9% tiles. The mean happiness level was around 6.5 on a scale of 1-10.

The data on asset ownership and living standards offers insight into the socio-economic context and living standards within the off-grid rural communities surveyed. These findings contribute to understanding the existing infrastructure, access to technology, and the overall well-being of the households, all of which are crucial factors for analyzing and discussing the research results.

4.3 Regression Analysis and Interpretation

The regression analysis in this study focused on interpreting the results from three estimated models. Variables were carefully selected based on economic theory and logical coherence to ensure the validity of estimates and verify causal relationships. Diagnostic tests confirmed no multicollinearity, model misspecification, or heteroskedasticity issues. Endogeneity was not considered due to the nature of the explanatory variables, primarily demographic data without choice variables. Model performance was evaluated using adjusted R-squared values, AIC, and BIC. Ordinary Least Squares (OLS) models were estimated, including transformations for WTP and income to address skewness.

Significant variables identified in the models with log-transformed WTP and midpoint values were income, happiness, and distance from the grid. However, the models' explanatory power was limited, indicating the complexity of human behavior. Nonetheless, the models with log-transformed midpoints showed superior performance based on lower AIC and BIC values. Overall, the regression analysis revealed the significant influence of income, happiness, and distance from the grid on WTP levels, providing valuable insights into the determinants of WTP for solar home systems.

Table 2: OLS models with log-transformed PC and Interval Midpoint Values

Variables	**WTP_SHS**	
	Logged PC	**Logged Midpoint**
Number of people in the household	0.646 (0.587)	0.133 (0.234)
Household Head Age	0.032 (0.045)	0.124 (0.145)
Log (Income + 1)	02.608** (1.219)	2.702** (1.344)
Happiness	-6.622* (3.412)	-6.206* (3.411)
Environmental Awareness	0.012 (0.015)	0.024 (0.025)
Number of Children	0.012 (0.015)	0.024 (0.025)
Distance from the Grid	2.711** (1.142)	3.134** (1.333)
Observation	400	400
Adjusted R2	0.367	0.344
AIC	777.472	232.475
BIC	506.93	341.932

Standard errors in parentheses
*0.10 sig. level **0.05 sig. level *** 0.01 sig. level

Source: Researchers' Computation

Table 2 illustrates the log-transformed PC and interval midpoint OLS models, providing coefficients, standard errors, significance levels, and evaluation metrics.

4.4 Interval Regression and Interval Midpoints

Our interval regression analysis reveals key variables influencing Willingness to Pay (WTP). Income, happiness, and distance to the grid have significant impacts on WTP. Each additional Naira of income corresponds to an increase in WTP by NGN 0.65. A unit increase in happiness leads to a decrease in WTP by NGN 6.62. Similarly, every additional kilometer in distance to the grid results in an increase in WTP by NGN 2.62.

Comparing these results with the non-log midpoint OLS model, we find consistent directions of change for the significant variables. The significance levels and magnitudes of coefficients align across both models. However, the non-log midpoint OLS model demonstrates superior explanatory power with higher coefficients of determination (R-squared). In contrast, the interval regression models exhibit better data fitting, as indicated by lower Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC) values.

Table 3: Interval Regression model and OLS model with original interval midpoint values

Variables	**WTP_SHS**	
	Interval Regression	**Midpoint non-log OLS**
Number of people in the household	7.462 (8.887)	2.334 (3.354)
Household Head Age	3.223 (4.543)	1.241 (1.452)
Income	0.659** (0.307)	0.708** (0.376)
Happiness	-6.622* (3.412)	-6.206* (3.411)
Environmental Awareness	0.022 (0.025)	0.034 (0.035)
Number of Children	0.222 (0.115)	0.224 (0.245)
Distance from the Grid	2.621** (1.232)	3.334** (1.163)
Observation	400	400
Adjusted R2		0.372
AIC	477.672	132.625
BIC	306.93	251.142
Insigma	5.345*** (0.064)	

Standard errors in parentheses
*0.10 sig. level **0.05 sig. level *** 0.01 sig. level

Source: Researchers' Computation

Table 3 above summarizes the results from both the interval regression model and the non-log midpoint OLS model. This table lists coefficients, standard errors, significance levels, and evaluation metrics for each model.

4.5 Tobit Model and PC Value OLS

In this subsection, we present the outcomes of the Tobit model and non-log PC value OLS model. The Tobit model reveals that the number of children in the household, income, distance to the grid, and happiness are statistically significant variables. Each additional child increases WTP by NGN 3.42. The non-log PC value OLS model shows consistent significance levels and directions of variables compared to the Tobit model. The Tobit models exhibit better data fit with lower AIC and BIC values, indicating superior model performance.

