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Financial inclusion and energy access: Evidence from Kenya

Michael Mbate[a,*], El Hadji Fall[b]

[a] London School of Economics and Political Science, Houghton Street, WC2A 2AE, London, UK
[b] United Nations Development Programme, 1 United Nations Plaza, 10017, New York, United States

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ABSTRACT

This paper examines the relationship between financial inclusion and energy access, leveraging micro-level survey data from Kenya (2016–2018) and employing propensity score matching to establish causal linkages. The analysis reveals that financial inclusion significantly enhances energy access, with distinct variations across financial institutions and energy types. Financial inclusion operates through three critical mechanisms: increasing households' willingness to pay for energy, alleviating upfront connection costs via flexible payment schemes, and enabling seamless energy-related transactions through digital platforms. These findings underscore the importance of inclusive financial policies and the role of formal and informal financial institutions as intermediaries in addressing energy poverty.

1. Introduction

Energy is critical to a country's long-run economic growth and social transformation. At the macro-level, reliable, affordable and modern energy can transform an economy through various channels, such as industrial and firm productivity, organizational efficiency and public service delivery (Jack, 2022; Stern, 2011). At the micro-level, access to energy can improve an individual's well-being and quality of life, boost income-generating activities, and support basic tasks and routines such as cooking, heating, lighting and food storage. Consequently, most health and education indicators, such as life expectancy, nutrition and school enrollment are positively associated with per capita energy consumption (Lloyd, 2017). The imperative for universal energy access is also underpinned by the United Nations Sustainable Development Goals (United Nations, 2022).

However, energy access in Africa is still low despite high demand and massive opportunities to broaden grid connections and invest in renewable energy such as solar and wind. The consequences of a lack of clean energy are catastrophic, and each year, approximately 500 000 premature deaths are recorded in Africa due to polluting fuels and the lack of access to clean cooking facilities (IEA, 2023). According to IEA (2022), electricity reaches only 50% of the population on the continent. In addition, only one-third of the population has access to clean cooking, with approximately 890 million households using traditional toxic fuels. Africa also lags behind other regions in grid connection, with thirteen countries having less than 25% access to electricity compared to only one in developing Asia (World Bank, 2018). It is also estimated that Africa accounts for less than 3% of global renewables capacity (Zero Carbon Analytics, 2023).

Access to finance is a crucial barrier to households' access to clean energy in most developing countries. Approximately 57% of African adults have no bank account and are excluded from the formal financial system (Fintech BPC, 2022). This lack of financial inclusion significantly hampers access to credit, savings, and insurance products that could enable investments in clean energy solutions, particularly for rural households. In addition, informal financial institutions, such as community savings groups, rotating credit schemes, and microfinance, while widespread, often lack the scale and support needed to fund larger, long-term investments like solar home systems or clean cooking technologies. Despite the potential of digital financial services to bridge these gaps, limited digital literacy, inadequate infrastructure, and regulatory challenges continue to constrain their impact in many parts of the African continent. The lack of financial inclusion perpetuates a cycle of energy poverty (Barry et al., 2011; Guta, 2020; Ouma et al., 2017).

While numerous studies have explored the relationship between financial inclusion and energy access, significant research gaps remain.

* Corresponding author. London School of Economics and Political Science, Houghton Street, WC2A 2AE, London, UK.
E-mail addresses: mikembate@gmail.com (M. Mbate), El.hadji.fall@undp.org (E.H. Fall).

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First, the existing literature has predominantly focused on formal financial institutions (Koomson & Danquah, 2021), overlooking the critical role of informal financial intermediaries, such as community savings groups and microfinance, which are often more accessible in low-income settings and highly relevant for the poor and the marginalized. Second, many studies have adopted a macro-level perspective (Xie et al., 2024), offering limited insights into the effectiveness of micro-level interventions in shaping household energy consumption patterns, despite growing evidence that household behavior and incentives play a pivotal role in determining energy choices (Camara et al., 2017). Third, the underlying mechanisms linking financial inclusion to energy access remain inadequately explored (Addai et al., 2022), with much of the existing research narrowly emphasizing income-related factors (Gafa & Egbendewe, 2021). Finally, several studies have relied on perception-based measures of financial inclusion and energy access (Carè et al., 2025), which may not accurately capture the objective realities due to their subjective nature.

To fill in these gaps, the objectives of this paper are threefold. First, it estimates the causal link between financial inclusion and energy access using household-level data. It assesses whether access to either formal or informal financial institutions and mobile money accounts increases access to renewable and non-renewable energy sources. Second, the paper examines the main channels through which financial inclusion affects energy access by focusing on three key policy areas: households' willingness to pay for the energy, payment schemes that facilitate the payment of energy costs and the role of digital platforms in facilitating the payment of energy-related fees.

The empirical analysis focuses on Kenya for several reasons. First, the country represents a dual financial ecosystem, with a robust formal financial sector coexisting alongside a deeply entrenched informal financial network, offering an opportunity to evaluate how these systems individually and collectively influence energy access outcomes. Second, Kenya has experienced a rapid electrification surge in recent years, with access rates climbing from 53% in 2016 to 75% by 2021 (AfDB, 2021). This transformation underscores the potential for targeted interventions in energy policy, providing an ideal setting for studying household-level impacts. Third, Kenya's leadership in mobile money innovation offers a lens through which to explore how digital financial tools can reduce barriers to energy investments, an aspect that can distill policy lessons for other countries.

Several key findings emerge. First, the econometric results show a positive relationship between financial inclusion and households' access to energy. Households with access to both formal and informal financial institutions are more like to access energy, including renewable energy such as solar and they are likely to reduce the use of harmful energy types such as open wicks and pressure lamps. Second, an in-depth analysis of the underlying mechanisms shows that financial inclusion increases the willingness to pay for cleaner energy by alleviating income-related constraints for costly types of energy sources, offsetting the significant upfront costs of getting connected through flexible payment schemes that are tailored to households' income and facilitating the payment of user charges through digital payment platforms.

This study contributes to the literature in several ways. First, it redirects attention from the traditionally emphasized supply-side constraints of energy access - such as energy production and distribution - to the less explored demand-side constraints. It highlights how financial barriers can impede energy access, especially for poor households, and demonstrates the potential of financial inclusion strategies to reduce the cost burdens of energy connectivity, including renewable energy sources. Second, the analysis of underlying mechanisms, which is conducted using highly disaggregated data, not only reconciles the ongoing academic and policy discourse on the determinants of energy access, but also showcases how flexible financing models and digital platforms can boost energy access while simultaneously enhancing the uptake of cleaner energy technologies and reducing the use of harmful energy types. Third, the research design provides a methodological advancement to the literature by merging survey data with quasi-experimental techniques to offer more precise measurements of household energy outcomes while uncovering the underlying causal relationship. The adoption of Propensity Score Matching (PSM) addresses endogeneity concerns by controlling for potential selection bias – as there might exist systematic difference between the households who are financially included and those who are not. Finally, this paper broadens the scope of policy discussions by providing crucial insights into the complexity of designing financial policies, revealing how various financial products can be strategically employed to boost household energy access.

The rest of the paper is organized as follows. Section 2 briefly summarizes the theoretical and empirical literature on the link between financial inclusion and energy access, while Section 3 presents the data and empirical strategy. Section 4 presents the main results and the underlying mechanisms. Section 5 concludes with policy implications.

2. Review of the literature

2.1. Theoretical underpinnings of the link between financial inclusion and energy access

The link between financial inclusion and energy access can be theoretically understood through several channels, each of which offers an insight into the mechanisms through which financial services can influence household energy decisions.

First, the income channel posits that financial inclusion enhances household income potential, thereby increasing affordability for modern energy solutions. Access to formal financial services, such as credit or microfinance, enables households to invest in productive activities, thereby generating additional income that can be allocated to energy expenditures (Lay et al., 2013). Informal financial arrangements, while less structured, also facilitate incremental income growth, particularly for low-income households in underserved areas. Second, the savings channel underscores the role of financial systems in enabling resource accumulation for energy investments. Formal financial institutions provide secure savings instruments that allow households to gradually build the capital required for high upfront energy costs, such as grid connections or renewable energy installations. Informal mechanisms, including savings groups and ROSCAs, further augment this process by enabling community-driven resource pooling for energy-related expenditures (Hoffmann et al., 2022).

Third, the borrowing channel highlights the role of credit in overcoming the liquidity constraints that impede energy access. Formal financial institutions offer loan products with lower interest rates and extended repayment terms, facilitating investments in costly but sustainable energy technologies. Conversely, informal credit arrangements provide more flexible, albeit often higher-cost, solutions for covering immediate energy needs, such as the purchase of energy-efficient appliances (Boutabba et al., 2020).

Fourth, the information channel emphasizes the role of financial institutions as knowledge intermediaries. Beyond providing financial resources, these institutions disseminate information on energy technologies and their benefits, increasing adoption rates. Partnerships between financial providers and energy firms can result in innovative products such as pay-as-you-go energy systems, which align financial solutions with household needs and preferences (Koomson & Danquah, 2021). Finally, the transaction facilitation channel reflects the transformative impact of digital financial platforms on energy payments. Mobile money can reduce transaction costs and enable pay-as-you-go schemes, thereby lowering barriers to energy adoption. This channel is particularly important in rural and peri-urban areas, where traditional banking infrastructure is often absent (Perros et al., 2024).

2.2. Empirical evidence

2.2.1. Financial inclusion and energy access

Financial inclusion is an essential determinant of energy access (Khelifa & Arsi, 2021; Sadorsky, 2010). For instance, Addai et al. (2022) find that access to financial services in Ghana increases households' energy consumption. This evidence is consistent with Koomson and Danquah (2021), who find that households' net income is an important channel through which financial inclusion reduces energy poverty. Babatope (2022) finds that financial inclusion, proxied by the proportion of ATMs per 1000 adults, positively increases electrification rates in West Africa while Xiao (2023) documents that financial inclusion improves the transition to a low-carbon green economy.

