



Impact of solar energy subscription on the market performance of micro, small & medium enterprises in Nigeria

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ABSTRACT

Access to clean, affordable and reliable energy is a major developmental challenge in Africa. The present study investigates the determinants and impact of adopting solar energy on Micro, Small & Medium Enterprises (MSMEs) market performance in Lagos, Kano and Ondo states in Nigeria using survey data from 700 MSMEs. We estimated the average treatment effect on the treated (ATT) and average treatment effect (ATE) of adopting solar energy on MSMEs' income. The findings indicate that adoption of solar energy is associated with an increment in MSMEs' monthly earnings by 27% (nearest neighbor matching), 24% (Kernel matching) and 23% (radius matching). The study points out that powering MSMEs through solar energy decreases their energy expenditure. By adopting solar energy, MSMEs using the national grid and standby generators can cut down their average monthly energy expenditure by 36.64%. MSMEs' decision to adopt solar energy is influenced by trade-offs between the possible production, economic and environmental effects as well as business owners, business, and product characteristics. To the extent that governments, non-governmental organizations and policymakers are committed to providing reliable, cheaper and cleaner energy systems, they must raise broader awareness of the potential benefits of adopting solar energy.

1. Introduction

The current global energy crisis has accentuated the urgency and importance of developing and promoting reliable, cheaper and cleaner energy systems. Across Africa, the lack of a stable energy supply is one of the daunting challenges affecting business growth and performance, particularly businesses in the informal sector. Sub-Saharan Africa is described as starved for electricity with the region's power sector significantly underdeveloped in energy access, installation capacity, and overall consumption (International Energy Agency, 2022a; Ozoegwu and Akpan, 2021). Energy crisis has detrimental effects on domestic economy, particularly on firms' productivity and earnings.

The Nigerian situation is no different; the country's energy situation is characterized by an unreliable conventional grid plagued by load-shedding and rationing of electricity by the Nigeria Electricity

Regulatory Commission (NERC). Given the continuous increase in population, the country's in-house supply of energy remains inadequate and unable to meet its demand. The Nigerian economy suffers grossly from the energy crisis with notable effects highlighted as poverty, economic decline, low standard of living and citizens facing hardships (Roy et al., 2023). Indeed, access to a reliable electricity supply is an important factor for the operations of most small and medium size companies which are the bedrock of the Nigerian economy. Within Nigeria itself, electricity outages and irregular supply significantly affect SMEs' performances and these have led to closure of many manufacturing businesses. Due to the failure of grid-based supply, over 80 % of SMEs in Nigeria rely on generators to power their operations (Roy et al., 2023). This classified the country as one of the leading importers of generators in the world (Babajide and Brito, 2021). Generators nonetheless pose a set of environmental challenges such as noise

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and air pollution. They also require fuel to run which is an expensive undertaking, driving up the cost of production.

Transitioning to clean technologies can be a promising solution for Nigeria's energy crisis and Africa's as a whole. For instance, Africa is considered home to 60% of global solar energy resources. However the per capita use is the lowest globally. Only 1% of the population have installed solar power system (International Energy Agency, 2022b). Indeed, the electricity system in Nigeria relies mainly on hydropower and thermal power stations, but solar power can be the cheapest source of clean energy. Nigeria itself has the resources to follow the global trend of focusing on a sustainable and reliable technology to diversify its energy mix. Solar off-grid solutions have been hailed as a cheaper alternative for electricity provision to rapidly increase electrification in areas that still lack electricity access. The Federal Government's Rural Electrification Agency (REA) has indeed adopted solar mini grids as the primary rural electrification resource to provide clean, affordable electricity to underserved and unserved households and businesses in Nigeria (Electricity Hub, 2019). Under the 2017 NERC Regulations for Mini-Grid Systems, a framework for the establishment and operation of mini-grids has been provided, to accelerate electrification of low and non-electrified areas. The REA is partnering with private sector off-grid energy companies to implement electrification projects across Nigeria; one of these developers is Rensource. This partnership is expected to boost provision and uptake of clean energy as well as bridging the gap between desired and available energy. With this national decentralized electrification program in partnership with the private sector in Nigeria, there is the need to investigate factors that influence the decision of MSMEs to adopt solar energy and its corresponding economic impacts on users.

An overview of existing literature on solar energy and its adoption shows that some studies have focused on the environmental impacts of solar energy adoption (e.g., Chaurey and Kandpal, 2009; Nugent and Sovacool, 2014). Another segment of the literature focuses only on barriers and determinants of adoption solar energy technologies (e.g., Borchers et al., 2014; Burke et al., 2019; Guta, 2018; Kelebe et al., 2017) without accounting for the economic impacts of adoption. Hence, there is limited scientific evidence (e.g., Chakrabarty and Islam, 2011; Pueyo and DeMartino, 2018) on how subscription to solar energy affects the performance of Micro, Small and Medium Enterprises (MSMEs), particularly in developing economies.

The objective of this study is to (i) investigate the drivers of MSMEs' adoption of solar technology, and (ii) examine the impacts of this adoption on market performance. To the best of our knowledge, this is one of the few studies that uses rigorous analytical approach and survey data to measure the economic impact of adoption of solar energy, particularly in sub-Saharan Africa.

