Equitable subsidy amounts for upfront energy costs in developing countries

Abstract

We investigate the sensitivity of households to subsidy amounts for proposed investments in a solar lighting system or an electricity grid connection. Using a large household microdata sample from the World Bank for a group of 12 developing countries, the results show that having a formal bank account significantly influences the willingness to pay for a solar lighting system or for grid access, but this effect diminishes with delayed payment options. Economically constrained households, such as those without a formal bank account, are not sensitive to subsidies for solar lighting systems, which may be too expensive, but they are sensitive to subsidies for cheaper investments. Our interaction analysis reveals that households without a bank account (and thus constrained by financial conditions) who are offered an investment with a 66% subsidy are more likely to be willing to pay than those households with a bank account and who receive a full price offer without any subsidies. We can then calculate equitable subsidy amounts, which we normatively define as the amounts necessary to give each household an equal probability of being willing to pay the upfront cost. For example, when there are no subsidies for households with a formal bank account, equitable subsidy amounts for households without a formal bank account are approximately 43% for a solar lighting system and 65% for a grid connection.

Keywords: Bank account, Developing country, willingness to pay. electricity grid access, solar energy.

1. Introduction

A general consensus in the current literature concerning the interaction of energy and development is that transitioning to renewable energy sources, such as solar power, has become increasingly urgent. This is owing to the disproportionate nature of the global challenges arising from climate change as well as energy security for low-income countries (see, e.g., Østergaard et al., 2022). Hence, a growing body of literature has focused on finding the potential determinants of renewable energy adoption (see, e.g., Aguirre & Ibikunle, 2014; Przychodzen & Przychodzen, 2020; Qin et al., 2022). However, underexplored research areas include conceptual and empirical foundations for equitable subsidy amounts and household responses to delayed payment potential. Other underexplored aspects include comparisons across energy options such as solar lighting and grid connections and developing country analysis covering multiple countries with large sample sizes and many explanatory variables.

Among the existing studies on related topics, an increasing number have focused on the adoption or uptake of solar energy, in the form of solar lighting, solar electricity generation and solar hot water systems. This is mainly because solar energy is considered effective in providing clean and sustainable energy, which is also cost-effective because modern solar PV technology has significant potential to mitigate climate change (see an overview by Creutzig et al., 2017). Despite the attractiveness of solar energy, the adoption rate in developing countries remains low, hindered by factors such as high initial

setup costs, low levels of financial development, barriers to technology, and high inequality (see a systematic review by Konzen et al., 2024).

Therefore, finding the right incentives to stimulate solar uptake, especially in developing countries, has become increasingly important. The current literature focusing on solar uptake in developing countries is growing but still lacking in comprehensiveness, since most of these studies focus on a particular region or country. For example, Wyllie et al. (2018) examine the barriers to solar energy adoption in Barbados and identify a number of issues ranging from disinterest to change, insufficient education and awareness, social stigma to investment challenges and political infighting. Salite et al. (2022) look at the case of Mozambique and find that pricing is the main issue, which is caused mainly by government involvement in the manufacturing sector, as well as unreliable imported solar panels due to lax market regulation and low product standards. Ockwell et al. (2018) look at this issue with a particular focus on sociocultures and politics for Africa and contend that social practice should be viewed as an important factor in the understanding of green energy access in developing countries. Durga et al., (2024) examined the barriers to solar uptake in sub-Saharan Africa with a special focus on farmers and identified a number of issues related to rural development.

A common theme from the above studies on low-income countries is that they focus mainly on the determinants (i.e., enablers and inhibitors) of solar uptake in a single country or regional space, with a lack of attention to the global picture and limited assessment of the role of subsidies in driving incentives for solar adoption. Intuitively, subsidies can potentially solve the affordability problem for households and businesses, thereby generating better reliability and access to such technology. This is especially relevant for rural areas where the above problems persist with greater severity (see, e.g., Liu et al., 2018). To the best of our knowledge, the only known study that has a broad international focus for low-income countries is Mahn et al. (2024), which covers a sample of developing countries in Africa, Asia and Latin America. However, this study likewise focuses on determinants only, without examining the role of subsidies.

Current studies on the role of subsidies in solar adoption are conducted mainly for high-income countries, with a few focused on upper-middle income countries. There is, however, significantly less

evidence from low-income countries. For example, Best et al. (2019), Best & Trück (2020), and Higgins et al. (2014) explored similar research for Australia, Mundaca & Samahita (2020) explored Sweden, and Hughes & Podolefsky (2015) focused on a solar subsidy program in California. Zhang et al. (2022) looked at this issue for the utility-scale solar PV industry in China. One case study on low-income countries was a study by Best & Nepal (2022), which focused on the role of savings and subsidies in solar uptake in Nepal. The paper nevertheless focuses only on one country in South Asia and does not provide systematic empirical evidence for low-income countries worldwide. Most other developing country studies had sample sizes of fewer than 1,000 households (Best et al., 2023). At this point, we can clearly identify a significant gap in the literature for understanding the role of subsidies vis-à-vis optimal subsidies in solar uptakes. Moreover, exploring databases across low-income countries with a global focus is a rare combination that this paper provides.

Our key findings relate to economic variables, subsidies, and interactions between economic and subsidy variables. We find that economic variables such as having a bank or mobile money account tend to have more robust influences on willingness to pay in the shorter term. In contrast, these economic variables are less likely to have significant influences on willingness to pay for planned payments with longer repayment periods. In addition, sensitivity to subsidies is most evident for households with a formal bank account. It is possible that economic constraints restrain the willingness to pay and sensitivity to subsidies for households without a formal bank account. We also find that households that do not have a formal bank account but who receive a large subsidy offer are more likely to be willing to pay for a solar lighting system than are households with a formal bank account but a zero subsidy offer. This suggests that the high subsidy offer is more than compensating for the constraint of having no formal bank account. This relationship is not evident for electricity grid connections, suggesting that different subsidy amounts are appropriate in different contexts, as calculated below.

Hence, the contributions of this study are fourfold: (1) We analyse an international sample of twelve low-income countries, which cover Asia, the Caribbean and Africa, providing broad empirical evidence on the determinants of willingness to pay for either electricity grid connections or solar lighting systems in these countries. This analysis considers the influence of delayed payment options. (2) We define an

equitable subsidy amount conceptually. (3) We empirically assess the role of subsidies and attempt to quantify an equitable level of subsidy for our sample. (4) The WTP and equitable level of subsidies calculated in this study can inform policy makers not only in the low-income countries covered in the sample but also in international energy NGOs that aim to promote the adoption of accessible renewable energy across developing countries.

Our contributions contrast with strands of prior literature. For example, stated choice studies (such as discrete choice experiments) might produce WTP but often do not have large sample sizes or many control variables[1] and do not consider WTP variation across economic groups (which aligns with some past and potential policy approaches). On the other hand, large household studies generally do not calculate WTP and face limitations in informing policy design related to subsidy magnitude.