While financial inclusion can expand access to energy by providing credit or loans, evidence shows that this effect can vary along critical dimensions, especially by the type of financial institution. In Kenya, Hsu et al. (2021) find that access to microfinance institutions increases the likelihood of adopting cleaner cooking solutions. Sunio et al. (2021) find that, unlike private banks, commercial institutions under the control of governments are likely to finance renewable energy due to their mandate to support national development. In Togo, Boutabba et al. (2022) find that microfinance, which typically offers smaller amounts of money with less collateral requirements, tend to reduce energy vulnerability. Despite extensive studies on the role of financial inclusion in enhancing energy access, the literature still lacks a nuanced understanding of how various financial institutions, both formal and informal, shape energy access through specific financial products. There is also an absence of conclusive evidence on how households respond to the array of financial services offered - whether through microfinance loans, commercial bank loans, or government-backed financial schemes - and the subsequent impact on their energy consumption patterns and preferences.

2.2.2. Financial inclusion and willingness to pay (WTP)

Another strand of the literature has focused on behavioral factors such as households' WTP for energy. In Ghana, Tweregou (2014) find that households are willing to pay more than they currently pay to access electricity, contingent on factors such as income, size and level of education. On the other hand, Amoah et al. (2019) find that Ghanaian households are willing to pay approximately USD 17 per month for a reliable energy supply. This amount is equivalent to 7% of their monthly income. In Ethiopia, Meles et al. (2021) find that a household's WTP is USD 1.4 for a 3-h reduction in power outages in the evening and USD 1.8 to avoid daytime or nighttime outages relative to those occurring in the morning. In Burkina Faso, Senegal and Rwanda, Sievert and Steinbuks (2020) find that households are willing to commit more than 10% of their monthly expenditure to pay for electricity. There is also significant variation in the WTP and transition from non-renewable to renewable sources. For instance, Meried (2021) shows that most rural households in Ethiopia are willing to transition from traditional to cleaner energy sources, although this varies depending on the type of energy, with a higher preference for hydropower compared to solar and transitional fuels. Sievert and Steinbuks (2020) find that households' WTP for electricity access in sub-Saharan Africa (SSA) increases with income and is double for grid connections what it is for off-grid technology such as solar.

It is evident that the existing literature predominantly focuses on estimating the magnitude of households' WTP or its determinants. Nevertheless, there is a notable absence of data in the existing literature on how households' WTP might be enhanced for different energy types depending on the energy costs that households are likely to incur. Additionally, the existing studies do not focus on how WTP is conditional on the type of financial institution, highlighting a significant opportunity for further investigation.

2.2.3. Financial inclusion and payment schemes

Another body of studies shows that the impact of financial inclusion on energy access depends on modalities to offset energy costs (Valickova & Elms, 2021). It is estimated that connection charges in SSA are among the highest in the world, ranging from 52% of a household's monthly income in Uganda to 100% in Burkina Faso and up to 144% in Rwanda (Golumbeanu & Barnes, 2013). To incentivize households to invest in energy, the literature highlights the role of different payment systems, with a distinction between lump sum payments, where all costs are paid upfront, instalment plans consisting of smaller amounts paid at pre-determined intervals, and pre-and-post payments (IRENA, 2020). The preference for each of these payment systems also varies considerably depending on the type of energy. For instance, Barry and Creti (2020) find that flexible payment loans in Ghana are associated with increased purchases of solar kits and panels for lighting and charging service. In Kenya, Abdullah and Jeanty (2011) find that rural households are more likely to favor monthly connection payments over a lumpsum amount for grid connection while Entele (2020) shows that households in Ethiopia prefer a grid connection to solar power irrespective of the payment scheme.

The current research predominantly concentrates on either highlighting the high cost of energy access or the trade-off between different payment schemes. However, there is a discernible gap in the empirical studies regarding how households respond to how this gap can be narrowed to improve energy access.

2.2.4. Financial inclusion and mobile money payment

Finally, theoretical propositions increasingly highlight the role of financial innovations, particularly mobile money platforms, in transforming energy access through enhanced payment mechanisms. Horvey et al. (2024) argue that digitalization is a critical enabler of renewable energy adoption, with higher levels of digital integration fostering a more sustainable energy system in SSA, while low digital penetration constrains progress. Digitized energy subsidies further illustrate this potential by improving targeting accuracy and reducing inefficiencies in disbursement systems. However, the penetration of mobile money does not uniformly translate to improved energy access. In many parts of SSA, even though a large segment of the population may have mobile money accounts, access to both renewable and non-renewable energy sources remains limited. The infrastructure for energy supply, particularly for renewable sources like solar or wind, is not as developed or accessible. This disconnect means that while people can easily pay for services digitally, the actual delivery of these services, especially consistent and reliable energy, lags behind (Lin & Huang, 2023).

3. Data and model specification

The data was obtained from the Multi-Tier Framework Survey, a cross-sectional, nationally representative survey that contains comprehensive information on households' energy sources in all 47 counties in Kenya, including marginalized and slum areas. The data consists of over 3000 households and was collected between 2016 and 2018 by the World Bank. The households were selected using stratified random sampling, stratified at the county, rural/urban residence, and electrification levels. The counties were divided equally between rural and urban, and household selection was proportional to each county's population based on the 2009 census. The survey contains detailed data and information on households' social and economic attributes, especially access to different types of energy. The survey also provides detailed and quantifiable information on choice experiments to elicit willingness to pay for different energy sources and costs.

The descriptive analysis of the survey data provides critical insights into household energy access patterns, overall consumption trends, and the evolving financial landscape in Kenya. Fig. 1 illustrates the rising energy consumption, reflecting increasing demand driven by various factors such as population growth, urbanization, and expanding industrial activity. Fig. 2 highlights the high share of renewables in the country's energy mix, indicating progress toward cleaner energy sources.

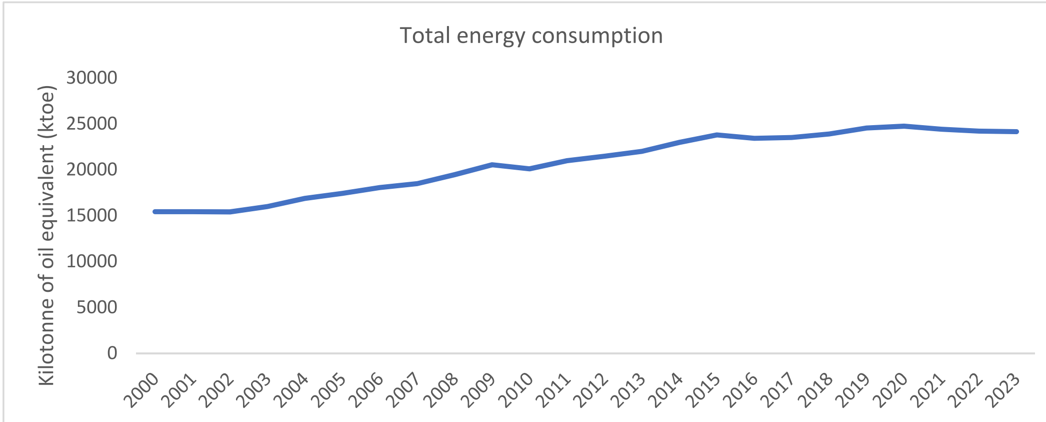


Fig. 1. Trends in Total energy consumption in Kenya.
Source: Enerdata (2025).

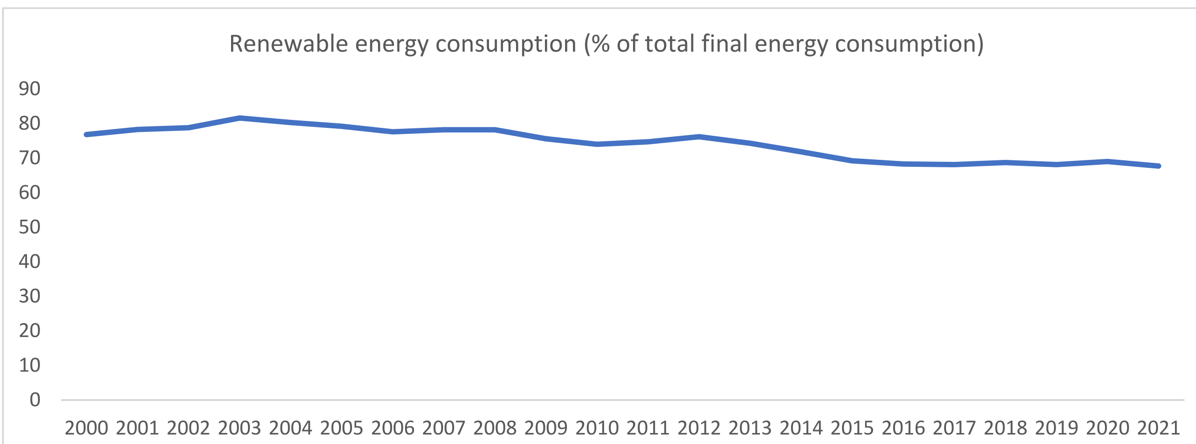


Fig. 2. Proportion of renewable energy in total energy consumption in Kenya.
Source: World Development Indicators (2025).

However, despite this shift, challenges remain in ensuring affordability and accessibility, particularly for rural and underserved communities. Regarding energy production, Fig. 3 reveals a continued reliance on hydro and geothermal power, which have historically been the country's primary energy sources. At the same time, the growing contributions of solar and wind signal a diversification of Kenya's energy landscape, reflecting efforts to enhance sustainability and energy security.

The evolution of Kenya's financial sector has played a significant role in shaping household access to energy. Understanding trends in financial inclusion provides crucial context for analyzing how different financial instruments influence household decision-making and affordability. Fig. 4 illustrates the expansion of formal and informal financial services, reflecting increased access to banking, credit facilities, and digital financial platforms. Fig. 5 further illustrates that financial inclusion exhibits notable gender disparities in Kenya, with women often facing more significant barriers to accessing formal financial services. These trends are particularly relevant in the context of energy access, where financial constraints often determine the ability of households to invest in modern energy solutions.