In terms of contribution, insights from this study provide evidence to support formulation of sustainable energy policies to guide rollout of clean energy systems in Africa. Second, the findings of contribute to building knowledge towards attainment of sustainable development goal seven (i.e., SDG7-affordable and clean energy). Finally, this research contributes to the body of scientific evidence on how solar mini-grids affect MSMEs' performance in the face of an unreliable and erratic electricity supply context. The novelty of this study lies in accounting for heterogeneity in propensity score matching (PSM) of MSMEs' performance by performing exact matching on gender ownership of enterprises, type of product traded and location of the business enterprise. In this way, we are able to minimize the impact of any systematic biases in our estimation.

The rest of the paper is organized as follows. The next section reviews literature on adoption of solar energy. Followed by the methodology, results and discussion of results and lastly the conclusions including implication of the study findings.

2. Brief literature on adoption of solar PV systems and impacts

A number of factors drive adoption of solar PV alternatives for energy. Institutional factors such as general cost of electricity from the national grid and organizational processes and procedures of electricity distribution companies are major determinants of use of solar energy as an alternative means of power by Small and Medium Enterprises (Anaba and Olubusoye, 2021; Semelane et al., 2021). Furthermore, government policy support for solar also affects adoption of solar systems (Anaba and Olubusoye, 2021). Structural aspects such as reliability of the existing main grid can drive adoption of solar PV systems. Deutschmann et al. (2021) notes that firms and households are willing to pay more for reliable power supply in contexts where expenses on alternative power sources to the main grid are high.

Furthermore, business characteristics, the economic sector of operation, ownership status, stock and usage of equipment and appliances, presence of other solar technologies, and views about the use of renewable energy are also important determinants of the probability of adoption of solar panel systems (Hancevic and Sandoval, 2023). Perceived usefulness, perceived ease-of-use, compatibility, and perceived trust are also significant predictors of adoption of solar PV systems (Ahmed et al., 2022; Endrejat et al., 2020). The adoption of solar PV technologies can further be affected by the economic aspects such as cost, access to credit and income of the users. Alrashoud and Tokimatsu (2019) argue that the cost of solar panel systems strongly affects their acceptability by SMEs. The level of income affects adoption of solar PV systems (Abdul-Salam and Phimister, 2019; Blimpo et al., 2020; Guta, 2018) by dampening purchasing power (Karakaya and Sriwannawit, 2015). Also, income level weighed against the cost requirements of investment and installation (Lee and Callaway, 2018) affects the decision of MSMEs to subscribe to off-grid solar systems. Access to credit also affects adoption (Abdul-Salam and Phimister, 2019) reason being that, the high initial costs associated with purchasing and installing PV can be a crucial challenge, especially for most low-income households. Social factors such as membership to market associations (Grossman, 2020) and social interaction (peer) effects (Bollinger and Gillingham, 2012) also have an effect on adoption of solar PV systems.

In terms of impact, access to reliable solar energy boosts income-generating activities (Blimpo et al., 2020) through several channels. This can be through opening avenues for adopters to generate income and through increased working hours (Obeng and Evers, 2010). Solar PV adoption can positively impact on a firm's corporate image, economic sustainability and environmental sustainability and can also increase access to information and communication technology (Jacobson, 2007). Solar PV systems can additionally allow enterprises to generate more income, and spend less on energy while at the same time experiencing reduced exposure to health risks (Wassie and Adaramola, 2021). There is limited evidence (Codina et al., 2023) around how adoption of specific solar PV systems impact on users across Africa, particularly those studies that assess economic benefits associated with adoption of solar energy.

3. Materials and methods

3.1. Sample selection and data collection

Data used in this study was collected from 700 Micro, Small & Medium Enterprise (MSME) owners from July and August 2020. Three hundred (300) of the sample were subscribers of solar energy provided by Rensource energy limited and the remaining 400 were non-subscribers of solar energy. The selection of the respondents followed multiple stages. First, three states (i.e., Kano, Lagos, and Ondo) were purposely selected because Rensource was only operating in these states at the time of the survey. In the next stage, we selected five markets where MSME owners have subscribed to Rensource solar energy. The markets include Sabon Gari market located in Kano state, Iponri market located in Lagos state, and Isikan, Nepa 1 and Nepa 2 markets located in

Ondo state. After selecting the markets, we relied on a sample frame of subscribers in each of the markets to randomly select the respondents (See Table 1).

The variation in the sample sizes is based on proportional sampling based on the total number of subscribers in the various markets. For the non-subscribers, we used simple random sampling to select the respective samples from the same markets. A list of MSMEs that have not subscribed to solar energy was prepared. It is worth mentioning that the non-subscribers were selected from different sections of the same markets where MSMEs have not subscribed to solar energy.

We collected on MSMEs owners' socioeconomic, business, demographic characteristics of subscribers and non-subscribers in the selected markets. The social, economic, demographic, institutional and technological factors that influence the use of Rensource solar energy were also captured in the structured questionnaire. The structured questionnaire captured information on sales, income and expenditures on diesel, petrol and electricity bills. Lastly, the structured questionnaire solicited information on benefits associated with the use of solar energy. We employed enumerators (research assistants) from the Development Strategy Centre, Enugu, Nigeria, for the data collection. We used Development Strategy Centre because it is a well-established agency with rich experience in local and international research. The centre has a pool of research fellows across different states in Nigeria. We conducted face-to-face interviews. A team consisting of four enumerators and a supervisor was formed in each state for the data collection. The supervisor monitored the data collection process, and review responses to ensure data quality.