The remainder of the study is organised as follows: Section 2 presents the research background and theoretical framework underlying the research questions; Section 3 describes the data and econometric approach; Section 4 examines the results; and Section 5 discusses possible explanations for the results, policy implications and conclusions.

2. Background and theoretical framework

2.1 Background

There is a growing body of literature on the adoption of alternative sources of energy across the world. These studies are well integrated within the renewable energy field and simultaneously contribute to a clean environment for sustainable development goals (SDGs). Using large surveys on solar device use across three continents, Mahn et al. (2024) highlighted the importance of demographic and socioeconomic characteristics in solar energy adoption. This paper is important because it provides evidence across income groups by countries, thereby providing specific policy guidelines to support access to alternative sources of electricity[2]. However, such studies covering geographical regions by

[1] Many papers in this area of research are unable to explore this level of details as a results of data limitation. We follow recent papers in energy economics that showed controls to be important thereby producing robust results.
[2] This contribution is relevant to support design of policy intervention programs for access to electricity in low-income countries where grid electricity supply to the population is largely interrupted and access is disproportionately low for rural dwellers relative to urban dwellers.

income level do not consider the consumer capacity for the adoption of renewable energy sources. The adoption of renewable energy for low-income households can be impacted by affordability issues, indicating that capacity should be an integral consideration for policy efforts. In fact, policymakers will be able to design targeted policies if there is evidence of how distribution capacity across households affects the adoption of alternative energy sources. One of the major barriers to research of this nature is access to quality datasets on capacity.

In this study, we proxy for capacity with willingness to pay for solar energy using data from the World Bank. This variable is merged with the access-to-grid variable to investigate the complementarity or substitution effects of alternative energy sources across countries. Such interaction provides a framework for examining how subsidies can be designed to enable energy equity (Best, 2023). To the best of our knowledge, only a few studies exist on the role of willingness to pay in energy equity, all of which use small-scale samples. One strand of this literature uses single-country analysis predominantly within Africa (some recent examples are Afriyie et al., 2024; Almanzar & Ulimwengu, 2019; Ayodele et al., 2021; Nketiah et al., 2022; Numata et al., 2021; Oseni, 2017; Siyaranamual et al., 2020; Taale & Kyeremeh, 2016; Wen et al., 2022). One major setback of this approach is the limitation to policy framework due to restrictions to variation in aggregate income and micro socioeconomic levels. There is a need to cover extensive variation in economic factors to provide a framework for policy analysis across regions. Hence, our paper contributes to the literature on how WTP for grid and solar energy relate to each other via the same large-scale MTF survey. We also explore microlevel socioeconomic characteristics as an additional layer of economic factors. These data match the willingness to pay for both solar and grid energy, providing knowledge for intensive margins of interaction of economic capacity and preference for energy adoption.

The established link between WTP and subsidies is a critical issue for policy formulation. The distinguishing factor of the current research is supporting policy-related evidence in this area of research. In sum, it would be interesting to link the WTP variation to socioeconomic variables. This could use the same or similar variables as those used in previous studies but would relatively have far-reaching policy implications. For example, many existing policies tend to have restricted eligibility on

the basis of economic criteria, but they do not seem to have considered WTP variation in much or any detail.

The data structure explored in this paper provides a context to investigate both extensive margins and intensive margins of the variables of interest, thereby revealing differential impacts of the WTP across socioeconomic groups similar to patterns observed for adoption. These intensive margins are yet to be explored in this context, which further substantiates the extension of analysis across diverse countries. A priori expectation is that cross-country income-level analysis (low/middle/high) will yield further heterogeneous results.

2.2 Theoretical framework and hypotheses

Our theoretical framework for this research is drawn from the literature on the perspectives of alternative energy sources. One of the theories is the multicriteria decision-making model for optimal energy adoption across alternatives (Ullah et al., 2021). While existing theories applies to both production (Przychodzen & Przychodzen, 2020) and utilisation (Opeyemi, 2021) components of the energy mix, we focus on the latter to address our research question. Following prior studies (Graber et al., 2018; Liang et al., 2022), we assume that consumers have an exhaustive energy mix for household electricity consumption from only two sources—grid connections and solar power. In this framework, while need is an important factor for energy choices, households explore trade-offs across energy options by considering prevalent economic capacity—affordability. However, support from intervention programs can enable important structural shifts in the disposition of households towards adoption and willingness to pay for alternative sources. These details are central to the research questions addressed in this paper, as they evaluate accruable shifts in demand elasticity across options with such support. This scenario is plausible for low socioeconomic groups, which are largely captured in the sample of countries explored. Moreover, households also balance their budget allocation for a basket of consumption items, implying that there is a need to carefully consider the most efficient and effective energy options.

Equation (1) illustrates a simple consumer utility function of a household (HH) i. This function incorporates energy choice as a component separately from other HH consumption items. The aim here is to achieve a combination with optimal utility given a budget constraint.

$$U_i = \alpha_i f[Solar\ panels] + \beta_i f[Grid\ connection] + (1 - \alpha_i - \beta_i) g[Other\ items] \quad (1)$$

The optimal utility differs across HHs, as it mainly depends on the allocated weights for α and β. For example, heterogeneity in derivable utility for HHs with the same choice can be achieved by placing different weights on α_i and β_i. These insights enable us to provide support for alternative hypotheses towards shifts in investment plans for alternative energy sources. There are three specific elements of our estimation models in Section 3 as follows: (i) alternative energy sources are available for electricity supply, namely solar power and grid connection; (ii) there is availability of energy subsidies or payment plan options; and (iii) there is variation in available subsidy support.

Hypothesis 1: Households consider one energy source for electricity supply.

Hypothesis 1 posits that consumers consider only one energy source for electricity supply. We assume that grid connections are already established for most households, so (i) a continuous grid supply may be retained or (ii) switching to solar energy as a replacement for grid electricity may be considered.

For the first case, where energy consumers retain grid connections, electricity market deregulation has led to increasing pressure on the pricing regime for grid supply across developing countries, with an increase in price elasticity (Klug et al., 2022; Lee et al., 2020). The provision of subsidy support considered in this paper may ease pressure, thereby enabling more consumers to support payments. The availability of a payment plan also provides a sustainable support for dealing with disconnection from the metered supply. For the second case, energy consumers could opt for the replacement of grid energy with solar panels. This may be achieved via a common substantial initial investment to recoup the sunk cost over time (Mahn et al., 2024). Such investment may be impracticable for low-income HHs, thereby requiring support to make the switch. The background for such substitutability may differ across HH units. This includes access to a steady electricity supply, which may not be available from grid

connections, and cost considerations. There is extensive literature on the potential for substitutability of energy sources (Leonard et al., 2020; Opeyemi, 2021). This body of literature is largely premised on the deployment of clean energy for a sustainable environment, which is outside the scope of this paper (Ortega-Arriaga et al., 2021; Yang et al., 2023).

Equation (1) shows that under this hypothesis, the consumer utility function considers a grid connection and solar energy as mutually exclusive. Depending on the energy preference of HH units, they may select grid or solar units to maximise their utility function. The remainder of the consumption component of the HH utility function is a constant such that it contributes nothing to the price elasticity of energy demand.

