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Determinants of Solar Technology Use as an Electricity Source: The Case of Households in Off-Grid Areas of Ethiopia: A Country-Level Analysis

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Abstract

Access to electricity through solar technology is of utmost importance in Ethiopia, a country where more than half of the households lack access to electricity. The objective of this research is to pinpoint the key factors influencing the uptake of solar technology devices on a national level in Ethiopia. The study relies on data from 907 households in Ethiopia that are not connected to the main grid (off-grid) using the World Bank's Global Survey data on energy access. The households are selected from all regions of Ethiopia using a proportionate random sampling method. The study employed the two-step Heckman sample selection model to examine the sequence in which households have access to an electrical source prior to utilizing solar technology equipment. The location of households (rural), educational level (high school graduate), ownership and size of agricultural land ($P<0.01$), and market visit ($P<0.1$) all have a significant impact on the adoption of solar technology. Similarly, market visit and location have a significant impact on electricity access ($P<0.05$), while saving in banks has a significant impact on both electricity access and solar technology adoption ($P<0.01$). In order to accelerate the achievement of universal access to electricity in Ethiopia, it is important to target rural households with specific socio-economic conditions, coupled with utilizing off-grid alternatives like certified solar technology devices. Additional research is needed to assess the adoption of solar technology, particularly in areas already connected to the main grid, and to formulate comprehensive and inclusive policies involving multiple stakeholders.

Key words: Solar device use, access to electricity, Adoption, Grid, Heckman Selection

Introduction

Africa is home to around 39% of the world's renewable energy potential, the most of any other continent, and it isbelieved that renewable energy capacity in Africa could reach 310 GW by 2030 (IRENA and AfDB 2022). However, population growth in Africa continues to outpace new access to electricity, with an estimated 560 million Africans still without access to electricity in 2030. Access to electricity needs to be three times faster in Africa's cities and four times faster in remote areas to reach SDG 7. (AEFR, 2023) Almost half of Africans without access to electricity today live in the Democratic Republic of the Congo (DRC), Ethiopia, Nigeria, Tanzania, and Uganda (IEA, 2022).

Ethiopia, one of the sub-Saharan African countries, has an annual exploitable electric energy potential of 7.5 Petawatt hours (PWh) from solar energy, 4 PWh from wind energy, and 0.2 PWh from hydroelectric energy (Gudina et al., 2014). Given the average irradiation of 5.5 kWh/m2/day in Ethiopia, stand-alone solar PV systems could represent a cost-effective way to provide the benefit of low-cost electricity (Lemma, 2014). These benefits contrast with the current utilization of the off-grid potential and access of the country. The aggregate power generation capacity of the country from all sources amounted to 5,589 MW. Hydropower provided 86% of total capacity, whereas solar power contributed 0.4% (20 MW) despite its potential (IEA, 2022).

As a result,of the mismatch between the potential and actual production a majority of households (57%) in Ethiopia depend only on a single energy source. Among these households, 23.9% rely on off-grid power, while 33.1% of Ethiopian households have access to electricity through the grid. It is estimated that over 43% of Ethiopia's population lacks access to electricity (Padam et al., 2018). Furthermore, according to Getachew et al. (2018), 31% of rural families rely on kerosene for their main lighting, while 36% make use of electric batteries. Despite the existence of the main-grid energy infrastructure, there are still a number of households that are not connected to the electrical grid.

To address the difficulty of power access, the Ethiopian government announced the National Electrification Program (ENEP) in November 2017, with the goal of achieving universal energy access by 2025, in accordance with SDG 7. The plan is for 65% of the population to be connected to the grid and 35% to use off-grid technology like solar panels and mini-grids (ENEP, 2017). In 2025, the off-grid expansion effort will target the remaining 5.7 million households to achieve NEP's universal access goal (NEP2.0,2019).

However, traditional grid expansion, which has been the primary method of electrification in nearly all countries globally including Ethiopia, has significant limitations in securing access to electricity supply. Centralized grid-based electrical systems frequently fail to extend their reach to rural locations and typically cater exclusively to privileged groups, leaving many impoverished individuals, households, and businesses without access (Karekezi, 2002; Palit, D.; Chaurey, 2011; Winther, T., 2012).

United Nations Environment Programme (UNEP) during 1989 coined the term “Cleaner Production” and states that “… the continuous application of an integrated preventive environmental strategy applied to processes, products, and services to increase overall efficiency and reduce risks to humans and the environment” (Power, 2018). In line with this the rapid growth with solar photovoltaic technologies has been continuously fulfilling increasing energy demand, although technical barriers of low cell efficiency, high upfront cost, lack of financial mechanism and effectively low performance kept the research community to think beyond (Few et al., 2019).

As a result, the study focuses on households in which centralized grid-based electrical systems typically fail to provide multiple advantages to many disadvantaged persons, households, and businesses who live in remote places from the main grid.

