Energy Economics 123 (2023) 106723

Contents lists available at ScienceDirect

Energy Economics

journal homepage: www.elsevier.com/locate/eneeco

Assets power solar and battery uptake in Kenya

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ARTICLE INFO

Keywords:
Asset
Electricity grid
Financial account
Kenya
Solar
Battery

ABSTRACT

Solar and battery adoption for households offers many benefits that motivate increased understanding of what drives investment. This paper uses microdata from a household survey in Kenya to investigate factors explaining investment in solar home systems, solar lighting systems, solar lanterns, and solar batteries. Key findings highlight the importance of assets for each investment type. Households are more likely to have a solar home system when they have bank or mobile money accounts, and when they own land with large values. Households are less likely to adopt solar systems when they are unable to afford grid connection, compared to households who are far away from electricity grids. Interaction analysis reveals that off-grid households without a mobile money account in key disadvantaged counties have lower solar home system adoption. A key policy implication is that support could be targeted to households with low levels of assets, in addition to existing support for suppliers.

1. Introduction

Greater investment in household solar and battery devices offers many potential benefits for households and broader communities. Increased energy access can align with Sustainable Development Goal 7 of the United Nations. A transition toward renewable energy production is also a key part of climate mitigation strategies to enhance sustainability at a global scale. In recognition of these benefits, there is strong motivation for improved understanding of drivers of investment in household solar devices.

Most solar adoption studies focus on developed countries, such as those in the Organisation for Economic Co-operation and Development (OECD). Approximately 71% of studies have been for members of the OECD (Best et al., 2023), despite these countries accounting for smaller shares of global aggregates such as around 20% of the global population. This provides scope for extra contributions for developing countries.

A smaller but growing number of studies have focused on various developing countries. Studies for South Asia cover solar intentions in India (Urpelainen and Yoon, 2015), non-income drivers in Bangladesh (Komatsu et al., 2011), and a study of India that used both household- and village-level data to assess asset influences on actual uptake (Aklin et al., 2018). For Africa, asset influences have been investigated for Ethiopia (Guta, 2018), Uganda (Aarakit et al., 2021), and Tanzania (Rahut et al., 2018). In addition, studies of solar intentions include one for Nigeria (Thompson et al., 2021).

This paper contributes through being substantially different to two prior papers on solar uptake in Kenya. One paper on Kenya conducted a study of intentions (Abdullah and Jeanty, 2011). Another key paper used a Kenyan survey from 2005 to 2006 to provide insights on energy transitions, although did not include asset variables (Lay et al., 2013).

This paper seeks to contribute through more comprehensive analysis of asset influences while also considering a current policy focus on spatial differences. This differs to most papers which have not investigated asset influences, or which focus on a single variable for housing values. This paper assesses seven different asset variables while controlling for three different locational variables. The paper provides a novel integration of two key alternatives for policy focus on assets or location through interaction analysis. The analysis of three different solar size categories is relevant in the context of gradually expanding energy access, even if affordability constraints may prevent large-system investments in the short term.

The paper's analysis of small battery uptake in a developing country is another novel contribution. There is very little literature on actual battery uptake for any country, in contrast to the massive literature for solar panel adoption (Alipour et al., 2021). Some Australian examples of early battery studies include the use of a survey of around 2000 households covered by the National Electricity Market (Best et al., 2021a) and a survey of around 600 Queensland households (Alipour et al., 2022). In addition, a study of California uses zip-code and census-tract data, noting the novelty of research on disparities in uptake of residential batteries (Brown, 2022). Given the small number of battery studies and existing focus on developed countries, early analysis of

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https://doi.org/10.1016/j.eneco.2023.106723
Received 16 August 2022; Received in revised form 29 April 2023; Accepted 1 May 2023
Available online 13 May 2023

battery uptake has the potential to be influential in setting the agenda for many future research papers.

The paper rests primarily on a fundamental economic framework, while also considering a broader context related to behavioural theories. A fundamental part of broader economic theories is the importance of wealth effects, where wealth or assets are positively linked to consumption and investment (Cooper and Dynan, 2016; Modigliani, 1966). Another key economic principle is substitution, which applies to this context since solar systems can be a substitute for grid supplied electricity. Of the numerous behavioural theories, Wolske et al. (2017) integrated numerous frameworks such as Diffusion of innovations, Theory of planned behavior, and Value-belief-norm theory. A generalisation is that these theories, and solar-uptake studies which refer to these theories, have a strong focus on social dimensions such as the importance of peer effects (Curtius et al., 2018).

The financial burden of upfront costs for energy investments is a key barrier which motivates analysis of assets and payment mechanisms. While income is often included in analysis of solar uptake, studies are increasingly focusing on assets, such as in Australia and Ethiopia (Best et al., 2021b; Best and Trück, 2020; Guta, 2018). For payment mechanisms, Lee et al. (2016) note that the financing challenge relating to the large upfront cost has been reduced through companies in Kenya integrating mobile money payment approaches. While there is great potential for spreading the upfront cost over time, most households have historically paid for solar devices up front (Dubey et al., 2019).

There are also a range of non-economic barriers which can be classified as socio-technical or institutional (Samoita et al., 2020). A key socio-technical barrier is where a lack of knowledge on maintenance of systems (Karakaya and Sriwannawit, 2015) may dissuade the initial investment. An important institutional barrier for households who seek to connect solar panels to the grid is the long and complicated licensing process which has existed in Kenya (Samoita et al., 2020). Institutional barriers can also include policy and political elements related to how policies are implemented.

Related socio-demographic issues may also be important. Education may help in shaping attitudes and providing relevant knowledge for solar uptake (Oluoch et al., 2020). However, Smith and Urpelainen (2014) did not find evidence that education was influential for solar power use in Tanzania. Gender may also be relevant for household decision-making related to solar devices (Kennedy et al., 2019; MacEwen and Evensen, 2021; Ojong, 2021; Winther et al., 2018). For example, Guta (2018) found that female-headed households were more likely to have solar panels in rural Ethiopia.

Electricity provides numerous benefits, if barriers such as the upfront costs are overcome. These are evident at a daily frequency across many sectors such as household and small-enterprise sectors. For households, electricity can promote increased satisfaction from higher-quality lighting and further leisure opportunities such as increased time spent on watching television (Wagner et al., 2021). Mugisha et al. (2021) refer to a case study in Kenya of the benefits of electricity supply in allowing small enterprises to use power tools and other electrical equipment.

There are many potential benefits of solar devices for households. Education can be enhanced, as evident in higher math scores for students who received solar-powered lamps in Kenya (Evans and Mendez Acosta, 2021). Kenyan evidence also exists for the effectiveness of solar devices in powering communication devices (Jacobson, 2007; Mugisha et al., 2021). Solar home systems have also been shown to enhance sustainability through reduced energy expenditure in Kenya, following reduced use of more traditional energy forms such as kerosene for lighting (Wagner et al., 2021). This transition also provides health benefits from avoidance of toxic fumes from burning kerosene (George et al., 2020). A further benefit of solar devices can be income-generating activities, where private or community solar devices are made available for services such as mobile phone charging for a fee (Roche and Blanchard, 2018).

2. Data and method

2.1. Study area

Access to electricity has increased recently in Kenya, with growth from 56% of the population having access in 2017 to 71% in 2020. This was higher than the 2020 average for Sub-Saharan Africa at 48% but lower than the global average of 90% (World Bank, 2023). Approximately 50% of households in Kenya have had access to electricity through the national grid with another 20% having off-grid access such as through solar home systems (Dubey et al., 2019).

There is major geographical variation, as rural households are around four times more likely to lack access (Dubey et al., 2019; Kimutai and Talai, 2021). Major gaps in access are pronounced in northern Kenya, leading to adverse socio-economic impacts (Mwau and Mwaniki, 2022). For example, based on the 2019 Kenya Census, <3% of households used electricity for lighting in Turkana and West Pokot counties (Mwau and Mwaniki, 2022). The 2019 Kenya Census also reported that 26% of connected households in Turkana West in northern Kenya had unreliable access with blackouts at least twice a week (Mwau and Opiyo, 2022).

In line with the major benefits of solar devices, there has been renewed policy focus within Kenya and more broadly within East Africa (Hansen et al., 2015; World Bank, 2017). World Bank support has included a project named the 'Kenya: Off-grid Solar Access Project (KOSAP) for Underserved Counties'. These 14 underserved counties were designated as 'marginalised' by the Kenyan Commission on Revenue Allocation (World Bank, 2017). KOSAP support involves US$150 million in credit from the International Development Association. The funding was planned for 2018–2023 to promote solar access for households and communities, along with capacity building. However, only 26% had been disbursed by November 2022 and the project has been extended until 2025 (World Bank, 2022).