3.2. Conceptual and empirical framework

MSMEs decision to subscribe to solar energy follows the random utility theory (Lancaster, 1991). With the unreliable nature of the national grid system, rising cost of fuel for generators and the risk of fire, as well as the potential environmental and economic benefits of using solar energy, the study assumes that MSMEs subscribe to solar energy use based on the expected benefit. When faced with different sources of electricity (e.g., national grid electricity, generators and or solar energy), a rational MSME owner is assumed to choose solar energy US_r , if the utility obtained the MSME is greater than relying on the national grid or generators, US_n . Thus, $S_r > US_n$. In line with the random utility theory, this assumption translates into a binary decision and modelled as:

$$SL_{ir} = \beta_r X_i + \mu_{ir} \quad (1)$$

where SL_{ir} is a binary variable taking on the value of 1 if MSME owner is a subscriber of solar energy supplied by Rensource energy limited and 0 if MSME owner has not subscribed to any solar energy. X_i represents a vector of MSMEs' business, social, economic, location and market-level characteristics. Parameters to be computed are denoted by β_r and μ_{ir} is a random disturbance term. Equation (1) is estimated using a probit regression model. If the MSME owner subscribes to solar energy, the expected benefits are not observable to the evaluator. However, X_i is observed and captured in the data collection process. The net benefit obtained from subscription to solar energy is denoted as Y^* and specified as a function of X_i and subscription:

$$Y_i^* = \beta SL_i + \alpha X_i + \varepsilon_i; SL_i = 1 [Y_i^* > 0] \quad (2)$$

Subscription to the solar energy provided by Rensource is not randomized and as such it is possible for MSMEs that have subscribed to solar energy (treated group) and non-subscribers (control group) to vary in term of both their treatment status and their characteristics. This can affect both subscription decision and the outcome variables (e.g., monthly income, net income). We address this bias by using matching approaches (nearest neighbor matching, radius matching, and kernel-based matching) to ensure that non-subscribed MSMEs is matched with similar MSMEs that have subscribed to solar energy. In this way, we are able to compute the impact of subscription as the difference between a MSME subscriber and the matched comparison case. We also matched the MSMEs by the kind of product they sell and also by time-invariant characteristics, such as gender and state.

We calculated the average treatment effect on the treated (ATT) in propensity score matching (PSM). Estimating treatment effects based on the propensity score requires two assumptions. The first is the conditional-independence assumption, which requires that the common variables affecting treatment assignment and treatment-specific outcomes are observable. The second assumption is that ATT_{PSM} is only defined within the region of common support. Once the propensity is calculated, the impact of treatment for a given MSME i , represented as Ψ_i , can be computed using the ATT and the average treatment effect (ATE). The ATT is of greater interest than the ATE in this particular research context because it is more realistic to examine the effect of subscription on MSMEs who have subscribed to use Rensource solar energy. For a MSME subscriber with characteristics X_i , the expected outcome is specified as:

$$E(\Psi_{isr} / X, SL = 1) \quad (3)$$

The expected outcome for MSME non-subscriber is specified as:

$$E(\Psi_{isn} / X, SL = 0) \quad (4)$$

The change in outcome (i.e. monthly earnings and monthly net income) resulting from subscribing to solar energy is the difference between equation (3) and equation (4). This estimate is the ATT, specified as:

$$ATT_{PSM} = E(\Psi_{isr} / X, SL = 1) - E(\Psi_{isn} / X, SL = 0) \quad (5)$$

ATT measures the average effect of subscription on MSMEs that have subscribed to solar energy. By contrast, the ATE is the difference between the expected outcome with treatment (subscribers) and the expected outcome without treatment (non-subscribers). In general, the mean impact of subscription is obtained by averaging the impact across all MSMEs in the population. ATE specified as:

$$ATE_{PSM} = E(\Psi_{isr} / X, SL = 1) - E(\Psi_{isn} / X, SL = 0) \quad (6)$$

Ψ_{isr} is the monthly earnings of MSMEs that have subscribed to solar energy and Ψ_{isn} is the monthly earnings of MSMEs that did not subscribe. In other words, the ATE is the average impact, at the population level, of moving non-subscribers from the untreated group to the treated group (Austin, 2011). Then, in order to support the results of subscription on average income of MSMEs we conduct a set of robustness test. We precisely analyse the impact of subscription on the monthly earnings and net income of merchant's businesses. It is relevant to take account of the trade-off between the increase of the revenues and the costs of Rensource' services. Therefore, in addition to monthly earnings, we computed net monthly income for the MSMEs and used it an outcome variable.

Table 1
Respondents by state and market.