The contributions of this paper to the existing body of knowledge are, first, that no such electricity access and solar technology adoption study has been carried out using large nationally representative household datasets from all the regions of Ethiopia. Secondly, a Heckman probit selection model has been used to identify the determinants of households on access to electricity sources and use of solar technology devices sequentially, using representative data from more than 900 households. Thirdly, in the past, not much literature has focused on the access to electricity and adoption of solar technology devices, dedicated only to studying household characteristics that live in places where no main grid is available. Few empirical studies on solar technology adoption in Ethiopia have targeted rural households or specific regions (Yibelta et al., 2021; Guta, 2018; Guta, 2020; Abebe D. et al., 2023; Mekuria, 2016; and Amare et al., 2023).

In addition to a thorough examination of the literature pertaining to solar technology studies carried out in Ethiopia and other developing countries,we have reviewed the theories of adoption and energy transition to gain a better understanding of the findings and research gaps of the study in the following sections.

Theory of Adoption and Energy Transition

Given the above facts within the scope of this section, the factors that influence the demand for solar energy technology in rural households are of particular interest. So far, the theory of consumer behavior in economic decision-making has been well researched. The choice to adopt solar PV at the home level is influenced by the theory of consumer behavior in economic decision-making. Rogers (2003) argues in his theoretical model of diffusion of innovations that the adoption of an invention, such as solar PV in this study, may be seen as an "innovation-decision process" that consists of many distinct phases, one of which is the choice whether to accept or reject the innovation.

The hypothesis argues that potential adopters become interested in new innovations as they gather information about them, and their knowledge influences whether they choose to accept or reject the technology. In addition to information, several behavioral, social, technical, financial, and socioeconomic aspects have a role in influencing the decision to accept innovation (Rogers, 2003). This theory offers a valuable structure for analyzing the factors influencing the adoption of solar PV in homes, and it has been extensively utilized in academic research (Qureshi et al., 2017; Palm, 2016).

On the other hand, researchers frequently make use of two primary theories in order to explain the energy transition process and the energy choices made by households. These theories are known as the "energy ladder" and the "energy stacking" [Campbell BM et al., 2003; Heltberg R, 2004]. According to the energy ladder (fuel switching) concept, when households are presented with a variety of alternatives for energy consumption, they move from one kind of fuel to another as their income level grows [Hosier RH and Dow J, 1987]. The model places home energy sources into three distinct levels, beginning at the bottom of the energy ladder and working its way up to the top: 1) Primitive, which consists mostly of fuelwood, agricultural leftovers, and dung cakes; 2) Transitional, which includes charcoal, kerosene, and coal; and 3) Advanced or modern, which includes electricity, liquefied petroleum gas (LPG), biogas, and other forms of biofuels [Hosier RH and Dow J., 1987).

The energy ladder model posits that a household's income level is the primary factor influencing the energy decisions they make. Researchers often study energy consumption patterns in households of varying income levels by examining the "energy ladder" concept. This theory proposes that as families enhance their socioeconomic status, they transition from less efficient, inexpensive, and more polluting technologies such as dung, fuel wood, and charcoal to more sophisticated alternatives(Baldwin, 1986).

However, the energy-stacking model proposes that household energy choices and transitions in developing nations may not necessarily follow a sequential progression from one energy source to another, unlike the energy ladder model. According to this approach, households should vary their energy sources and use "multiple fuels" regardless of their financial level (Masra et al., 2000). Households utilize several fuels to improve energy efficiency and take advantage of synergies between traditional and modern fuels(Kebede etal2024;Narinaetal 2008). According to the energy stacking model, families do not quickly shift the fuels they use based on their income. Instead, changes occur gradually due to complex interactions including economic, technological, and social variables (Muller C, Yan H, 2018).

With the emergence of the energy stacking model challenging the traditional energy ladder model and an increasing amount of empirical research showing that households' energy choices are influenced by various social, economic, and cultural factors, it is now common to analyze household energy decisions from multiple perspectives. (Masra et al., 2000).The complex nature of energy switching processes implies that other factors other than wealth may impact energy usage (Ishola et al., 2023).

Literature Review

Research indicates that technology developers and implementers must consistently evaluate the obstacles, motivations, and ongoing awareness linked to the adoption of new technologies. Inadvertently, acknowledging technological advancements may inadvertently generate additional challenges that hinder adoption, which further demands a periodic review of technology adoption.(Salim et al., 2019; Sovacool et al., (2019). Despite various improvements and updates in solar technology, the issue remains: how can we improve the adoption of solar technology among households? What are the determinants of solar technology adoption in a specific nation, given its different socioeconomic and cultural context? In answer to these questions, several researchers had conducted investigations in various nations, including the followingliteratures:

Sylvia M. et al.'s (2018) study of Uganda's National Electrification Survey found that flexible payment mechanisms are positively associated with solar home systems and kit adoption. However, influential people were insignificant, and grid access negatively impacted the adoption of both systems. They argued that rural residence, income, and house type were significant drivers of solar PV adoption. Education attainment was positive but insignificant for the type of solar PV adopted. In addition, the gender of the household head was also significant for solar kit adoption. They recommended policy interventions that focus on affordability and recommended that solar companies continue offering flexible payment options to rural households.