A US$42 million component of KOSAP was specifically designated for stand-alone solar systems for households. It is a contribution toward a larger project of the Government of Kenya with World Bank support, called the North and North Eastern Development Initiative (NEDI), noting that KOSAP includes four counties which are not covered by NEDI. An indirect incentive for solar products has also been available through value-added-tax (VAT) exemption, which was re-instated in 2021 after initially being introduced in 2013 (IEA, 2016; GOGLA, 2021).

Incentives for energy uptake in Kenya have tended to focus on supply issues rather than direct support for households. The two financing instruments in the KOSAP both go directly to solar service providers, rather than households (World Bank, 2017). The first part involves capped and competitively awarded incentives, while the second part is a debt facility. These instruments help solar service providers to manage upfront hardware costs and default risk where customers pay for systems with instalments. Solar service providers receiving financial assistance have been announced as including Green Innovation Ventures Enterprises Ltd (2022). Providers sometimes offer incentives to households who promptly repay loans for solar products, such as in the case of a company named Solibrium (UNESCO, 2019). A small proportion at around 5% of households have also received solar systems for free from government or non-government organisations (Dubey et al., 2019; ESMAP, 2021). Policy support and use of batteries has been minor in Kenya (Dubey et al., 2019; ESMAP, 2021).

2.2. Data and sampling

The survey used for this paper was conducted by the World Bank (ESMAP, 2021). It includes a nationally representative core group of around 3300 households which covers all of Kenya's 47 counties. Households were selected through stratified random sampling by county based on the proportion of the population in each county in the 2009 census, the most recent census before the household energy survey was completed. In addition, the mapping for the primary sampling units referred to the 2015 Revision of UN World Population Prospects (Dubey et al., 2019). Stratification included a 50–50 rural-urban split at the national level (Dubey et al., 2019). While this is a substantial rural proportion for the survey, it is still below the rural proportion for the Kenyan population (World Bank, 2023). However, the sample also includes oversampling with over 1000 additional households from the 14 underserved counties, in addition to households from these counties from the core sample. The oversampled counties mostly have rural populations which often rely on pastoralism (Dubey et al., 2019), leading to 57% of the total sample being from rural areas.

The survey was run by a consortium involving ESMAP, EED Advisory and the Stockholm Environment Institute. They conducted personal interviews, including computer assisted personal interviews with tablets (Dubey et al., 2019). Pre-testing of the survey was undertaken in late 2016 and the survey data was collected in 2016 and 2017. This process aimed to have well-structured and comprehensible questions, while excluding redundant or ambiguous questions (Dubey et al., 2019). The timing of the survey used in this paper being from 2016 to 17 is advantageous, as it comes just before the commencement of the KOSAP support in 2018. This allows for an assessment of locational differences prior to the influence of the policy support.

The ESMAP survey drew on World Bank expertise following experience in other developing countries. Inclusion and exclusion of questions was also motivated by the key focus on accurately estimating energy access as well as types and quality of access. The exclusion of variables such as those related to environmental perceptions or peer effects are examples of practical omissions which help to ensure that the interviews were not too long. Interview duration was a focal point for the survey (Dubey et al., 2019). Practical exclusions such as for environmental perceptions have been common for non-OECD countries (Best et al., 2023).

The sample of nearly 4600 households was approximately 73% of the targeted number of 6300 (Dubey et al., 2019). Nairobi and counties to its west have the most respondents, indicated by the darker shading in Fig. 1. The 14 underserved counties, which are in the north and east other than the inclusion of Narok and the exclusion of Mombasa (as shown in Appendix Fig. A.1), also have relatively large numbers of respondents due to the oversampling strategy. This motivates the use of probability weights from the data provider, which give a higher weight to households which represent larger numbers of other households.

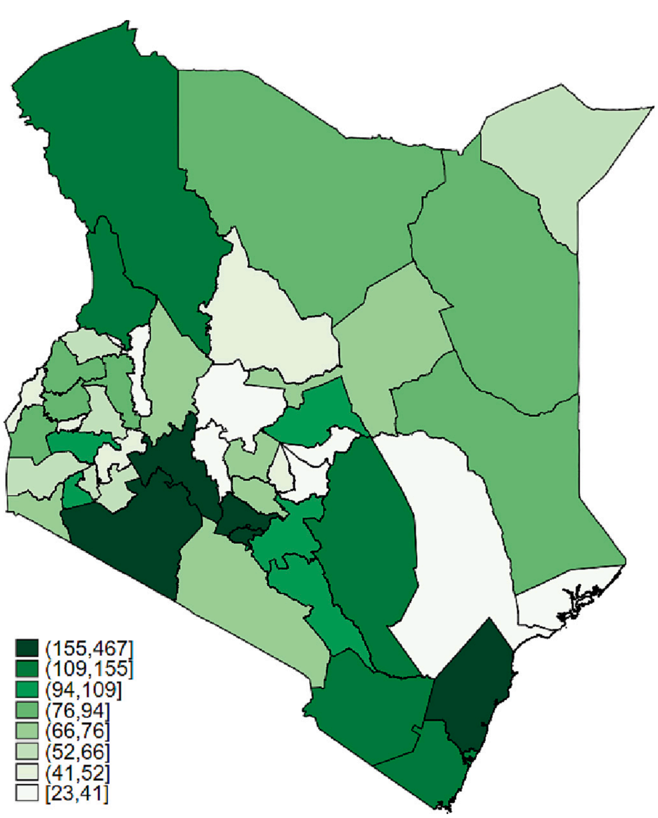

Fig. 1. The number of survey respondents per county. Data: ESMAP (2021); Hijmans and University of California (2015).

Appendix Table A.1 gives the detailed breakdown of the sample by county, showing that most counties outside of the capital city have a rural majority in the sample. The following counties are part of the 14 underserved counties group and have a majority of rural households: Isiolo, Kilifi, Kwale, Lamu, Narok, Taita Taveta, Tana River, Turkana, Wajir, and West Pokot. The remaining underserved counties with a majority of urban households in the survey are: Garissa, Mandera, Marsabit, and Samburu. Solar home system adoption was particularly high in some counties north of Nairobi, such as Nyandarua and Meru, although the sample size for Nyandarua was very small.

For the regression analysis in Section 3, 23 households are dropped due to missing probability weights. The sample for this paper also excludes 22 households who had chosen not to get a grid connection because of satisfaction with their current energy situation. This could theoretically relate to having solar devices, so the exclusion helps to avoid concern on reverse causation. Results which control for the number of rooms contribute to a lower sample size as this variable is stated by only 4372 households. Also, the household head is only identified by 4023 households. In 25 cases where two household heads were identified, this paper designates the head as the individual with the lower age, and the higher income for one case with equal ages. Most results do not use these variables to maintain a large sample.

2.3. Data analysis and variables

Variable selection aligns with the insights from previous literature reviews (e.g. Alipour et al., 2020) which show the commonly assessed and important variables from prior studies. For example, the top four variables of income, education, age, and home ownership are all included in this paper. In addition, this paper assesses the understudied aspect of assets, which includes key economic variables with strong policy relevance. Many other demographic and housing variables are also included in this paper, consistent with prior studies (Alipour et al., 2020). Variable descriptions are given in Appendix Table A.2.

While studies would ideally account for every potentially important factor, international literature reveals that even high-quality publications tend to focus on a subset of factors. For example, Wolske et al. (2017) and Jacksohn et al. (2019) account for social factors and income but not assets. Socio-demographic variables are included in a minority of studies, with around 25% of studies assessing gender and 45% assessing education (Best et al., 2023). Systematic differences in variable coverage exist, as Best et al. (2023) show that cross-sectional studies of actual solar uptake are less likely to investigate peer effects.

A caveat for this paper is that some social aspects are not included, such as personality traits or peer effects, due to unavailability in the ESMAP (2021) data. However, a previous study in a developed-country context finds that personality traits have low relevance when key socio-demographic and housing characteristics are included (Jacksohn et al., 2019). In addition, a study of Nepal found that included measures to proxy peer effects had little impact on key economic variables (Best and Nepal, 2022).

