Journal of Digital Food, Energy & Water Systems [JD-FEWS]

JDFEWS 4 (2): 159-177, 2023
ISSN 2709-4529

Evaluating Prospective Energy Services Demand for Residential Solar Photovoltaic (RSPV) Generated Electricity in Lagos State, Nigeria

Aquila JESULEYE
Department of Project Management Technology, The Federal University of Technology, Akure, Nigeria; oajesuleye@futa.edu.ng

Olatubosun ORIOLA
Federal Ministry of Science and Technology, National Centre for Technology Management, Nigeria; aoriola@ymail.com

Adeyemi ADEPOJU
Department of Project Management Technology, The Federal University of Technology, Akure, Nigeria; aoadepoju@futa.edu.ng

Received: 08 December 2023

Review: 21 December 2023

Accepted: 21 December 2023

Published: 30 December 2023

Abstract: The ongoing energy and climate crisis demand transition to sustainable energy resources aided by accurate estimation of energy demand to guide policies for adequate planning of renewable fueled electricity generation technology in urban areas. This study evaluated the electricity demand for standalone residential solar photovoltaic (RSPV) technology by potential household adopters of the technology in the metropolitan area of Lagos state, Nigeria plagued with endemic epileptic grid electricity supply. The study adopted quantitative research design with structured questionnaire to solicit information from the respondents. Three hundred and twenty-six (326) responses from the potential adopters were analysed with a model for analysis of demand for energy (MADE-II) and Pareto tool. The results show that space cooling services has the highest energy intensity of 7.59 kWh/hh/day while the entertainment services have the lowest energy intensity of 0.84kWh/hh/day. The study concluded that the household energy services demand for electricity by the potential RSPV technology adopters from the solar module panel is 31.59kWh/hh/day. The study further conclude that the respondents guided by their consciousness of the quantity of energy demand carefully select appliances base on the energy requirements of the appliances. The study recommends effective planning, monitoring, and controlling of operation and performance of the household appliances vis-a-viz the operation and performance of the stand-alone RSPV system to minimise the energy demand and optimize the energy services output. Further study could investigate the smart integration and interaction of the household appliances with the stand alone RSPV system to minimise the energy demand and optimise the performance of both the supply and demand system.

Keywords: *Energy demand; MADE II; Residential Solar Photovoltaic; Energy Services; Adopters; Energy intensity*

JDFEWS 4 (2): 159-177, 2023
ISSN 2709-4529

1.0 Introduction

Urbanisation and energy demand has been identified to be consequentially related to Climate change and global warming [1]. The progress of urbanisation, population growth, economic development, and living standards iscorrespondingly increasing the demandfor energy services in urban areas resulting to large carbon footprint. About 55% (4.2 billion) of the world population projected to reach about 6.5 billion (two third) by 2050 live in cities and significantly responsible for more than 80% of global gross domestic product [2]. The urban areas generate an estimated 75% of human caused global emission of carbon dioxide (CO_2) as a result of about two thirds of global final energy use and significant indirect consumption of energy embodied in products and other material goods [2], hence improving environmental performance of the energy system in the urban area is an indispensable necessity to attain green growth. Green growth entails economic advancement that promotes development characterized by environmental sustainability, reduced carbon emissions, social inclusivity and in other words operates on the pedestal of sustainable socio-economic systems driven by transition from non-renewable (fossil) energy to renewable resources [1].

Solar energy, based on its large technological potential and being amongst the cleanest energy sources, is used to generate electricity directly with solar photovoltaic technology [3, 4]. The solar photovoltaic (PV)electricity generation technology is considered to be the most sustainable and environmentally friendly technology among the available renewable electricity generation technologies [5, 6]. Therefore, accelerating the deployment of solar PV Technology is crucial to fill the energy gap, mitigate climate change and realise green growth.