Hypothesis 2: Households consider a mix of energy sources for electricity supply.

This hypothesis tests the adoption of a complementary energy mix approach for consumption purposes. Over time, complementary energy sources are increasingly adopted for household electricity supply as an approach to facilitate reliable supply in low-income countries (Guta et al., 2022; Jeuland et al., 2021). This is also linked to the growing affordability of alternative sources of electricity and the diffusion of such economic prospects for residents of low- and middle-income countries (Bogdanov et al., 2021).

The option of energy complementarity contrasts with the mutually exclusive nature of the energy consumption patterns in Hypothesis 1. Using the energy options available in our data, this means that consumers adopt both grid connections and solar energy for household energy demand; however, the composition may differ across households. This hypothesis is feasible in various scenarios. First, consumers may consider the adoption of alternative sources of energy if the prevailing energy pricing regime is less expensive for existing energy sources (e.g., grids) before the introduction of a new energy source (e.g., solar energy). A body of literature shows that cost and the pricing system play important roles in the interaction of the adoption of solar and grid electricity for low-income and rural households (Ahmad et al., 2024; Heleno et al., 2020). The energy mix may also play out if prices match across energy sources, although other factors may be considered when determining preferences in this

scenario. This may include access to raw materials for local generation, such as sunshine and wind (Frysztacki et al., 2021).

In this section, we aim to test whether consumers respond to support opportunities—subsidies and payment plans—through diversification of their household energy consumption. The introduction of a support system may relax the capacity to incur the fixed costs required to invest in solar units, which may have been impracticable without support (Best & Nepal, 2022; Boccard & Gautier, 2021; Rydehell et al., 2024; Y. Zhang et al., 2011). While there is extensive support of this nature in high-income countries, it is rare in low-income countries. Additionally, the extant literature does not provide clear cut evidence on the extent to which this approach will distort preferences for traditional energy supplies such as grid energy, especially in the context of developing countries. Our study seeks to address this gap by providing clarity around the magnitude of the impact of energy support plans on willingness to pay upfront or defer payments for access to the electricity grid or for a solar lighting device.

2.3 Research design and questions

A priori, the theoretical framework under Hypothesis 1 suggests that there may be observed elasticity of demand for only one energy source. The introduction of an intervention support may alter the observed elasticity depending on the socioeconomic background of consumers. Hypothesis 2 provides a dual elasticity framework where both grid and solar connections share responses to price regimes. We test the above hypotheses in our analysis by using the energy sources as outcome variables in separate estimation models (see Section 3). Our paper provides a unique context across an overlapping conceptual framework to provide a context for the interrelationship across variables of interest. The main theories of interest in the paper include WTP for energy transition (Blazquez et al., 2020; Tan et al., 2023), energy preference (Alipour et al., 2021; Mamkhezri et al., 2020) and potential shifts with intervention programs. The latter highlights the importance of the support structure in influencing elasticity, which underlies substitution and complementary energy effects. Importantly, the alteration of pricing systems for affordable energy, such as payment plans, can have cross-price elasticity effects (Gao et al., 2021).

We use data linkage methods to incorporate important variables that capture extensive determinants of willingness to pay for solar energy and connection to the grid electricity supply. The datasets also include variables on payment plan preferences for a subsample of countries in our analysis. This depth of data means that we are able to undertake consumer preferences to invest in alternative energy plans. Another underlying potential for available information is an opportunity to understand perspectives across household socioeconomic groups within and across countries. Importantly, our sample consists of a conglomerate of countries across continents, which is used to form repeated cross-sectional data for the purpose of our analysis. We undertake an explorative approach to our study to build on the emerging literature concerning the socioeconomic determinants of solar panel uptake in developing countries via household surveys (Akrofi & Okitasari, 2023; Durga et al., 2024; Mahn et al., 2024). Our study is also uncommon in its combination of microdata from 12 national household surveys across three continents. Hence, this paper aims to address three primary research questions as follows:

- *Do subsidies or opportunities for payment plans affect the willingness to pay for a solar lighting system or the electricity grid? (Section 4.1)*
- *What are the sociodemographic drivers of willingness to pay for either energy source? (Section 4.2)*
- *What are the extensive and intensive margins in the effects of economic factors on the willingness to pay for either energy source? (Section 4.2)*

The first question essentially measures how the availability of an energy support system interacts with the choice and preference for energy sources, whereas the second and third questions examine the heterogeneity in preferences. Specifically, the third question unravels how economically constrained households react to incentives to pay for grid access/solar systems in low-income countries. Understanding this link provides a useful context for the design of intervention programs targeting vulnerable groups within the system. Moreover, the emphasis on studying WTP for grid access can provide insights into how households can circumvent their energy deficiencies but also has environmental benefits, as houses without grid access tend to use less efficient and thus more contaminant energy sources, such as coal for heating or diesel generators for electricity.

Our research context combines two strands of literature. Studies calculating willingness to pay have often been based on discrete choice experiments with smaller samples and often focus on product attributes rather than policy-relevant variables such as economic characteristics (Uz & Mamkhezri, 2024). In contrast, studies of actual uptake have sometimes used larger samples with more control variables (e.g., Mahn et al., 2024) but without assessing responses to potential subsidies. In this study, we assess responses to potential subsidies across 12 countries with large samples and many policy-relevant explanatory variables. It is the combination of willingness-to-pay analysis with a large sample of policy-relevant variables, which facilitates our novel contribution to inform policy design.

3. Methods and Data

3.1 Data

Microdata were obtained from the Multi-Tier Framework (MTF) Survey, which is a tool developed by the World Bank's Energy Sector Management Assistance Program (ESMAP, 2020) to assess the status of energy access in low- and middle-income countries. This recognises that energy access is a multidimensional concept that goes beyond simply providing households with access to electricity and considers other factors, such as reliability, affordability, and adequacy. The MTF Survey collects data on various aspects of energy access, including the type of energy source and the affordability of energy for households. The survey also collected data on socioeconomic factors that may affect energy access, such as income and education levels. The quality of the data allows for structural quantitative analysis that will be useful for informing policy decisions. This includes enabling the identification of areas where interventions are needed to improve energy access.

While studies drawn from the MTF survey have been published before (e.g. Best, 2023; Mahn et al., 2024), a key distinction is that we now investigate a subsample of multicountry households who are not connected to the national grid. These households were asked about their willingness to pay for either a grid connection or a solar lighting system. This willingness to pay is linked to different potential randomised subsidies. In addition, respondents are asked if they would pay for solar or grid investments if a delayed payment were an option. These different variables allow for the pursuit of novel research

questions, including determining willingness to pay for different technologies with different subsidy amounts and different payment options.

To build a reliable dataset, we address several issues related to the MTF framework. While the survey design entailed a questionnaire with the same set of questions for every surveyed country, its application in each country was performed separately by different agencies. This presents several issues, such as misconceptions in variable names, coding differences (for survey questions and responses), and language barriers. To overcome these issues, the dataset had to be merged on an ad hoc basis by harmonising each survey's questions one by one, identifying and correcting any discrepancies and recodifying all the questions manually. After the datasets were merged, the frequencies of each variable were compared between countries to identify any discrepancies or possible errors[3]. Each of the current 12 publicly available surveyed countries included an experimental section to identify willingness to pay. This sample represents our final dataset for the empirical analysis of this paper. Figure 1 provides details of the worldwide dispersion of our sample countries.