Several key relationships that are evident in the data will be the focus of the ensuing analysis in Section 3. For example, Fig. 2 shows the proportion of households in the survey with each type of solar device, split by whether the household has a bank account. There is a substantial difference for solar home systems, which are the largest capacity solar devices. There are also higher proportions of solar devices in respect of solar lighting systems and solar lanterns for households with bank

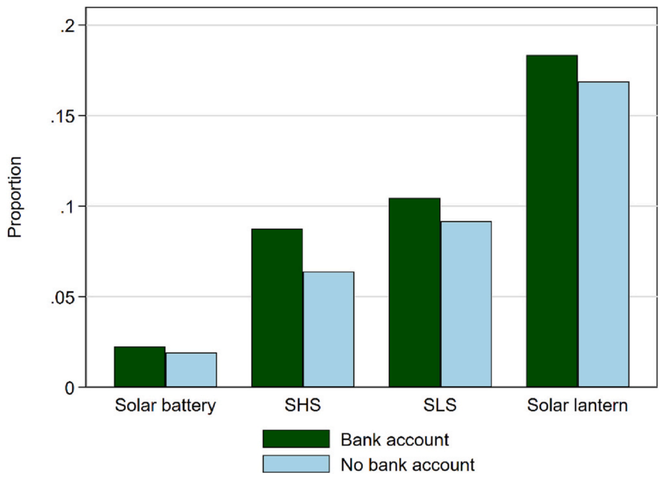

Fig. 2. Proportions of households with solar devices, for households with a bank account and those without. SHS = solar home system; SLS = solar lighting system. Data: World Bank Multi-tier Framework Survey (ESMAP, 2021).

accounts compared to those with no bank account. Section 3 investigates if these relationships hold when controlling for other variables.

Fig. 3 shows solar home system (SHS) proportions for eight categories based on an interaction of three binary variables. These three variables are grid connection, location in an underserved county, and mobile-money accounts. The four bars on the left half, for off-grid households, are mostly much higher than for the four grid-connected bars on the right. However, there is a low SHS proportion for the third group which is off-grid households in an underserved county and without a mobile money account (0U0). This already raises the possibility that for policies that focus on off-grid households in underserved counties, an additional focus can be on households who also lack financial means such as mobile-money accounts.

Fig. 4 gives the proportion of households with solar devices for four categories: households with a connection to the electricity grid, unconnected households who state that they are too far away from the grid, unconnected households who cite the high connection cost as the main reason for their lack of a connection, and other unconnected households. While there are higher proportions with solar home systems for households which are not connected to the grid, compared to connected households, there are substantial solar differences depending on the reason for being unconnected. Capital constraints are suggested by the low solar proportion for households who cite the high cost of connection as the main reason for their lack of a grid connection. Section 3 investigates if this implication of the importance of assets is robust to the more systematic empirical analysis.

2.4. Models

The structure of the modelling is shown in Eq. (1):

$$S_h = \alpha + \boldsymbol{L}_h'\beta + \boldsymbol{A}_h'\gamma + \boldsymbol{E}_h'\rho + \boldsymbol{G}_h'\psi + \boldsymbol{D}_h'\mu + \varepsilon_h \tag{1}$$

The paper uses a probit model for regression approaches based on data for each household (h). Extensions of this model include interaction variables that are included in separate regressions. The dependent variable in each case is based on a binary variable equal to one for households with each solar device. The different dependent variables in separate regressions relate to households with a solar home system, solar lighting system, solar lantern, or solar battery. The definitions of these variables are given in Table A.2. The explanatory variables in the vectors on the right of Eq. (1) are also categorised and described in Table A.2. These include vectors for location (L), assets (A), other economic (E), grid (G), and socio-demographic (D) variables. Eq. (1) also shows the constant (α). Similar results can be obtained with logit or linear probability models.

Entropy balancing is also employed in the appendix of this paper. This is a matching approach that is appropriate for observational data where randomised controlled trials are not undertaken (Athey and Imbens, 2016; Hainmueller, 2012; Hainmueller and Xu, 2013). The method involves assessing a binary 'treatment' variable. For example, having a bank account can be used to classify households into the 'treatment' group, while other households are classified into the 'control' group. Entropy balancing aims to match the two groups by

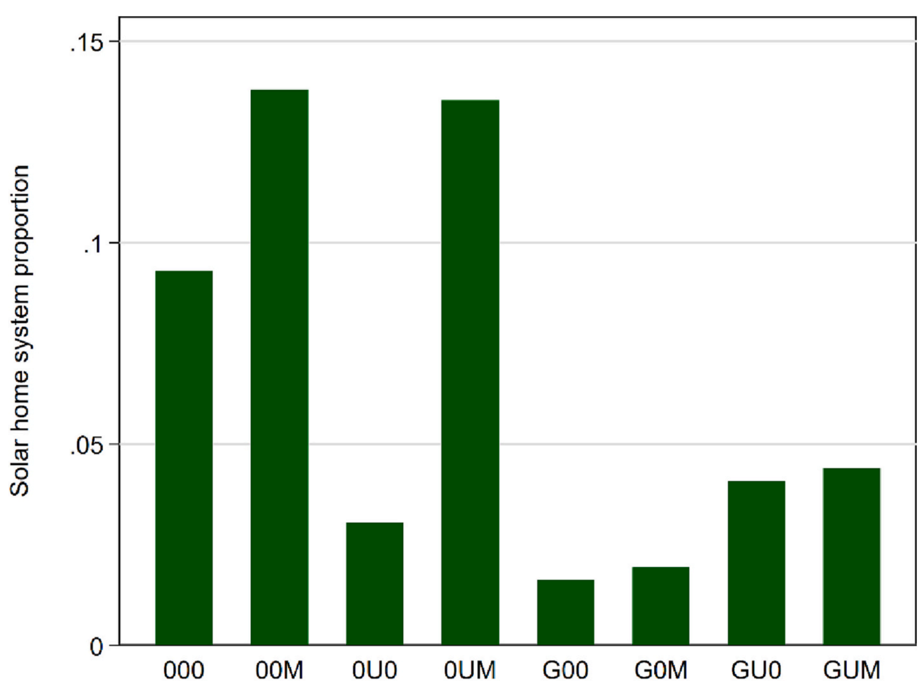

Fig. 3. Proportions of households with solar home systems for eight categories based on grid status (yes = G; no = 0), underserved county location (yes = U; no = 0), and mobile money accounts (yes = M; no = 0). Data: World Bank Multi-tier Framework Survey (ESMAP, 2021).

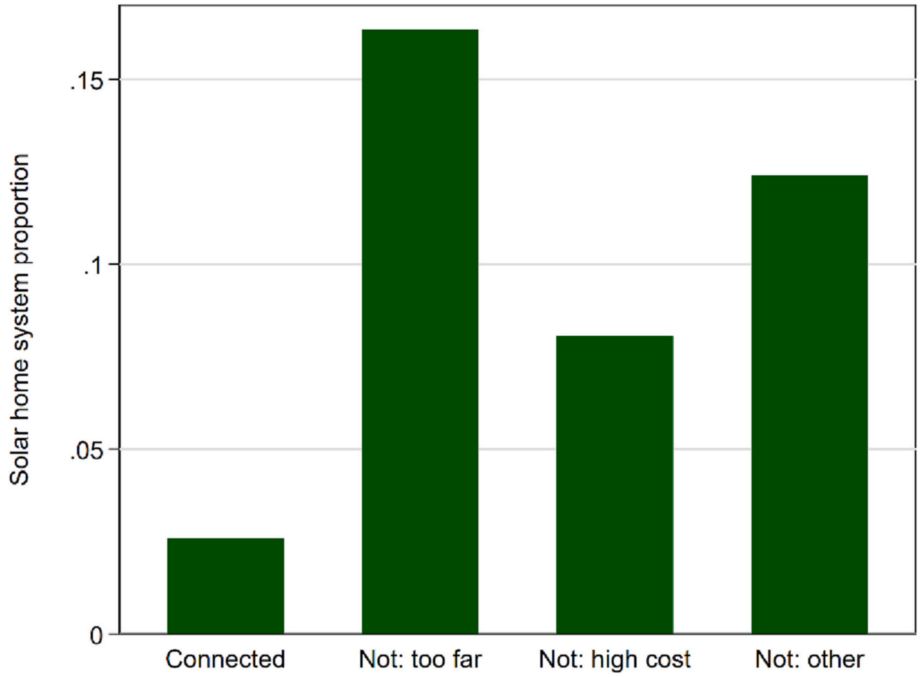

Fig. 4. Proportions of households with solar home systems for categories based on grid connection or the main reason for no connection. Data: World Bank Multi-tier Framework Survey (ESMAP, 2021).

weighting the control group to produce covariate moments which match the treatment group as closely as possible. The covariates are the same as in Eq. (1).

3. Results

There are many positive and significant coefficients for asset-related variables when explaining solar home system adoption in Table 1. Some of these coefficients are positive and significant when either excluding or including the grid coefficients, while some asset coefficients are only significant in one column. Three asset aspects which are significant in both columns are the mobile money account, the top level for types of livestock, and the top land value coefficients. Dwelling ownership and the second-highest level of livestock types are positive and significant only when not including the grid coefficients in column (1). In contrast, the bank account and transport or agricultural equipment coefficients become significant in column (2) when including the grid coefficients. The material for the dwelling construction also has a significant influence in explaining solar-home-system investment. Households which have traditional mud structures are less likely to have solar home systems.

