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RESEARCH ARTICLE

Reducing carbon footprint by replacing generators with solar PV systems: a contingent valuation study in Lagos, Nigeria

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Abstract

Nigeria is endowed with abundant sunshine year-round; thus, solar PV would solve the environmental problems associated with petrol-powered generators. However, it is unclear whether households are willing to transition. Thus, we analyze households' willingness to pay (WTP) for solar PV under four scenarios: (i) WTP when a solar PV is complemented with a generator, (ii) WTP when a solar PV completely displaces a generator, (iii) WTP when a solar PV is complemented with a generator, plus a subsidy, and (iv) WTP when a solar PV completely displaces a generator, given a subsidy. We find that WTP for solar PV is higher when it can displace generators completely. Subsidy plus monthly rather than upfront payment would scale up the adoption of solar PV by about 6 per cent. Furthermore, the cost benefit analysis results show that solar PV investment is profitable. Thus, there is a need to implement policies aimed at scaling up the energy transition.

Keywords: CBA; climate change; generators; installment; subsidy; solar PV; willingness to pay

JEL classification: Q1; Q5; Q51; Q54

1. Introduction

There are reports that the world is at a climate tipping point (IPCC, 2021). As a result, more protests, strikes and demonstrations against climate change have taken place recently than ever before (Diklich, 2017). These protests, strikes and demonstrations are a reaction to rapid atmospheric carbon dioxide growth which reached 145 per cent of the pre-industrial level in 2017, primarily linked to the massive burning of fossil fuels (WMO, 2019). Therefore, there is global warming, drought, and rising sea levels. Africa and parts of Asia are the worst hit continents. It is projected that developing countries, especially in sub-Saharan Africa, will share 90 per cent of global fossil fuel consumption by 2025. The region is caught up in inadequate energy access and environmental degradation from petrol-powered generators (IPCC, 2018, 2021).

The UN has called for urgent and global action to combat climate change using clean energy, as encapsulated in its goals 7 and 13. Also, many countries have indicated their commitment to ensuring that the global mean temperature increase is limited at 1.5^{o}C above pre-industrial levels, and achieving net-zero carbon emissions by 2050 (International Institute for Applied Systems Analysis, 2016; IPCC, 2018; IEA, 2020a, 2020c). However, this goal can only be met if 70 to 85 per cent of the worldwide electricity supply comes from renewable sources by 2050 (Climate Central, 2018). Although the global share of electricity production from fossil fuels is declining, it still contributes to over 65 per cent of the worldwide total and about 25 per cent of the worldwide greenhouse gas (GHG) emissions (WEC, 2016; IEA, 2020b). Furthermore, it is predicted that global GHGs will increase by 50 per cent by 2050, driven mainly by a 70 per cent growth in emissions from an 80 per cent rise in energy demand (OECD, 2011). This casts doubt on meeting the Paris Agreement targets as the world continues to experience unprecedented warm temperatures.

Sub-Saharan Africa's fossil-based generation has been snowballing and stands at over 64 per cent. The IEA (2019) reports that although Africa is the most endowed with solar resources, installed solar PV capacity on the continent is about 5 gigawatts (GW), which is less than 1 per cent of the worldwide total. In Nigeria, total electricity coming from fossil fuels has risen steadily since the discovery of oil in 1979 and now exceeds 81 per cent (see online appendix A1 and figure A1). In addition, the country experiences the highest power outages globally – an average of about six hours per day – voltage fluctuations, distorted transmission and distribution, and an ambiguous billing system. As a result, over 44 per cent of urban households and 86 per cent of businesses rely on generators for electricity (GIZ, 2015; NBS, 2016).

Globally, Nigeria is the largest market for backup generators. It accounts for 16 per cent of worldwide consumption of energy from generators. Backup generators produce about 13,000 MW. This is more than the 12,522 MW of total installed grid capacity. Thus, the country spends more on generators than on grid electricity (IFC, 2019; USAID, 2020). Nigeria spends an average of \$112 million on imported generators annually. At the same time, businesses and households spend \$21.8 billion on petrol (GIZ, 2015). It is estimated that companies and households spend about \$50 billion yearly on inefficient self-generation at \$0.60/kWh running cost. In comparison, the Levelized cost of a home solar system is \$0.20/kWh. Therefore, transitioning to solar PV would save around \$4.4 billion for families and businesses annually (REA, 2017; Lazard, 2018; IFC, 2019).

Aside from the monetary costs, the average yearly concentration level of particulate matter ($PM_{2.5}$) in Lagos alone is about 68 μg/m^3, which is comparable to Beijing's. This figure is over and above the 10 μ g/m^3 level recommended by the WHO. The sulfur content is 3000 parts per million (ppm) in diesel and 1,000 ppm in gasoline. Overall, on average, it is responsible for 23.8 deaths per 1000 people, higher than Africa's 18.4 deaths per 1000 people (World Bank, 2020). A significant proportion of this pollution comes from the transport sector and generators.

The Nigerian government aims to significantly reduce use of generators, from 74 to 18 per cent by 2030. Furthermore, it targets 12 per cent share of total electricity from off-grid systems. Thus, off-grid systems would produce 8,000 MW of electricity by 2030 (NACOP, 2016b). Furthermore, since Nigeria has abundant sunshine year-round, off-grid solar PV would produce the cheapest, cleanest, and most sustainable electricity in the long-run (ODI, 2016; IEA, 2019).

An off-grid or stand-alone solar PV uses batteries to store power, which can be used during off-peak. It is adaptable to specific needs and applications. Depending on the PV system's capacity, the panel(s) can be mounted or placed on the rooftop, ground, wall, or pole. This feature is appealing because it allows homeowners and

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renters to adopt a suitable type. Besides, it is cheaper than generators and varies from small, medium, to large scale (Sovacool, 2014; Madziga *et al.*, 2018). For example, an 80 watt portable PV system can power bulbs, TV, fans, and cell phones at the same time (Business Day, 2019).