State	Market	Users (treated)	Non-Users (controlled)	Total
Kano	Sabon Gari	180	250	430
Lagos	Iponri	75	100	175
Ondo	Isikan	26	26	95
	Nepa 1	14	16	
	Nepa 2	5	7	
Total		300	400	700

4. Results and discussion

4.1. Descriptive results

The results in Table 2 highlight that the average business owner is 44 years. The monthly electricity bill of solar energy users who relied on the national grid prior to subscription ranged from ₦ 200 to ₦ 36,000 with an average bill of ₦ 3,152, whereas non-users on average paid ₦ 3139 per month for electricity. In terms of fuel cost, the results indicate that solar energy users on average spent ₦ 10,888 on fuel for generators per month prior to subscription to the solar energy whereas non-users on average spent ₦ 8022 on fuel for generators per month, with a significant mean difference of ₦ 2866. After subscribing to solar energy, the results indicate that the average monthly bill was ₦ 5144 with minimum and maximum bills of ₦ 300 and ₦ 20,000, respectively. In terms of fuel cost, solar energy users who were only using generators prior to subscription on average saved ₦ 5744 on fuel cost.

Comparing the average cost of fuel per month for non-users to the solar energy users' average bill per month, we find that the average fuel cost is ₦ 2878 higher than the average cost of those using solar energy. Nonetheless, the average monthly cost of solar system is higher than the average cost for electricity from the national grid. This is expected given the frequency of electricity outages that merchants experience. In terms of fuel cost, users of the solar energy on average save ₦ 5744. However, it is worth mentioning that some merchants (25% of subscribers) resorted to using both the national grid and generators because of the unreliability of the national grid electricity.

They automatically switched to generators when the national grid went off, hence incurring costs of fuel for the generators, the generator itself and national grid. Using a before and after comparison, the results suggest the average bill of ₦ 5144 per month paid for Rensource solar energy is lower than the combined average cost of electricity and fuel for generators per month (i.e. ₦ 14,040). Thus, MSMEs using solar energy on average save about ₦ 8896 per month, and this represents a 36.64% reduction in electricity expenditure.

4.2. Drivers of MSMEs' choice of electricity supplier

The MSMEs' ranking of different characteristics of electricity and electricity providers that influence their choice of electricity supplier is presented in Table 3. It is worth mentioning that the question asked was in relation to electricity suppliers in general and not specifically about Rensource solar energy.

The results indicated that the reliability of electricity supply is

Table 3

Determinants of choice of electricity suppliers.

Characteristic	Users (N = 300)		Non-Users (N = 400)	
	Mean Rank	Rank	Mean Rank	Rank
Reliability	10.82	1st	8.98	1st
Affordability (user fees)	9.51	2nd	8.61	2nd
Ease of access	9.04	3rd	7.54	8th
Flexibility of use	9.03	4th	8.48	3rd
Risk of fire outbreak	8.83	5th	7.75	6th
Installation cost	8.65	6th	8.14	4th
Frequency of maintenance	8.38	7th	7.58	7th
User-friendliness	7.90	8th	7.30	9th
Noise generation	7.85	9th	6.92	11th
Flexible payment plan	7.81	10th	7.97	5th
Air pollution	7.18	11th	6.90	12th
Health problems	6.88	12th	7.18	10th
Environmental problems	6.61	13th	–	–
Prone to theft	5.87	14th	6.05	13th
No alternative supplier	5.65	15th	5.59	14th
Kendalls W	0.125		0.079	
Chi-Square	523.75***		406.40***	
Degree of freedom	14		13	

***p < 0.01, **p < 0.05, *p < 0.1.

ranked as the most important characteristic that influences the choice of both users and non-users for a given source of electricity. This ranking can be attributed to user fatigue with frequent power load shedding that has plagued the energy sector. Indeed, frequent outages are the main factors of income loss and economic and social costs in the economic sectors (Chakravorty et al., 2014). The second most important attribute is affordability of the electricity as ranked by both categories of merchants. The 3rd and 4th most important attributes for solar energy users are ease of access and flexibility of use whereas flexibility of use and installation cost are considered as the 3rd and 4th most important attributes by non-users. The 5th, 6th and 7th most important attributes that drives their choice of electricity supplier are risk of fire outbreak, installation cost and frequency of maintenance. In contrast, non-users rank flexible payment plan, risk of fire outbreak and frequency of maintenance as the 5th, 6th and 7th most important attributes that lead their choice of electricity supplier. Then, theft and no alternative source are ranked as the least important factors that determine users and non-users' choice of electricity supplier. The significant chi-square for the Kendall's ranking of the attributes implies that the MSMEs are in agreement with the ranking of the attributes drivers.

Table 2

Merchants and enterprise characteristics for users and non-users of solar energy.