The grid variable coefficients are significant in column (2) of Table 1 compared to the reference category of households who are not connected to the grid because it is too far away or not available. The negative and significant coefficient for households who do have a grid connection shows the lower incentive to get a solar home system when electricity is already available from the grid. There is also a negative and significant coefficient for households who do not have a grid connection because of the cost of connection being too high. These households are less likely to get a solar home system because they face affordability issues. They have revealed that they find the cost of grid-connection to be too high, so the same capital-constraint principle applies for investment in solar home systems.

A robustness test in Appendix Table A.3 with all 4590 households produces similar results compared to Table 1, as expected given that only 45 households were dropped for Table 1. A further robustness test in the available Stata code gives similar results when controlling for the 47 counties rather than the 8 provinces (and dropping the underserved counties variable). This produces a higher pseudo R-squared value of 0.26.

Variance inflation factors for a linear probability model have an average of 1.8, as displayed through available Stata code. This is well below a threshold of 10 that is used to indicate multicollinearity problems. This suggests that multicollinearity is not an issue for this study.

There is a negative and significant interaction coefficient for households who are in underserved counties and who do not have a mobile money account in Table 2. There is therefore a suggestion that these households are less likely to have solar home systems, all else equal, compared to households without a mobile money account in other regions. The statistical significance is at the 10% level. Policy attempts to support uptake of solar home systems in these underserved counties could consider targeting assistance to households without mobile money accounts.

Table 3 uses bank accounts instead of mobile-money accounts for the interaction. Table 3 reinforces the point that having a bank account is a positive indicator of being more likely to have a solar home system. The first row suggests this with a positive coefficient which is significant at the 5% level. There is no significant impact of being in an underserved county for households without a bank account, based on the second row.

Table 4 has coefficients for a three-way interaction of variables for grid status, underserved-county location, and mobile-money accounts. The reference category is off-grid (G0) households in underserved counties (U1) who do not have a mobile money account (M0). This is equivalent to the third bar in Fig. 3 (0U0). There are positive and significant coefficients for two of the other off-grid groups. These are households with mobile-money accounts (one group in underserved counties and the other group in other counties; these are the groups relating to the second and fourth bars in Fig. 3). Focusing on off-grid households in underserved counties (G0U1), it is evident that a mobile-money account has a positive association with solar home system investment. This result is based on the positive and significant coefficient for G0U1M1, which only differs to the reference group in the value for mobile money accounts. The negative impact of grid connection on having a solar home system is evident in the negative coefficients

Table 1
Probit results for solar home systems.

	(1)	(2)
Rural	0.411***	0.042
	(0.111)	(0.121)
Underserved county	0.168	−0.053
	(0.138)	(0.142)
Bank	0.073	0.208**
	(0.089)	(0.089)
Informal	0.051	0.061
	(0.094)	(0.097)
Mobile money	0.299**	0.361***
	(0.133)	(0.138)
Reference: no livestock		
2 types of livestock	0.269*	0.204
	(0.146)	(0.152)
3+ types of livestock	0.508***	0.359**
	(0.148)	(0.151)
Transp. or ag. equip.	0.172	0.256**
	(0.107)	(0.109)
Reference: no land owned		
Top land value	0.343***	0.370***
	(0.123)	(0.129)
Dwelling owned	0.452***	0.246
	(0.155)	(0.155)
Rent free	0.413*	0.171
	(0.222)	(0.237)
Ref: other dwelling types		
Single house, one household	−0.040	−0.062
	(0.110)	(0.111)
Group of dwellings, 1 h/h	0.071	0.052
	(0.176)	(0.173)
Mud structure	−0.280**	−0.396***
	(0.109)	(0.112)
Number of people	0.023	0.021
	(0.020)	(0.021)
Ref: unconnected, too far		
Connected to grid		−1.275***
		(0.167)
Unconnected, high cost		−0.462***
		(0.120)
Unconnected, other reason		−0.276**
		(0.126)
Probability weights	Yes	Yes
Observations	4545	4545
Pseudo R^2	0.133	0.190

Notes: ***, **, * show statistical significance at the 1%, 5%, or 10% level. Coefficients are not shown for constants, provinces, livestock = 1 type, and land values below the top category.

Table 2
Interaction coefficients for underserved-county and mobile-money-account variables.

	Coefficient	Standard error
Reference: U0M0		
U0M1	0.201	(0.128)
U1M0	−0.516*	(0.290)
U1M1	0.261	(0.202)

Notes: * shows statistical significance at the 10% level. U stands for underserved county (yes = 1; no = 0). M stands for mobile money accounts (yes = 1; no = 0). Controls match Table 1: column (2). There are 4545 observations. Results are for SHS.

for G1 groups, although only one of these is significant when the reference group is G0U1M0.

Key outcomes are similar in Table 5 for the smaller sample with the extra control variables. This suggests robustness of the key outcomes to both differing control sets and different samples. There are positive and significant coefficients for bank accounts, having 3+ types of livestock, transport/agricultural equipment, and the top land value. The mud structure and grid coefficients are negative and significant, matching Table 1.

Table 3
Interaction coefficients for underserved-county and bank-account variables.

	Coefficient	Standard error
Reference: U0B0		
U0B1	0.217**	(0.098)
U1B0	−0.030	(0.173)
U1B1	0.133	(0.160)

Notes: ** shows statistical significance at the 5% level. U stands for underserved county (yes = 1; no = 0). B stands for bank accounts (yes = 1; no = 0). Controls match Table 1: column (2). There are 4545 observations. Results are for SHS.

Table 4
Interaction coefficients for a three-way interaction.

	Coefficient	Standard error
Reference: G0U1M0		
G0U0M0	0.384	(0.309)
G0U0M1	0.564*	(0.299)
G0U1M1	0.736**	(0.368)
G1U0M0	−1.435***	(0.434)
G1U0M1	−0.465	(0.315)
G1U1M0	−0.261	(0.477)
G1U1M1	−0.079	(0.355)

Notes: ***, **, * show statistical significance at the 1%, 5%, or 10% level. G stands for grid (yes = 1; no = 0). U stands for underserved county (yes = 1; no = 0). M stands for mobile money accounts (yes = 1; no = 0). Controls match Table 1: column (2). There are 4545 observations. Results are for SHS.

The additional variables produce some significant coefficients in Table 5. There is a positive and significant coefficient for the number of rooms. This is consistent with larger housing structures having more roof space, all else equal. Compared to the reference case of monogamous married couples, there are negative coefficients when the household head has another marital status. Significance is evident for the 'never married' and 'divorced' cases. There is a positive and significant coefficient for the education variable (school). This suggests that some knowledge is useful in promoting solar-home-system investment.

There are substantial asset-related marginal effects in Table 6 for solar home systems (SHS). These include 2.7 and 5.4 percentage points for bank accounts and the top land value respectively. Similar magnitudes for asset-related variables are also evident with an alternative method of entropy balancing in Appendix Table A.4. Substantial capital constraints are also evident for solar home systems in Table 6, based on the marginal effect of nine percentage points for households citing the high connection cost as their main reason for not having a grid connection.

Some common themes are evident in Table 6 for explaining investment in different solar types. Having a bank or mobile money account is positively associated with each of solar home systems, solar lights, and solar lanterns. Having a grid connection is associated with lower likelihood of investment in each of the three solar types, and also for solar batteries.

Table 6 also reveals some intuitive differences in explanations for asset influences on the different solar types. Asset-related variables appear to be more important for solar home systems, compared to solar types which have smaller capacities. While there are positive and significant coefficients for the transport/agricultural equipment and top land-value variables in the solar-home-system column, both of these variables are insignificant in the solar-lantern column. Asset importance for solar batteries is evident with positive and significant coefficients for both livestock variables. In addition, unshown coefficients for the second- and third-highest land values are also positive and significant, contrasting to the case for the other solar types where the unshown coefficients are insignificant.

Table 6 also shows some differences across solar types for building tenure and building materials. There is a negative and significant

Table 5
Probit results, extra controls.