The 2021 research by Yibeltal T. examined the energy choices of rural households in southern Ethiopia, specifically on cooking and lighting. He examines the factors influencing rural households' choices on sources of energy for cooking and lighting in southern Ethiopia based on data from a cross-sectional survey including 660 households. He found a significant relationship between household cooking fuel choices and factors such as distance to wood sources, household size, income level, and location.In addition, he realized the fact that wealthier households were more likely to use cleaner fuels, while poorer households used kerosene and dry-cell batteries.

Guta's (2020) study on energy-efficient and renewable energy technologies in central Ethiopia found that wealthy households are more likely to adopt these technologies due to their financial resources. Factors such as household size, assets, education level, participation in off-farm income-generating activities, membership in local cooperatives, and access to financing also influence the adoption of these technologies. Guta's 2018 study in Woliso, Oromia region also found that wealthy and educated households are more likely to adopt solar energy technologies, with female-led households embracing it more than male-headed ones. He recommends policymakers focus on household wealth, education, and awareness to encourage rural households to adopt these technologies.

Jann Lay et al., (2013) Conducted a study on households' choices of lighting fuels in Kenya, focusing on the adoption of solar home systems (SHS)a device which is a small, stand-alone system that generates electricity from the sun and stores it in a battery for use at night or on cloudy days. The objective was to provide new evidence on factors influencing the use of decentralized and less carbon-intensive energy sources in developing countries. The study uses a representative survey from Kenya and finds that income and education are key determinants of SHS adoption. Interestingly, the presence of SHS in the proximity of a potential user increases the likelihood of adoption. Contrary to expectations, there is no negative correlation between grid access and SHS use.

Mohd Irfan'set al., (2018), study examines the influence of entrepreneurship on the adoption of solar photovoltaic technology among Indian households. The research, based on 1551 households, found that entrepreneurship positively influences the likelihood of adopting solar technology. The study also found that the likelihood increases with family size, rural residence, and casual workforce, while decreases with age, income, and higher caste. The findings suggest several implications to promote higher adoption rates of solar photovoltaic technology among Indian households.

DongyingSuna'set al., (2024)study entitled Decoding the shift: Assessing household energy transition and unravelling the reasons for resistance or adoption of solar photovoltaic on home energy transition in Ghana shows that household values, attitudes, and factors including cost implications, performance expectancy, technological complexity, and market design are significant barriers to the adoption of solar photovoltaic (SPV) systems. Energy independence, cost savings, peer influence, and environmental considerations are crucial factors driving the adoption of solar photovoltaic systems in Ghanaian households. This study offers unique insights on home behavior in Ghana's energy sector, emphasizing the potential for solar PV systems to become the primary renewable energy source by the middle of the century.

The study conducted usingthe stage model , which is the model for developing behavioral interventions, onthe process of solar photovoltaic adoption by residential households in the Philippines by Nogin Bunda et al.,(2023) examines the process of solar photovoltaic adoption among residential households in the Philippines using the stage model, focusing on the transition from no interest to installation. It highlights the importance of understanding the benefits of solar energy, financial barriers, and knowledge and informational barriers in influencing adoption. The findings suggest that emphasizing the return on investment and selling excess energy could increase the likelihood of households fully adopting solar panels. The results provide insights for policymaking and the development of tailored marketing strategies to promote solar energy adoption in residential households in the Philippines.

Abdoulganiouret al., (2023) examine the adoption of solar PV systems in rural Burkina Faso, a sub-Saharan African country. The research, involving 6300 households, found that rural households engaged in economic activities are more likely to adopt solar PV systems. The adoption of solar PV technology is strongly associated with household head age, gender, family size, and education. The findings suggest that financial support and micro-credit should be targeted more to increase energy diversity in rural households.

The study by Aarakitet al., (2021) found that Uganda has potential for increased solar photovoltaic (PV) adoption, but its uptake is relatively low. The research used data from the 2018 National Electrification Survey to analyze factors influencing households' choice of solar PV systems. The study found that flexible payment mechanisms were positive for solar home systems and kits, while influential people were insignificant. Grid access negatively impacted the uptake of both solar kits and home systems. Rural residence, income, and house type were significant drivers of the solar PV type adopted.attainment was positive but insignificant for the type of PV adopted. Policy interventions should address affordability and solar companies should continue offering flexible payment options to rural households.

The Abebe D. et al., (2024) study explores the socioeconomic impacts of solar home systems in rural Ethiopia, particularly in the Amhara region. They examined the socioeconomic impacts of pay-as-you-go (PAYGO) and found that the use of PAYGO SHS does not significantly impact household income but reduces monthly energy expenditure. It also positively influences school-aged children to study at night, improves the health of family members, enables women to reallocate their time, and enhances safety and security. The document suggests that wider dissemination of SHS to target populations will require more effective intervention and marketing efforts.

Alemu Mekonnen et al.'s (2023) study on the adoption of solar lanterns in rural Ethiopia highlights the importance of subsidies in promoting their use. The study used a Becker-DeGroot-Marschak (BDM) bidding mechanism to analyze the impact of subsidies and information on adoption rates. The findings indicate that higher subsidy levels increased the adoption rate, while information about benefits did not significantly affect adoption rates. Households with grid electricity were less willing to pay for solar lanterns, suggesting that universal electricity and clean energy access may not be achieved without subsidizing household-level solar lighting.