Fig. 6 further disaggregates financial service usage, highlighting the growing prominence of mobile money as a critical enabler of seamless transactions and flexible payment models, particularly for energy-related expenses. Other financial services such as commercial banks, SACCOs, and informal groups also play an important role in facilitating access to credit, enabling long-term energy investments, and supporting households in financing upfront connection costs for both grid and off-grid energy solutions.

3.1. Descriptive analysis

Table 1 presents the summary statistics. Concerning financial inclusion, at least 55% of households have a bank account in a formal institution, although there is significant variation as indicated by the high standard deviation. On the other hand, 23% of households have accounts in informal financial institutions. Access to mobile money accounts is the most prevalent mode of financial inclusion, with at least 83% of households accessing digital payment systems. The indicators that proxy energy access show that at least 46% of households are connected to the national grid, while 35% have access to solar power. A sizeable number of households use candles and open wicks (18%), while less than 10% have access to pressure lamps and generators.

An assessment of social-economic characteristics reveals that males head most households, and the average age is 43 years, although with significant variation across households. The sample is relatively balanced between rural and urban households. In terms of educational achievements, 52% of households have reached primary school, 29% have reached secondary school, and 8% have university or vocational training, suggesting a reasonable understanding of energy issues. Occupationally, while 23% of household heads are involved in non-farm wage employment, 14% are self-employed in agriculture, and 13% are either non-farm

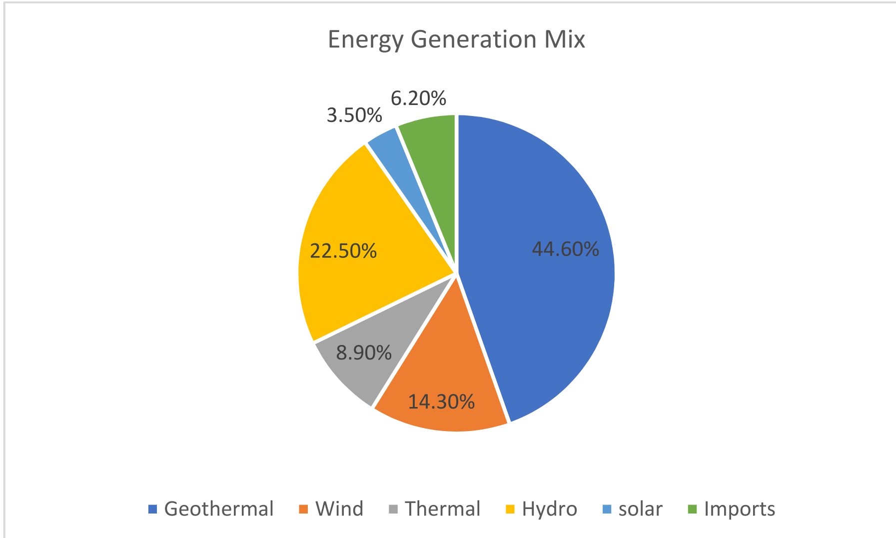


Fig. 3. Energy generation mix – as of December 2023.
Source: Energy and Petroleum Regulatory Authority (2025).

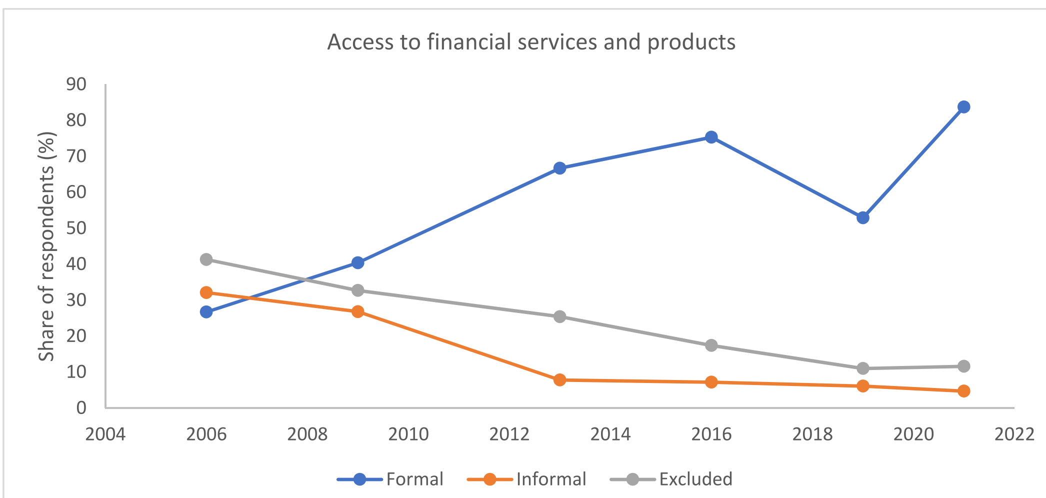


Fig. 4. Trends in access to financial services and products in Kenya.
Source: 2021 FinAcess Household Survey

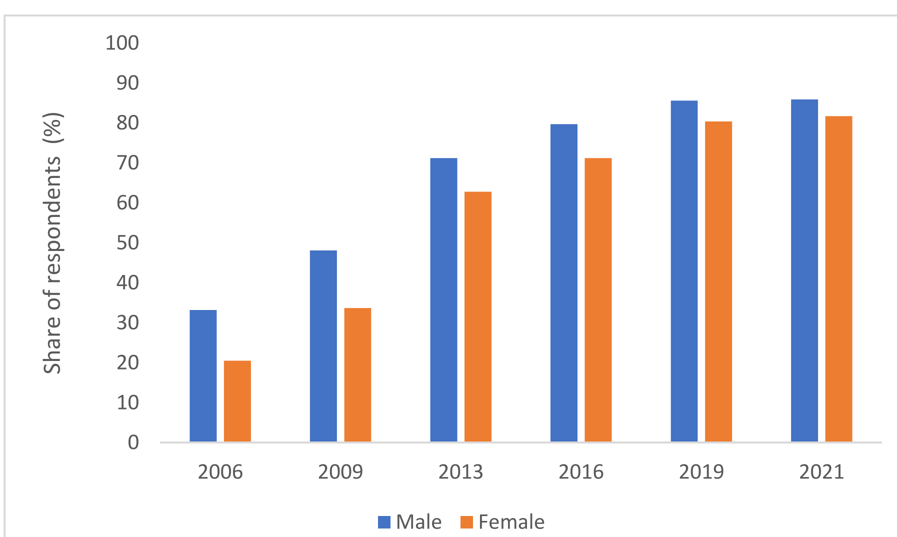


Fig. 5. Trends in Financial Inclusion in Kenya, by gender.
Source: 2021 FinAcess Household Survey

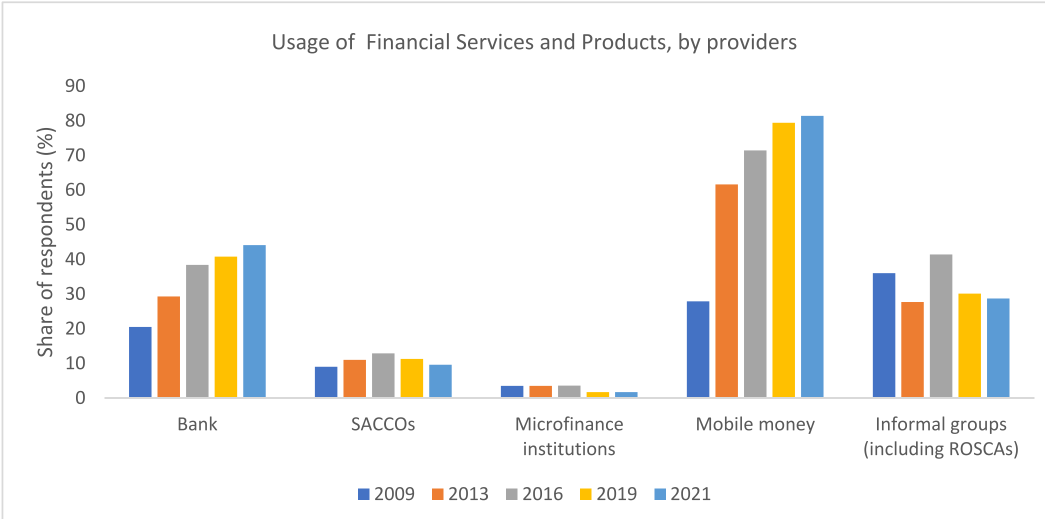


Fig. 6. Proportion of usage of various financial services and products in Kenya.
Source: 2021 FinAcess Household Survey

Table 1
Summary statistics.

Variable	Obs	Mean	Std. Dev.	Min	Max
Financial inclusion					
Account ownership in a formal institution	3359	0.549	0.498	0	1
Account ownership in an informal institution	3359	0.23	0.421	0	1
Ownership of a mobile money account	3359	0.832	0.374	0	1
Access to energy					
National grid	3359	0.461	0.499	0	1
Generator	3359	0.013	0.114	0	1
Batteries	3359	0.047	0.212	0	1
Candles	3359	0.182	0.386	0	1
Open wick	3359	0.181	0.385	0	1
Pressure lamps	3359	0.007	0.086	0	1
Solar	3359	0.356	0.479	0	1
Household characteristics					
Age	3350	43.821	14.6	17	104
Gender (male-female)	3359	0.82	0.384	0	1
Marital status (married-single)	3359	1.919	1.859	1	2
Location (rural-urban)	3359	0.436	0.496	0	1
Education (primary, secondary, tertiary)	2844	0.952	0.826	0	3
Occupation (self-employed, non-farm, unemployed)	3352	1.181	1.546	1	3
Dwelling characteristics					
Duration of stay	3359	16.319	16.555	1	83
Type of dwelling	3359	1.026	0.819	1	2
Own dwelling	3359	0.697	0.46	0	1
Type of wall	3359	3.18	1.174	0	2

Source: calculations from survey data.

entrepreneurs or unemployed.