Recent studies [7, 8, 9] shows that residential sector is the largest electricity consumer in Nigeria and account for about 59% of the country's electricity consumption, hence the sector can speed up the progress of tackling energy deficit and reduction of greenhouse gas (GHG) emission to mitigate climate change by rapid deployment of residential photovoltaic (RSPV) technology.The appropriate deployment of residential solar PV (RSPV) technology demandsintegrated planning involving dedicated policies, regulations and creation of energy demand profile for households [10]. A better understanding of residential energy demand is vital to transition of the energy system towards renewable sources from fossil energy sources. To adequately evaluate the household electricity demand for residential solar PV technology, it is vital to identify the energy services need of the households [6, 11]. Electrical power audit is paramount to ascertain the energy use of the households in order to plan for the suitable capacity of PV system that would meet the households' energy services demand [12, 6].

Past studies [13, 7, 4]) on estimation of energy demand for solar PV system are based on retrospective survey of the technology users which may not be suitable for accurate energy demand forecasts to aid policy makers in development of energy supply and provision of valuable suggestions for energy supply system operations planning. This study uses prospective surveys to evaluate the electricity demand of potential household users of RSPV technology to fill this methodology gap in literature. Furthermore, studies on application of solar off grid electricity generation had focused more on rural dwellers that does not have the financial capability to pay for the solar PV services, most especially in the sub-Saharan Africa [14, 15, 17] while there is dearth of studies on the application of the system in urban areas that contribute large amount of greenhouse gases to the environment and also has the financial buoyancy to pay for the services are lacking.

2.0 Literature Review

The concept of energy service is commonly used in very diverse fields and activities. Though there are notable differences in how energy services are conceptualised, it has been commonly argued that what people demand are the benefits provided by energy for human well-being and the society not energy or its carrier [18,19,20]. According to

JDFEWS 4 (2): 159-177, 2023
ISSN 2709-4529

[21] energy services are "energy forms and processes from where consumers ultimately derive and realise the value of energy carriers like electricity and gas" (p 3). Energy services are also described as the functions performed by the use of energy thus energy services drive energy consumption and energy demand [20].

In the residential sector, [22] identified the most common form of energy service as refrigeration, lighting, cooking, heating, water heating and space heating while [21] observe the common forms of energy services to include illumination, space conditioning, water heating, communications, and information processing. [23] describe what energy produces as lighting, cooling, cooking, space, and water heating, etc. and [18] categorised the urban household energy services for the low-income households as Cooking, Lighting, space heating and cooling, refrigeration, television, telephony, radio, mobile phone charging and hot water. According to the study, the middle-income households have all the low-income services plus entertainment, refrigeration and freezing, clothes washing and drying, computing, and surfing of the internet, advanced telecommunication while the high-income households have all the middle-income services plus luxury practices such as swimming in a heated pool, going to the bathroom with a heated toilet to the sound of music, and watching television while cooking. [7] considered lighting, Computing/internet, entertainment, process heating, cooking, water pumping, space cooling, ventilation, and refrigeration services as the forms of energy services in their study on Solar photovoltaic contribution to energy mix in selected Nigerian estates. These forms of energy services were adopted to guide this study.

When electricity is used as the energy carrier, provision of electricity to the consumers for the derived demand while ensuring the security of the power system is the conventional approach of providing energy services [21]. Much of the investment and operational decision making associated with this approach is focused on the supply side of the power system, while the potential contributions of the demand side are less regarded. This approach is increasingly becoming unfavourable due to growing electricity demand, deteriorating load factors and the evolving environmental concerns. Hence, [22] posited that there is a continuing increase in recognition of the significance of the demand-side of energy. According to [21] evaluation of the demand for energy can be approached in two ways. The first approach is by the actual energy consumption of the conversion technology used to deliver the service. The second approach is by specifying the required temporal changes to a variable directly related to the service, such as the volume of hourly consumption of hot water and the hourly temperature in a room. The accuracy of the first method relies on the immediate conversion of electricity to the corresponding energy service by the appliance. In contrast, the second method faces a challenge in assessing the hourly consumption of hot water through the electricity consumption of water heaters, as certain households utilize storage-type heaters. For energy services involving the instantaneous conversion of electricity to services, like lighting, or scenarios where the benefit stems not from the converted energy form but from the resulting process, such as information processing, the actual electricity consumption can be considered synonymous with the energy equivalent or demand [21]. This approach was adopted for this study because all the energy conversion technologies (appliances) studied instantly converts energy to services such as lighting, water pumping and ventilation services.