Amare et al.,(2023) conducted a study entitled Climbing up the ladder: households' fuel choice transition for lighting in Ethiopia. The research paper discusses how factors like education, fuel costs, and location are positively influencing households' transition to cleaner fuel sources for lighting in Ethiopia. The study shows that as household income rises, the likelihood of choosing cleaner fuel sources also increases. Investments in education can boost household productivity and incomes, leading to a quicker adoption of cleaner fuels. Understanding and addressing these determinants are crucial for promoting sustainable lighting practices in developing nations.

2. Research Methodology and Sampling

2.1 Research Methodology

2.1.1 Study Area and Data source

This study, with a cross-sectional design, has been conducted using World Bank data from the Global Survey on Energy Access. The Energy Sector Management Assistance Program (ESMAP), which Had been launched in 17 countries across Africa, Asia, and Latin America, supports the data collection. The Ethiopian national energy access survey was launched as one of the global surveys to collect data on household-level energy access and usage in developing countries.

Ethiopia is a historical country located in the Horn of Africa, bordering Kenya, South Sudan, Eritrea, Djibouti, and Somalia. Geographically, Ethiopia extends from 3° 24′ to 14° 53′ of northern latitude and from 33° 00’ to 48° 00' of eastern longitude. It has approximately 1.1 million km^2 of landmass [AFDB, 2021]. and its altitude ranges from 125 m below sea level to 4533 m above sea level (I.B. Friis et al., 2010).
By the constitution of 21 Aug 1995, Ethiopia was reorganized into nine ethnically-based regional states (kilil): Afar, Amhara, Benishangul-Gumaz, Gambela Peoples, Harari Peoples, Oromia, Somali, Southern Nations Nationalities and Peoples, Tigray; with two separate self-governing administrations (astedader akabibi) in: Addis Ababa capital city, and from 2004, the Dire Dawa chartered city. The regions and the city administrations were further subdivided into 73 zones, 731 woredas, 10 sub-cities in Addis Ababa, and 14,850 rural and 1,478 urban kebeles. The Multi-Tier Framework (MTF) Energy Access Household Survey in Ethiopia was conducted across all the regions in the country, including both rural and urban grid and off-grid areas, for the development of a baseline to track progress toward the achievement of universal access (NEP2.0,2019). The Global Survey on Energy Access conducted in Ethiopia is a full-scale national survey of the energy access, electricity source, and utilization in both grid and off-grid areas of both urban and rural representative households across Ethiopia.

2.1.2Sample size and Technique

The data were representative at the national, urban, rural, and provincial levels. The household sample selection was based on a two-stage stratification strategy, with equal allocation between urban and rural areas and equal allocation between electrified and non-electrified households. During the first stage of sampling, a total of 337 enumeration areas were selected based on probability proportional to the size of the total enumeration areas in each stratum (urban and rural) of each region. The first stage of sampling entailed selecting primary sampling units, or CSA enumeration areas.

For the rural sample, 151 enumeration areas were selected from all regions of the country. A total of 186 enumeration areas were selected for urban areas in the country. The MTF survey was conducted on households across 11 regions in Ethiopia. These 11 regional states are divided into zones, districts, and kebeles in urban areas or peasant associations in rural regions (local government units) in order by the Ethiopian Federal Democratic Republic. The 1991 government transition separated Ethiopia into nine semi-autonomous regional states, one federal capital (Addis Ababa), and one special administrative division (Dire Dawa)based on ethnic, linguistic, and cultural identity.

The entire sample comprises 907 households, which indicates that they cannot connect to the main grid because of their geographical distance among the complete sample of 4317 households. Using this, households conducted in-depth research in both rural and urban locations throughout all Ethiopian regional states to examine the distinctive socio-economic characteristics of households that adopt solar technology as an electricity source.

2.2 Analytical approach and Model Selection

2.2.1 Theoretical framework

Access to electricity and the decision to use solar technology for lighting are modeled as a two-step process in which access to electricity comes first, followed by the adoption of solar technology. Households' decision to use the solar technology only occurs when the expected utility with participation (U_{qi}) is greater than without participation (U_{ri}) i.e$U_{qi}>U_{ri}$. The utility function provided by $U_{qi}$and $U_{ri}$and ahouseholds' decision reveals what gives the ithhousehold the highest utility. Following the random utility maximization theory, the utilityfrom the two alternatives are$U_{qi}= \beta_{qi}X_{qi}+ \varepsilon_{qi}$and $U_{ri}= \beta_{ri}X_{ri}+ \varepsilon_{ri}$. Where $X_{qi}$and X_{ri}represent socioeconomic factors, households' characteristics,andexternalsupportfactorsthatinfluencehouseholds'decisiontouse the Solar technology devices for lighting,β_{qi}andβ_{ri}areparameterstobeestimatedandε_{qi}andε_{ri}aretheerrortermsassumedtobeindependentandidenticallydistributed (W. H Green ,2002)

2.2.3 Empirical Model Selection

In this study, the dependent variables which are both access to electricity source for lighting and use of a solar technology are dichotomousnecessitates the use of selection model. Heckman sample selection model is used to analyses the data because of its accurate and appropriate statistical method, and referred to a probit model with sample selection. The model is a two-step method used to estimate a sample selection when the two dependable variables are dichotomous. The model is akin to a censored probit or double probit model or bivariate probit model with selection. Notably, the use of solar technology was dependent on the households' access to electricity source for light; hence, it was necessary to account for selectivity bias, as the sample used for the analysis solar technology use is non-random and must be distinct from the sample for the study of access to electricity source.