Despite these fantastic solar PV features, the upfront costs continue to hinder its wide-scale adoption in Nigeria (Nduka, 2021). For instance, Babajide and Brito (2021) provide the costs of solar PV systems with 0.92 kW solar capacity ($3, 220) and 2 kW solar capacity ($6, 043) in Nigeria. In comparison, the cost of a 2KVA generator is around $3, 204 – meaning that the solar PV's cost is about twice the generator's cost. Other factors are lack of information and myopia/shortsightedness, where agents undervalue clean energy (Gerarden *et al.*, 2017).

As solar PV's cost continues to decline and the number of renewable energy companies grows in Africa, it is pertinent to investigate households' preferences and willingness to pay for solar PV. Although the government has declared its support for a market-driven off-grid solar power transition, little has been done regarding financial policy incentives (ODI, 2016).

An effective way to help households would be through subsidies. Another way is an installment payment option, similar to how households pay their electricity bills. These are responsible for creating over 300 active energy communities across the UK, generating up to 193.9 MW of electricity (Community Energy England, 2020). Thus, this study investigates the most effective financing options for urban households to achieve affordable, clean and sustainable energy. Through this study, policymakers could determine whether or not to provide households with energy subsidies and other incentives. Furthermore, this would give businesses insight into households' energy preferences and influence their investment decisions.

We use the discrete choice method recommended by the NOAA blue-ribbon panel (Arrow *et al.*, 1993) to elicit willingness to pay (WTP) for a home solar system (HSS). We are the first to incorporate subsidy and installment payment options into the valuation directly. Evidence shows that HSS subsidy is an incentive for energy transition in many countries as it reduces the upfront costs of the technology (Yang *et al.*, 2018; Vaidy, 2019). We further analyze the cost-benefit of HSS, thus completing the welfare analysis circle.

From here, the paper proceeds as follows: We discuss the environmental and sustainability policies in section 2 and provide the methodology in section 3. Next, the results and discussion are given in section 4, including the cost-benefit analysis of HSS. Finally, the paper ends with section 5, which provides some conclusions and policy implications of the findings.

2. Environmental and sustainability policies

In furthering Nigeria's aim to combat environmental degradation, the government made the Nigerian Bio-fuel Policy and Incentives (NBPI) in 2007. The government plans to integrate bio-fuel into the energy mix primarily for automotive and power generation. It would be produced from municipal solid waste, crops, trees, industrial wastes, cellulose-based, and materials. It is anticipated that the program would be fully implemented in 10 years. It is meant to be private sector-driven. The government would provide the enabling environment and tax incentives for 10 years. However, there would be a pollution tax on oil and gas upstream activities. This policy aims to reduce carbon dioxide (CO_2) emissions significantly in 2020 (FRN, 2007).

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Regarding the United Nations' goal of combating climate change and the Paris agreement's target of reducing the global mean temperature, Nigeria is committed to contributing its quota. It demonstrates this in the Nigeria Climate Change Policy Response and Strategy (NCCP-RS), 2012, and the Nigeria Intended Nationally Determined Contribution (N-INDC), 2015. These policies are targeted at adapting and mitigating climate change by building a resilient economy that would ensure food security, electricity access, and economic development by 2030. By these policies, the country is committed to achieving sustainable economic growth through more energy-efficient ways. Aggressive research and development, science and technology are significant elements of the policies. The comprehensive national climate change policy identifies the private sector and massive awareness campaigns as crucial to combating climate change. In response to the COP21 objectives, the Nigeria INDC envisages a 20 per cent unconditional contribution below the business as usual (BAU) (FRN, 2015b; FME, 2020).

However, conditional on international cooperation, financial support, investment, technology, and capacity development, the country would contribute 45 per cent below the BAU. It is estimated that adhering to the unconditional scenario, the BAU emissions per capita would be 3.4 tonnes CO_2e by 2030. Under the conditional setup, the BAU emissions per capita would be about 2 tonnes CO_2e in the same year. The country is determined to end gas flaring, develop 13 GW off-grid PV, increase energy efficiency to 30 per cent, displace transport by car with the bus, improve power supply, and transition to climate-smart agriculture (FRN, 2013).

Concerning energy, the policy proposes a decentralized transmission infrastructure that can withstand climate change. Renewable energy (RE) stands out as a veritable candidate in the system. The government plans to build more power stations and ensure that companies adopt green technology in line with global best practices. It promotes the displacement of liquid fuels with natural gas, including building power plants at gas flaring sites that utilize the gas rather than losing it, and end charcoal use.

The Nigerian government has identified dirty power-generating technology as the primary cause of CO_2 emissions; thus it plans to reduce CO_2 emissions by 31 million tonnes using solar power (FRN, 2015a). Currently, Nigeria has less than 30 MW of installed off-grid solar PV capacity (Business Day, 2019). However, the government plans to achieve 5,545 MW of off-grid solar PV capacity by 2030 (NACOP, 2016a).

3. Methodology and data

3.1 Overview

We use the dichotomous choice contingent valuation (CV) method because the primary objective is to estimate the mean WTP. In addition, this method is simple and does not require a high level of cognitive ability. It is also suitable for a wide variety of populations. However, it may be affected by affirmative bias. We tried to circumvent this by clarifying to respondents that they would be responsible for the payment.[1] In addition, we reminded respondents of the opportunity cost of signing up for the program. Finally, we encouraged respondents to imagine it was a real choice and to be as honest as possible. It is, however, essential to note that all stated preference studies are subject to a certain degree of hypothetical bias.