There are various literatures with different perspective and methods to analyse the household energy demand. According to [24] the theoretical frameworks are categorise based on discipline and integrated perspectives. The dominating disciplines in the disciplinary frameworks are economics, engineering, sociology and anthropology, and psychology. The engineering frameworks considers the physical laws to analyses the technology aspect of household energy demand [25]. The economic frameworks analyse the effects of income levels, energy prices, taxes and other economic and some behavioural factors [26]. The psychology frameworks consider the human behavioural aspect of household energy demand [27], while the sociology and anthropology frameworks analyse the social and cultural context of the household energy demand. The study of [28] suggest that the disciplinary frameworks which are developed on specific discipline such as economics, engineering, sociology and anthropology, and psychology

JDFEWS 4 (2): 159-177, 2023
ISSN 2709-4529

approach that has been used to guide energy policies over the years may be limited in the analysis of today's complex problems in the energy sector. This is because the disciplinary frameworks have some inadequacies and could not analyse the interactions between the various disciplines, and similarly are not able to properly explain the disjunction between the actual and predicted household energy demand [29]. The integrated perspective combines different discipline to form a robust framework for analysis of energy demand and adequately proffer energy demand solutions. [30] conceptualise a framework of household energy demand combining economics, engineering, sociology and anthropology, and psychology approaches but the idea did not translate to simulation models. Similarly, the study of [31] conceptualise an integrated framework based on socio-technical systems concepts that did not transform to modelling method. These theoretical frameworks serve as bases for all the studies on household energy demand modelling techniques [24].

Several models are developed for forecasting and estimating household energy demand and the associated carbon emission over the years. Principally two main epistemic approaches are used to model household energy demand and the consequential emissions of carbon dioxide namely top-down and bottom-up approaches with ongoing progress in development of the robust hybrid of the two approaches [32,33]. The top-down techniques which is mainly econometric method uses existing interaction between the energy sector and the general economy to predict and forecast the behaviour of household energy demand and carbon emissions at aggregate level when the policy parameters are changed within the models. The bottom-up techniques comprising of building physics and statistical method concentrates only on the energy sector, models household energy demand and carbon emissions by disaggregating the statistical or building physics method that contains high level of details. According to [24] there are significant variations in these models on the bases of disaggregation levels, complexity, output resolution, aggregation of output levels, performed scenario analysis, validation of model, and how they are made available for the public to scrutinize. The scholars further assert that there is a need to find more robust and sophisticated modelling techniques that take into account the associated complexity and burden of household energy demand and carbon emissions problems due to the chaotic nonlinearity, high interdependence and qualitative nature of some of the variables involved.

According to [4,7] the Model for Analysis of Demand for Energy (MADE-II) which appropriately combines the application of engineering process, econometric and statistical techniques to analyse demand for energy in various economic sectors is flexible and applicable for projection of energy demand over short and long period of time is suitably developed for developing countries such as Nigeria. These characteristics make the model suitable for this study.