Finally, 69% of households own their current dwelling, with an average stay of 16 years. Approximately 66% of the dwellings are single houses occupied by one household, while multiple households occupy 8%. Blocks plastered with cement constitute 34% of the type of wall used to construct the houses, while 25% of the walls are made from traditional mud bricks.

Table 2 presents the correlation matrix. The results reveal that financial inclusion is positively associated with increased access to the national grid, generators and solar, and reduced access to harmful energy types such as open wicks and pressure lamps. These findings are consistent with the theory discussion in Section 2.

3.2. Econometric analysis

The baseline specification to test the relationship between energy access and financial inclusion takes the form:

$$Energy\ Access_i = \alpha + \beta_1 Financial\ inclusion_i + \beta_2 X_i + \beta_3 Z_i + \varepsilon_i \quad \text{Eq.1}$$

Where *Energy Access* represents whether household *i* has access to either renewable or non-renewable energy. The key independent variable is *financial inclusion*, and β_1 is the parameter of interest. To control for factors that might influence *Energy Access* and *Financial Inclusion*, X_i *is* a vector of individual-level controls that includes age, gender, marital status, location, level of education of the household head and occupation. The variable Z_i represents dwelling characteristics such as the duration of stay in the dwelling, the type of dwelling, dwelling ownership and the type of wall, factors that capture households' incentives to invest in energy, while ε_i is the error term.

3.2.1. Outcome variable: energy access

Measuring energy access is complex and different studies have proposed different metrics that are related to different theoretical and conceptual frameworks such as capacity, duration, reliability, quality, affordability, legality and health and safety (World Bank, 2014). In this analysis, energy access is defined using one of the World Bank's Multi-tier Framework criteria, where access is related to the concept of connection or accessibility, which in itself is also a means to many ends. The definition is adopted as it ensures alignment between the theoretical concept of energy access and the survey design, enhancing measurement validity and minimizing bias. By focusing on connection or accessibility, the definition reflects the practical realities of energy use and supports robust empirical analysis consistent with the World Bank's Multi-Tier Framework (World Bank, 2015). Thus, the main dependent variable, access to energy, is computed as a binary variable that takes the value of 1 if a household is connected to at least one type of non-renewable energy source such as the national grid, a generator, batteries, candles, open wick or pressure lamps, or renewable energy such as solar.

3.2.2. Independent variable: financial inclusion

For this analysis, the key explanatory variable, financial inclusion, is measured using three key indicators that capture access to financial institutions. The first one is whether the household head has a bank

Table 2
Pairwise correlation matrix.

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
(1) Account in formal inst.	1.000														
(2) Account in informal inst.	0.174*	1.000													
(3) Mobile money account	0.260*	0.119*	1.000												
(4) National grid	0.323*	0.045*	0.147*	1.000											
(5) Generator	0.062*	0.031	0.038*	0.020	1.000										
(6) Batteries	0.005	0.026	0.021	−0.166*	0.061*	1.000									
(7) Candles	−0.145*	−0.051*	−0.046*	0.400*	−0.021	−0.069*	1.000								
(8) Open wicks	−0.252*	−0.053*	−0.144*	−0.325*	−0.027	−0.046*	−0.196*	1.000							
(9) Pressure lamps	−0.051*	−0.043*	−0.011*	0.017	0.020	−0.003	−0.023	−0.032	1.000						
(10) Solar	0.02*	0.035	0.025*	−0.319*	0.024	0.140*	−0.145*	−0.161*	−0.006	1.000					
(11) Age	−0.062*	0.049*	−0.116*	−0.198*	0.004	0.015	−0.215*	0.130*	−0.001	0.091*	1.000				
(12) Location	0.186*	−0.020	0.075*	0.558*	0.031	−0.102*	0.306*	−0.228*	−0.006	−0.217*	−0.236*	1.000			
(13) Duration of stay	−0.115*	0.047*	−0.071*	−0.257*	−0.010	0.053*	−0.220*	0.167*	0.026	0.111*	0.604*	−0.346*	1.000		
(14) Own dwelling	−0.158*	0.029	−0.098*	−0.488*	0.013	0.092*	−0.366*	0.190*	−0.011	0.233*	0.404*	−0.496*	0.438*	1.000	
(15) Type of wall	−0.054*	−0.007	−0.011	−0.142*	−0.025	0.002	−0.089*	0.034	−0.002	0.084*	0.022	−0.086*	0.068*	0.105*	1.000

**$p < 0.05$.
Source: own calculation from survey data.

account in a formal financial institution. Formal institutions are categorized as commercial banks, cooperative credit unions (SACCOs) or microfinance. The second indicator is whether a household head has an account in an informal financial institution, defined as either a rotating saving and credit association (ROSCAs) or group savings. The third indicator is whether a household head has an active mobile money account. These definitions are appropriate for two main reasons. First, they capture a broader spectrum of financial engagement, encompassing formal institutions and informal mechanisms, reflecting the reality of financial systems in many developing contexts where households often rely on a combination of these services to meet their needs. Second, by isolating the distinct contributions of formal, informal, and digital mechanisms, they provide insights into the specific pathways through which each type of financial service impacts energy access (World Bank, 2015).

3.2.3. Control variables

X_i represents time-varying individual-level characteristics that help mitigate the omitted variable bias and is motivated by an extant body of empirical studies on the determinants of energy access. For instance, residential energy use has been found to increase with age (Karimu et al., 2016), while higher levels of education raise energy access by creating awareness of the value of energy (Baiyegunhi and Hassan (2014). On the other hand, occupations, such as non-farm activities, that require energy as an input increase the likelihood of accessing energy (Liao et al., 2019), while the evidence on the effects of gender and marital status remains mixed (Ishengoma & Igangula, 2021). The locality indicator incorporates the fact that residents in rural areas are less likely to have access to energy due to the vast energy distribution costs (Gitau et al., 2019).

Z_i represents dwelling characteristics that might simultaneously affect a household's incentives to invest in energy or for energy companies to install energy due to the physical conditions of the house. The model includes indicators for whether the household owns the house, the duration of stay, the type of wall and occupancy status. It is anticipated that incentives to invest in energy will be higher for households who own the dwellings, those who have resided there for a longer duration and those whose occupancy consists of multiple households due to scale economies. Similarly, households whose residence consists of mud walls are less likely to invest in energy, especially the national grid, since these structures do not typically support such connections (Yaguma et al., 2023).

3.3. Identification

Eq. (1) is estimated using PSM. Compared to similar studies (Addai et al., 2022; Koomson & Danquah, 2021), this technique has the advantage of addressing endogeneity concerns related to self-selection bias. First, households that are financially included (the treated group) might differ from those that are not (the untreated group), and comparing these groups directly could lead to biases due to imbalances in both observed and unobserved covariates prior to treatment (World Bank, 2019). To address this concern, the econometric analysis compares the outcome variable (energy access) of individuals in the treatment group (those with access to financial services) with the energy outcomes of those in the control group (without access to financial services) who have similar observable characteristics (Getler et al., 2016). For each individual in the treatment group and in the pool of control group, PSM computes the probability that this individual will get treated based on the observed values of its characteristics. The average treatment effect (ATE) is calculated by taking the average difference between the treatment and potential outcomes for each individual (Austin, 2011).

The identification strategy relies on the comparison group being like the treatment group in all aspects, except that the treatment group is financially included while the comparison group is not. Therefore, no differences between the treated and control individuals should correlate with potential outcomes (Getler et al., 2016).

Formally, the standard PSM framework is denoted by

$$T_i = Y_i(1) - Y_i(0) \quad \text{Eq. 2}$$

Where T_i refers to each of the three treatment arms (account in a formal institution, account in an informal institution, and mobile money account) for each household head, $Y_i(1)$ is the potential outcome with access to a financial institution (whether the household has energy access) and $Y_i(0)$ is the potential household outcomes without energy access. The measurement of the impact of financial inclusion is thus obtained by comparing energy access for those with access with their outcomes if they did not have any access. However, this is unobserved as households are only observed after being treated (accessing financial services). The PSM framework estimates the counterfactual outcome whereby the propensity score is the conditional probability of being assigned to a particular treatment given a pre-determined list of observable characteristics. The average treatment effect (ATE), which is the mean impact of financial inclusion, is obtained by averaging the effect across all the individuals and is denoted by

$$\text{ATE} = E(Y1 - Y0) \quad \text{Eq. 3}$$

Two key assumptions must hold for PSM to produce unbiased estimates. First is the conditional independence assumption, which necessitates that after controlling for a set of characteristics, the potential outcomes are independent of the treatment status. Second is the common support condition, which implies that the probability of receiving or not receiving the treatment must be between 0 and 1. (Rosenbaum & Rubin, 1985). Although PSM can estimate various types of outcomes, the ATE, which is the effect on all individuals (treatment and control), is of more interest because it captures the average treatment of the entire population and is also preferable in instances where every treatment might potentially be offered to every individual (Benedetto et al., 2018).

3.4. Matching techniques

Four matching techniques are implemented for robustness purposes. The first one is kernel matching, which constructs the counterfactual outcome for treated units by calculating a weighted average of all control group observations. Weights are assigned based on the proximity of control units' propensity scores to those of treated units, with higher weights given to closer matches. This method is advantageous due to its efficiency, as it leverages the entire control sample, thereby reducing variance. The second technique is nearest neighbour, where each treated unit is matched to the control unit with the closest propensity score. The third technique is inverse probability weighting, which adjusts for potential biases by reweighting observations based on the inverse of their propensity score. This corrects for differences in the distribution of treated and control groups, effectively addressing potential biases from missing potential outcomes. The final technique is caliper/radius matching, which imposes a predefined caliper (equal to one-quarter of the standard deviation of the propensity score) around each treated unit's propensity score, using control observations within this range as matches. By restricting matches to a narrow radius, it enhances match quality and ensures robustness, especially when the availability of comparable control units varies significantly. Finally, standard errors are computed using bootstrap technique with 1000 replications (Getler et al., 2016; Yin et al., 2023).