	Coefficient	Standard error
Rural	0.021	(0.134)
Underserved county	−0.114	(0.168)
Bank	0.196*	(0.101)
Informal	0.025	(0.110)
Mobile money	0.146	(0.140)
Ref: no livestock		
2 types of livestock	0.111	(0.167)
3+ types of livestock	0.324**	(0.163)
Transp. or ag. equip.	0.315***	(0.116)
Ref: no land owned		
Top land value	0.282**	(0.143)
Dwelling owned	0.149	(0.183)
Rent free	0.140	(0.269)
Ref: other dwelling types		
Single house, one household	−0.092	(0.119)
Group of dwellings, 1 h/h	−0.036	(0.181)
Mud	−0.382***	(0.127)
Number of people	0.016	(0.026)
Ref: Unconnected, to far		
Connected to grid	−1.540***	(0.191)
Unconnected, high cost	−0.632***	(0.132)
Unconnected: other reason	−0.474**	(0.136)
Rooms	0.028*	(0.015)
Ref: no income/not stated		
Income <1000 KES	−0.234	(0.306)
Income ≥ 1000 & < 10,000	−0.018	(0.153)
Income ≥ 10,000 KES	0.217	(0.132)
Self-employed	−0.083	(0.113)
Female	0.251	(0.165)
Ref: married, monogamous		
Married, Polygamous	−0.150	(0.233)
Cohabitating, Single Partner	−0.392	(0.397)
Never Married	−1.058***	(0.402)
Divorced	−0.855*	(0.498)
Separated	−0.229	(0.355)
Widowed	−0.280	(0.206)
School	0.627***	(0.196)
Age	0.006	(0.004)

Notes: ***, **, * show statistical significance at the 1%, 5%, or 10% level. Coefficients are not shown for constants, provinces, livestock = 1 type, and land values below the top category. Probability weights are used. There are 3783 observations. The pseudo R-squared is 0.229. Results are for SHS.

Table 6
Marginal effects from probit models for each type of solar device.

	SHS	Solar Lights	Solar Lantern	Solar Battery
Rural	0.006	−0.018	−0.027	−0.016
	(0.016)	(0.022)	(0.024)	(0.015)
Underserved county	−0.007	0.025	0.017	0.032***
	(0.019)	(0.019)	(0.023)	(0.009)
Bank	0.027**	0.027**	0.059***	0.003
	(0.012)	(0.013)	(0.018)	(0.007)
Informal	0.008	0.012	0.003	−0.009
	(0.013)	(0.015)	(0.019)	(0.008)
Mobile money	0.047***	0.064***	0.040*	0.008
	(0.018)	(0.018)	(0.022)	(0.010)
Reference: no livestock				
2 types of livestock	0.027	0.052**	0.086***	0.030***
	(0.021)	(0.023)	(0.029)	(0.011)
3+ types of livestock	0.052**	0.055*	0.047	0.022**
	(0.023)	(0.030)	(0.030)	(0.009)
Transp. or ag. equip.	0.033**	0.032*	0.019	0.000
	(0.014)	(0.018)	(0.021)	(0.008)
Reference: no land owned				
Top land value	0.054***	0.019	0.017	0.008
	(0.020)	(0.023)	(0.027)	(0.008)
Dwelling owned	0.032	0.041	−0.051*	0.000
	(0.020)	(0.028)	(0.029)	(0.019)
Rent free	0.022	0.002	−0.080	−0.060**
	(0.031)	(0.042)	(0.056)	(0.027)
Ref: other dwelling types				
Single house, one h/h	−0.008	0.019	−0.009	0.000
	(0.015)	(0.017)	(0.020)	(0.009)
Group of dwellings, 1 h/h	0.007	−0.001	−0.006	0.017
	(0.024)	(0.020)	(0.030)	(0.014)
Mud structure	−0.052***	−0.015	0.049**	−0.021***
	(0.015)	(0.015)	(0.021)	(0.007)
Number of people	0.003	0.011***	0.005	−0.002
	(0.003)	(0.003)	(0.004)	(0.002)
Ref: unconnected, too far				
Connected to grid	−0.171***	−0.107***	−0.118***	−0.064***
	(0.027)	(0.024)	(0.030)	(0.018)
Unconnected, high cost	−0.094***	−0.013	−0.014	−0.032**
	(0.026)	(0.024)	(0.029)	(0.016)
Unconnected, other reason	−0.061**	0.019	0.025	0.000
	(0.029)	(0.026)	(0.031)	(0.018)
Probability weights	Yes	Yes	Yes	Yes
Observations	4545	4545	4545	4545
Pseudo R^2	0.190	0.139	0.120	0.251

Notes: ***, **, * show statistical significance at the 1%, 5%, or 10% level. Coefficients are not shown for constants, provinces, livestock = 1 type, and land values below the top category. Neighbouring Province 1 and 4 are combined for the Solar Battery regression since no surveyed households in Province 4 have a Solar Battery.

dwelling-ownership coefficient for solar lanterns. This is reasonable, as mobile solar lanterns could be a practical approach for residents who may not have the right to make dwelling alterations with larger solar home systems. The coefficient for the building construction using mud also differs across columns. There is a positive and significant coefficient for the solar lanterns column in contrast to the negative and significant coefficients for solar home systems and batteries. Larger solar panels (used in solar home systems) may be more appropriate for more modern construction techniques than the traditional mud structures.

4. Discussion

The asset variables were particularly important in Section 3, which is consistent with the fundamental economic framework referring to wealth effects. The lesser importance of income also aligns with fundamental economic intuition as solar adoption entails an upfront cost that is most directly overcome via accumulated assets. While other financing mechanisms exist, most solar systems in Kenya have been bought and fully paid at purchase (Dubey et al., 2019). The strong negative link between grid-connection and solar adoption is also consistent with expectations based on the fundamental economic concept of substitution. The four-level variable for grid connection also aligns with the framework of wealth effects, since households who are unconnected to grids because of high cost are also less likely to be able to afford the upfront cost of solar systems.

A central takeaway from the paper is that the importance of asset-related variables for solar investments is evident for many types of asset variables. In the case of Kenya, households are more likely to have solar home systems when they have larger land values or more livestock types. Payment mechanisms are also important, as having bank accounts raises the likelihood that households have solar home systems. The importance of payment mechanisms is consistent with the analysis of George et al. (2020) who focused on a pay-as-you-go model.

There is overlap in the key results with findings for developed countries and also some novel insights. The key role of assets in promoting solar uptake matches the usual outcome for developed countries in the minority of studies which account for assets (e.g. Best and Trück, 2020; Best et al., 2021b). The interaction analysis in this paper reveals novel differences across locations for the influences of payment mechanisms. Another novel aspect in this paper is the analysis of magnitudes of differences by grid connection, which is often not relevant for developed countries where most households are connected to a large grid.

In relation to battery uptake, this paper provides novel results related to asset impacts. The very limited literature on small battery uptake, which has started in developed countries, has either not included asset variables or used an indirect proxy of financial pressure (Alipour et al., 2022; Best et al., 2021a; Brown, 2022). It is possible that future studies of both developed and developing countries could find positive links between assets and battery uptake, as in this paper, following the consistent link between assets and solar-panel uptake.

While there would be greater marginal benefits from solar devices for homes with no electricity, compared to households with a grid connection, there is still much potential for solar home devices for grid-connected households. Solar devices can be a substitute electricity source that can provide power at some times when there are grid outages. Solar panels for grid-connected households can also contribute to climate-change mitigation and broader sustainability goals.

5. Policy implications and conclusion

Several policy-relevant insights come from the analysis. There is scope to increase the focus on solar investment for grid-connected households, in addition to the current focus on off-grid households in the KOSAP. Additional financial incentives might also be necessary to allow more households to afford upfront costs for solar and battery solutions in pursuit of 100% electricity access in Kenya (Dubey et al., 2019). This can include financial incentives targeted directly at households, in addition to supporting providers. In doing so, different amounts of support for different households may be suitable, as willingness and ability to pay varies across households (Dubey et al., 2019). Many other benefits can also be realised with support beyond the household scale, such as solar-powered water pumps to give access to clean water for drinking and cooking like at Nyandiwa (UNESCO, 2019).

The detailed interaction analysis also reveals key policy insights. Instead of just focusing on location, a possible policy change could be to direct support to households without financial accounts. This is based on there being some evidence that households in underserved areas may be less likely to have solar panels when they are also lacking financial accounts such as mobile money accounts. An even more specific approach can target off-grid households in underserved counties as the results show that having a mobile money account could raise investment in solar home systems in these areas. Household targeting can also be directed at households with low assets. This would be a reform of an existing energy policy, which is one category of the opportunities described by George et al. (2019).

Holistic policy strategies can aim to support households in obtaining different types of solar device depending on the characteristics of each household and the links identified in this paper for solar adoption. Assets appear to be most important for the largest category of solar device (solar home systems), as expected. Assets are also important for adoption of solar lighting systems. The small and more transportable solar lanterns may be more appropriate for households who live in traditional structures that mainly use mud bricks.