[1] Power generation, transmission, and distribution were done solely by the government until 2013, when the sector was privatized (Nduka, 2021). Recently, the government has indicated that solar power investment will be private sector driven (NACOP, 2016a; ODI, 2016).

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During the focus groups and pilot study, we asked participants to state the maximum amount of money they would pay each month to acquire a solar PV. Next, we analyzed the data and generated five bids for each scenario (in all, twenty bids were used). The bids ranged from NGN400 ($1.10) to NGN3,000 ($8.29).[2] Each of the bids was then randomly assigned to different subsamples. This method has been applied in other studies (Borzykowski *et al.*, 2018; Nduka, 2021; Kim *et al.*, 2021).

3.2 Survey design and data collection

The questionnaire consisted of three sections after a brief introduction of the study's purpose with a description of Nigeria's energy policy. The first section asked respondents' opinions on RE and their current energy situation. The second part contained a description of a PV system and the dichotomous choice valuation (CV) questions. The valuation questions asked respondents to indicate whether or not they would vote to own a home solar system. Finally, a follow-up question asked those who gave a "no" or " do not know" response to indicate why. Aside from affordability (corner solutions) issues, other reasons were treated as protests.

Finally, in line with best practices, questions about households' characteristics were asked and ended with a debrief that asked whether respondents understood the questionnaire. The survey was conducted in-person by four well-trained research assistants (two males and two females) using paper-based questionnaires. This method made it possible to use pictures of solar panels and the Nigerian Pidgin language to answer respondents' questions.

The survey took place in Lagos State (mainly urban) – located in the southwest of Nigeria; the study area is shown in online appendix figure A2. It shares a boundary with the Republic of Benin and has an estimated population of over 12 million, making it the most populous state in Nigeria (NBS-UNICEF, 2017). It is the fifth-biggest economy in Africa with one of the highest standards of living. There is significant pressure on the energy supply because of its massive population. A higher proportion of Nigeria's CO_2 emissions comes from Lagos as households and firms rely mainly on generators (Siemens, 2011). Due to budget limitations, only three hundred and fifty households were randomly surveyed in a systematic order of every fourth house in each road. The sample size is sufficient for the bid vectors used. Also, it is worth noting that the spike model and non-parametric models are efficient in estimating WTP even when the sample size is relatively small (see Borzykowski *et al.*, 2018). The main survey lasted from July 2018 to September 2018.

3.2.1 Survey scenarios and hypotheses

The scenarios and survey set-up are are shown below:

- Imagine that a nationwide referendum is held in Nigeria today on the adoption of a home solar system (HSS). Assume that the HSS would cost between NGN250,000 and NGN600,000. And it is guaranteed by law that the money collected by a company will be used solely for this program. How would your household vote if it involves an extra bill on top of your monthly electricity bill for the next 5 years to have a HSS installed for you? Please note that this amount would reduce your consumption of other goods you could use the money for as well.

[2]NGN is Nigerian Naira, the Nigerian currency. The average exchange rate was NGN362/US$1 when the data was collected.

- **Scenario I:** The HSS and the national grid can satisfy all your electricity demand, **except** the demand for refrigerator and air conditioning during periods of blackouts. These you would have to power using a/your generator during time of blackout.
- *If a majority votes "yes" to the program, how would you vote? Yes [ ] No [ ] Don't know [ ]. Would your household be willing to pay an additional NGN... bill per month? Yes [ ] No [ ] Don't know [ ].*
- **Scenario II:** The HSS and the national grid can satisfy **all** your electricity demand without any need for generator. *If a majority votes "yes" to the program, how would you vote? Yes [ ] No [ ] Don't know [ ]. Would your household be willing to pay an extra NGN... bill per month? Yes [ ] No [ ] Don't know [ ].*
- **Suppose the government decides to pay 20 per cent of the cost for you.**
- **Scenario III:** The HSS and the national grid can satisfy all your electricity demand, **except** the demand for refrigerator and air conditioning during periods of blackouts. These you would have to power using a/your generator during blackouts. *If a majority votes "yes" to the program, how would you vote? Yes [ ] No [ ] Don't know [ ]. Would your household be willing to pay an additional NGN... bill per month? Yes [ ] No [ ] Don't know [ ].*
- **Scenario IV:** The HSS and the national grid can satisfy **all** your electricity demand without any need for generator. *If a majority votes "yes" to the program, how would you vote? Yes [ ] No [ ] Don't know [ ]. Would your household be willing to pay an additional NGN... bill per month? Yes [ ] No [ ] Don't know [ ].*
- **Hypothesis 1:** WTP in scenario III should be higher than in scenario I.
- **Hypothesis 2:** WTP in scenario IV should be higher than in scenario II.

3.3 Deriving willingness to pay

WTP is the amount of money that makes respondent n indifferent between using a generator or other dirty energy alternatives as backup (the status quo) and the proposed off-grid solar. Thus, incorporating WTP into the linear random utility model gives

$$\alpha_1 x_n + \beta(y_n - WTP_n) + \epsilon_{1n} = \alpha_0 x_n + \beta y_n + \epsilon_{0n}, \tag{1}$$

where y is the income level, x is a vector of socio-demographics and attributes of the choice, and ϵ the random part of preferences independently and identically distributed (IDD) with mean zero.

Solving for WTP gives

$$WTP_n = \frac{\alpha x_n}{\beta} + \frac{\epsilon_n}{\beta}, \tag{2}$$

where $\alpha \equiv (\alpha_1 - \alpha_0)$ and $\epsilon \equiv (\epsilon_1 n - \epsilon_0 n)$.