3.5. Validation tests

Several tests are conducted to assess the quality of the matching procedure. First, the common support assumption is tested by displaying the distribution of propensity scores for households with and without financial inclusion across the three treatment arms. As illustrated in Fig. 7, there is significant evidence of overlap, suggesting that most of the households in the treatment groups were successfully matched with similar individuals in the control group.

Second, Fig. 8 examines the distribution of household characteristics for households with and without access to financial services in each treatment arm. The results show that there are no systematic differences in these pre-treatment characteristics, and hence this is unlikely to explain the difference in energy access.

Third, Table 3 reports statistics corresponding to the bias reduction test. The results show that the matched sample has a median bias of 1.6, which is significantly lower than 9.6 for the unmatched sample, suggesting that the PSM provides better counterfactuals to the treated individuals.

4. Main results

Table 4 reports the main results that correspond to Eq. (1) For the estimates in Panel A, the coefficient in column (1) is positive and statistically significant at the 1% level, suggesting that formal institutions increase the likelihood of using the national grid by almost 17%. In column (2), access to formal institutions increases the use of generators by only 1.3% and solar by 27.8% (column 7). In addition, the reliance on open wicks reduces by almost 15% (column 5). The results in Panel B reveal that access to informal financial institutions has a positive effect on accessing the national grid by 23.7% and access to solar power by 21.4%. The effect on pressure lamps is a reduction of 18% and is significant at the 10% level. Finally, the results in Panel C portray the positive effect of mobile money access on accessing the national grid (32.7%) and generators (8%) and reducing open wicks of almost 9%.

These findings reveal the significant role of different financial institutions in shaping household energy access, underpinned by the theoretical concepts of financial inclusion, resource allocation, and technology diffusion. Access to formal financial institutions likely improves grid and solar energy access by providing substantial loans or credit options that enable households to afford large-scale energy investments (Yin et al., 2023). The formal sector's typically lower interest in financing smaller, less stable energy sources may explain the smaller effects seen for generators. Conversely, informal financial institutions, with their more flexible, credit arrangements, tend to enhance access to grid and solar power but perhaps facilitate this through more community-based, smaller-scale funding mechanisms that are easier for less financially stable households to access (SEEP Network, 2007). Finally, mobile money dramatically reduces transaction costs, thereby increasing access to both traditional and alternative energy sources, while also decreasing reliance on more traditional forms like open wicks and pressure lamps, which tend to be less advocated for by mobile service providers (USAID and PowerAfrica, 2024).

4.1. Robustness checks

The main results are robust to multiple validation tests. First, to address the possibility that outliers might be driving the results, Eq. (1) is re-estimated after dropping all extreme values (values that are three times greater or smaller than the standard deviation). The results are reported in Table 5 and the estimates across columns (1) to (7) are quantitatively similar to those reported in the main findings.

The second robustness check examines whether the results are sensitive to the level of household income (Koomson & Danquah, 2021; Lay et al., 2013). Table 6 presents the results obtained from re-estimating Eq. (1) but controlling for household income in the matching techniques. Across the different specifications, the coefficient of financial inclusion remains positive and statistically significant for access to the national grid, generators, and solar, while it is negative for pressure lamps and open wicks, confirming earlier findings.

Finally, Table 7 reports estimates obtained from re-estimating Eq. (1) using alternative matching techniques as discussed in Section 3.5. Panel A presents nearest neighbour estimates, panel B implements the inverse probability technique and panel C reports the estimates obtained using the radius/caliper approach. Across columns (1) to (7), the coefficient of financial inclusion remains positive and statistically significant for the national grid, generators, pressure lamps and solar power and negative for open wicks, suggesting that the results are not influenced by the selection of the estimation technique.

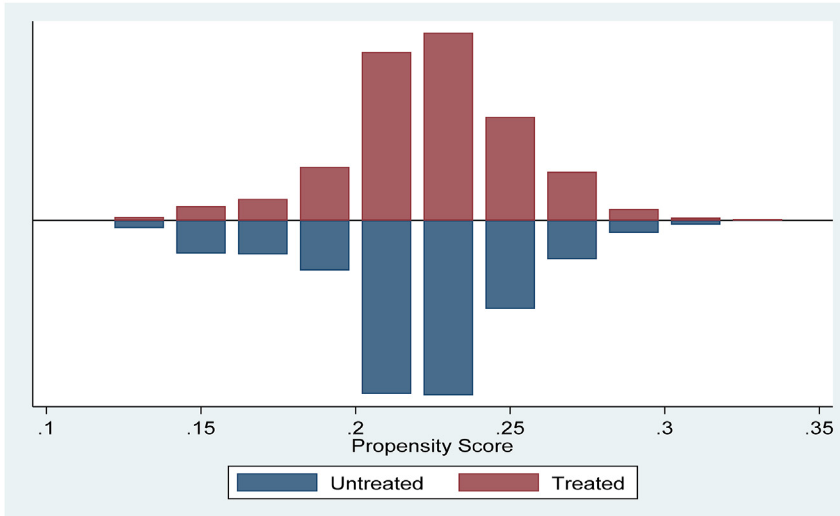
4.2. Heterogeneous effects

To better understand the varying impacts of financial inclusion on energy access, the analysis further disaggregates the independent variable by examining the specific types of financial institutions available to households. Table 8 presents the results of re-estimating Eq. (1) separately for each of the financial institutions.[1] Overall, the results show that each financial institution plays an important role in promoting access to renewables and reducing the use of non-renewable energy types The estimates in Panel A show that both group savings and ROSCAs have a positive effect on the use of generators and solar power and simultaneously reduce the likelihood of using open wicks. The estimates in Panel B show that access to commercial banks, credit cooperatives and microfinance increases the likelihood of connecting to the grid, using generators and solar power, while reducing the usage of open wicks.

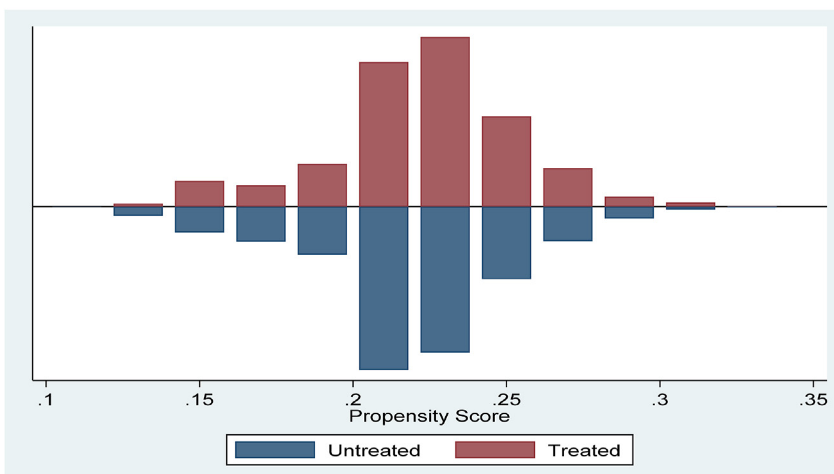
There are several explanations for these findings. Group savings schemes and ROSCAs tend to involve smaller, community-based pools of funds, often supporting more incremental or smaller-scale financing,

[1] The results are robust to different matching techniques (Appendix A).

Panel (a): Common support (T = access to formal institutions)



Panel (b): Common support (T = access to informal institutions)



Panel (c): Common support (T = access to mobile money account)

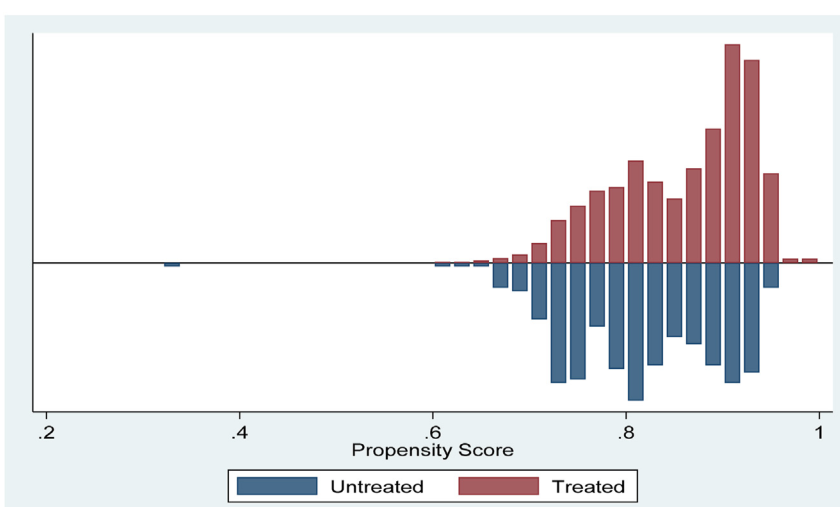


Fig. 7. Evidence of common support.