In such cases, a Heckman probit model with sample selection is preferred in order to correct for selectivity bias since households with and without access to electric city source may have different likelihoods of using solar technology device. Various researchers such as Van den Broeck and et.al. (2013),Deresa et al., Asrat P and Simane (2017a) also used Heckman probit in different setting foranalyzing probit with sampleselection accounting for selectivity bias.

The model is appropriate for the study; first, because the two dependent variables are dichotomous in nature. Second, the model allowed the ascertainment of the two steps leading to household`selectricity source adoption in a single model, in addition to taking into consideration the choice ofelectricity sources leading to solar technology uses.(Heckman, 1979;Van De Ven and Van Praag, 1981,Florence et.al, ,2023).

As a result, in this paper, a Heckman probit model is used to jointly estimate the probability of access for the electricity source and use of solar technology devices and to control for selection bias. It consists of a selection equation (the electricity source access stage) and an outcome equation (the solar technology use stage) (Wooldridge, 2009).

y_1=1if[αX+βZ+s>0](Access to electricity stage)

y_2=1 if[γX+u>0] $and y_1$=1 (Use of SolarTechnology Device$stage$)=0,$otherwise$

Access to electricity is the first dependent variable (y_1) indicating whether the householdhas access to electricity source(value = 1) or not (value = 0). Two alternative variables are used for the second dependent variable (y_2) since it is defined as use of Solar Technology Device(value = 1) or not used (value = 0). The model detailcan be expressed as follows:

$Z = \alpha_0 + \alpha_1 X_1 + \alpha_2 X_2 + \alpha_3 X_3 + \alpha_4 X_4 + \alpha_5 X_5 + \ldots . \alpha_n X_n + u_2 \ldots$ 4

Equation (4) is the second stage Heckman probit sample selection model which represents theoutcome equation, where Z is the dependent variable which represents the probability ofthe use of solar technology devices .$\alpha_1 \alpha_2 \alpha_3 \alpha_4 \alpha_5$ and α_n are the coefficient that will beestimated, while examining the factors affecting households use if solar technology ,$X_1 X_2 X_3 X_4 X_5$.........$X_n$where$u_2$istheresidualterm.

$y_1 = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \ldots \beta_n X_n + u_1$ ..5

Equation (5)above, is the first stage of the Heckman probit sample selectionmodel, which represents the selection equation, wherey_1 is the dependent variable representing the probability of Access to electricity source ;$\beta_1 \beta_2 \beta_3$and$\beta_4 \beta_5$..........β_n,arethecoefficientwhile factors affecting Households access to electricity sourceare represented as $X_1 X_2 X_3 X_4$ $X_5 ... X_n$ where$u_1$istheresidualterm:

According to Van de Ven and Van Pragg (1981)
The probit equation is$y = (\boldsymbol{x_j} \boldsymbol{\beta} + u_{1j} > 0)$
The selection equation is$y^{select} = (\boldsymbol{Z_j} \Upsilon + u_{2j} > 0)$
Where$u_1 \sim N(01)$
$u_2 \sim N(01)$

$$Corr\ (u_1, u_2) = \rho$$

Hence when $\rho \neq 0$, the sum of the log likelihoods from these two models will equal the log likelihood of the probit model with sample selection; Hence Heckman probit provides consistent, asymptotically efficient estimates for all the parameters in such models.

When the error terms from the selection and the outcome equations are correlated ($\rho \neq 0$), the standard probit techniques yield biased results (Asrat P and Simane 2017a; Deresaet al.,2011; Van de Ven and Van Praag 1981).Thus, the Heckman probit provides consistent and asymptotically efficient estimates for all parameters in such model.

As it was mentioned previously, the dependent variable for the selection equation is whether a household has or has not chosen to access an electricity source. The explanatory variables include socio-demographic, environmental, and institutional factors selected based on hypothesized relationships described in literature on factors affecting electricity sources. In the case of the outcome model, the dependent variable is whether a household has chosen or not to use the solar technology device for lighting. The explanatory variables are chosen based on the solar technology adoptionliterature (Guta ,2020, Masamitsu,2018, Ther Aung et al.,2021; Yibeltal etal,2021; Guta, 2018).) The hypothesized explanatory variables for the Heckman's two-step model used in this study are described in the section that presents the empirical model results.

2.1 Working hypotheses and Variable Specification

Households' decision to use new technologies at any time is influenced by the combinedeffectofsocioeconomic,demographic,institutionalandbiophysicalfactors, whicharerelated to their objectives and constraints. More specifically, the findings of variousempirical studies on the use of solar technology and access to electricity, the existing theoreticalexplanations, and the authors' knowledge in the Ethiopia energy sector were used to select nine explanatory variables and structure the working hypotheses. The potential explanatory variables, to be used in the Heck probit model which are hypothesized to influence the access to electricity and use of solar technology devices inthestudyareaarepresentedinTable1.