Thus, the expected WTP incorporating preference uncertainty (ϵ) is given as (Haab and McConnell, 2002):

$$E_\epsilon(WTP_n \backslash \alpha, \beta, x_n) = \frac{\alpha x_n}{\beta}, \tag{3}$$

where β is the marginal utility of income.

The conventional parametric models underlying the estimation of WTP_n in equation (2) (like probit and logit models; see, for example, Hanemann and Kanninen (2001)) can give a negative WTP value when the majority of respondents indicate a "no" answer to the single bounded dichotomous choice questions. This anomaly spurred the development of the spike or mixture model of Kriström (1997). The author introduced a spike at zeros to correct the excess zeros, and failure to do this will yield an inflated mean WTP value (Borzykowski *et al.*, 2018). It is a common practice in CV studies with open-ended questions format to treat zero responses as a protest and exclude them from the analysis. Whether or not including or excluding zero responses from CV surveys produces a biased WTP remains inconclusive (Meyerhoff and Liebe, 2006; Frey and Pirscher, 2019).

Unlike the conventional models, Kriström (1997) argues that in a private good setting, zero consumption of a good may be due to corner solutions. As a result, zero bidding does not translate into zero probability of WTP. While some zero bids are a true reflection of preferences, zero being the reservation price of individuals that are indifferent to the increase in the provision of [a] public good, others may be motivated by protest behavior (Strazzera *et al.*, 2003: 133). Thus, it is pertinent to identify "true" zero bidders and protest responses in practice. This can be done through a follow-up question that probes respondents' reasons for indicating zero responses.

Further, a nonparametric model like the Turnbull (1976) model is efficient in estimating WTP even when there is too many zeros. It uses the lower bound WTP, and therefore does not overestimate the value. It is useful when the sole objective is to estimate the WTP and not the underlying factors that influence WTP (Haab and McConnell, 1998; Bateman *et al.*, 2002). The full canonical model of Turnbull (1976) is discussed in detail in (Haab and McConnell, 1997, 2002: 26–29).

Cost-benefit analysis (CBA) uses the net present value (NPV) criterion which is the NPV of the expected stream of benefits minus the project's cost (Ross *et al.*, 2005). We use it to calculate the stream of net benefits produced by the HSS. Although the NPV has been criticized in the literature because it does not provide sufficient answers on the profitability of the investment (see Helfert, 2001), it does show whether or not an investment is feasible. If the NPV is positive, it is viable to invest in the project, whereas resources should not be invested in it if it turns out negative.

The formula is given as:

$$NPV = -\sum_{t=0}^{N} \frac{K_t}{(1+r)^t} + \sum_{t=0}^{N} \frac{B_t - C_t}{(1+r)^t}, \tag{4}$$

where NPV is net present value and K_t is the cost of the technology, which is derived by multiplying the market price of the technology by the total number of urban households. B_t is the stream of expected benefits – the sum of the WTP values totalled over the number of urban households. C_t is the stream of maintenance costs and r is the discount rate or the deposit money bank lending rate which reflects the investor's time preference for money. Finally, t is the lifespan of the technology.

4. Results and discussion

4.1 Descriptive statistics

Table 1 presents the variables used in the analysis. The average age of respondents is 37 years; 67 per cent are males.[3] Nearly half (44 per cent) of respondents have a university

[3]The unequal distribution of males and females in Lagos, where the percentage of males is higher than females, sometimes means that a sample from the population would be male-biased.

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Table 1. Summary statistics of model variables

Variable	Description	Mean (Std. Dev.)
Bid1	=bids offered in scenario I	1512.23 (705.915)
Bid2	=bids offered in scenario II	2012.23 (705.915)
Bid3	=bids offered in scenario III	1212.23 (566.419)
Bid4	=bids offered in scenario IV	1609.79 (563.862)
Age	=age of respondents in years	37.28 (11.000)
Male	=1 if respondent is a male, 0 otherwise	0.67 (0.472)
Uni degree	=1 if respondent has a university degree, 0 otherwise	0.44 (0.497)
Marriage	1= if respondent is married, 0 otherwise	0.66 (0.473)
Children	=1 if respondent has more than two children, 0 otherwise	0.27 (0.445)
Employment	1= if respondent is employed, 0 otherwise	0.91 (0.284)
log(Income)	=log of monthly income	11.59 (0.802)
Own generator	=1 if respondent uses a generator, 0 otherwise	0.72 (0.448)
Own house	=1 if respondent owns a house, 0 otherwise	0.15 (0.357)
REK	=1 if respondent's knowledge of RE is good, 0 otherwise	0.30 (0.460)
T1 (in scenario I)	=1 if respondent answered yes, 0 otherwise	0.64 (0.480)
T2 (in scenario II)	=1 if respondent answered yes, 0 otherwise	0.70 (0.458)
T3 (in scenario III)	=1 if respondent answered yes, 0 otherwise	0.63 (0.483)
T4 (in scenario IV)	=1 if respondent answered yes, 0 otherwise	0.76 (0.428)

Note: NGN: Nigerian Naira. The average exchange rate was NGN362/US$1 when the data was collected.

degree, 66 per cent are married, and 27 per cent have at least two children. The vast majority of respondents (91 per cent) are employed. The average monthly income (at level) is NGN139,853.50 ($386.34). It is noteworthy that an overwhelming 72 per cent of respondents own a generator. It is easy to find a house where all the occupants own a generator. A similar survey in Lagos found that 78.1 per cent of the sample owned a generator (Oseni, 2017).