[Figure 1]

3.2 Dependent variables

The dependent variable is binary and equal to one when households indicate their willingness to pay for an energy investment of either a solar lighting system or a connection to the national grid. For solar lighting systems, there are two tiers of products: low capacity and large capacity (defined in the MTF as tiers 1 or 2). There is just one alternative for access to the electricity grid.

The interviewer randomly selects one of two solar devices and a random subsidy to offer (high, low or no subsidy). From there, the respondent is asked if he is willing to pay X (where X is the full price adjusted for the subsidy offer) for that energy alternative. If the response is no, the interviewer repeats the question, offering a deferred payment of "6 monthly installments". If the response was no, then 12 and, finally, 24 months were given as options. As each household choice is classified into one binary

[3] We selected the Kenya questionnaire as the default, following Best (2023) , and coded the rest of the sampled countries to follow variables names and codification.

category, its choice can be understood as a multinomial choice, where 0 is understood as not willing to pay, 1 is willing to pay the lump sum of the offered amount, and {2,3,4} accepts one of the deferred payment plans. Alternatively, for grid access WTP, the questions remain the same but change the deferred payment choices for 0, 3, 6, and 12 months.

[Figure 2]

[Table 1. Sample availability and deferred payment preferences.]

3.3 Explanatory variables

The key explanatory variables include aspects related to how much the household would have to pay for the energy investment. Households are randomly allocated to groups with a price offer of 33%, 66%, or 100% commercial value (some sampled countries had random subsidies betheen 0% and 100%, which were aggregated into one of these three categories). We can then calculate the quantity of the subsidy as the total price minus the price offer. We either use this calculated subsidy amount in thousands of USD or a categorical variable for the three offer percentages. In the case of the WTP for solar devices, a second explanatory variable is added for being offered a low-capacity (0) or high-capacity (1) solar device.

3.4 Control variables

The other explanatory variables are in one of three groups: economic, housing, and locational. The economic variables for households include binary variables for formal bank accounts, informal banking, and mobile money accounts. Housing variables include binary variables for owning a dwelling, living rent-free, mud construction, and having a solar lighting system already (solar lighting systems are small and so households can have more than one), along with a categorical variable for the type of dwelling. The three location variables are for the country, a rural versus nonrural binary variable, and a category for reasons for not having a grid connection, such as feeling that they are too far away from the grid or that the price of the installation is too high.

[Table 2]

3.5 Methodological approach

The models used in the paper, which are based on variables assessed in previous literature reviews and meta-analyses, are described in equations (2) & (3) (Alipour et al., 2021; Best et al., 2023; Mahn et al., 2024).

$$WTP_grid_h = \alpha + \boldsymbol{S'}_h\beta + \boldsymbol{H'}_h\gamma + \varepsilon_h \quad (2)$$

$$WTP_solar_h = \alpha + \boldsymbol{S'}_h\beta + Tier_capacity_i + \boldsymbol{H'}_h\gamma + \varepsilon_h \quad (3)$$

Initially, a multinomial logit model is used to account for the nature of the several possible categories into which the dependent variable for each household (h) can fall into[4]. The dependent variables, in separate regressions, are household willingness to pay for grid access (upfront payment or deferred to 3, 6 or 12 months) or for a solar lighting system (analogously, 0, 6, 12 or 24 months), depending on the level of offered subsidy S'_h and the $Tier_capacity_i$ (low = 0, high = 1) of the offered solar device. These variables are defined in greater detail in Table 2. Equations (2) and (3) also include all household-level controls (H) and country dummies.

The foundation for our empirical analysis of equitable subsidy amounts is normative. We define equitable subsidies as the subsidy amount or percentage discount, which is necessary to equalise the probability of households being willing to pay for the energy investment when comparing (i) an economically disadvantaged household receiving a subsidy to (ii) an economically advantaged household with no subsidy.

In our example, an interaction between a binary economic variable (e.g., having a bank account) and three subsidy amounts yields six categories of households. Relative to a baseline group of economically advantaged households (i.e., with a bank account) who do not receive a subsidy, an equitable subsidy would give a marginal effect of zero for the disadvantaged group (i.e., without a bank account). This hypothetical coefficient of zero implies that disadvantaged households with a subsidy have the same

[4] Linear probability models produce similar results.

probability of being willing to pay as economically advantaged households without a subsidy (i.e., the subsidy has equalised the probability of being willing to pay).

In the usual case where coefficients from regressions are not precisely zero, we can use interpolation when there is a negative coefficient for a low (or zero) subsidy and a positive coefficient for a higher subsidy. For example, if the coefficient for disadvantaged households with no subsidy is -0.02 and the coefficient for disadvantaged households with a 33% subsidy is 0.01, we can use interpolation to calculate that a zero coefficient would be two-thirds of the distance along the interval from a zero subsidy to 33%, resulting in an equitable subsidy of 22%.

We perform similar analyses by dividing the sample by country to determine whether the results differ greatly and to determine country-specific magnitudes for future fine-tuned policy recommendations.

4. Results

4.1 Willingness to pay and deferred payments

Table 3 (columns 1-4) presents the effects of economic variables and the willingness to buy a solar lighting system via a multinomial logit regression. The categorical dependent variable with five levels has one level for respondents who are not willing to purchase a solar lighting system, regardless of the length of the repayment period (as a baseline). The other four categories are for different time horizons. The first category is for households that are currently willing to purchase solar lighting systems without delay. The next category has a six-month repayment period and then a twelve-month repayment period. The last category is for payments within 24 months.

Compared with the base outcome of households that are not willing to purchase a solar lighting system, the results reveal a negative relationship between the offered price for the solar lighting system and willingness to pay, although this relationship is statistically significant in only two of the four cases. Additionally, the size of the solar device has a negative and significant coefficient for the immediate

payment column (significant at the 5% level). This suggests a lower willingness to pay for larger solar systems when payments need to be made immediately.

In addition, there are significant coefficients for asset-related variables when explaining the current willingness to purchase a solar lighting system, but primarily for immediate potential payments. For example, there are positive and significant coefficients for having a formal bank account and for having an existing solar lighting system in the first column for '0 months to pay'. These results suggest that asset variables influence the current willingness to purchase a solar lighting system rather than purchases with delayed payment options.

Analogously, the results in columns 5 to 8 present the interactions between economic variables on the willingness to pay for an electric grid connection. In this case, the results suggest that in comparison with the base outcome of households that are not willing to pay for grid access, both the subsidy amount and a deferred payment plan (of three months) significantly influence their disposition to pay. As expected, a higher offer price (i.e., a lower subsidy) is associated with households being less likely to be willing to pay for the zero and three months to pay columns. However, the effects disappear for longer payment durations (6 or 12 months). This may indicate that longer payment durations are less connected to economic realities, such as the offer price. Instead, households that are willing to pay for these longer durations might make decisions on the basis of noneconomic factors.