Table 1. Lists of Explanatory variables and Expected sign

Explanatory Variable	Variables Description and unit of measurement	Expected sign	Empirical studies Supporting the expected relationship
Credit	Access to Credit	+/-	Abdoulganiour et al., (2023);
Land ownership	Land as a proxy for the wealth henceBinary, 1 if the land is owned and	+	Guta (2018) and Yibeltaletal., (2020),
Age of Household	Continuous, the age of the household in years	+	Mohd Irfan's et al., (2018), Abdoulganiour et al., (2023)
High School	Binary, 1 if a household high schoolcompleted and 0 if otherwise	+	Jann Lay et al., (2013)Sylvia M. et al.'s (2018) Jann Lay et al., (2013); Jann Lay et al., (2013); Aarakit et al., (2021)
Location	Binary 1 if rural 0 otherwise	-/+	Sylvia M. et al.'s (2018); Guta (2020) Yibeltaletal., (2021), Aarakit et al., (2021) Mohd Irfan's et al., (2018),
Own Bank account	Binary 1 if owned and 0 otherwise	+	M. Aklin et al. (2018) and Guta (2018),

Household Size	Continuous, the size of the household respondent	+	Yibeltaletal., (2021), Guta (2020)
Market Visit	Binary 1 if frequent Visited the market and 0 otherwise	+	DongyingSuna's et al., (2024) Abebe D. et al., (2024)
Land Size	Continues, the higher the land size the higher adoption	+	Ishola et al., (2023);Guta (2018)

2. Results and Discussion

2.1 Descriptive results

The variables included in the model are described in Tables 2-3, which contain the descriptive statistics utilized in the model. The econometric results were depicted in Tables 5 and Table 6.

Table 1 shows that 88.1% of the participants were male-headed households, while 11.9% were female-headed households. Among households, 91.2% of them had male household heads and had the greatest rate of solar technology adoption. Almost 98% of the adopters lived in rural locations, whereas the smallest number of adopters lived in urban areas. Conversely, 9.4% (32) of these adopters have finished high school, and 79.40% (269) have credit access, while 79.4% (269) of those who have credit access use the solar technology in their house daily.

Conversely, 19.1 percent of the participants have bank accounts, of which 22.7% use solar home systems. On the other had56.1 percent of household heads frequently go to the market to obtain information. Moreover, a significant majority of the participants (82.5%) owned land, which acts as a reliable predictor of their socioeconomic position. Likewise, approximately 82.1% of the respondents owned agricultural land, of which 89.7% bought solar technology for lighting their houses.

Table 2. Summary of Variables used in the model

Lists of Variables	Choices	Adoption of Solar Technology Devices		
Gender	Adopter Types	Non-Adopter	Adopter	Total
	Female	60	30	90
		14.30%	8.80%	11.90%
	Male	359	309	668
		85.70%	91.20%	88.10%
Credit	No Access credit	`103	70	173
		24.60%	20.60%	22.80%
	Access to Credit	316	269	585
		75.40%	79.40%	77.20%
High School complete	Completed	14	32	46
		3.30%	9.40%	6.10%
	Not completed	405	307	712
		96.70%	90.60%	93.90%
Location	Rural	384	333	717
		91.60%	98.20%	94.60%
	Urban	35	6	41
		8.40%	1.80%	5.40%
Saving at Bank	NO	351	262	613
		83.80%	77.30%	80.90%
	Yes	68	77	145
		16.20%	22.70%	19.10%
Own Farm Land	No	101	35	136
		24.10%	10.30%	17.90%
	Yes	318	304	622
		75.9%	89.7%	82.1%
Market Visit	No	169	164	333
		40.30%	48.40%	43.90%
	Yes	250	175	425
		59.70%	51.60%	56.10%

Household Age size and land

The study findings indicate notable disparities among those who utilize solar technology and those who do not, across several dimensions. The average age of those using solar technology was 43.02 years, which was nearly identical to the average age of those who did not use this technology, which was 43.54 years. Household heads with access to electricity who did not adopt had a somewhat smaller family size, averaging 4.95 individuals, compared to users with an average family size of 5.41 persons. Households with Electricity access and solar technology had an average land area of 2.8 hectares, whereas households without solar systems had an average land size of 2.27 hectares.

Table 3. Access to electricity, household and land size

Access to Electricity	Solar		House hold size	Age of Head	Land Size(ha)
Access to Electricity	No solar Use	Mean	4.95	43.02	2.27
		N	419.00	419.00	419.00
		Std. Deviation	2.24	13.37	2.05
	solar use	Mean	5.41	43.54	2.84
		N	339.00	339.00	339.00
		Std. Deviation	2.21	13.42	6.21

Similarly, respondents who have access to electricity access and utilize solar equipment had an average land size of 5.4 hectares. The average land size for respondents without access to electricity is 1.8 hectares for solar users and 1.6 hectares for non-users. Households lacking electricity access and not using solar technology typically have an average land area of 2.2 hectares.

2.2 . Econometric Results

The maximum likelihood estimation approach was used to provide parameter estimates for the Heckman model. Furthermore, significant variables were identified to explain the factors that impact the access to electricity and the adoption of solar technology.