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However, only 15 per cent of respondents own a house. We asked respondents to rate their RE knowledge on a five-point Likert scale ranging from poor to good. About 30 per cent reported having good knowledge about RE. While 64 per cent of respondents showed a positive WTP for off-grid PV, on the condition that they still use their generators, the number increased to 70 per cent when the option of doing away with their generators was offered. The figure decreases marginally (63 per cent), assuming a 20 per cent subsidy. At the same time, it increases significantly (76 per cent) when generators are displaced completely. The mean bids in the four scenarios are NGN1,512.23 ($4.18), NGN2,012.23 ($5.56), NGN1,212.23 ($3.35), and NGN1,609.79 ($4.45).

Other variables not used in the regression show that power blackouts last for about 7 h per day, on average. This result is consistent with NBS (2016). Only 1.8 per cent of respondents own PV systems ranging from 25 kW to 300 kW. They were installed between 2016 and 2018. The mean household size is 4 persons. A mere 1.2 per cent of respondents belong to an environmental group.

Most of our sample's characteristics are comparable to official documents and other surveys that involved many more households. For instance, the NBS-UNICEF (2017) multiple indicator cluster survey involving 33901 households in Nigeria shows that 98.8 per cent of Lagos residents live in urban areas with an average household size of 4. Only 15.3 per cent own a house, whereas 77.5 per cent are renters. The median monthly income in Lagos is between N75,000 and N100,000 ($207.18 and $276.24) (Renaissance Capital, 2011).

4.2 Regression results

Table 2 presents the results of probit and linear probability models (LPM). When interpreting the independent variables' coefficients, the reader should note that the dependent variable is the probability of answering yes to the bid presented to respondents or the likelihood of paying the offer. Thus, a positive coefficient signifies the probability of responding yes and vice versa.

It is also worth noting that the two models' coefficients can be compared using the following rough approximation (Amemiya, 1981: 1488): $\widehat{\beta}_{Probit} \simeq 2.5\widehat{\beta}_{LP}$. Thus, the coefficients of the probit and LPM presented in table 2 are not significantly different. In terms of model selection, the probit model is preferred in all four scenarios over the LPM because it has smaller Akaike information criterion and Bayesian information criterion.

The coefficients of the bids in all the scenarios are as expected and are statistically significant. It shows that the probability of a "yes" declines as the bid increases. More details regarding the bids are available in online appendix A2 and figures A3–A6. The coefficients of other covariates show that the WTP for solar PV increases among male respondents in scenarios II and III. In other words, female respondents are less likely to say "yes". Nduka (2021) obtained a similar result about Nigerian rural households and concluded that women were more risk-averse in the energy transition. However, elsewhere women have been reported as indicating a higher WTP than their male counterparts (Kosenius and Ollikainen, 2013). WTP for solar PV increases with education in scenario I. Similar findings have been reported in several countries (Han *et al.*, 2020; Kim *et al.*, 2021).

Households with more than two children are willing to pay more for solar PV in scenarios I and II than their counterparts. Although we did not ascertain the ages of the children, studies have shown that school children in Nigeria and other developing countries usually struggle with homework in poorly illuminated houses because of inefficient

Table 2. Model estimates

Variable	Probit (I) Coeff. (SE) [ME]	LPM (I) Coeff. (SE)	Probit (II) Coeff. (SE) [ME]	LPM (II) Coeff. (SE)
Bid	−0.0005 (0.0001) [−0.0002]	−0.0002 (0.00004)	−0.0005 (0.0001) [−0.0002]	−0.0001 (0.00003)
Age	−0.009 (0.008) [−0.003]	−0.003 (0.002)	−0.014 (0.008) [−0.005]	−0.003 (0.202)
Male	0.204 (0.164) [0.076]	0.068 (0.058)	0.517 (0.171) [0.177]	0.158 (0.056)
Uni deg	0.451 (0.158) [0.163]	0.152 (0.053)	0.224 (0.171) [0.073]	0.069 (0.050)
Marriage	−0.206 (0.191) [−0.074]	−0.075 (0.065)	−0.320 (0.205) [−0.101]	−0.101 (0.060)
Children	0.343 (0.196) [0.121]	0.120 (0.068)	0.503 (0.209) [0.152]	0.157 (0.063)
Employment	0.049 (0.269) [0.018]	0.011 (0.097)	0.201 (0.268) [0.069]	0.054 (0.086)
ln(income)	0.155 (0.116) [0.057]	0.055 (0.039)	0.366 (0.117) [0.121]	0.106 (0.033)
Own generator	0.104 (0.164) [0.039]	0.039 (0.055)	0.444 (0.173) [0.154]	0.137 (0.053)
Own house	0.029 (0.237) [0.011]	0.003 (0.080)	−0.018 (0.239) [−0.006]	−0.012 (0.068)
RE knowledge	0.264 (0.172) [0.095]	0.095 (0.056)	0.435 (0.192) [0.135]	0.129 (0.050)
Cons	−0.811 (1.272)	0.195 (0.443)	−3.072 (1.333)	−0.405 (0.404)
N	327	327	327	327
R^2	0.09	0.12	0.16	0.18
LL	−192.32	–	−167.89	–
AIC	408.65	428.48	359.78	376.74
BIC	454.13	473.96	405.26	422.22