Focusing on the control variables, having any type of banking account and owning a previous solar system are determinants of willingness to accept the subsidies for grid connections, but primarily when the payment duration is shorter. The limited explanatory power of key control variables for deferred payments suggests that households may place less emphasis on economic constraints as the payment deadline extends.

The results suggest that households might be considering economic constraints less as the time for payment increases. In the following results, we therefore focus on the willingness to outrightly purchase solar lighting systems or grid access rather than delayed payment. A multinomial model is therefore not required for our subsequent results.

[Table 3]

4.2 Equitable subsidy analysis

Table 4 focuses on the influence of different subsidy offers on the willingness to pay for either a solar lighting system (columns 1 to 3) or a grid connection (columns 4 to 6). We also present subsample results, which are based on whether a household has a formal bank account.

As shown in column 1, a $1000 increase in the subsidy offered is associated with a 12 percentage point increase in the probability of being willing to purchase a solar lighting system. When this sample is split according to having access to a formal banking account, there are different results. For the subsample with no bank account, the coefficient for the subsidy offer is not statistically significant, whereas the results for the subsample with a bank account display a positive and significant coefficient for the subsidy offer variable, increasing the effect up to 38 percentage points. This finding shows that the group with a bank account appears to be sensitive to the subsidy offer, whereas there is no evidence here that the group without a formal bank account is responsive to the subsidy offer. It is possible that constrained households without formal bank accounts are less sensitive to subsidies because they are more likely to feel unable to afford the upfront cost. Further analysis of the controls reveals a positive and statistically significant coefficient effect from having a previous solar light system in the household. These results support Hypothesis 2 while also supporting the results of Meriggi et al., (2021) on the positive effect of learning about the benefits of having a solar device and being more sensitive to subsidies to acquire another device.

Table 4 also have similar results when explaining the willingness to pay for a grid connection. However, the only group responsive to the subsidy is those with a bank account. The apparently greater sensitivity of hosueholds with a formal bank account when asked about their willingness to pay for a grid connection is consistent with the solar lighting case. One possible explanation is that many households without a bank account are not sensitive to subsidy changes because they do not think they can afford the investment, even with a large subsidy[5]. Another possible explanation is that households without a

[5] In the supplemental material we repeat this analysis separating the sample into those who are offered a large solar device and a small solar device with similar results.

bank account have less experience with making relatively large investments, so their responses could be random rather than reflecting economic perspectives.

Being the owner of its dwelling is a large incentive for paying for grid access but not for a solar device. This makes sense, as a portable solar device can be taken by the renter if it changes living places, but the installation costs for connecting to the grid cannot be deemed refundable.

[Table 4. Equity subsidy analysis]

In Table 5, we investigate whether any subsidy discount percentage is sufficient to make the constrained group (no bank account) more likely to be willing to purchase relative to the unconstrained group. This is evident in column 1 of Table 5, where households that do have a bank account and are asked to pay the full price of the solar lighting system (No subsidy/Bank=1) are less likely to be willing to pay than the constrained group with a 66% subsidy offer by 5% percentage points (statistically significant at the 1% level). Moreover, an unconstrained household with no subsidy has a similar likelihood of accepting the solar subsidy as a constrained group with a low percentage subsidy. Finally, an unconstrained household with a low subsidy has a similar likelihood of accepting its subsidy as a constrained group with a high subsidy (66%) (5% to 6%, with statistical significance at the 1% level).

Equitable subsidy amounts can be calculated via regression coefficients. For example, the positive and significant coefficient for the 66% subsidy for households with no bank account suggests that these households are more likely to be willing to pay for a solar lighting system than the reference category of a zero subsidy for households with a bank account. The equitable subsidy, which we defined as the amount necessary to equalise the probability of investment between advantaged and disadvantaged households, is therefore less than 66%. Additionally, there is a negative point estimate for households without a bank account who were offered a 33% subsidy. Therefore, it is plausible to suggest that the equitable subsidy is more than 33%. With reference to the coefficient magnitudes and by interpolating between the 33% and 66% subsidies, we calculate a 43% equitable subsidy amount.

[Table 5]

Analogously, column 2 shows differing results for willingness to pay for access to the electric grid. In this case, constrained households (Bank = 0) without a subsidy offer (i.e., a zero subsidy offer) are less likely to be willing to pay for a grid connection by 11 percentage points compared to the baseline of unconstrained households (Bank = 1) without a subsidy offer. This marginal effect is statistically significant at the 5% level. The other two coefficients for constrained households are not statistically significant, although the *p* value of 0.1373 for the low subsidy case is close to a 0.1 cut-off. On the basis of the negative coefficient of –0.0872, which suggests that constrained households with a low subsidy may also be less likely to be willing to pay for a grid connection than the baseline, it is therefore reasonable to infer that an equitable subsidy should be greater than 33%. Likewise, the positive point estimate of 0.0025 for the high subsidy suggests that an equitable subsidy should be less than 66% but very close to 66% because the coefficient of 0.0025 is very close to zero (and not significantly different from zero, with a *p* value of 0.9384). More specifically, we calculate an equitable subsidy of 65% on the basis of interpolation between coefficients of –0.0872 and +0.0025 for the low (33%) and high (66%) subsidies, respectively.

Finally, in the supplementary files (Tables A3 & A4), we repeat this analysis, presenting them one country at a time. These results present policymakers with specific onsite targeting dynamics that may not be readily available in the general results.

4.3 Additional Analyses

In previous analyses, bank account ownership was used to proxy a household's socioeconomic level. One motivation for doing so was that this variable has high coverage across sample countries. This section complements this approach by including the HH's declared income in the models. However, this information has low coverage, as only 30% of the respondents declare it. To circumvent this issue, we exploit the declared main occupation of each household head plus the rest of the available demographic data and perform predictive modelling to impute the missing income data.

Specifically, each HH with declared income was classified into low-, medium- and high-income brackets. Then, a random forest classifier model was trained on the observed data, which obtained a

70% accuracy rate of correctly identifying each income bracket. There are some cases where the prediction is straightforward. For example, when a respondent declares income and has a main occupation such as "Intern/free labour/voluntary work", "Student", "unemployed", "job seeker", or "housewife", it is, in almost all cases, zero or close to zero USD. The model was then used to estimate the missing income values, ensuring consistency across the dataset and preserving the integrity of the relationships between variables.

Table 6 repeats the analysis from Section 4.2, where we test the influence of different subsidy offers on the willingness to pay for either a solar lighting system (columns 1 to 3) or a grid connection (columns 4 to 6). The results remain fairly similar to those reported previously, where for both energy alternatives, only the unconstrained group is sensitive to subsidies.