Variable	Description	Users (N = 300)				Non-Users (N = 400)			
		Min	Max	Mean	Std. Dev	Min	Max	Mean	Std. Dev
Household size	Number of people in the household	1	15	5 ^b	3	1	17	5 ^b	3
Age	Age of business owner in years	17	82	44 ^a	11	18	72	42 ^a	11
Household income	Proportion of household income from trading (%)	10	100	77 ^a	28	8	100	79 ^a	27
Monthly income	Average monthly income from trading (₦) ^c	5000	800000	145926 ^a	146018	3000	800000	116436 ^a	113128
Business age	Age of business in years	1	40	13 ^b	9	1	50	12 ^b	8
Employees	Number of employees	1	15	2 ^b	2	1	16	3 ^b	2
Branches	Number of shop branches	1	7	1 ^b	1	1	6	1 ^b	1
Rensource bill	Rensource solar energy bill [price per month] (₦)	300	20000	5144	3780	–	–	–	–
Electricity bill ^d	Electricity bill [price per month] (₦) for national grid	200	36000	3152 ^b	3705	300	30000	3139 ^b	2857
Fuel cost ^e	Amount spent on fuel (petrol/diesel) for generators per month (₦)	490	80000	10888 ^a	8501	500	100000	8022 ^a	8315

Note: **Rensource solar users:** generator only users = 55 (18%), National grid only users = 22 (7%), Both = 74 (25%), No electricity (neither generator nor national grid) = 149 (50%). **Non-Users:** generator only users = 167 (42%), National grid only users = 37 (9%), Both = 85 (21%), No electricity (neither generator nor national grid) = 111 (28%).

¥Values for Rensource subscribers are fuel cost for generators prior to subscription.

^a Means of variables with "a" indicate that the means are significantly different between users and non-users using t-test for difference in means.

^b Means of variables with "b" indicate that the means are not significantly different between users and non-users using t-test for difference in means.

^c Exchange rate US\$ 1: ₦ 380 (Source: Central Bank of Nigeria).

^d Values for Rensource subscribers are electricity bill in price per month prior to subscription.

4.3. Empirical results

4.3.1. Factors driving MSMEs' decision to adopt solar energy

Table 4 presents probit estimates of factors driving subscription to solar energy. The results show that the proportion of household income from trading has negative and significant influence on subscription to solar energy. This is mainly because the livelihood of those households is

Table 4
Probit estimates of factors influencing subscription to Rensource solar energy.

Variable	Variable definition	Coefficient	R. std error	t-value
<i>Merchant characteristics</i>				
Age	Age of business owner in years	0.007	0.005	1.41
Gender	1 if business owner is male, 0 otherwise	0.010	0.150	0.07
Education	Years of formal education	0.004	0.011	0.37
Household size	Number of people in the household	−0.009	0.018	−0.50
Household income	Proportion of household income from trading (%)	−0.005*	0.002	−2.06
Non-Membership	1 if business owner is not member of merchant group, 0 otherwise	−0.356*	0.151	−2.36
Sabon Gari (Kano)	Name of market	−0.062	0.383	−0.16
Iponri (Lagos)	Name of market	0.136	0.384	0.35
Isikan (Ondo)	Name of market	0.159	0.407	0.39
NEPA 1 (Ondo)	Name of market	0.049	0.444	0.11
<i>Business characteristics</i>				
Employees	Number of employees	−0.024	0.030	−0.78
Owned shop	1 if shop is individual or family owned, 0 otherwise	0.211	0.144	1.47
Fire outbreak	1 if fire outbreak occurred in the past five years, 0 otherwise	0.586***	0.130	4.50
Credit access	1 if merchant has access to credit for the business, 0 otherwise	0.326*	0.139	2.34
Branches	Number of shop branches	0.204*	0.099	2.05
<i>Product traded</i>				
Food products	1 if the merchant sells food products, 0 otherwise	−0.247	0.196	−1.26
Clothing, shoes, bags & textiles	1 if the merchant sells clothing, shoes, bags and textiles, 0 otherwise	0.455**	0.138	3.29
Electronics	1 if the merchant sells electronics, 0 otherwise	0.166	0.184	0.91
Cosmetics	1 if the merchant sells cosmetics and operates a beauty salon, 0 otherwise	0.081	0.218	0.37
Homeware & kitchenware	1 if the merchant sells home and kitchen products, 0 otherwise	0.096	0.367	0.26
<i>Energy characteristics</i>				
Reliability	1 if reliability of energy source is ranked as very important, 0 otherwise	1.189***	0.145	8.18
Fuel Cost	Amount spent on fuel (petrol/diesel) for generators per month (₦)	−0.000	0.000	−1.00
Constant				−2.139***
Pseudo R ²				0.25
Wald chi ² (19)				117.71
Number of observations				700

*, **, *** denote 10%, 5% and 1% significant levels respectively.

highly affected by the state of the business. Mostly as the initial capital cost in solar energy and its batteries is higher compared to diesel generators (Babajide and Brito, 2021). Thus, the investment in solar energy constitutes a barrier to solar PV adoption in Nigeria. Indeed, the sampled merchants are mainly MSMEs, a category of SMEs in Nigeria that Etuk et al. (2014) describe as those that operate at the subsistence level mainly to provide employment and income to their owners. Not being a member of a merchant group was found to be negative and significant. This implies that business owners who do not join merchant groups or associations are less likely to subscribe to the solar energy, relative to those who are members of merchant groups or associations. Even if Rensource works with market associations through the Rural Electrification Agency, about 78% of our surveyed merchants are not members of market groups. Which makes it more difficult for actors like Rensource to reach merchants not affiliated to a group.