Table 2. *Continued.*

Variable	Probit (III) Coeff. (SE) [ME]	LPM (III) Coeff. (SE)	Probit (IV) Coeff. (SE) [ME]	LPM (IV) Coeff. (SE)
Bid	−0.0004 (0.0001) [-0.0001]	−0.0001 (0.00004)	−0.0002 (0.0001) [−0.00008]	−0.00007 (0.00004)
Age	−0.001 (0.008) [−0.0007]	−0.0005 (0.003)	−0.005 (0.008) [−0.002]	−0.001 (0.002)
Male	0.344 (0.161) [0.131]	0.123 (0.061)	0.261 (0.168) [0.082]	0.079 (0.054)
Uni deg	−0.029 (0.158) [−0.011]	−0.009 (0.057)	0.096 (0.166) [0.029]	0.033 (0.494)
Marriage	−0.180 (0.190) [−0.067]	−0.064 (0.068)	−0.270 (0.200) [−0.079]	−0.083 (0.058)
Children	−0.141 (0.190) [−0.053]	−0.052 (0.073)	0.247 (0.205) [0.072]	0.084 (0.064)
Employment	0.074 (0.267) [0.028]	0.021 (0.99)	0.514 (0.256) [0.177]	0.171 (0.095)
ln(income)	0.196 (0.113) [0.074]	0.070 (0.041)	0.114 (0.119) [0.035]	0.039 (0.035)
Own generator	−0.083 (0.164) [−0.031]	−0.024 (0.058)	0.233 (0.169) [0.074]	0.079 (0.054)
Own house	−0.143 (0.224) [−0.057]	−0.052 (0.083)	−0.071 (0.236) [−0.022]	−0.030 (0.074)
RE knowledge	0.091 (0.162) [0.034]	0.029 (0.058)	0.109 (0.176) [0.033]	0.031 (0.050)
Cons	−1.449 (1.237)	−0.027 (0.461)	−0.737 (1.311)	0.243 (0.402)
N	327	327	327	327
R^2	0.05	0.07	0.05	0.06
LL	−203.94	–	−171.50	–
AIC	431.88	452.75	367.01	377.03
BIC	477.36	498.23	412.49	422.51

Notes: Standard errors (in parentheses are robust), ME [in brackets] is marginal effects, LPM is linear probability model. I to IV correspond to the respective scenarios. N is number of observations, LL is log-pseudolikelihood, AIC is Akaike information criterion, and BIC is Schwarz's Bayesian information criterion. **Note**: We omitted the MEs in the LPM because they are equal to the model coefficients.

sources of energy (Thiam, 2011; Nduka, 2021), and sometimes they suffer serious burns because of overturned kerosene lamps (Chamania *et al.*, 2015).

Age is marginally significant in scenario II only, implying that the probability of saying "yes" decreases with being an older respondent. This could be because of having many years of experience with the status quo energy sources; thus, older respondents are reluctant to accept a change. Another reason might be that younger respondents are more conscious about the environment due to the recent increase in climate change discussions. Similar findings have been obtained in other countries (Kosenius and Ollikainen, 2013; Dagher and Harajli, 2015).

The probability of WTP increases with monthly household income in scenarios II and III. This is consistent with the standard demand theory. The implication is that wealthy households are more likely to adopt solar PV than their counterparts. Our finding is in line with other CV studies (Han *et al.*, 2020; Nduka, 2021) and (Guta, 2018) who found that wealthy Ethiopian households were more likely to pay for solar PV than low-income families.

The coefficient of generator ownership is positive and statistically significant in scenario II, where respondents were given the option of displacing generators completely with solar PV. Thus, self-generating households are more likely to pay for a solar PV than their counterparts. This could be because it is more expensive to run a generator than a PV system. Our sample spends about NGN6,196.37 ($17.12) on generators and NGN5,132.79 ($14.18) on grid electricity bills each month, totaling NGN11,329.16 ($31.30). Thus, about 8.1 per cent of households' monthly income is spent on electricity. Our finding is consistent with Oseni (2017), who reported that generator owners were willing to pay more for reliable grid electricity than non-owners.[4] *Insight*: Generator users are willing to pay more for solar PV than their counterparts only if it can fully substitute for generators. Dagher and Harajli (2015) also found that generator users in Lebanon were willing to displace generators with solar PV.

The probability of answering "yes" increases with having good knowledge about RE in scenario II. Thus, knowledge about RE is critical for Nigerians to substitute generators for solar PV. Our finding is consistent with Zografakis *et al.* (2010), Zorić and Hrovatin (2012), Guo *et al.* (2014) and Štreimikienė and Baležentis (2015), who found that Lithuanians' WTP increased by 17 per cent point after the respondents' RE knowledge increased.

The coefficient of log(income) in scenario II, where a generator is displaced, is 0.37 and is precisely estimated with a standard error of 0.11. The associated marginal effect at the mean is 0.12. This suggests that a 10 per cent increase in monthly household income (a change of 0.1 in log(income)) is associated with an increase of 0.012 in the probability of WTP. Similarly, in scenario II, the marginal effect of generator ownership implies that owning a generator is estimated to increase the probability of WTP for solar PV to displace a generator by 0.15, with 95 per cent confidence interval (CI) [0.03, 0.27]. Also, being well-informed about RE increases the probability of WTP by 0.14, with 95 per cent CI [0.03, 0.24].

We test for interviewer effects using a dummy variable and present the results in online appendix table A4. It is not statistically significant at the 5 per cent level, and the results are not different from the main results in table 2.

[4]Non-generator users in Nigeria rely on grid electricity, which is irregular. Thus, households switch to kerosene lanterns, candles, battery-powered torches, and electric rechargeable lanterns during periods of power blackouts.

4.3 Welfare estimates

We estimate two parametric models and one nonparametric model. As per tables 3 and 4, the monthly mean WTP of respondents when a solar PV is complemented with a generator is NGN3,451.74 ($9.53) compared to NGN3,999.97 ($11.04) when it completely displaces a generator. Respondents are willing to pay more to own a solar PV if it can serve as a complete backup than they are prepared to pay using a generator. The noise and air pollution of the petrol-powered generator could be responsible for this discrepancy. The difference between the two scenarios' WTP values is statistically significant. Also, the WTP values from the three models are statistically significantly different. A study in Lagos found that households were willing to pay $7.48 to reduce the incidence of an electric power outage (Oseni, 2017).