[Table 6]

5. Policy implications and conclusion

In our analysis, we find interesting insights into the underlying determinants of the willingness to purchase solar or grid access and the response to subsidies. These insights build on exposition from the literature, which recognises price as an important factor in the implementation of low-cost solutions for the improvement of general welfare in low-income countries. As energy demand is price-elastic, offering higher subsidy rates would deliver the highest adoption rates. However, with a limited program budget, there are limitations to the scope of beneficiaries. Thus, policymakers seek to understand the dynamics of policy strategies to achieve a maximum adoption rate in every situation. One way to achieve this is by understanding how the willingness to pay for solar and grid access changes depending on socioeconomic status, proxied by bank account ownership. Relevant bodies can then use this input to lower subsidies, thereby maximising reach. Furthermore, by presenting our results not only in a general model but also country by country, future work and policy implementations in those explicit countries can use these data to fine-tune program designs to increase coverage.

This paper provides an approach for calculating equitable subsidies, which we define as the amount of subsidies to disadvantaged households, which equalises the probability of household investments when advantaged households do not receive a subsidy. This is useful given that most prior studies assessing willingness to pay tend to focus on product attributes rather than policy-relevant variables. Similarly, studies of actual uptake generally avoid quantifying subsidy amounts from a policy-design perspective.

Our results suggest that equitable subsidy amounts may differ substantially across different contexts. For example, we calculated an equitable subsidy of approximately 43% for solar lighting systems on average. In addition, the equitable subsidy for connections to the national grid substantially differed at 65%. The additional analysis for each country separately also allows the evaluation of variation in responses to subsidy coverage. Our results also assess the potential role of delayed payments in a complementary framework. We find that economic variables such as subsidy amounts and banking variables tend to be less closely related to the willingness to pay when there are longer delays to proposed payments. This may imply that policymakers should focus on immediate payments for investments, given that household responses to delayed payment options may not reflect their economic realities. Alternatively, if policymakers seek to use delayed payment options, they may need to develop more sophisticated means of eliciting accurate household responses that reflect their economic context.

Our definition of equitable subsidy amounts has wide potential applicability across any household investment and for any country. Given the inherent challenge of policy design, there is a pressing need for more tailored policies, which means that prior subsidies are generally both inefficient and inequitable. Inefficiency comes from the widely acknowledged non-additionality of subsidies for many technologies. The inequitable aspect comes from disadvantaged households still being unable to afford investments, even when they are offered a large subsidy. Table 7 presents a resumed subsidy equity analysis for each country separately.

[Table 7]

Our study has two main policy implications. We explore this topic by filling an important gap in the literature concerning the limited evidence concerning equity concerns around the adoption of solar and grid energy for developing countries while addressing the usual data limitations in those economies.

First, our approach provides an empirical basis for decisions on the magnitudes of suitable subsidies. We use household-level data with many control variables and substantial sample sizes across 12 countries and three continents, which allows direct inferences on the magnitude of the required subsidies in each case. The findings of this paper are useful to justify subsidies that vary more across groups, as opposed to the same subsidy for all (or many households). This greater precision allows for the design of subsidies that are more equitable and more cost-effective. Second, to the best of our knowledge, this is the first paper to build a robust conceptual framework for dual electricity access that captures the complementarity and substitutability of energy adoption in a way that suits low-income countries. This study is novel in its approach to energy subsidies for this setting, shedding light on the importance of rebate payments commonly used to provide relief for transition across energy in high-income countries.

For future work, we propose expanding the data coverage by increasing the number of relevant variables from the survey. This may be complemented by increased data availability covering other countries. While we do not anticipate any substantial changes in the findings presented in this paper, the inclusion of additional countries from the middle-income group may provide further insight into the relevance of subsidies in this group relative to the observed patterns in the low-income country sample.

Data availability

The data are available following successful registration from the following website: https://microdata.worldbank.org/index.php/home.

The Stata codes for merging all datasets, building the set of recoded variables and all regression scripts are available in the Supplementary material.

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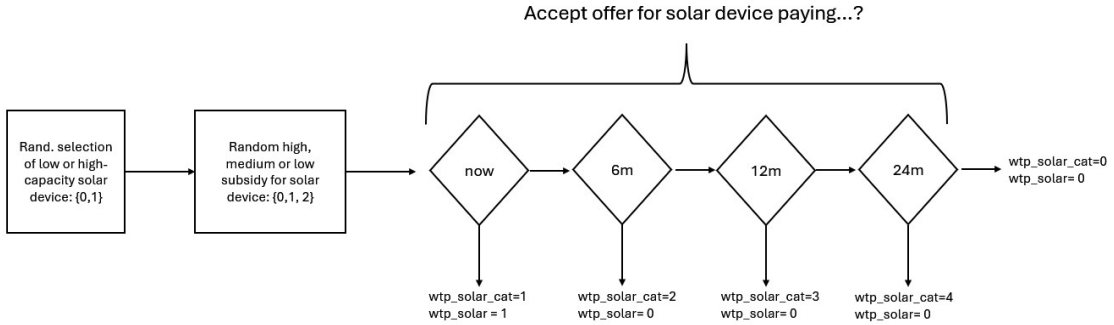
Tables

Figure 1. World map with each country's data availability.



World map with a dot in every sampled country. These countries include Honduras in the Caribbean; Ethiopia, Kenya, Liberia, Niger, Nigeria, Rwanda, São Tomé and Príncipe and Zambia in Africa; and Nepal, Myamar and Cambodia in East Asia.

Figure 2. Research design for WTP questions.



The questions concerning willingness to pay for electricity grid access are analogous but without a random selection of a solar device, and the payment plans are 0, 3, 6 and 12 months.

Table 1. Sample availability and deferred payment preferences.

Grid Access WTP w' deferred payments	0 months to pay	3 months to pay	6 months to pay	12 months to pay	Not willing to pay	Total
Ethiopia (ETH)	825	156	178	222	186	1567
Honduras (HND)	173	0	17	21	68	279
Kenya (KEN)	1327	218	144	157	664	2510
Cambodia (KHM)	585	18	7	8	66	684
Liberia (LBR)	366	47	37	19	73	542
Myamar (MMR)	352	161	120	150	143	926
Niger (NER)	1562	86	63	65	339	2115
Nigeria (NGA)*	-	-	-	-	-	-
Nepal (NPL)	1618	62	51	28	117	1876
Rwanda (RWA)*	243	-	-	-	1419	1662
São Tomé and Príncipe(STP)	718	57	30	36	144	985
Zambia (ZMB)	829	109	126	128	1097	2289
Total	**8355**	**914**	**773**	**834**	**2897**	**13773**
Solar Device WTP w' deferred payments	0 months to pay	6 months to pay	12 months to pay	24 months to pay	Not willing to pay	Total
Ethiopia (ETH)*	-	-	-	-	-	-
Honduras (HND)	23	7	19	51	112	212
Kenya (KEN)	565	245	247	225	967	2249
Cambodia (KHM)	121	19	18	19	381	558
Liberia (LBR)	1198	402	384	367	566	2917
Myamar (MMR)	112	137	113	73	491	926
Niger (NER)	232	79	112	162	1478	2063
Nigeria (NGA)	424	148	243	168	925	1908
Nepal (NPL)	128	26	36	34	183	407
Rwanda (RWA)	73	105	79	97	1249	1603
Sao Tomas (STP)	118	89	84	93	559	943
Zambia (ZMB)	387	92	215	158	1397	2249
Total	**4085**	**1505**	**1693**	**1553**	**8565**	**17401**

Details on willingness to pay for all 12 sampled countries, separated by each payment plan. *: Not considered in the deferred payments analysis, as a different sampling approach was used or data were not available

Table 2. Variable descriptions.