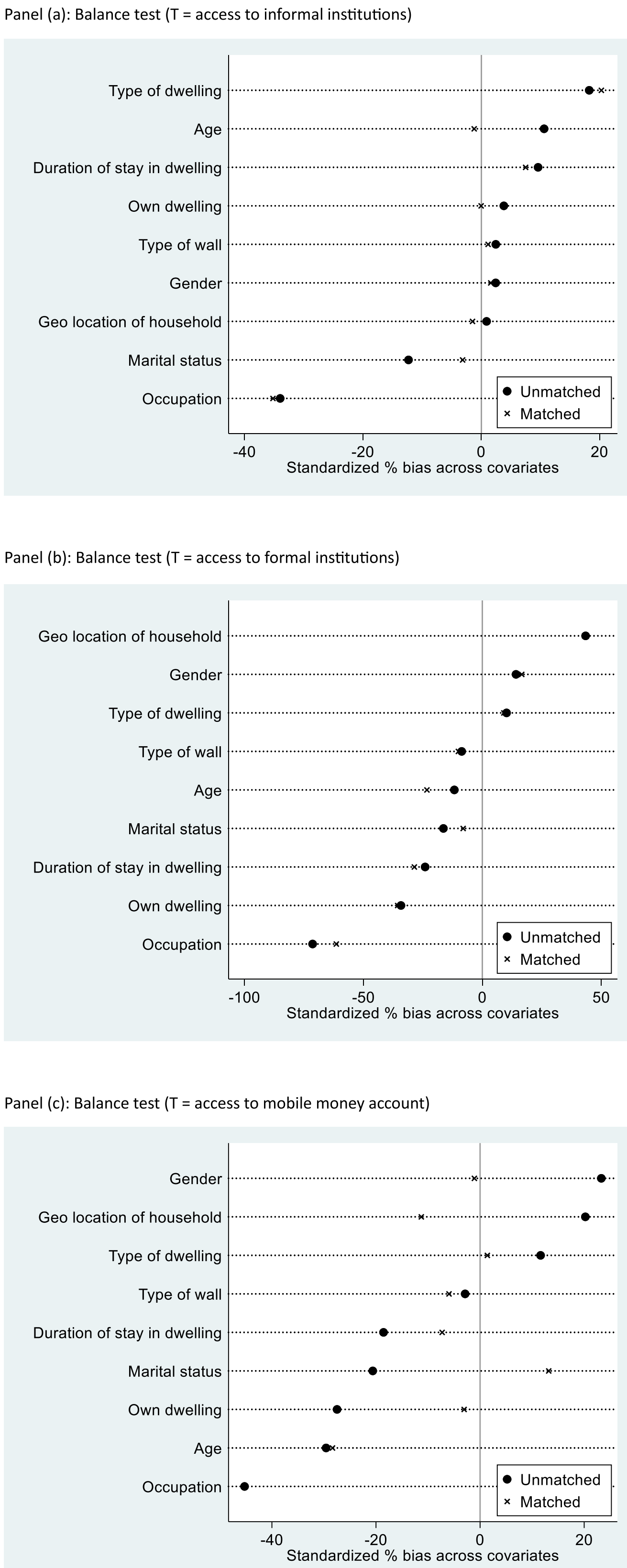


Fig. 8. Covariate balance test.

which aligns well with the lower upfront costs associated with generators and solar installations. They also tend to discourage households from using harmful energy such as open wicks (Lin & Wu, 2022). Conversely, commercial banks, cooperatives and microfinance typically have larger capital reserves and can offer more substantial loans, enabling individuals to afford grid connection costs, which are often high due to infrastructure demands, in addition to other energy types such as generators and solar.

4.3. Discussion of potential mechanisms

This final section examines the channels through which financial inclusion enhances households' access to renewable and non-renewable energy. As discussed in Section 2, it explores the role of households' willingness to invest in energy, flexible payment schemes and digital innovation through mobile money.

4.3.1. Willingness to pay (WTP)

Theoretically, financial inclusion can increase a household's energy access by alleviating income constraints, facilitating savings or enhancing the capacity to borrow from financial institutions. To empirically assess the WTP mechanism, a critical challenge that has plagued the literature is the need for actual measures of household WTP (Amoah et al., 2019; Tweregou, 2014). An essential contribution of this analysis is to overcome this challenge by using the survey data that directly asks individuals whether they would be willing to pay 33%, 67% or 100% of the connection fee to access renewable or non-renewable energy.

Using these measures, the following model is estimated:

$$WTP_j = \gamma Financial\ Inclusion_i + \beta_1 X_i + \beta_2 Z_i + \varepsilon_i \qquad \text{Eq. 4}$$

Where *j* refers to the *WTP* for either grid or solar connection, *Financial Inclusion* is a binary variable that takes the value of 1 for households with access to either formal or informal financial institutions, and X_i *and* Z_i represent household and dwelling characteristics as defined in Eq. (1). The coefficient of interest is denoted by γ, which captures how financial inclusion affects the WTP for the grid or solar.

The estimated results are presented in Table 9. Columns (2) and (3) indicate that households with access to formal financial institutions are willing to pay up to 67% and 100% of the total connection fee to access the grid. In contrast, columns (4) and (5) show that households with access to informal financial institutions are willing to pay up to 33% and 67% to access solar energy. [2] These findings highlight the critical role of financial institutions—both formal and informal—in shaping households' willingness to pay (WTP) for energy services. Households with access to formal financial institutions demonstrate a significantly higher WTP for grid connections, up to 100%, likely due to the enhanced credit access and financial security provided by these institutions. Conversely, households relying on informal financial institutions exhibit a lower WTP for solar energy, up to 67%, reflecting the constrained liquidity and limited risk-sharing mechanisms inherent to informal systems, which aligns with the findings of Lia et al. (2019).

There are several reasons that can explain these findings. First, households with access to formal financial institutions benefit from enhanced credit access, which allows them to afford higher upfront costs associated with grid connections. This increased financial security enables them to undertake long-term investments in modern energy infrastructure (Lay et al., 2013). Second, formal financial institutions provide structured repayment plans, which reduce the financial burden on households and increase their willingness to commit to larger expenditures. Third, informal financial institutions, while more accessible in low-income settings, typically lack the resources and risk-sharing mechanisms necessary to support high-cost investments. As a result, households reliant on these systems are more likely to prioritize less capital-intensive energy options, such as solar energy (USAID and PowerAfrica, 2024).

[2] These results are robust to different matching techniques (Appendix B).

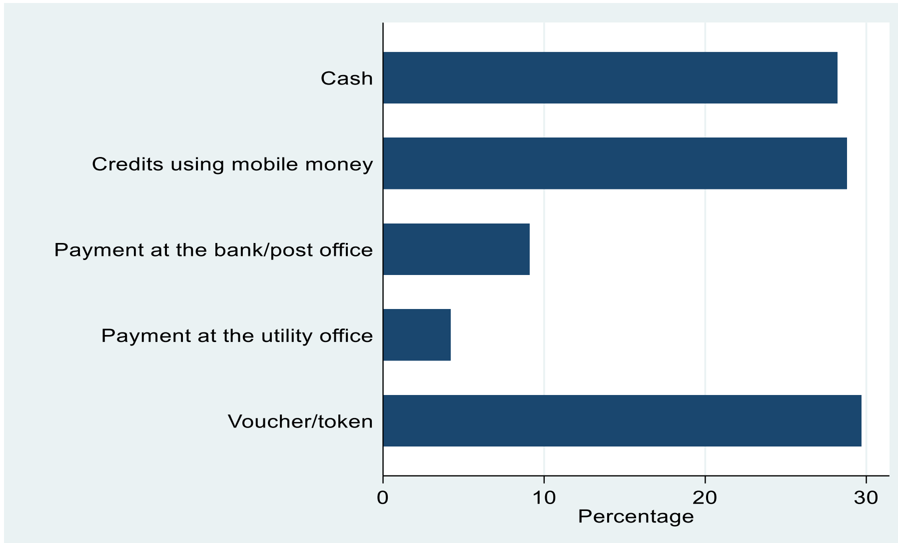


Fig. 9. Most typical ways to pay electricity bills.
Source: own calculation from survey data.

Table 3
Bias reduction tests.

Sample	Mean bias	Median bias	p > chi2	B	R	%Var
Unmatched	10.6	9.6	0.000	45.8*	0.66	50
Matched	8	1.6	0.000	42.9*	0.69	67

* if B>25%, R outside [0.5; 2].

hypothetical situations designed to elicit their preferences for paying a lump sum or opting for installment plans to access energy services.

Table 10 presents the results obtained from re-estimating Eq. (1) separately for formal and informal financial institutions and for each of the three-monthly instalment plans proposed.[3] The results underscore the dual importance of payment structures and financial inclusion in enabling energy access. The results in columns (1) to (3) reflect a preference for up-front payments to access grid connections, while the

Table 4
Main results: Financial inclusion and energy access – Kernel matching estimates.

	(1) National grid	(2) Generators	(3) Batteries	(4) Candles	(5) Open wicks	(6) Pressure lamps	(7) Solar
Panel A: Access to a formal institution	0.169***	0.013***	0.007	−0.002	−0.148***	−0.010	0.278***
	(9.25)	(2.76)	(0.73)	(-0.11)	(-8.49)	(-0.011)	(3.64)
Panel B: Access to an informal institution	0.237**	0.005	−0.001	0.006	−0.032	−0.180*	0.214**
	(2.01)	(1.03)	(-0.08)	(0.34)	(-1.48)	(−1.71)	(2.11)
Panel C: Access to a mobile money account	0.327***	0.081***	0.005	−0.020	−0.088***	−0.004	0.003
	(4.64)	(4.34)	(0.44)	(−0.81)	(−3.65)	(−1.05)	(1.13)
Number of observations	3350	3350	3350	3350	3350	3350	3350

t statistics in parentheses $^{**}p < 0.05$, $^{***}p < 0.01$, $^{*}p < 0.1$.

Table 5
Financial inclusion and energy access (accounting for potential outliers).

	(1) National grid	(2) Generators	(3) Batteries	(4) Candles	(5) Open wicks	(6) Pressure lamps	(7) Solar
Access to a formal institution	0.171***	0.014**	−0.010	−0.002	−0.135***	−0.024***	0.281**
	(8.54)	(2.35)	(-0.84)	(-0.11)	(-7.29)	(-3.68)	(2.07)
Access to an informal institution	0.255**	0.002	−0.002	0.037	−0.021	−0.167**	0.222**
	(2.13)	(0.26)	(-0.16)	(1.58)	(-0.88)	(-1.97)	(2.11)
Access to a mobile money account	0.122***	0.012***	0.012	−0.001	−0.081***	−0.101	0.012***
	(3.98)	(3.58)	(1.08)	(-0.05)	(-2.99)	(-1.58)	(3.58)
Number of observations	2879	2879	2879	2879	2879	2879	2879

t statistics in parentheses $^{**}p < 0.05$, $^{***}p < 0.01$, $^{*}p < 0.1$.

4.3.2. Flexibility of payment

The second mechanism is the potential of financial inclusion to enhance energy access through flexible payment schemes for grid and off-grid connections. To explore this possibility, the analysis employs choice experiment scenarios in which households were presented with

[3] These results are robust to different matching techniques (Appendix C).