Regarding business characteristics, we found the number of shop branches has a positive and significant influence on subscription to Rensource solar energy at 1%, signifying that MSMEs with more branches are more likely to subscribe to the solar energy. This can rise through the channel of income; that merchants who own more than one shop also have higher incomes and are able to overcome the cost hurdle of solar adoption. It can also be through a cost management strategy, that merchants with more than one shop would incur much higher costs of energy if they are to use generators and diesel across a number of shops. Furthermore, it can also be the case that a bigger proportion of their household income comes from the shops and therefore investing in solar is an investment into a venture that directly supports much of their livelihoods, especially in light of constant power outages.

The fire outbreak variable is positive and significant at 1% level, indicating that MSMEs that have experienced electricity-related fire outbreaks over the past five years are more likely to subscribe to solar energy, compared with those that have not experienced an electricity-related fire outbreak before. The frequent power load shedding has led to reliance on generators and the subsequent problem of frequent fire outbreaks poses a challenge to markets and as such, merchants in markets are more likely to adopt a more reliable and safer energy source (Adenle, 2020). The significant and positive coefficient of access to credit drives merchants to subscribe to Rensource solar energy. Qureshi et al. (2017) notes credit constraint as the most significant barrier in the diffusion of solar PV system.

In terms of type of product traded, the results reveal that MSMEs who sell clothes (shoes and textiles) products are more likely to subscribe to Rensource solar energy, compared with those selling products in the reference category (i.e. manufacturing, stationery, sewing and agro-chemicals). Manufacturing, stationery and sewing often require higher power to operate which may be limiting for users if solar is unable to sufficiently power the machinery they use. This can be more so during periods when the sun's intensity is not as great. Clothing shops need lighting for visibility of their products so that buyers can have an appreciation of the products and buy. Food products for instance usually require preservation and power is a key input at all stages of the food value chain. For example, cold storage such as provided by ice makers particularly can allow communities to store fish (food) for longer periods of time (Kyriakarakos et al., 2020). Although with a positive and non-significant parameter, merchants operating beauty salons and selling cosmetic products are more likely to subscribe to Rensource solar energy.

Reliability of the energy supply is highly significant and positive and this implies that MSMEs who rank the reliability of a given energy supply as a very important driver in their decision to subscribe to energy are more likely to adopt solar energy. This is in line with Deutschmann et al. (2021) who highlighted that firms and households are willing to pay more for reliable power supply in contexts where expenses on alternative power sources to the main grid are high. This is supported by Lee and Callaway (2018) who propose that decentralized solar solution is competing with grid systems in terms of reliability.

4.3.2. Treatment estimates from the PSM

Table 5 indicates the average treatment effect on the treated (ATT) and average treatment effect (ATE) of solar energy adoption on the monthly earnings of MSMEs. We present *t*-test estimates (after matching) in Appendix I to confirm that there are no significant differences in means for the variables in the selection model. The ATT results show that the adoption of solar energy is significantly associated with an increase in monthly earnings across the different matching methods.

Specifically, adoption of solar energy is associated with an increase in MSMEs' monthly earnings by 27% (₦ 31,259) from the nearest neighbor matching (NNM). The common support region is [0.04; 0.86]. For the radius and kernel matching, the adoption of the solar energy is associated with increase in MSMEs' monthly earnings by 23% (₦ 27,633) and 24% (₦ 28,265), respectively.

Comparing our findings with other studies, the range of percentage changes in monthly earnings from 23% to 27% for the ATT and 25%–37% for the ATE is in line with the findings of Sánchez et al. (2015) who unveiled that the use of renewable technologies in a Brazilian program increase revenues of users by 35.6%. The ATE estimates further highlight that adoption of solar energy by the MSMEs is significantly associated with higher monthly earnings. These findings are supported by Babajide and Brito (2020) who pointed out that adoption of solar energy has the potential to generate additional income and minimize fuel expenditure.

Pueyo and DeMartino (2018) found that adoption of solar mini-grids by rural microenterprises in Kenya did not improve business performance after two years. This finding is contrary to what we find in Nigeria. This difference may be due to the short duration for economic impacts to be realized. Another reason may be the differences in location and type of businesses which was not accounted for in the study of Pueyo and DeMartino (2018). For instance, Pueyo and DeMartino (2018) acknowledged that the business performance of enterprises such as barbering saloons, video halls and mobile phone dealers improved after using solar mini-grids. In our study, we accounted for locational and product differences by performing exact matching on location of the business, kind of product sold and markets (see Table 7).

In Table 6, we further present the results of the ATT of solar energy usage on the monthly net income of MSMEs. Adoption of the solar energy is associated with increase in MSMEs' monthly net income by 27% (₦ 26,692) from the nearest neighbor matching. From the kernel matching, the effect of solar energy adoption is an increase in monthly net income of MSMEs by 24% (₦ 22,976). The radius matching indicates similar results. The increase of net revenues is mainly important for merchants who installed solar system from Rensource and paid the subscription fee. The recorded increase in income is supported by recent macroeconomic analysis of Ben Jebli et al. (2020). The authors find that the use of renewable energies increases the value-addition and this translates into increase in income.

In Table 7, we present the matched results to account for heterogeneity in relation to gender, state, product type and market. The results

reveal that within the same gender category, MSMEs that adopt solar energy obtain significantly higher monthly earnings (₦ 30,475) than non-adopters. Within the same state, MSMEs adopting solar energy obtain significantly higher monthly earnings (₦ 31,829) than non-adopters.