Policy can also focus on helping renters to access solar systems. This paper showed some evidence that dwelling owners in Kenya are more likely to access larger types of solar systems. In contrast, there is some evidence that dwelling owners are less likely than renters to have portable systems such as solar lanterns. Portable options are more suitable for renters who do not have the right to modify their residence. Policy could initially build on these intuitive outcomes by expanding access to portable solar systems for renters.

Future studies could also refer to other frameworks such as the Diffusion of Innovations or other socially focused frameworks. There are future opportunities for assessing peer effects and environmental perceptions in developing countries. This would be a further contribution in the future, given that prior studies of non-OECD countries have been substantially less likely to assess these influences (Best et al., 2023). This could be useful in the context of a growing focus on clean energy investments in Africa to address sustainability and climate challenges (Sy et al., 2019).

CRediT authorship contribution statement

Rohan Best: Conceptualization, Methodology, Formal analysis, Writing – original draft, Writing – review & editing.

Data availability

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

Appendix A. Appendix

Table A.1
Key statistics from the survey, split by county.

County	Sample	Rural proportion	Underserved = 1	SHS proportion
Baringo	71	0.82	0	0.13
Bomet	65	0.82	0	0.03
Bungoma	77	1.00	0	0.05
Busia	47	0.77	0	0.06
Elgeyo Marakwet	41	0.61	0	0.00
Embu	41	0.66	0	0.10
Garissa	91	0.32	1	0.02
Homa Bay	54	0.83	0	0.09
Isiolo	67	0.63	1	0.01
Kajiado	74	0.42	0	0.19
Kakamega	83	0.78	0	0.05
Kericho	52	0.62	0	0.02
Kiambu	210	0.39	0	0.09
Kilifi	281	0.58	1	0.03
Kirinyaga	51	0.75	0	0.02
Kisii	95	0.73	0	0.02
Kisumu	103	0.38	0	0.11
Kitui	129	0.90	0	0.10
Kwale	155	0.66	1	0.07
Laikipia	38	0.68	0	0.24
Lamu	23	0.52	1	0.04

(continued on next page)

Table A.1 (*continued*)

County	Sample	Rural proportion	Underserved = 1	SHS proportion
Machakos	105	0.35	0	0.10
Makueni	104	0.77	0	0.05
Mandera	55	0.09	1	0.29
Marsabit	79	0.49	1	0.10
Meru	109	0.91	0	0.23
Migori	73	0.58	0	0.08
Mombasa	118	0.04	0	0.03
Muranga	76	0.84	0	0.04
Nairobi	467	0.00	0	0.01
Nakuru	175	0.39	0	0.09
Nandi	66	0.80	0	0.05
Narok	214	0.74	1	0.07
Nyamira	55	0.73	0	0.11
Nyandarua	29	1.00	0	0.48
Nyeri	67	0.84	0	0.13
Samburu	46	0.37	1	0.15
Siaya	79	0.81	0	0.09
Taita Taveta	117	0.59	1	0.09
Tana-River	38	0.92	1	0.05
Tharaka-Nithi	40	0.73	0	0.15
Trans Nzoia	60	0.62	0	0.03
Turkana	140	0.64	1	0.07
Uasin Gishu	94	0.46	0	0.04
Vihiga	45	0.89	0	0.02
Wajir	94	0.69	1	0.05
West Pokot	152	0.92	1	0.14

Notes: Underserved = underserved county: these are shown in Fig. A.1; SHS = solar home system.

Table A.2
Variable descriptions.

Variable	Description
Dependent (S)	
Solar home systems (SHS)	Solar home systems have historically been considered as an alternative to the grid but also include on-grid systems that are complements to the grid (Lay et al., 2013). For the World Bank Multi-Tier Framework survey (Dubey et al., 2019), SHS are any solar devices in the largest capacity category (they are larger in capacity than solar lighting systems and solar lanterns). Typically, one SHS has been able to power appliances such as televisions or refrigerators and has been sufficient to reach a Tier 3 electricity access level on the Multi-Tier Framework, where Tier 0 is no access and Tier 5 is full access (Dubey et al., 2019). The SHS variable in this paper is a binary variable equal to one for 350 households who report having at least one solar home system. 43 of these households report having more than one.
Solar lighting systems (SLS)	A binary variable equal to one for 452 households with a SLS. 48 of these households report having more than one. These SLS have small/medium capacity and are sufficient for a Tier 1 electricity-access classification for an entire household, based on the Multi-Tier Framework (Dubey et al., 2019).
Solar lanterns	A binary variable equal to one for 810 households with at least one solar lantern. 117 of these households report having more than one. Solar lanterns power only a single light bulb and are only sufficient for part of a household to be classified as Tier 1.
Solar battery	A binary variable equal to one for 96 households where “Solar” is the electricity source used to recharge a battery.
Location (L)	
Province	Binary variables for the 8 Kenyan provinces.
Rural	A binary variable equal to one for non-urban households (57% of surveyed households).
Underserved county	A binary variable equal to one for households in one of 14 underserved counties (34% of surveyed households). These 14 counties have been designated as ‘marginalised’ by the Commission on Revenue Allocation by the Government of Kenya (World Bank, 2017) and are the focus of the KOSAP which funds energy development from 2018 to 2023. The 14 counties are: Garissa, Isiolo, Kilifi, Kwale, Lamu, Mandera, Marsabit, Narok, Samburu, Taita Taveta, Tana River, Turkana, Wajir, and West Pokot.
Asset-related variables (A)	
Bank	A binary variable equal to one for households with a bank account holder in a formal institution (52%).
Informal	A binary variable equal to one for households with an account holder in an informal institution (22%).
Mobile money	A binary variable equal to one for households with a mobile money account (81%).
Livestock	A variable with four categories: 1. No livestock owned by the household (56%); 2. One type of livestock owned (24%); 3. Two types of livestock owned (12%); 4. Three or more types of livestock owned (8%).
Equipment	A binary variable equal to one for households who own any transportation or agricultural equipment (14%).
Land value	The total value of agricultural land that is owned by the household, if it were for sale. The paper uses five categories: 1. No land owned (53%); 2. Land owned but no plausible value supplied (17%); 3. From one thousand to less than half a million Kenyan shillings (11%); 4. From half a million to less than a million Kenyan shillings (6%); 5. Greater than or equal to a million Kenyan shillings (13%).
Dwelling owned	A binary variable equal to one for households who own their dwelling (71%).
Rent-free	A binary variable equal to one for households who use their dwelling for free (4%), as opposed to renting.
Dwelling type	A variable with three categories: 1. A single house occupied by one household (67%); 2. A group of enclosed dwellings occupied by one household (10%); 3. Other dwelling types (23%).
Mud	A binary variable equal to one when the main material of the walls of the dwelling is reported as mud bricks (traditional dwelling) (27%).
Rooms	The number of rooms occupied by the household, excluding the kitchen and bathrooms (average = 2.9).
Other economic (E)	
Income	A variable for the monthly income from the *main* occupation of the household head, with 4 categories: 1. Less than one thousand Kenyan shillings (2%); 2. From one thousand to less than ten thousand Kenyan shillings (20%); 3. Greater than or equal to ten thousand Kenyan shillings (36%); 4. Not stated/no income (42%). This variable is only used in one table, due to the high non-response rate.
Self-employment	A binary variable equal to one where the household head's main occupation was self-employment over the last 12 months (32% of surveyed households).
Grid (G)	

(*continued on next page*)

Table A.2 (*continued*)

Variable	Description
Grid	A variable with four categories: 1. Connected to the electricity grid (44%); 2. Not connected mainly because the grid is too far away or not available (15%); 3. Not connected mainly because of the high cost of connection (23%); 4. Not connected mainly because of another reason (18%).
Socio-demographic (D)	
People (#)	The number of people who live and eat their meals in the household (average = 4.2).
Female	A binary variable equal to one when the household head is female (18%).
Marital status	A variable with seven categories for the household head: 1. Married, monogamous (73%); 2. Married, polygamous (5%); 3. Cohabitating, single partner (2%); 4. Never married (7%); 5. Divorced (2%); 6. Separated (3%); 7. Widowed (9%).
School	A binary variable equal to one when the household head has ever attended school (81%). This ignores quantity of schooling years.
Age	The age of the household head in years (average = 43.8).

Table A.3
Probit results for solar home systems, sample of 4590 households.