As would be expected, house owners are willing to pay more than renters in scenarios I (NGN4,689.38/$12.95 compared to NGN3,087.31/$8.53) and II (NGN5,172.25/$14.29 relative to NGN3,627.60/$10.02), respectively. A difference in the two means test shows that homeowners' and renters' mean WTP values in scenario I are not significantly different. However, the difference is significant in scenario II.

4.4 Giving households a 20 per cent subsidy

Next, we consider the situation where households are given a 20 per cent subsidy. In tables 5 and 6, households' mean WTP is NGN3,174.67 ($8.76) when a solar PV is complemented with a generator and NGN5,278.52 ($14.58) without a generator. These are significantly different. A cross-method comparison shows that the two parametric models' WTP are significantly different in scenario III but not in scenario IV. Homeowners' mean WTP is NGN4,034.58 ($11.15) compared to renters' NGN2,913.55 ($8.05). In the fourth scenario, homeowners are willing to pay NGN7,849.35 ($21.68), while renters are willing to pay NGN4,572.97 ($12.63). Again, there is a significant difference in the means.

Overall, the mean WTP values are plausible since they are by far less than households' average monthly income and total energy spending. Thus, transitioning to solar PV would leave families with more disposable income and improve their welfare.[5]

Regarding the first hypothesis specified in section 3.2.1, the WTP (NGN3,451.74/$9.53) of scenario I is marginally higher than scenario III (NGN3,174.67/$8.76). Intuitively, this could be attributed to embedding. However, it is negligible because the difference is not significant. The second hypothesis holds as the WTP (NGN5,278.52/$14.58) of scenario IV significantly outweighs scenario II (NGN3,999.97/$11.04).

Interestingly, a recent private-sector-driven home solar system (HSS) government program, Nigeria Electrification Project (NEP), offers to provide HSS to households that can pay at least NGN5,250 per month (SEforALL, 2021).

4.5 Cost-benefit analysis of solar PV investment

A typical HSS would supply electricity for 8 h during periods of blackout. With a load of 500 watts (w) (which includes two standing fans, one TV, and six energy-saving bulbs), the required PV capacity is 4000w. The PV system comprises a 1.5KVA Techfine pure

[5]We further estimate the WTP of generator owners and non-owners and present the results in online appendix tables A1 and A2.

Table 3. Scenario I: WTP when solar PV is complemented with generators

	Full sample			House renters			House owners		
	Probit	Spike	Turnbull	Probit	Spike	Turnbull	Probit	Spike	Turnbull
WTP	NGN2442.87	NGN3451.74	NGN1493.50	NGN2324.88	NGN3087.31	NGN1524.98	NGN2555.77	NGN4689.38	NGN1718.16
S.E	(285.24)	(409.57)	(75.40)	(349.03)	(409.52)	(85.60)	(380.70)	(1249.02)	(123.12)
95% CI	1883.79-3001.94	2649.00-4254.49	1345.69-1641.30	1640.79-3008.98	2284.66-3889.97	1357.19-1692.77	1809.60-3301.95	2241.35-7137.42	1476.84-1959.48
N	327	327	327	234	234	234	93	93	93

Notes: The WTP values (in Nigerian Naira), standard errors (in parentheses), and confidence intervals (CIs) of the probit model are constructed through the delta method. We also used the Krinsky and Robb (1986) method (KR). Although the WTP values from both procedures are the same, their confidence intervals differ. The delta method produces symmetric CIs, while the KR yields non-symmetric CIs (Jeanty, 2007). The results are available from the author upon request.

Table 4. Scenario II: WTP when solar PV completely displaces generators

	Full sample			House renters			House owners		
	Probit	Spike	Turnbull	Probit	Spike	Turnbull	Probit	Spike	Turnbull
WTP	NGN3691.50	NGN3999.97	NGN2121.45	NGN3713.66	NGN3627.60	NGN2011.86	NGN3364.32	NGN5172.25	NGN2316.95
S.E	(579.64)	(365.04)	(83.20)	(863.55)	(368.88)	(100.31)	(445.30)	(1086.46)	(157.41)
95% CI	2555.42-4827.59	3284.50-4715.44	1958.37-2284.53	2021.12-5406.19	2904.60-4350.59	1815.24-2208.48	2491.53-4237.10	3042.80-7301.69	2008.41-2625.49
N	327	327	327	234	234	234	93	93	93

Notes: The WTP values, standard errors (in parentheses), and confidence intervals (CIs) of the probit model are constructed through the delta method.

Table 5. Scenario III: WTP when solar PV is complemented with generators

	Full sample			House renters			House owners		
	Probit	Spike	Turnbull	Probit	Spike	Turnbull	Probit	Spike	Turnbull
WTP	NGN2171.44	NGN3174.67	NGN921.14	NGN2273.34	NGN2913.55	NGN1210.46	NGN1992.62	NGN4034.58	NGN837.57
S.E	(391.05)	(437.73)	(30.88)	(657.46)	(453.60)	(69.84)	(327.71)	(1199.91)	(86.07)
95% CI	1404.99-2937.89	2316.73-4032.60	860.60-981.68	984.7082-3561.94	2024.50-3802.59	1073.57-1347.35	1350.31-2634.92	1682.79-6386.37	668.87-1006.27
N	327	327	327	234	234	234	93	93	93

Notes: The WTP values, standard errors (in parentheses), and confidence intervals (CIs) of the probit model are constructed through the delta method.