Variable	Description
Variables and data	
Solar/grid willingness to pay (WTP)	Binary variable equal to one when households indicate their willingness to pay for an energy investment of either a solar lighting system or a connection to the national grid given a random payable amount.
Solar/grid subsidies offer (%)	Random subsidy offered to households for paying for grid access or solar lighting device, being classified as No Subsidy (0%), Low subsidy (33%) and High subsidy (66%).
Offer price of Solar/grid device (USD)	Equivalent (in thousands USD) of offered value when paying for grid access/solar device.
Solar/grid subsidies offer (USD)	Equivalent (in thousands USD) offered subsidy amount when paying for grid access/solar device.
Random solar device	Binary variable being one if the random solar device offered to the household is of large capacity. Only 7 of 11 avaliable countries offer two alternatives, the rest only one small lighting system, thus categorised with the value 0.
Controls	
Bank	Binary variable equal to one for households with a bank account holder in a formal institution.
Informal	Binary variable equal to one for households with an account holder in an informal institution.
Mobile money	Binary variable equal to one for households with a mobile money account.
Dwelling owned	Binary variable equal to one for households who own their dwelling.
Rent-free	Binary variable equal to one for households who use their dwelling for free, as opposed to renting.
Dwelling type	Variable with three categories: 0. A single house occupied by one household; 1. A group of enclosed dwellings occupied by one household 2. Other dwelling types.
Mud	Binary variable is equal to one when the main material of the walls of the dwelling is reported as mud bricks (traditional dwelling).
Grid access choice	Variable with three categories: ; Not connected mainly because the grid is too far away or not available (base); Not connected mainly because of the high cost of connection; Not connected mainly because of another reason.
Rural	A binary variable equal to one for nonurban households.
Solar lighting system	Binary if it has a solar lighting system, which can power two or more light bulbs and allow part or the entire household to be classified in Tier 1 for Capacity (Very low load, between 3–49 W) (Bhatia & Angelou, 2015)

Table 3. Willingness to pay depending on deferred payments.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Solar WTP				Grid WTP			
VARIABLES	0 months to pay	6 months to pay	12 months to pay	24 months to pay	0 months to pay	3 months to pay	6 months to pay	12 months to pay
Larger solar device	-0.6072**	-0.3976	-0.2060	0.2027*				
	(0.0258)	(0.1285)	(0.1120)	(0.0923)				
Offer price of solar device (USD)	-1.1802	-1.1618*	-0.4235	-0.4962***				
	(0.2075)	(0.0783)	(0.1455)	(0.0023)				
Offer price for grid access (USD)	0.5377***	0.2844***	0.1436	0.1254	-8.5357**	-2.4898**	1.2398	0.6656
	(0.0000)	(0.0076)	(0.2515)	(0.4768)	(0.0381)	(0.0172)	(0.2465)	(0.6847)
Account in Formal banking	0.0010	0.0083	0.2663***	0.1984	0.8337***	0.1367	-0.0083	0.1587
	(0.9891)	(0.9176)	(0.0042)	(0.1191)	(0.0020)	(0.3238)	(0.9647)	(0.4396)
Rural dwelling	0.4257***	0.5053**	0.2674***	0.2969**	0.1235	0.0035	0.0015	-0.0325
	(0.0000)	(0.0220)	(0.0000)	(0.0109)	(0.5004)	(0.9902)	(0.9957)	(0.8816)
Account in Informal banking	0.6140***	0.4293***	0.1354	0.0498	0.6530***	0.9887***	0.8856***	0.2769
	(0.0000)	(0.0000)	(0.3325)	(0.7086)	(0.0001)	(0.0000)	(0.0008)	(0.3124)
Mobile banking	-0.0260	-0.3125*	-0.2326	0.1581	0.8637***	0.7103***	0.1117	0.4638***
	(0.8330)	(0.0743)	(0.2051)	(0.3585)	(0.0000)	(0.0000)	(0.6878)	(0.0000)
Owner of dwelling	-0.1326	-0.1922	-0.3129	0.2937	0.6484***	0.2866	0.5492	0.4789**
	(0.5554)	(0.4728)	(0.1625)	(0.2961)	(0.0051)	(0.1779)	(0.1061)	(0.0110)
Free of rent	0.0408	0.0469	0.0511	0.0534	0.0353	-0.1069	-0.3858**	0.3123
	(0.6540)	(0.8430)	(0.7842)	(0.7700)	(0.8916)	(0.6496)	(0.0423)	(0.1496)
Type of dwelling = 1, Single house occupied by one household	0.1010	0.2394	0.3071*	0.1631	-0.0537	-0.1064	0.0133	0.1177
	(0.7461)	(0.3393)	(0.0776)	(0.3948)	(0.7925)	(0.5732)	(0.9244)	(0.7072)
Type of dwelling = 2, group of enclosed dwellings occupied by one household	-0.1110*	-0.1090	0.0968	-0.0283	0.2505	0.1075	0.3542	0.4792*
	(0.0914)	(0.4163)	(0.4819)	(0.8526)	(0.2507)	(0.6226)	(0.2207)	(0.0765)
Walls Material: adobe	0.4824***	-0.1682	0.0979	0.0655	-0.2929***	-0.0006	0.0447	0.0545
	(0.0000)	(0.2809)	(0.4205)	(0.7814)	(0.0026)	(0.9977)	(0.6140)	(0.7422)
Solar lighting system	-0.2601	-0.1678	-0.2621**	-0.0366	0.8622***	0.4635***	0.3265**	0.2392
	(0.1413)	(0.2560)	(0.0400)	(0.7268)	(0.0000)	(0.0085)	(0.0495)	(0.4326)
Connection to the grid = 5, Unconnected, Installation too expensive	-0.0699	0.0409	-0.1780	0.0684	-0.0273	0.1762	0.4160**	0.2125
	(0.5976)	(0.8664)	(0.3102)	(0.7742)	(0.8601)	(0.1217)	(0.0160)	(0.3831)
Connection to the grid = 7, Unconnected, Other reason					-0.0323	0.0633	0.0562	0.1243
					(0.8089)	(0.6482)	(0.8254)	(0.6309)
Constant	-0.9048*	-1.8458***	-1.5862***	-0.9405***	1.3524***	-0.2507	-0.7714	-0.5003
	(0.0780)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.6176)	(0.1675)	(0.3959)
Observations	15,930	15,930	15,930	15,930	13,657	13,657	13,657	13,657
Overall R-Square	0.0865	0.0865	0.0865	0.0865	0.116	0.116	0.116	0.116

Multinomial logit model of willingness to pay for a solar lighting device or for a connection for the electricity grid. Robust (clustered) p values are in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Table 4. Equity subsidy analysis.