Tables 7 and 8 present the econometric findings derived from utilizing the Heckman probit selection model and evaluating the marginal effects, respectively. The standard Heckman probit model was assessed with regards to its explanatory power with the Robust option. The Heckman model with robust choices exhibited superior explanatory power compared to the standard Heckman selection model.

Both models demonstrate that the majority of explanatory factors and their corresponding marginal values are statistically significant in affecting access to electricity and usage of solar products, aligning with the predicted direction. The calculated marginal effects measure the expected changes in the probability of access to electricity and use of solar technologyin response to a one-unit change in an explanatory variable.

The test findings revealed the existence of a sample selection problem, where the error terms are dependent on the outcome and selection models.This justifies the use of a model with a rho value that is substantially different from zero (chi2(1) = 1.2e+06; Prob > chi2= 0.00001). In addition, the likelihood function of the Heckman probit model demonstrated statistical significance (Wald chi2(9) =64.94;with P < 0.00001), indicating its robust explanatory capability, as presented in table 4 below.

Table 4. Probit model with sample selection

	Heckman probit Estimation			Heckman probit Estimation with Roboust option		
	(Outcome Model)	(Selection Model)	(3)	(Outcome)	(Selection model)	(6)
Variables	**Solar Use**	**Access to Electricity**	**rho**	**Solar**	**Access to Electricity**	**rho**
Saving at Bank	0.500*** (-0.13)	0.898*** (-0.21)		0.500*** (-0.125)	0.898*** (-0.193)	
Land Size	0.0265* (-0.0159)			0.0265* (-0.0152)		

Market Visit	-0.151* (-0.0895)	-0.210** (-0.107)		-0.151* (-0.0898)	-0.210** (-0.106)	
Credit	0.102 (-0.106)	-0.105 (-0.124)		0.102 (-0.104)	-0.105- (0.122)	
Age	-0.0037 (-0.00322)			-0.00375 (-0.00325)		
Household Size	0.0253 (-0.0191)			0.0253 (-0.019)		
Location	-0.866*** (-0.258)	-0.578** (-0.246)		-0.866*** (-0.278)	-0.578** (-0.25)	
High School completed	0.697*** (-0.17)			0.697*** (-0.17)		
Agricultural land ownership	0.481*** (-0.14)	-0.0746 (-0.143)		0.481*** (-0.129)	-0.0746 (-0.144)	
Constant	-0.838*** (-0.219)	1.182*** (-0.18)	4.478 (-19,639)	-0.838*** (-0.209)	1.182*** (-0.185)	4.478*** (-0.0040)
Observations	905	905	905	905	905	905
LR test of indep. eqns. (rho = 0): chi2(1) =0.02Prob > chi2 = 0.8862				Wald test of indep. eqns. (rho = 0): chi2(1) = 1.2e+06;Prob > chi2= 0.0000		
Number of obs= 905Censored obs= 147 Uncensored obs= 758Wald chi2(9)= 75.48 Log likelihood = -871.7499;Prob > chi2=0.0000				Probit model with sample selectionNumber of obs = 905;Censored obs=147;Uncensored obs=758; Wald chi2(9) =64.94 ; Log pseudolikelihood = -871.7499Prob> chi2= 0.0000		

Standard errors and robust standard error in parentheses;
*** p<0.01, ** p<0.05, * p<0.1

Table 5.Summary of Marginal effects Results

variable	dy/dx	Std.Err.	z	P>z	[95% C.I.]		X
Saving at Bank	0.194	0.051	3.810	0.000	0.094	0.294	0.169
Land Size	0.010	0.006	1.740	0.082	-0.001	0.021	2.404
Market Visit	-0.057	0.034	-1.680	0.093	-0.124	0.009	0.577
Credit	0.038	0.038	0.990	0.322	-0.037	0.113	0.776
Age	-0.001	0.001	-1.160	0.247	-0.004	0.001	43.404
Household Size	0.010	0.007	1.330	0.183	-0.004	0.024	5.105
Location	-0.261	0.059	-4.450	0.000	-0.377	-0.146	0.057
High School completed	0.272	0.065	4.220	0.000	0.146	0.399	0.062
Agricultural land	0.168	0.041	4.080	0.000	0.087	0.249	0.820

(*) dy/dx is for discrete change of dummy variable from 0 to 1.y = Pr(AdoptersSolar=1) (predict); =.36549533

The findings of the electricity access selection model are displayed in Table 4. The results suggest that being an urban dweller in location and frequent visits to the market were favorable variables that predicted access to electricity ($p<0.01$). Similarly, access to credit loans ($P<0.01$) is a favorable factor that influences the adoption of solar technology positively. Furthermore, factors such as agricultural land and credit access have failed to predict the electricity access of households in the study area, proving to be insignificant.

The outcome model using robust analysis showed a positive correlation between the adoption of solar technology devices and the age of the household head, household size, frequent market visits, agricultural land ownership, and household size. These factors were found to be successful predictors of solar technology adoption, as detailed in the following paragraph.