Table 6. Scenario IV: WTP when solar PV completely displaces generators

	Full sample			House renters			House owners		
	Probit	Spike	Turnbull	Probit	Spike	Turnbull	Probit	Spike	Turnbull
WTP	NGN5114.15	NGN5278.52	NGN2050.19	NGN5831.47	NGN4572.97	NGN1471.08	NGN5079.70	NGN7849.35	NGN2034.35
S.E	(2376.76)	(766.16)	(64.54)	(3382.14)	(720.65)	(62.31)	(3213.11)	(2892.38)	(90.41)
95% CI	455.77-9772.52	3776.87-6780.17	1923.69-2176.69	-797.40-12460.35	3160.51-5985.42	1348.94-1593.22	-1217.89-11377.30	2180.38-13518.32	1857.13-2211.57
N	327	327	327	234	234	234	93	93	93

Notes: The WTP values, standard errors (in parentheses), and confidence intervals (CIs) of the probit model are constructed through the delta method.

Table 7. CBA results of solar PV

Discount rate (%)	NPV
11.5	NGN258,121,962,485.35
12.5	NGN225,746,446,343.20
13.5	NGN197,675,924,584.80

sine wave Inverter, four 250w of solar panels (1,000 watts), one 40A MPPT charge controller, and two 200AH Techfine Gel Deep Cycle batteries. The battery bank's storage capacity is 4800w. When fully charged, it could withstand the total load for 9 h. The installed solar panels' capacity of 1,000w could generate about 820w per h after accounting for 18 per cent energy losses due to resistance and heat. With the average peak sunlight of 5 h, the installed panels' capacity can charge the batteries fully. The solar panels have a 25 year lifespan, and the batteries could last 4–5 years if well looked after before replacement. The cost of the PV system is NGN633,000 ($1, 748.62). See online appendix table A3 for more details.

We use equation (4) to perform the CBA at the interest rate of 11.5 per cent, which is the rate set by the Central Bank of Nigeria. We estimate that it will take households 15 years to pay back the cost at the mean monthly WTP value of NGN3,999.97 ($11.04). With 15,184,692 total urban households in Nigeria, the NPV remains positive even at higher interest rates. We assume that, within the 15 years, the PV batteries will be replaced twice by households, bringing the total cost to NGN1,160,000 ($3, 204.42). This is still beneficial to households compared to a generator's total cost of NGN1,245,000 ($3, 439.23). We compute this using households' average monthly cost of running a generator plus the price of a 2KVA generator of NGN130,000 ($359.12).

Table 7 shows the benefits of solar PV investment to firms after 15 years. At three different interest rates, the benefits are NGN258 bn ($721 m), NGN225 bn ($621 m), and NGN197 bn ($544 m). Note that we used the second scenario's mean WTP to perform the CBA because it assumes the complete replacement of generators with a solar PV. We did not compute the CBA using scenario four's WTP value because of the uncertainty about the government giving a solar PV subsidy.

5. Conclusion and policy implications

Some insights emerge from our results. First, the WTP for solar PV is higher when it can displace generators completely. Thus, more households are willing to adopt solar PV to satisfy their energy needs. Second, generator users are willing to pay more for solar PV than their counterparts only when it can replace generators. Third, the proportion of positive bidders increases under a subsidy option. Subsidy plus monthly rather than upfront payment would increase the adoption of home solar systems by about 6 per cent. Thus, solar PV subsidies serve as an incentive for more Nigerians to adopt solar PV. Fourth, adopting solar PV through the installment payment model would save households about NGN26,356.44 ($72.81) annually compared to generators.

Likewise, investors would make enormous profits. Thus, investment in solar PV under this payment model is a win-win between households and investors. Finally, we find that education, number of children, income, generator ownership, and RE knowledge are predictors of WTP for solar PV. Thus, policymakers should consider these when designing policies to scale up solar PV adoption in Nigeria, especially in educating people about solar energy.

Besides monetary benefits, solar energy has enormous use and non-use environmental and health values over fossil fuel-powered generators. Moreover, solar energy is more sustainable than fossil fuels. Therefore, transitioning to RE will solve many environmental problems associated with fossil fuel burning. To this end, Nigeria should be proactive in the transition process. However, it should be noted that the energy transition would negatively impact generator and fuel businesses, especially as the Nigerian economy is oil-driven. Thus, policymakers should try and minimize the potential losses.

Achieving the 2030 target of reducing the CO_2 level through solar PV would require that import duties on solar PV are scrapped. In addition, policies that affect both the demand and supply sides need to be adopted to compete with other nations in the energy transition. Instead of imposing taxes on solar panels, there is a need to subsidize the cost. For instance, subsidies on petroleum products can be channeled towards solar energy. Moreover, while the subsidy on fossil fuels is recurrent, the subsidy on solar PV is a one-off. Subsidy and tax incentives for investors have helped many households to own solar PV in the UK, generating up to 193.9 MW of electricity and preventing 65,200 tonnes of CO_2 emissions (Community Energy England, 2020).

Communities and civil society organizations need to support the energy transition. For example, low-income households can create "Esusu" - - people with similar interests develop it to encourage saving and raise a substantial amount of money for members. They stipulate specific funds, and members contribute to a collective pool every month. The total contribution is given to one person at the end of every month on rotational basis. This is a form of microfinance, which is popular in every part of Nigeria, similar to community energy organizations in the UK (see Exeter Community Energy, 2020).

Nigeria should leverage declining solar PV prices and abundant sunshine to improve households' welfare. The Central Bank of Nigeria should set a different interest rate for RE. In addition, policymakers need to mandate banks to provide interest-free loans to households to adopt solar PV.

It is worth mentioning that due to budget limitations, we surveyed only 350 households in Lagos state. Also, although Lagos is the economic hub of Nigeria, there are many other megacities. This is only a start to investigating how Nigerians perceive adopting more environmentally friendly alternative energy sources. Thus, we hope that the results of this study will motivate further research on this issue. It is pertinent for researchers to explore and extend this research further using a larger sample size because it is critical in helping to shape Nigeria's energy transition.

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