Table 6
Financial inclusion and energy access (controlling for household income).

	(1) National grid	(2) Generators	(3) Batteries	(4) Candles	(5) Open wicks	(6) Pressure lamps	(7) Solar
Access to a formal institution	0.132***	0.034**	−0.034	0.009	−0.067***	−0.009***	0.321**
	(16.54)	(2.34)	(-0.82)	(0.26)	(-2.68)	(-3.76)	(2.52)
Access to an informal institution	0.863***	0.003	0.149	0.019	−0.050**	−0.008	0.251**
	(2.74)	(0.40)	(0.00)	(0.73)	(-2.17)	(-1.52)	(2.20)
Access to a mobile money account	0.169***	0.051*	0.018	0.023	−0.080***	−0.002	0.040**
	(5.98)	(1.75)	(1.42)	(0.98)	(-4.89)	(-0.48)	(2.04)
Number of observations	2493	2493	2493	2493	2493	2493	2493
Pseudo R2	0.166	0.166	0.166	0.166	0.166	0.166	0.166

t statistics in parentheses $^{**}p < 0.05$, $^{***}p < 0.01$, $^{*}p < 0.1$.

Table 7
Financial inclusion and Energy Access (alternative matching techniques).

	(1) National grid	(2) Generators	(3) Batteries	(4) Candles	(5) Open wicks	(6) Pressure lamps	(7) Solar
Panel A: Nearest-Neighbor Matching							
Access to a formal institution	0.171***	0.014**	−0.010	−0.002	−0.135***	−0.024***	0.281**
	(6.66)	(2.38)	(-0.84)	(-0.11)	(-7.00)	(-3.55)	(2.17)
Access to an informal institution	0.347**	0.005	−0.001	0.006	−0.032	−0.190*	0.217**
	(2.11)	(1.03)	(-0.08)	(0.34)	(-1.48)	(-1.79)	(2.19)
Access to a mobile money account	0.377***	0.091***	0.005	−0.020	−0.084***	−0.004	0.003
	(4.56)	(4.74)	(0.44)	(-0.81)	(-3.74)	(-1.05)	(1.13)
Panel B: Inverse Probability Weighting							
Access to a formal institution	0.161***	0.018**	−0.010	−0.002	−0.145***	−0.028***	0.291**
	(8.54)	(2.15)	(-0.84)	(-0.11)	(-7.01)	(-3.11)	(2.01)
Access to an informal institution	0.763***	0.003	0.149	0.019	−0.060**	−0.008	0.261**
	(2.71)	(0.40)	(0.00)	(0.73)	(-2.27)	(-1.52)	(2.30)
Access to a mobile money account	0.347***	0.071***	0.005	−0.020	−0.094***	−0.004	0.003
	(3.56)	(4.64)	(0.44)	(-0.81)	(-3.57)	(-1.05)	(1.13)
Panel C: Caliper/Radius							
Access to a formal institution	0.172***	0.020**	−0.011	−0.017	−0.167***	−0.071***	0.271**
	(6.65)	(2.01)	(-0.99)	(-0.31)	(-4.23)	(-2.87)	(2.11)
Access to an informal institution	0.712**	0.011	0.161	0.022	−0.081**	−0.035	0.381**
	(2.41)	(0.50)	(0.02)	(0.52)	(-2.45)	(-1.72)	(2.38)
Access to a mobile money account	0.415***	0.051***	0.008	−0.018	−0.089***	−0.010	0.012
	(2.88)	(3.54)	(0.84)	(-0.71)	(-2.76)	(-1.09)	(1.43)
Number of observations	3350	3350	3350	3350	3350	3350	3350

t statistics in parentheses $^{**}p < 0.05$, $^{***}p < 0.01$, $^{*}p < 0.1$.

increasing likelihood of solar adoption with longer payment plans is shown in columns (4) to (6).

There are several reasons that can explain these findings. First, households with access to formal financial institutions benefit from structured financial mechanisms, such as savings and credit access, which enable them to manage large, one-time payments for grid connections. This financial support not only alleviates liquidity constraints but also increases households' confidence in making significant investments in reliable and long-term energy solutions (Grimm et al., 2017). Second, informal financial systems, while more accessible for lower-income households, typically lack the resources to support large, upfront expenditures. As a result, these households are more likely to adopt decentralized energy systems, such as solar, which become financially viable through longer payment plans (Saim & Khan, 2021). Third, flexible installment schemes align with the income patterns of lower-income households, which are often irregular and unpredictable. These plans reduce financial strain and enable broader access to clean energy technologies (Lee et al., 2019).

4.3.3. *Mobile money account payment*

The final mechanism examines how financial inclusion eases the processes of paying for energy services. Fig. 9 shows that at least 28% of households prefer using mobile accounts to pay electricity bills.

Table 11 presents results from Eq. (1) that assess whether access to mobile money accounts increase households' capacity to pay for renewable and non-renewable energy. Recent advancements in the accessibility and affordability of digital financial services in Africa have enabled millions to transition from cash-based transactions to formal, secure digital financial platforms. The estimates in column (1) show that having a mobile money account is associated with a 54.7% increase in paying for electricity user fees while column (2) shows that having a mobile money account increases the likelihood of purchasing solar devices by almost 15%. In both specifications, the estimates are statistically significant at the 1% level.[4]

[4] These results are robust to different matching techniques (Appendix D).

Table 8
Differential effect of financial inclusion on energy access (Kernel matching estimates).

	(1)	(2)	(3)	(4)
	National grid	Generators	Open wicks	Solar
Panel A (Informal institutions):				
Group savings	−0.028	0.113**	−0.325*	0.171***
	(-0.73)	(1.99)	(1.84)	(2.67)
ROSCAs	0.036	0.102**	−0.379**	0.092**
	(1.27)	(2.13)	(−2.01)	(1.98)
Panel B (formal institutions):				
Commercial banks	0.265**	0.254***	−0.165*	−0.042
	(2.13)	(3.41)	(−1.85)	(-1.09)
Cooperatives	0.096**	0.221**	−0.221**	0.091**
	(2.32)	(1.97)	(−2.31)	(2.05)
Microfinance	0.083	0.182**	−0.084*	0.281***
	(1.04)	(2.22)	(−1.78)	(2.69)
Number of observations	3350	3350	3350	3350

t statistics in parentheses $^{**}p < 0.05$, $^{***}p < 0.01$, $^{*}p < 0.1$.

Table 9
WTP and energy access (Kernel matching estimates).

	(1)	(2)	(3)	(4)	(5)	(6)
	National grid			Solar power		
	33%	67%	100%	33%	67%	100%
Access to a formal institution	−0.002	0.042**	0.019*			
	(-0.18)	(2.01)	(1.68)			
Access to an informal institution				0.036**	0.032**	−0.010
				(2.16)	(2.22)	(-0.76)
Number of observations	3350	3350	3350	3350	3350	3350

t statistics in parentheses $^{**}p < 0.05$, $^{***}p < 0.01$, $^{*}p < 0.1$.

There are two main reasons to support these findings. First, for electricity bills, mobile money not only reduces transaction costs but also increases the convenience of making regular, timely payments without the need for physical travel, thus ensuring uninterrupted service (Perros et al., 2024). Second, mobile money accounts facilitate smaller transactions, which are suited for the payment structures often associated with renewable energy solutions, like solar devices, where pay-as-you-go models are often the most common modality of payment (Avom et al., 2023).

5. Conclusion and policy recommendations

This paper utilizes a comprehensive household-level dataset to explore the relationship between financial inclusion and energy access, using Kenya as a case study. Employing PSM techniques, the findings demonstrate that access to both formal and informal financial institutions increases the adoption of renewable energy technologies and reduces reliance on harmful energy sources. In addition, financial inclusion enhances the willingness to pay for energy by alleviating income constraints, offsets user costs through flexible payment schemes and enhances reduces transaction costs through digital platforms. These results highlight the potential for financial inclusion to address persistent energy poverty, particularly in contexts characterized by high energy costs and limited access to financing.

These findings have the following implications for policy. First, there is a need to expand financial inclusion with tailored instruments. Financial institutions should offer tailored instruments such as microloans, pay-as-you-go financing models, and savings-linked energy products that address the liquidity constraints that hinder energy investments. These could provide low-income households with the flexibility to finance grid connections and off-grid renewable technologies.

Second, there is a need to support informal financial institutions as key intermediaries. Policymakers should strengthen these institutions through targeted capitalization, such as concessional credit lines or grants, to enhance their capacity to finance energy-related investments. Tailored regulation can ensure transparency and consumer protection while preserving their grassroots accessibility. Capacity-building initiatives should focus on risk assessment and innovative financing models and leverage digital platforms to improve efficiency. Strategic partnerships with energy service providers can further enable bundled financial products, reducing transaction costs and enabling informal financial institutions to accelerate the adoption of renewable energy technologies.

Third, there is a need to leverage digital financial services for energy access. Policymakers should focus on fostering partnerships between fintech providers and energy companies to develop integrated solutions that integrate digital financial services into energy markets. Additionally, investments in digital infrastructure, such as expanding mobile network coverage, and initiatives to enhance digital literacy can ensure broader accessibility. Consequently, households can seamlessly transition to modern energy sources, reducing their reliance on traditional fuels and improving their energy security.

Finally, upfront costs need to be reduced through well-crafted subsidies and incentives. Governments and development partners should implement well-designed subsidies for renewable energy technologies, such as solar systems, to lower the initial adoption costs for low-income households. Tax incentives, including exemptions or reductions on energy-related equipment, can further enhance affordability while

Table 11
Digital payments and energy access (Kernel estimates).

	(1)	(2)
	National grid	Solar power
Access to mobile money account	0.547***	0.148***
	(28.16)	(4.89)
Number of observations	3350	2493

t statistics in parentheses $^{**}p < 0.05$, $^{***}p < 0.01$, $^{*}p < 0.1$.

Table 10
Flexible payment schemes and energy access (Kernel estimates).