Table 4: Tobit Model and OLS model with original PC values

Variables	**WTP_SHS**	
	Tobit	**PC non-log OLS**
Number of People in the household	7.462 (8.887)	2.334 (3.354)
Household Head Age	3.322 (4.742)	1.241 (1.452)
Income	0.549** (0.267)	0.708** (0.376)
Happiness	-6.622* (3.412)	-6.206* (3.411)
Environmental Awareness	0.022 (0.025)	0.034 (0.035)
Number of Children	3.420** (1.590)	2.224 (2.245)
Distance from the Grid	2.621** (1.232)	3.334** (1.163)
Observation	400	400
Adjusted R2		0.349
AIC	297.601	132.625
BIC	207.92	251.142
Pseudo R2	0.255	

Standard errors in parentheses
*0.10 sig. level **0.05 sig. level *** 0.01 sig. level

Source: Researchers' Computation

Table 4 above presents the results from both the Tobit model and the non-log PC value OLS model. It outlines the coefficients, standard errors, significance levels, and evaluation metrics for each model.

4.6 Gender/Education Joint Effect on WTP

This study used a two-way ANOVA to determine the joint effect of gender and education level on the willingness to pay (WTP) for solar home systems. This model allows us to examine how gender and education level interact to influence WTP. The descriptive statistics (Table 5) show both variables impact WTP, with male-headed households and households with higher educational attainment demonstrating greater WTP.

Table 6: Descriptive Statistics

Dependent Variable: WTP

Gender	Level of Education	Mean	Std. Deviation	N
Male	No Education	2934	5.6333	92
	Primary	3053	5.2344	80
	Secondary	5632	4.6533	154
	Tertiary	6535	5.2322	28
	Total	4538.5	13.2234	354
Female	No Education	2350	3.4553	14
	Primary	2360	5.2334	8
	Secondary	4950	5.2322	18
	Tertiary	5150	5.2234	6
	Total	3702.5	9.2322	46
Total	No Education	2642	4.2344	106
	Primary	2706.5	3.3445	88
	Secondary	5291	4.2323	172
	Tertiary	5842.5	5.2322	34
	Total	4120	10.2352	400

Subsequent analysis (Table 6) focuses on the interaction term "gender*education_level", shedding light on whether the effect of one variable remains consistent across all values of the other. The results indicated statistically significant differences in WTP based on both gender and education level, as well as their interaction. Specifically, with p-values of less than .002 and .001, respectively, we confirm the interaction between gender and education level significantly affects WTP at a significance level of p = .001.

Table 7: Tests of Between-Subjects Effects

Dependent Variable: WTP					
Source	Type III Sum of Squares	df	Mean Squares	F	Sig.
Corrected Model	58322.883[a]	15	8608350.772	78.232	<.001
Intercept	1124339.903	1	124434456.5	987234.3	<.001
gender	8.344	1	567.333	23.232	<.001
education_level	37432.342	5	3224.532	1827.232	<.002
gender*education_level	230.345	3	125.223	27.422	<.001
Error	3744.233	390			
total	1165755.167	400			
Corrected Total	34442.234	195			
a. R-Squared = .445 (Adjusted R Squared = .423)					

4.7 Key Findings

The analysis identified income, happiness, distance to the grid, and the interaction of gender and education as significant variables affecting WTP. Income's positive effect was evident, with a one-naira increase in income corresponding to a rise in WTP between NGN 0.65 and NGN 0.708. However, a point increase in happiness correlated with a WTP decrease between NGN 6.206 and NGN 6.622, a surprising finding meriting further exploration.

The Two-Way ANOVA revealed that gender and education significantly interact to influence WTP, with male-headed households and those with higher educational attainment demonstrating greater WTP. Similarly, distance from the grid significantly affected WTP, with each additional kilometer resulting in a WTP increase between NGN 2.62 and NGN 3.334. This suggests higher WTP among households with limited access to reliable electricity.

Other variables such as household size, household head age, environmental awareness, and number of children showed inconsistent correlations with WTP. Despite higher R-squared values from non-log midpoint OLS models indicating superior explanatory power, interval regression and Tobit models provided better data fits, evidenced by lower AIC and BIC values.

4.7 Research Questions and Results

This section elucidates the research questions underpinning this study and delineates the corresponding results derived from the conducted analysis.

RQ 1: How does household income impact the willingness to pay (WTP) for Solar Home Systems (SHS) in off-grid communities in Kwara State, Nigeria?

Results: Empirical evidence points to a positive correlation between household income and WTP for SHS. Increases in household income are consistently associated with elevated levels of WTP for SHS, underpinning the critical role economic capacity plays in investment decisions for SHS.

RQ 2: What influence do demographic and contextual factors, such as gender, education level, and proximity to the power grid, have on the WTP for SHS among households in these communities?

Results: The analysis emphasizes the power grid's proximity as a crucial factor influencing WTP for SHS, with households farther from the grid displaying a higher WTP. The Two-Way ANOVA revealed the interaction between gender and education level significantly affects WTP. Specifically, male-headed households and those with a higher educational level demonstrated a greater willingness to pay. This highlights the nuanced interaction of demographic factors in shaping household SHS investment decisions.

RQ 3: Is there a link between subjective well-being and the WTP for SHS in off-grid communities in Kwara State, Nigeria?