	(1)	(2)	(3)	(4)	(5)	(6)
		Solar WTP			Grid WTP	
VARIABLES	Full sample	Bank = 0	Bank = 1	Full sample	Bank = 0	Bank = 1
Larger solar device	-0.1146***	-0.1070***	-0.1613***			
	(0.0001)	(0.0004)	(0.0000)			
Solar subsidies offer (USD)	0.1186*	0.0767	0.3759***			
	(0.0815)	(0.1815)	(0.0005)			
Grid subsidies offer (USD)				1.3190	1.2085	1.9866***
				(0.1553)	(0.2185)	(0.0012)
Account in Formal banking	0.0675***			0.1518***		
	(0.0000)			(0.0001)		
Rural dwelling	-0.0092	-0.0094	-0.0160	0.0291	0.0144	0.0499**
	(0.4786)	(0.3943)	(0.4897)	(0.1791)	(0.5399)	(0.0109)
Account in Informal banking	0.0400***	0.0420***	0.0335	0.0369**	0.0590*	-0.0028
	(0.0007)	(0.0000)	(0.1951)	(0.0435)	(0.0506)	(0.9385)
Mobile banking	0.0759***	0.0705***	0.0887**	0.1341***	0.1265***	0.1316***
	(0.0000)	(0.0000)	(0.0144)	(0.0000)	(0.0000)	(0.0001)
Owner of dwelling	0.0071	0.0211	-0.0273***	0.0881***	0.0705**	0.1242**
	(0.5758)	(0.1725)	(0.0000)	(0.0089)	(0.0226)	(0.0119)
Free of rent	-0.0132	-0.0146	0.0050	0.0008	-0.0299	0.0689***
	(0.5013)	(0.4718)	(0.8377)	(0.9840)	(0.4968)	(0.0016)
Type of dwelling = 1, Single house occupied by one household	0.0010	-0.0054	0.0221	-0.0090	-0.0196	0.0315
	(0.9551)	(0.7197)	(0.4905)	(0.7579)	(0.5982)	(0.5128)
Type of dwelling = 2, group of enclosed dwellings occupied by one household	-0.0048	0.0215	-0.0363	0.0270	0.0383	0.0209
	(0.9104)	(0.6299)	(0.3713)	(0.4064)	(0.3155)	(0.7110)
Walls Material: adobe	-0.0169**	-0.0184**	-0.0081	-0.0572***	-0.0589***	-0.0488***
	(0.0183)	(0.0135)	(0.6151)	(0.0002)	(0.0056)	(0.0045)
Solar lighting system	0.0751***	0.0850***	0.0556**	0.1272***	0.1332***	0.1020***
	(0.0000)	(0.0000)	(0.0155)	(0.0000)	(0.0000)	(0.0000)
Connection to the grid = 5, Unconnected, Installation too expensive	-0.0289	-0.0197	-0.0732***	-0.0265	-0.0121	-0.0751***
	(0.1893)	(0.4561)	(0.0001)	(0.4791)	(0.7828)	(0.0005)
Connection to the grid = 7, Unconnected, Other reason	-0.0087	-0.0012	-0.0449***	-0.0122	-0.0095	-0.0346
	(0.6129)	(0.9546)	(0.0030)	(0.6467)	(0.7491)	(0.3708)
Observations	15,930	12,788	3,142	13,409	10,273	3,094

Average marginal effects (probit model) for the effect of subsidies on willingness to pay for a solar lighting device or grid access. Robust (clustered) p values are in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Table 5. Interaction effects.

VARIABLES	(1) Solar WTP	(2) Grid WTP
Larger solar device	-0.1046**	
	(0.0218)	
No Subsidy/Bank = 0	-0.0654**	-0.1112**
	(0.0210)	(0.0305)
No Subsidy/Bank = 1 (baseline)	0.0000	0.0000
	(.)	(.)
Low subsidy (33%)/Bank = 0	-0.0250	-0.0872
	(0.2111)	(0.1373)
Low subsidy (33%)/Bank = 1	0.0598***	0.1050***
	(0.0049)	(0.0017)
High subsidy (66%)/Bank = 0	0.0541***	0.0025
	(0.0012)	(0.9384)
High subsidy (66%)/Bank = 1	0.1242***	0.1642***
	(0.0000)	(0.0002)
Constant	0.1368***	0.4868***
	(0.0000)	(0.0000)
R-squared	0.1182	0.1814
Demographics	Yes	Yes
Observations	15,930	13,409

Regression model with interaction effects between subsidy percentage amounts and formal banking on WTP for a solar device and grid access. Robust (clustered) p values are in parentheses. Controls are omitted for brevity. *** p<0.01, ** p<0.05, * p<0.1.

Table 6 Additional analysis.

	(1)	(2)	(3)	(4)	(5)	(6)
		Solar WTP			Grid WTP	
VARIABLES	Full sample	Bank = 0	Bank = 1	Full sample	Bank = 0	Bank = 1
Larger solar device	-0.1140***	-0.1067***	-0.1590***			
	(0.0001)	(0.0005)	(0.0000)			
Solar subsidy amount (USD)	0.1169	0.0758	0.3601***			
	(0.1013)	(0.2090)	(0.0007)			
Grid subsidy amount (USD)				1.2624	1.1298	1.9953***
				(0.1840)	(0.2607)	(0.0008)
Account in Formal banking	0.0614***			0.1384***		
	(0.0000)			(0.0001)		
inc_cat = 0, Lower Income	-0.0089	-0.0136	0.0045	0.0905***	0.0887**	0.0834
	(0.6692)	(0.4324)	(0.9390)	(0.0086)	(0.0240)	(0.1910)
inc_cat = 2, Higher Income	0.0560***	0.0617***	0.0388**	0.1377***	0.1429***	0.1180***
	(0.0002)	(0.0011)	(0.0198)	(0.0000)	(0.0000)	(0.0019)
Demographics	Yes	Yes	Yes	Yes	Yes	Yes
Observations	15,930	12,788	3,142	13,409	10,273	3,094

Average marginal effects (probit model) for the effect of subsidies on willingness to pay for a solar lighting device or grid access. Middle income is denoted as the baseline. Controls are omitted for brevity. Robust (clustered) p values are in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Table 7 Equity subsidies by country.

	Equity subsidy	
	Solar device	Grid access
Ethiopia (ETH)	-	-
Honduras (HND)	0%	256%
Kenya (KEN)	44%	64%
Cambodia (KHM)	0%	45%
Liberia (LBR)	57%	78%
Myamar (MMR)	0%	110%
Niger (NER)	11%	171%
Nigeria (NGA)	49%	-
Nepal (NPL)	13%	21%
Rwanda (RWA)	0%	-
Sao Tomas (STP)	-	-
Zambia (ZMB)	37%	0%
Mean Average	**43%**	**65%**

Estimated equity subsidies for each sampled country in terms of the WTP for solar device or grid access. Missing values are for data limitations. The complete regressions are available in the supplementary files..