	(1)	(2)
Rural	0.257***	0.021
	(0.078)	(0.084)
Underserved county	0.046	0.008
	(0.089)	(0.093)
Bank	0.200***	0.326***
	(0.065)	(0.068)
Informal	0.008	0.039
	(0.071)	(0.073)
Mobile money	0.249***	0.305***
	(0.084)	(0.087)
Reference: no livestock		
2 types of livestock	0.320***	0.243**
	(0.095)	(0.098)
3+ types of livestock	0.542***	0.431***
	(0.104)	(0.109)
Transp. or ag. equip.	0.080	0.113
	(0.080)	(0.082)
Reference: no land owned		
Top land value	0.246***	0.225**
	(0.094)	(0.097)
Dwelling owned	0.529***	0.389***
	(0.117)	(0.123)
Rent free	0.473***	0.365**
	(0.176)	(0.182)
Ref: other dwelling types		
Single house, one household	−0.070	−0.090
	(0.080)	(0.083)
Group of dwellings, 1 h/h	−0.048	−0.078
	(0.111)	(0.114)
Mud structure	−0.167**	−0.250***
	(0.073)	(0.074)
Number of people	0.011	0.013
	(0.014)	(0.015)
Ref: unconnected, too far		
Connected to grid		−0.927***
		(0.105)
Unconnected, high cost		−0.323***
		(0.089)
Unconnected, other reason		−0.147*
		(0.088)
Probability weights	No	No
Observations	4590	4590
Pseudo R^2	0.104	0.143

Notes: ***, **, * show statistical significance at the 1%, 5%, or 10% level. Coefficients are not shown for constants, provinces, livestock = 1 type, and land values below the top category.

Table A.4
Entropy balancing results: average treatment effects on solar home system uptake.

Treatment	Average treatment effect	Standard error
Underserved 14	−0.005	(0.011)
Bank	0.028***	(0.008)
Informal	0.010	(0.010)
Mobile money	0.005	(0.017)
Bank and mobile money	0.030***	(0.008)
Land value (top category)	0.049***	(0.016)

Notes: *** shows statistical significance at the 1% level. Controls match Table 1: column (2). There are 4590 observations in each case; probability weights are not used as entropy balancing weights the 'control' group.

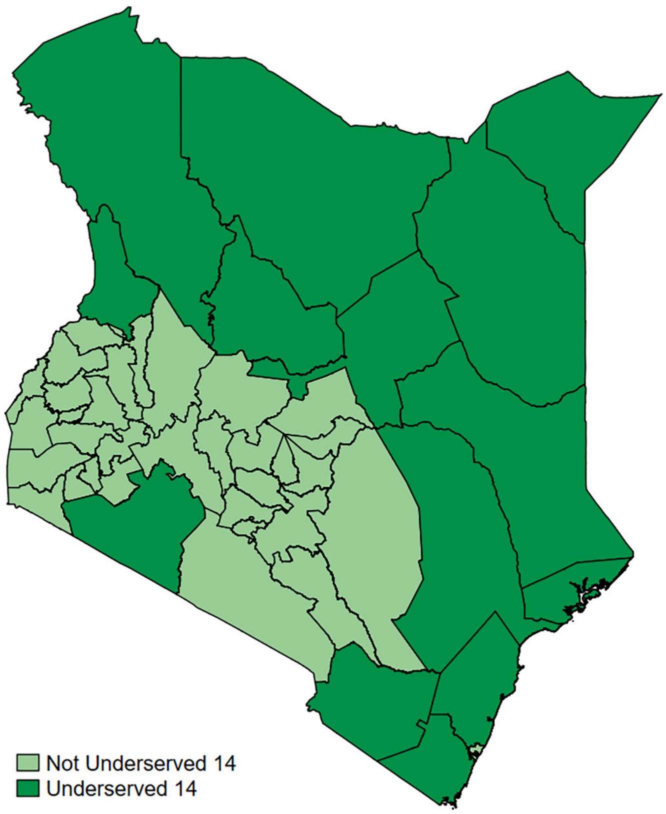

Fig. A.1. Designation of 14 underserved counties. Data: Hijmans and University of California (2015); World Bank (2017).

Appendix B. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.eneco.2023.106723.

References

Aarakit, S.M., Ntayi, J.M., Wasswa, F., Adaramola, M.S., Ssennono, V.F., 2021. Adoption of solar photovoltaic systems in households: evidence from Uganda. J. Clean. Prod. 329 https://doi.org/10.1016/j.jclepro.2021.129619.

Abdullah, S., Jeanty, P.W., 2011. Willingness to pay for renewable energy: evidence from a contingent valuation survey in Kenya. Renew. Sust. Energ. Rev. 15 (6), 2974–2983. https://doi.org/10.1016/j.rser.2011.03.016.

Aklin, M., Cheng, C., Urpelainen, J., 2018. Geography, community, household: adoption of distributed solar power across India. Energy Sustain. Dev. 42, 54–63. https://doi.org/10.1016/j.esd.2017.09.010.

Alipour, M., Salim, H., Stewart, R.A., Sahin, O., 2020. Predictors, taxonomy of predictors, and correlations of predictors with the decision behaviour of residential solar photovoltaics adoption: a review. Renew. Sust. Energ. Rev. 123, 109749 https://doi.org/10.1016/j.rser.2020.109749.

Alipour, M., Salim, H., Stewart, R.A., Sahin, O., 2021. Residential solar photovoltaic adoption behaviour: end-to-end review of theories, methods and approaches. Renew. Energy 170, 471–486.

Alipour, M., Irannezhad, E., Stewart, R.A., Sahin, O., 2022. Exploring residential solar PV and battery energy storage adoption motivations and barriers in a mature PV market. Renew. Energy 190, 684–698.

Athey, S., Imbens, G., 2016. The state of applied econometrics - causality and policy evaluation. J. Econ. Perspect. 31, 3–32. https://doi.org/10.1257/jep.31.2.3.

Best, R., Nepal, R., 2022. Saving and subsidies for solar panel adoption in Nepal. Appl. Econ. 54 (59), 6768–6783. https://doi.org/10.1080/00036846.2022.2083570.

Best, R., Trück, S., 2020. Capital and policy impacts on Australian small-scale solar installations. Energy Policy 136, 111082. https://doi.org/10.1016/j.enpol.2019.111082.

Best, R., Li, H., Trück, S., Truong, C., 2021a. Actual uptake of home batteries: the key roles of capital and policy. Energy Policy 151, 112186. https://doi.org/10.1016/j.enpol.2021.112186.

Best, R., Nepal, R., Saba, N., 2021b. Wealth effects on household solar uptake: quantifying multiple channels. J. Clean. Prod. 297, 126618 https://doi.org/10.1016/j.jclepro.2021.126618.

Best, R., Marrone, M., Linnenluecke, M., 2023. Meta-analysis of the role of equity dimensions in household solar panel adoption. Ecol. Econ. 206, 107754 https://doi.org/10.1016/j.ecolecon.2023.107754.

Brown, D.P., 2022. Socioeconomic and demographic disparities in residential battery storage adoption: evidence from California. Energy Policy 164, 112877.

Cooper, D., Dynan, K., 2016. Wealth effects and macroeconomic dynamics. J. Econ. Surv. 30, 34–55. https://doi.org/10.1111/joes.12090.

Curtius, H.C., Hille, S.L., Berger, C., Hahnel, U.J.J., Wüstenhagen, R., 2018. Shotgun or snowball approach? Accelerating the diffusion of rooftop solar photovoltaics through peer effects and social norms. Energy Policy 118, 596–602. https://doi.org/10.1016/j.enpol.2018.04.005.

Dubey, S., Adovor, E., Rysankova, D., Portale, E., Koo, B., 2019. Kenya beyond connections: access to electricity and clean cooking in Kenya based on the multi-tier framework survey and data analysis. ESMAP. https://doi.org/10.1596/24368.

ESMAP, 2021. Multi-Tier Framework for Measuring Energy Access - Kenya Household Survey 2016-2017, Ref. KEN_2016-2018_MTF_v02_M.

Evans, D.K., Mendez Acosta, A., 2021. Education in Africa: what are we learning? J. Afr. Econ. 30, 13–54. https://doi.org/10.1093/jae/ejaa009.

George, A., Boxiong, S., Arowo, M., Ndolo, P., Shimmon, J., 2019. Review of solar energy development in Kenya: opportunities and challenges. Renew. Energy Focus 29, 123–140.

George, A., Boxiong, S., Ndolo, P.O., Siagi, Z.O., Chepsaigutt, C., Kemunto, C.M., Arowo, M., Shimmon, J., Simiyu, P., Yabo, A.C., 2020. The solar energy access in Kenya: a review focusing on pay-as-you-go solar home system. Environ. Dev. Sustain. 22, 3897–3938. Springer Netherlands. https://doi.org/10.1007/s10668-019-00372-x. Springer Netherlands.

GOGLA, 2021. A big win for Kenya: Government reinstates VAT exemption on renewable energy products. https://www.gogla.org/news/a-big-win-for-kenya-government-reinstates-vat-exemption-on-renewable-energy-products. accessed 10 March 2023.