Furthermore, within the same product category, MSMEs adopting solar energy obtain significantly higher monthly earnings (₦ 28,961) than non-adopters. The product specific matching results is supported by Pueyo and DeMartino (2018). The authors assessed the impact of solar mini-grid on rural enterprises in Kenya and found that the usage of the solar mini-grid did not improve sales, monthly expenses and profit. However, the authors' found heterogeneity in the findings explained by the type of product or business for which the solar energy is used for. It was revealed that the business performance of businesses like barbering saloons, video halls and mobile phone charging increased with solar mini-grid subscription. This emphasizes the relevance of product specific matching used in this present study. This is an expected result as the availability (and affordability) of electricity and clean fuels is strongly related to income (Ritchie et al., 2019). Accordingly, Roche and Blanchard (2018) further indicated that solar energy can be designed for income-generating activities. From the within market matching, MSMEs adopting solar energy obtain higher earnings per month than non-adopters. Our findings concurs with the findings of Kumar (2014) on the analysis of income convergence and electricity consumption in India for the periods 1990–1991 and 2011–2012. The author reveals that (i) the disparities of grid connection among Indian states decreased, and (ii) there is a beta convergence between income and energy consumption among the states. Which means that poorer states quickly caught up their delay of energy network plants. Moreover, amongst the states, Lagos and Kano have the highest average monthly salary at ₦ 524,933 (\$1214) and ₦ 150,000 (\$347) respectively. As a robustness check, we estimate OLS to verify the effect of solar energy subscription on the monthly earnings of merchants. The OLS results (see Appendix II) confirms that the decision to subscribe to solar energy increases the monthly earnings, even if we do not control for counterfactuals.

5. Conclusion and policy implications

The energy sector in Africa is considerably underdeveloped in energy access, installed capacity, and overall consumption. Transitioning to clean energy is central to economic and social development in Africa. In this present study, we investigate the drivers of MSMEs' decision to subscribe to solar energy and the subsequent impacts on their monthly earning and net income. Based on the findings, we conclude that MSMEs' decision to adopt solar energy is largely dependent on the reliability, affordability (i.e., weekly or monthly bills), and flexibility of user fee payment, easy accessibility, flexible use, lower fire outbreak, and health risks, respectively. From the viewpoint of impacts, MSMEs that were beforehand using the national grid and/or standby fuelled generators, as well as those that had no alternative electricity source,

Table 5
ATT and ATE of solar energy adoption on the monthly earnings of MSMEs.

Average treatment effect on the treated (ATT)						
Outcome	Nearest neighbor matching ^a	% change	Kernel matching ^b	% change	Radius matching ^c	% change
Monthly earnings	31259** (12525.918)	27%	28265** (11392.192)	24%	27633** (11139.389)	23%
Average treatment effect (ATE)						
Outcome	Nearest neighbor matching ^d	% change	Kernel matching ^e	% change	Radius matching ^f	% change
Monthly earnings	40946*** (11194.62)	36%	29841** (9938.507)	25%	42646*** (10848.561)	37%

Notes: These results are based on propensity score matching. Standard errors are in parentheses; *p-value <0.1, ** p-value <0.05, *** p-value <0.001.

^a Nearest neighbor matching: treated (N = 300), control (N = 400).

^b Kernel matching: treated (N = 300), control (N = 400).

^c Radius matching: treated (N = 300), control (N = 400).

^d Nearest neighbor matching: treated (N = 300), control (N = 400).

^e Kernel matching: treated (N = 300), control (N = 400).

^f Radius matching: treated (N = 300), control (N = 400).

Table 6

Impact of solar energy subscription on the monthly net income of MSMEs.

Monthly net income ^a	Nearest neighbor matching ^b	% change	Kernel matching ^c	% change	Radius matching ^d	% change
ATT	26692** (11714.876)	23%	22976** (11259.307)	20%	22323** (11093.867)	19%
ATE	27502*** (10149.37)	24%	24013** (9711.639)	20%	26080** (11117.131)	21%

Notes: These results are based on propensity score matching. Standard errors are in parentheses; *p-value <0.1, ** p-value <0.05, *** p-value <0.001.

^a Exchange rate 1US\$: 380N (Source: Central Bank of Nigeria).^b Nearest neighbor matching: treated (N = 300), control (N = 400).^c Kernel matching: treated (N = 300), control (N = 400).^d Radius matching: treated (N = 300), control (N = 400).**Table 7**

Exact matching estimates on gender, product type and market (ATE).

Exact Matching on: ATE		
Monthly earnings	Gender	30475** (9927.024)
	State	31829*** (9968.477)
Product kind	Product kind	28961** (9876.024)
	Markets	30690** (9997.266)
Markets	Sabon Gari market (Kano State)	
	Iponri market (Lagos State)	31738*** (9885.889)
	Isikan market (Ondo State)	30493** (9961.788)
	NEPA 1 market (Ondo State)	30077** (9940.798)
	NEPA 2 market (Ondo State)	28293** (9732.333)

Notes: These results are based on propensity score matching. Standard errors are in parentheses; *p-value <0.1, ** p-value <0.05, *** p-value <0.001.

this study points out that the subscription to solar energy minimizes energy cost considerably. We conclude that MSMEs that have subscribed to use solar energy obtain significantly higher monthly earnings and net monthly income than non-subscribers of solar energy. Generally, we point out that powering MSMEs through solar energy decreases expenditure on electricity. We further conclude that even within the same gender, product type, location and market, adopting of solar energy yields higher income than non-subscription. In addition, we conclude that MSMEs' decision to adopt solar energy is influenced by the trade-offs between the possible production, economic and environmental effects as well as business owners, firm, and product characteristics.