Household Cash Savings

The use of solar technologyhas a positive correlation with saving money at the household level. A statistically significant link ($P< 0.01$) exists between the savings behavior of household heads and the adoption of solar technology.A respondentswho save the cash has a higher probability (19percentage points) at ($p < 0.01$)to adopt solar technology compared to an individual who do not save in the bank. High-income households are more inclined to invest in solar energy technologies due to their greater financial resources. This finding is consistent with the findings of M. Aklin et al. (2018) and Guta (2018),who both highlights saving as a crucial factor in the adoption of solar technology. Households that save cash are considered rich or affluent, and they are likely to have a high financial ability to invest in solar energy technology adoption.

Household Land Size

Further, the analysis has shown that the size of agricultural land, which serves as a measure of wealth, has a strong ($p < 0.01$) and favorable influence on the adoption of solar energy technology by households. According to the marginal analysis, there is a direct relationship between the growth in landholding by households and the adoption of solar technology devices. \

The finding aligns with the research conducted byGuta (2018) and Yibeltaletal., (2022), which concluded that families with a higher wealth base had a larger likelihood of investing in solar technology equipment. Furthermore, the study revealed that the age of households had a significant ($p < 0.01$) and favorable impact on the adoption of solar energy technology by rural households in Ethiopia. Consequently, the likelihood of older household heads adopting solar energy technology surpasses that of their younger counterparts.

Age of Household Head

The age of household heads has a favorable and considerable impact on the adoption of solar technology at significance level at ($P<0.01$). The positive effect of household age is most likely explained by the fact that older household heads typically have more wealth due to their ability to invest in renewable energy technology and their ownership of more productive assets, such as land. This finding aligns with Guta's (2018) research, though it contradicts the earlier notion from Aini and Ling (2013) that younger individuals are more inclined to pay for renewable energy sources due to their better understanding of the environmental benefits they offer.

Education

The analysis was conducted to determine the likelihood of adoption among households who has completed the high school and who did not complete high school. The result indicated completing the high school significantly affect the probability of solar technology use at ($P<0.01$). Consequently, A respondents who has completed the high school has a higher probability (27percentage points) at ($P<0.01$) to adopt solar gadgets compared in comparison to those who have not completed high school. This assertion is likely accurate due to the fact that homes who have achieved high school education havea wider range of opportunities to get alternate sources of power, in comparison to households that have not completed high school. The finding aligns with the research conducted by Khandker et al. (2018);Rahutet.al 2017 and Masamitsu et al. (2018), which demonstrated that the educational achievement of the household leader has a direct impact on the degree of awareness and environmental attitude of households. Hence, it is a crucial determinant that impacts those who choose to invest in renewable energy technology.

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Credit Access

The data pertaining to the credit opportunities in Ethiopia, which have positively impacted the adoption of solar technology devices, is currently inadequate.This means that households with access to microfinance are not utilizing the credit to purchase solar technology. The results are in contrast to Abdoulganiour et al., (2023);who found a positive impact of the credit on the adoption of the solar technology. SimilarlyGuta (2018) found that having access to financing has a favorable and substantial effect on the probability of usingsolar technology equipment. He justified thatoutcome enhanced institutional backing in fostering the adoption of solar technology to enhance the viability of utilizing solar technology.In this case either households may not use the credit for the solar technology or the data is not sufficient to support the impact of the credit.

Market Information

Market information on solar energy is a crucial indicator of the adoption of solar technology. The results indicated that having knowledge of the market has a statistically significant influence on the adoption of solar technology at <0.01. Enhancing respondents' information about the availability of solar PV systems in the market is anticipated to increase their likelihood of adopting solar energy. Hence the presence of market information is crucial for the adoption of technology in developing nations. Similarly, Inayatullah et al. (2020) and Chaofan Wang et al. (2023) emphasized the significance of market information in impacting the use of solar PV systems.

Conclusion and Recommendation

This study attempted to identify important factors that influence the electricity access and adoption of solar technology devices in places where the main grid facilities are not available. The empirical results show that in the places where households were deprived of the opportunity to use solar technology, the major factors supporting access to electricity were land size and ownership , market visit and location, savings at the bank, and the educational status of the households. The results in this paper have important implications for promoting solar technology for electricity access. Any policy intervention should take into account the socioeconomic factors listed above in order to improve access to electricity and the use of solar technology in off-grid areas that can't connect to the main grid. This will result in recognizing the heterogeneity in household characteristics, land holding, institutional patterns, and technology-specific factors.

One further consequence of the discoveries made in this study is the necessity to enhance the availability of electricity by targeting educated households in rural areas to be used as an entry point for the implementation of the Ethiopian government's policy for universal access to electricity. To assure universal electricity access, the

Ethiopian government should aim to target both rural areas using off-grid solutions such as certified solar technology devices, which improve both access to electricity and the well-being of rural households with regards to creating access to education and health.

The results also emphasize the necessity for additional research into the socioeconomic features of households that were located in the main grid areas that adopted solar technology as a backup source to understand the overall impact of solar technology adoption on both the grid and off-grid areas. Hence, it is crucial to develop strategies to guarantee electricity access for households that lack electricity by considering the aforementioned socioeconomic variables associated with the households to guarantee sustainable access to electricity and solar technology adoption.

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