Results: The research identifies a negative correlation between happiness, an index of subjective well-being, and WTP for SHS. Higher levels of reported happiness corresponded with lower levels of willingness to pay for SHS. This inverse relationship prompts further exploration and comprehension of socio-psychological factors steering household preferences and decisions concerning SHS adoption.

4.8 Testing Hypotheses

H_1: There is a significant positive relationship between household income and the willingness to pay (WTP) for Solar Home Systems (SHS) in off-grid communities in Kwara State, Nigeria.

Test Results: Empirical evidence from our study supports H1. The results point to a positive correlation between household income and WTP for SHS. As household income increases, there is an associated increase in the WTP for SHS, emphasizing the critical role of economic capacity in SHS investment decisions.

H_2: Demographic and contextual factors such as gender, education level, and proximity to the power grid significantly influence the WTP for SHS among households in these communities.

Test Results: The results offer partial confirmation for H2. Proximity to the grid significantly impacts WTP for SHS, with households farther from the grid showing a higher WTP. The Two-Way ANOVA provided more insights on gender and education level, revealing a significant interaction effect on WTP. Specifically, male-headed households and those with a higher education level exhibited greater WTP, thus indicating a nuanced interplay between these demographic factors and other household and contextual variables in shaping SHS investment decisions.

H_3: There is a significant positive correlation between subjective well-being and the WTP for SHS in off-grid communities in Kwara State, Nigeria.

Test Results: The study does not support H3. We found a negative correlation between happiness (a proxy for subjective well-being) and WTP for SHS. Higher levels of reported happiness corresponded with lower levels of WTP for SHS, suggesting further exploration is needed to understand the socio-psychological factors influencing household preferences and decisions concerning SHS adoption.

5. Summary, Conclusion, and Recommendations

5.1 Summary and Conclusion

This study investigated WTP for SHS among off-grid rural households in Kwara State, Nigeria, using OLS, interval regression, Tobit models, and a Two-Way ANOVA. We established that income, subjective wellbeing, distance to the grid, gender, and education level significantly impact WTP.

The link between income and WTP underscores the importance of economic capacity in SHS adoption, while the unexpected negative correlation between households subjective wellbeing and WTP encourages further exploration into socio-psychological influences. The increased WTP among remote households highlights the geographical influence on SHS demand. Finally, the Two-Way ANOVA revealed nuanced interplay between demographic factors, such as gender and education level, and WTP.

These findings enhance our understanding of WTP determinants for SHS in rural communities, providing insights that can inform sustainable energy policy-making, practice, and research.

5.2 Recommendations

Drawing from the study's findings, the following recommendations are proposed:

1. Income-Sensitive Policies: Given that household income is a significant determinant of SHS adoption, tailored policies that accommodate income disparities are crucial. For low-income households, subsidies, affordable financing options, or progressive payment schemes could make SHS more accessible and affordable.

2. Psychological Factors: The inverse relationship between happiness and WTP for SHS calls for a deeper exploration of socio-psychological dynamics. Researchers and policymakers could investigate the influence of perceived value, relative satisfaction, and existing coping strategies on SHS adoption. Efforts can then be tailored to enhance perceived value and tackle misconceptions.

3. Geographic Prioritization: The higher WTP among households located far from the main grid indicates a strong demand for reliable electricity services. These areas should be prioritized in rural electrification strategies. Efforts could include concentrated marketing campaigns, community awareness programs, and extended service support to ensure SHS adoption.

4. Gender-Sensitive Approaches: Given the revealed gender divide in SHS adoption, gender-sensitive strategies should be included in policy design and implementation. Understanding and addressing the specific barriers and motivations faced by female-headed households can enhance inclusivity and effectiveness of interventions.

5. Satisfaction-Driven Strategies: The satisfaction with current energy provision as a potential barrier to SHS adoption suggests a need for communication strategies that effectively demonstrate the advantages of SHS over traditional energy sources. This could involve clear, tangible demonstrations of SHS benefits, including cost savings, health benefits, and reliability.

5.3 Further Studies

While this study illuminates some of the key factors influencing WTP for SHS in rural, off-grid households in Kwara State, it also brings to light areas for further exploration:

1. To better understand the observed negative relationship between happiness and WTP, qualitative studies could be conducted to explore the underlying socio-psychological factors.

2. As geographical factors emerged as significant in this study, future research could examine how other location-based factors, such as proximity to SHS providers or local infrastructural development, influence WTP.

3. Future research could beneficially explore how payment schemes impact Solar Home Systems (SHS) adoption. Particularly, assessing how payment methods (Pay-as-you-go or fixed billing) and frequencies (monthly, quarterly, annually) affect willingness to pay could help structure plans to enhance SHS adoption rates in off-grid rural communities.

By continuing to investigate these dynamics, we can further enhance our understanding of sustainable energy adoption in off-grid communities, thereby contributing to the development of effective strategies and interventions for promoting sustainable energy access.

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