Regarding policy implications, we point out that understanding the underlying factors and features of solar energy that drive adoption is crucial for governments, policymakers, development organizations and developers of different solar energy products, as it can inform the design of policy interventions and programs intended to promote the use of solar energy, particularly in Africa, where energy crisis is very eminent. Secondly, the findings provide evidence that can enhance or shape investment in solar energy by MSMEs. We point out that future strategies and interventions aimed at enhancing uptake of solar energy should pay particular attention to the targeted users' personal and business characteristics, especially, the type of business or products sold, as these have significant influence on decision making regarding energy choice. To the extent that governments, non-governmental organizations and policymakers are committed to providing reliable, cheaper and cleaner energy systems, they must raise broader awareness of the potential benefits of adopting solar energy.

The study's findings and limitations propose some suggestions for future research. First, the PSM employed in this study only accounts for observed covariates. Nevertheless, we are certain that large sample size for the control group, matching on different heterogeneous variables and the use of different matching methods have reduced the impact of

any systematic biases. Future work might consider matching on both observables and unobservable covariates using empirical approaches that accounts for both observables and non-observable variables. Future research should also examine the impact of adoption of solar energy on health and environmental outcome variables.

CRedit authorship contribution statement

Enoch Owusu-Sekyere: Conceptualization, Data curation, Formal analysis, Funding acquisition, Methodology, Writing – original draft, Writing – review & editing, Investigation, Project administration, Software. **Fatoumata Nankoto Cissé:** Conceptualization, Formal analysis, Investigation, Validation, Writing – original draft, Writing – review & editing. **Esther Leah Achandi:** Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Validation, Writing – original draft, Writing – review & editing.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Enoch Owusu-Sekyere reports financial support was provided by European Investment Bank. Enoch Owusu-Sekyere reports financial support was provided by Global Development Network. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix I. Differences in means after matching (Monthly earnings)

Variable	Treated	Control	%bias	t	p > t
Age	43.967	42.967	9.0	1.12	0.264
Gender	0.642	0.618	5.1	0.61	0.540
Education	10.87	10.995	-2.7	-0.33	0.741
Household size	5.482	5.159	10.1	1.26	0.209
Household income	76.587	76.324	1.0	0.11	0.911
Membership	0.191	0.207	-3.9	-0.49	0.627
Market	1.632	1.640	-0.8	-0.10	0.924
Employees	2.401	2.384	0.9	0.10	0.917
Owned shop	0.823	0.826	-0.9	-0.11	0.915
Fire outbreak	0.301	0.300	0.2	0.02	0.982
Credit access	0.261	0.258	0.6	0.07	0.944
Food products	0.090	0.084	1.9	0.25	0.800
Clothing, Shoes, bags & textiles	0.492	0.482	1.9	0.22	0.822
Electronics	0.117	0.125	-2.3	-0.28	0.778
Cosmetics	0.080	0.080	0.0	0.00	1.000
Homeware & kitchenware	0.027	0.033	-3.7	-0.42	0.674
Reliability	0.933	0.936	-0.9	-0.17	0.869
Fuel cost	4697.3	4995.3	-3.9	-0.52	0.604
Ps-R-square	0.004				
Chi-square p > Chi-square	3.10				
Mean Bias	1.000				
Median Bias	2.8				
B	1.9				
R	14.4				
%Var	0.97				
	14				

Appendix II. Effect of solar energy subscription on the monthly earnings of merchants (OLS)

	(1)
	Monthly_earning
Subscription	28208.4*** (2.68)
Age	-206.6 (-0.45)
Gender	95.22 (0.01)
Education	1651.6 (1.49)
Household size	2428.9 (1.40)
Household income	422.6** (2.07)
Non-Membership	-27519.8** (-2.03)
Market	29048.0*** (3.94)
Employees	12177.7*** (3.78)
Owned shop	23288.9 (1.83)
Fire outbreak	-4816.0 (-0.39)
Credit access	2679.2 (0.18)
Food products	6331.5 (0.30)
Clothing, shoes, bags & textiles	26231.6** (2.03)
Electronics	4646.3 (0.32)
Cosmetics	7370.2 (0.44)
Homeware & kitchenware	-110981.8*** (-5.69)
Reliability	2483.4 (0.23)
Fuel cost	1.667 (1.79)*
_cons	-31472.0 (-0.80)
Adjusted R ²	0.74

(continued on next page)

(continued)

	(1)
	Monthly_earning
F	97.09
N	700

Notes: These results are based on propensity score matching.

T-values are in brackets.

Significance level: * indicates significant at 10%, ** indicates significant at 5%, *** indicates significant at 1%.

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