	(1)	(2)	(3)	(4)	(5)	(6)
	National grid			Solar power		
	3 months	6 months	12 months	6 months	12 months	24 months
Access to a formal institution	0.152***	0.040*	0.012	0.125**	0.213**	0.388***
	(3.32)	(1.78)	(1.11)	(2.22)	(1.98)	(3.12)
Access to an informal institution	0.231**	0.151**	0.039	0.256**	0.289**	0.372**
	(2.17)	(2.22)	(1.21)	(2.00)	(1.96)	(2.21)
Number of observations	1580	1580	1580	1580	1580	1580

t statistics in parentheses $^{**}p < 0.05$, $^{***}p < 0.01$, $^{*}p < 0.1$.

encouraging private sector participation in the energy market. These measures would address affordability barriers, particularly for first-time users, while complementing financial inclusion efforts to ensure broader energy access.

5.1. Limitations and further research

This study offers valuable insights into the relationship between financial inclusion and energy access, but it is not without limitations. First, the reliance on cross-sectional data constrains the analysis to a snapshot in time, limiting the ability to capture dynamic transitions in energy usage. Future research could address this gap by employing panel data to explore how households shift from non-renewable to renewable energy sources, providing a deeper understanding of the underlying drivers of energy transitions. Second, while financial inclusion is central to the study, its dual-edged nature warrants further exploration. Critics argue that financial inclusion is not always inclusive and can exacerbate household indebtedness. High interest rates and stringent borrowing requirements often pose significant barriers for low-income households, limiting their ability to leverage financial services for energy access. Investigating these dynamics, particularly the trade-offs between access to financial services, affordability, and financial sustainability, could enrich the discourse on the equitable role of financial inclusion in promoting energy access.

CRediT authorship contribution statement

Michael Mbate: Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Conceptualization. **El Hadji Fall:** Validation, Software, Resources, Project administration, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A

Table A1
Differential effect of financial inclusion on energy access (Nearest Neighbour estimates)

	(1)	(2)	(3)	(4)
	National grid	Generators	Open wicks	Solar
Panel A (Informal institutions):				
Group savings	−0.038	0.118**	−0.326*	0.179***
	(-0.63)	(1.98)	(1.89)	(2.69)
ROSCAs	0.036	0.108**	−0.388**	0.082**
	(1.28)	(2.18)	(2.06)	(1.99)
Panel B (formal institutions):				
Commercial banks	0.278**	0.256***	−0.175*	−0.052
	(2.16)	(3.44)	(1.88)	(-1.19)
Cooperatives	0.098**	0.228**	−0.226**	0.095**
	(2.38)	(1.98)	(2.36)	(2.15)
Microfinance	0.093	0.192**	−0.074*	0.281**
	(1.04)	(2.27)	(1.79)	(2.79)
Number of observations	3350	3350	3350	3350

t statistics in parentheses **$p < 0.05$, ***$p < 0.01$, *$p < 0.1$.

Table A2
Differential effect of financial inclusion on energy access (Inverse probability estimates)

	(1)	(2)	(3)	(4)
	National grid	Generators	Open wicks	Solar
Panel A (Informal institutions):				
Group savings	−0.040	0.123**	−0.455**	0.160***
	(-0.76)	(2.01)	(2.00)	(2.60)
ROSCAs	0.056	0.202**	−0.469**	0.082**
	(1.57)	(2.23)	(2.11)	(2.28)
Panel B (formal institutions):				
Commercial banks	0.266**	0.260***	−0.170*	−0.046
	(2.19)	(3.38)	(1.91)	(-1.51)
Cooperatives	0.091**	0.254**	−0.233**	0.081**
	(2.33)	(1.98)	(2.44)	(2.10)
Microfinance	0.071	0.184**	−0.074*	0.284***

(*continued on next page*)

Table A2 (*continued*)

	(1) National grid	(2) Generators	(3) Open wicks	(4) Solar
	(1.21)	(2.21)	(1.81)	(2.49)
Number of observations	3350	3350	3350	3350

t statistics in parentheses $**p < 0.05$, $***p < 0.01$, $*p < 0.1$.

Table A3
Differential effect of financial inclusion on energy access (Caliper/radius estimates)

	(1) National grid	(2) Generators	(3) Open wicks	(4) Solar
Panel A (Informal institutions):				
Group savings	−0.021	0.122**	−0.425*	0.171***
	(-0.71)	(2.31)	(1.94)	(2.67)
ROSCAs	0.036	0.102**	−0.469**	0.062**
	(1.27)	(2.13)	(2.21)	(2.10)
Panel B (formal institutions):				
Commercial banks	0.361**	0.259***	−0.175**	−0.052*
	(2.17)	(3.33)	(2.21)	(-1.69)
Cooperatives	0.099**	0.231**	−0.233***	0.191**
	(2.11)	(1.99)	(3.31)	(2.10)
Microfinance	0.094	0.199***	−0.074**	0.312**
	(1.04)	(3.22)	(1.88)	(2.42)
Number of observations	3350	3350	3350	3350

t statistics in parentheses $**p < 0.05$, $***p < 0.01$, $*p < 0.1$.

Appendix B

Table B1
WTP and energy access (Nearest Neighbour estimates)

	(1)	(2)	(3)	(4)	(5)	(6)
	National grid			Solar power		
	33%	67%	100%	33%	67%	100%
Access to a formal institution	−0.006	0.052**	0.019**			
	(-0.17)	(2.35)	(2.28)			
Access to an informal institution				0.035**	0.042**	−0.020
				(2.11)	(2.32)	(-0.66)
Number of observations	3350	3350	3350	3350	3350	3350

t statistics in parentheses $**p < 0.05$, $***p < 0.01$, $*p < 0.1$.

Table B2
WTP and energy access (Inverse probability estimates)

	(1)	(2)	(3)	(4)	(5)	(6)
	National grid			Solar power		
	33%	67%	100%	33%	67%	100%
Access to a formal institution	−0.005	0.062***	0.023**			
	(-0.38)	(2.87)	(1.98)			
Access to an informal institution				0.026***	0.011**	−0.020
				(3.16)	(2.42)	(-0.94)
Number of observations	3350	3350	3350	3350	3350	3350

t statistics in parentheses $**p < 0.05$, $***p < 0.01$, $*p < 0.1$.

Table B3
WTP and energy access (Caliper/radius estimates)

	(1)	(2)	(3)	(4)	(5)	(6)
	National grid			Solar power		
	33%	67%	100%	33%	67%	100%
Access to a formal institution	−0.003 (-0.135)	0.062** (2.01)	0.014** (1.98)			
Access to an informal institution				0.035** (2.19)	0.038** (2.35)	−0.080 (-0.96)
Number of observations	3350	3350	3350	3350	3350	3350

t statistics in parentheses ***p* < 0.05, ****p* < 0.01, **p* < 0.1.

Appendix C

Table C1
Flexible payment schemes and energy access (Nearest Neighbour estimates)

	(1)	(2)	(3)	(4)	(5)	(6)
	National grid			Solar power		
	3 months	6 months	12 months	6 months	12 months	24 months
Access to a formal institution	0.157*** (3.33)	0.042* (1.80)	0.014 (1.16)	0.135** (2.25)	0.224** (1.99)	0.391*** (3.16)
Access to an informal institution	0.241** (2.11)	0.157** (2.21)	0.041 (1.25)	0.266** (2.09)	0.271** (2.16)	0.401** (2.31)
Number of observations	1580	1580	1580	1580	1580	1580

t statistics in parentheses ***p* < 0.05, ****p* < 0.01, **p* < 0.1.

Table C2
Flexible payment schemes and energy access (Inverse probability estimates)

	(1)	(2)	(3)	(4)	(5)	(6)
	National grid			Solar power		
	3 months	6 months	12 months	6 months	12 months	24 months
Access to a formal institution	0.162*** (3.29)	0.046* (1.75)	0.011 (1.121)	0.123** (2.25)	0.216** (2.21)	0.381*** (3.10)
Access to an informal institution	0.243** (2.14)	0.158** (2.28)	0.034 (1.26)	0.257** (2.06)	0.243** (1.99)	0.375** (2.27)
Number of observations	1580	1580	1580	1580	1580	1580

t statistics in parentheses ***p* < 0.05, ****p* < 0.01, **p* < 0.1.

Table C3
Flexible payment schemes and energy access (Caliper/radius estimates)

	(1)	(2)	(3)	(4)	(5)	(6)
	National grid			Solar power		
	3 months	6 months	12 months	6 months	12 months	24 months
Access to a formal institution	0.173*** (2.99)	0.039* (1.88)	0.019 (1.19)	0.128** (2.28)	0.211** (2.31)	0.384*** (3.16)
Access to an informal institution	0.261** (2.37)	0.156** (2.27)	0.059 (1.31)	0.300** (2.06)	0.311** (2.14)	0.378** (2.25)
Number of observations	1580	1580	1580	1580	1580	1580

t statistics in parentheses ***p* < 0.05, ****p* < 0.01, **p* < 0.1.

Appendix D

Table D1
Digital payments and energy access (Nearest Neighbour estimates)

	(1)	(2)
	National grid	Solar power
Access to mobile money account	0.555***	0.151***
	(25.01)	(4.91)
Number of observations	3350	2493

t statistics in parentheses $**p < 0.05$, $***p < 0.01$, $*p < 0.1$.

Table D2
Digital payments and energy access (Inverse probability estimates)

	(1)	(2)
	National grid	Solar power
Access to mobile money account	0.561***	0.153***
	(26.61)	(5.01)
Number of observations	3350	2493

t statistics in parentheses $**p < 0.05$, $***p < 0.01$, $*p < 0.1$.

Table D3
Digital payments and energy access (Caliper/radius estimates)

	(1)	(2)
	National grid	Solar power
Access to mobile money account	0.510***	0.157***
	(28.04)	(4.52)
Number of observations	3350	2493

t statistics in parentheses $**p < 0.05$, $***p < 0.01$, $*p < 0.1$.

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