Green Innovation Ventures Enterprises Ltd, 2022. June 30, 2022 News. https://www.greeninnovationventures.com/give-ltd-funded-under-world-banks-kenya-off-grid-solar-access-project-kosap-facility/ accessed 10 March 2023.
Guta, D.D., 2018. Determinants of household adoption of solar energy technology in rural Ethiopia. J. Clean. Prod. 204, 193–204. https://doi.org/10.1016/j.jclepro.2018.09.016.
Hainmueller, J., 2012. Entropy balancing for causal effects: a multivariate reweighting method to produce balanced samples in observational studies. Polit. Anal. 20, 25–46. https://doi.org/10.1093/pan/mpr025.
Hainmueller, J., Xu, Y., 2013. Ebalance: a stata package for entropy balancing. J. Stat. Softw. 54, 1–18. https://doi.org/10.18637/jss.v054.i07.
Hansen, U.E., Pedersen, M.B., Nygaard, I., 2015. Review of solar PV policies, interventions and diffusion in East Africa. Renew. Sust. Energ. Rev. 46, 236–248. https://doi.org/10.1016/j.rser.2015.02.046.
Hijmans, R.J., University of California, 2015. First-level Administrative Divisions, Kenya. https://geodata.lib.berkeley.edu/catalog/stanford-fc462cc8966.
IEA, 2016. Tax Incentives for Renewable Energy. International Energy Agency. https://www.iea.org/policies/6007-tax-incentives-for-renewable-energy. (Accessed 10 March 2023).
Jacksohn, A., Grösche, P., Rehdanz, K., Schröder, C., 2019. Drivers of renewable technology adoption in the household sector. Energy Econ. 81, 216–226. https://doi.org/10.1016/j.eneco.2019.04.001.
Jacobson, A., 2007. Connective power: solar electrification and social change in Kenya. World Dev. 35, 144–162. https://doi.org/10.1016/j.worlddev.2006.10.001.
Karakaya, E., Sriwannawit, P., 2015. Barriers to the adoption of photovoltaic systems: the state of the art. Renew. Sust. Energ. Rev. 49, 60–66. https://doi.org/10.1016/j.rser.2015.04.058.
Kennedy, R., Numminen, S., Sutherland, J., Urpelainen, J., 2019. Multilevel customer segmentation for off-grid solar in developing countries: evidence from solar home systems in Rwanda and Kenya. Energy 186, 115728. https://doi.org/10.1016/j.energy.2019.07.058.
Kimutai, S.K., Talai, S.M., 2021. Household energy utilization trends in Kenya: effects of Peri urbanization. Eur. J. Energy Res. 1 (2), 7–11. https://doi.org/10.24018/ejenergy.2021.1.2.9.
Komatsu, S., Kaneko, S., Shrestha, R.M., Ghosh, P.P., 2011. Nonincome factors behind the purchase decisions of solar home systems in rural Bangladesh. Energy Sustain. Dev. 15 (3), 284–292. https://doi.org/10.1016/j.esd.2011.03.003.
Lay, J., Ondraczek, J., Stoever, J., 2013. Renewables in the energy transition: evidence on solar home systems and lighting fuel choice in Kenya. Energy Econ. 40, 350–359. https://doi.org/10.1016/j.eneco.2013.07.024.
Lee, B.K., Miguel, E., Wolfram, C., 2016. Appliance ownership and aspirations among electric grid and home solar households in rural Kenya. Am. Econ. Rev. 106 (5). PAPERS AND PROCEEDINGS 106.
MacEwen, M., Evensen, D., 2021. Mind the gap: accounting for equitable participation and energy democracy in Kenya. Energy Res. Soc. Sci. 71, 101843 https://doi.org/10.1016/j.erss.2020.101843.
Modigliani, F., 1966. The life cycle hypothesis of saving, the demand for wealth and the supply of capital. Soc. Res. (New York) 33, 160–217.
Mugisha, J., Ratemo, M.A., Bunani Keza, B.C., Kahveci, H., 2021. Assessing the opportunities and challenges facing the development of off-grid solar systems in eastern Africa: the cases of Kenya, Ethiopia, and Rwanda. Energy Policy 150, 112131. https://doi.org/10.1016/j.enpol.2020.112131.
Mwau, B., Mwaniki, D., 2022. Urbanization in North Rift Kenya. United Nations Human Settlements Programme, Nairobi, Kenya.
Mwau, B., Opiyo, R., 2022. Socio-Economic Development in Turkana West, Kenya. Volume I: Report on Socio-Economic Conditions. United Nations Human Settlements Programme, Nairobi, Kenya.
Ojong, N., 2021. The rise of solar home systems in sub-Saharan Africa: examining gender, class, and sustainability. Energy Res. Soc. Sci. 75, 102011 https://doi.org/10.1016/j.erss.2021.102011.
Oluoch, S., Lal, P., Susaeta, A., Vedwan, N., 2020. Assessment of public awareness, acceptance and attitudes towards renewable energy in Kenya. Sci. Afr. 9, e00512 https://doi.org/10.1016/j.sciaf.2020.e00512.
Rahut, D.B., Mottaleb, K.A., Ali, A., Aryal, J., 2018. The use and determinants of solar energy by sub-Saharan African households. Int. J. Sustain. Energy 37 (8), 718–735. https://doi.org/10.1080/14786451.2017.1323897.
Roche, O.M., Blanchard, R.E., 2018. Design of a solar energy Centre for providing lighting and income-generating activities for off-grid rural communities in Kenya. Renew. Energy 118, 685–694. https://doi.org/10.1016/j.renene.2017.11.053.
Samoita, D., Nzila, C., Østergaard, P.A., Remmen, A., 2020. Barriers and solutions for increasing the integration of solar photovoltaic in Kenya's electricity mix. Energies 13. https://doi.org/10.3390/en13205502.
Smith, M.G., Urpelainen, J., 2014. Early adopters of solar panels in developing countries: evidence from Tanzania. Rev. Policy Res. 31 (1), 17–37. https://doi.org/10.1111/ropr.12061.
Sy, A.N.R., Simbanegavi, W., Ndung'u, N., 2019. Africa's energy renewal: the twin challenges of energy deficit and climate change. J. Afr. Econ. 28, i4–i15. https://doi.org/10.1093/jae/ejy022.
Thompson, O.A., Ajiboye, B.O., Oluwamide, A.D., Oyenike, O.O., 2021. Analysis of factors influencing households' preference level for solar energy in urban areas of Southwest Nigeria. Int. J. Energy Econ. Policy 11 (3), 468–476. https://doi.org/10.32479/ijeep.10001.
UNESCO, 2019. Solar energy: changing rural lives in Kenya. The UNESCO courier 2019-3. United Nations Educational, Scientific and Cultural Organization e-ISSN 2220-2293. https://en.unesco.org/courier/2019-3/solar-energy-changing-rural-lives-kenya. e-ISSN 2220-2293.
Urpelainen, J., Yoon, S., 2015. Solar home systems for rural India: survey evidence on awareness and willingness to pay from Uttar Pradesh. Energy Sustain. Dev. 24, 70–78. https://doi.org/10.1016/j.esd.2014.10.005.
Wagner, N., Rieger, M., Bedi, A.S., Vermeulen, J., Demena, B.A., 2021. The impact of off-grid solar home systems in Kenya on energy consumption and expenditures. Energy Econ. 99, 105314 https://doi.org/10.1016/j.eneco.2021.105314.
Winther, T., Ulsrud, K., Saini, A., 2018. Solar powered electricity access: implications for women's empowerment in rural Kenya. Energy Res. Soc. Sci. 44, 61–74. https://doi.org/10.1016/j.erss.2018.04.017.
Wolske, K.S., Stern, P.C., Dietz, T., 2017. Explaining interest in adopting residential solar photovoltaic systems in the United States: toward an integration of behavioral theories. Energy Res. Soc. Sci. 25, 134–151. https://doi.org/10.1016/j.erss.2016.12.023.
World Bank, 2017. Kenya: Off-Grid Solar Access Project for Underserved Counties. The World Bank.
World Bank, 2022. Kenya: Off-grid Solar Access Project for Underserved Counties (P160009). Implementation Status & Results Report. Energy & Extractives Global Practice; IBRD/IDA; Investment Project Financing; FY 2018; Seq No: 10; ARCHIVED on 14-Nov-2022; ISR51989; Public Disclosure Copy.
World Bank, 2023. World Development Indicators. Access to electricity (% of population). https://data.worldbank.org/indicator/EG.ELC.ACCS.ZS. accessed 10 March 2023.