3.0 Methodology

Lagos state, the most populous and fastest growing megacity in Africa and the former capital of the federal republic of Nigeria with an estimated population of about 24 million [34] people and population density of about 5,000 persons/km^2 was selected for the study. The study area located in the southwest geopolitical zone of Nigeria lies approximately between longitude 2º42'E and 3º22'E and between latitude 6º22'N and 6º42' Nhas solar radiation intensity of between 3.54 and 5.43 kWh/m^{2}day [12] suitable for generating electricity with solar PV technology. The metropolitan area span over sixteen (16) of the twenty (20) local government areas of Lagos State and accounts for over 85% of the total population of the State. The study area is the economic centre of Nigeria hence energy consumption and GHG emission rate seems to be high in Lagos state compared to other states in Nigeria because of its high level of urbanisation and industrialisation. The state receives just about 1GW of electricity for an average of no more than 12 hours daily average i.e. 12 gigawatt-hours (GWh) per day (6.25% of the demand) from the national grid according to [35]. Estimate is pointing at the use of about 15 GW back-up capacity fossil fuel-based self-generated off-grid electricity (diesel and petrol back-up generators) in Lagos area which produces a very significant amount of

JDFEWS 4 (2): 159-177, 2023
ISSN 2709-4529

greenhouse gases emission and pollution that damages the environment. It appears to be an increasing interest in alternative and more sustainable electricity in Lagos state [12] and the willingness to pay for standalone photovoltaic electricity by businesses in Lagos is high [36].
The study used quantitative research design with structured questionnaire to seek information from the potential users of RSPV technology. Multi-stage sampling method was used for the study. Multi-stage sampling is common in green power uptake studies [37, 38, 39,40, 12] and is effective where there are many local government areas or municipalities that present logistic challenge [41]. At the first stage, purposive sampling technique was used to select the metropolitan area comprising a total of sixteen local government areas categorised as densely populated urban area out of the total 20 Local government areas, which is more than 50% of the local government areas in Lagos state [42]. [43] justified the choice of 50% when the study population is large in his paper on sampling a population in educational research. The second stage involved the use of proportionate sampling technique to select the potential adopter household population in each of the sixteen local government areas that make up the metropolitan area according to the population size of each local government areas. Simple random sampling technique was used to select the potential adopter households in each of the local government area at the third stage.

The study used [44] formula for sample size to calculate the appropriate sample size.

$$n = \frac{N}{1+N(e)^2}$$

n = sample size

N = population size

e = level of precision (probability error)

A total number of 400 questionnaires were administered to the respondents. Three hundred and fifty-five (355) completed questionnaires were returned; three hundred and twenty-six (326) were correctly completed and found suitable for analysis giving a response rate of 88.75%.

Model for Analysis of Energy Demand II (MADE-II) was adapted for the analysis. The model which suitably uses the combination of engineering process, econometric and statistical methods for the analysis of different economic sectors was developed at the Institute for Energy Economics and Rational use of Energy, University of Stuttgart, Germany in 1989. The model works on the perception that energy is a means to an end that functions with other factors of production to produce goods and provide services to the society. MADE-II is a flexible model used to project energy demand for short- and long-term period and suitable for solar energy demand analysis in developing countries (Jesuleye et al., 2010) which made it appropriate for this study.

The model as shown in Figure 1. Operates on 7 blocks of data inflow to analyse energy demand. Block 1 treats the general information about energy levels, the base year and future time periods, Block 2works on population development information while block 3 analyse the household sector useful energy demand data. The Households, Cottage Industries and Community Services are handled in blocks 4 and 5. Block 6 deals with energy intensity while efficiencies, penetration factors and sectoral demand for Solar electricity such as lighting, Water Pumping, Powering of TV, Video, Radio, Refrigeration, Ventilation, Cooking and Personal computers are treated in block 7. For the study, block 6 (energy intensities) of the MADE-II data inflow as shown in figure 1. was adapted to analyse the energy intensity of the selected household energy services. Nine categories of household energy services were selected and the total energy demand computed in block 7 (Solar electricity demand for energy services) with the appropriate selection of the energy conversion technologies - end use appliances (Diemuodeke et al., 2017; Somefun et al., 2020;

JDFEWS 4 (2): 159-177, 2023
ISSN 2709-4529

Jesuleye et al., 2020b). The end use appliances rates were based on the ratings of the public utility company (Ikeja Electricity Company) that service the study area.

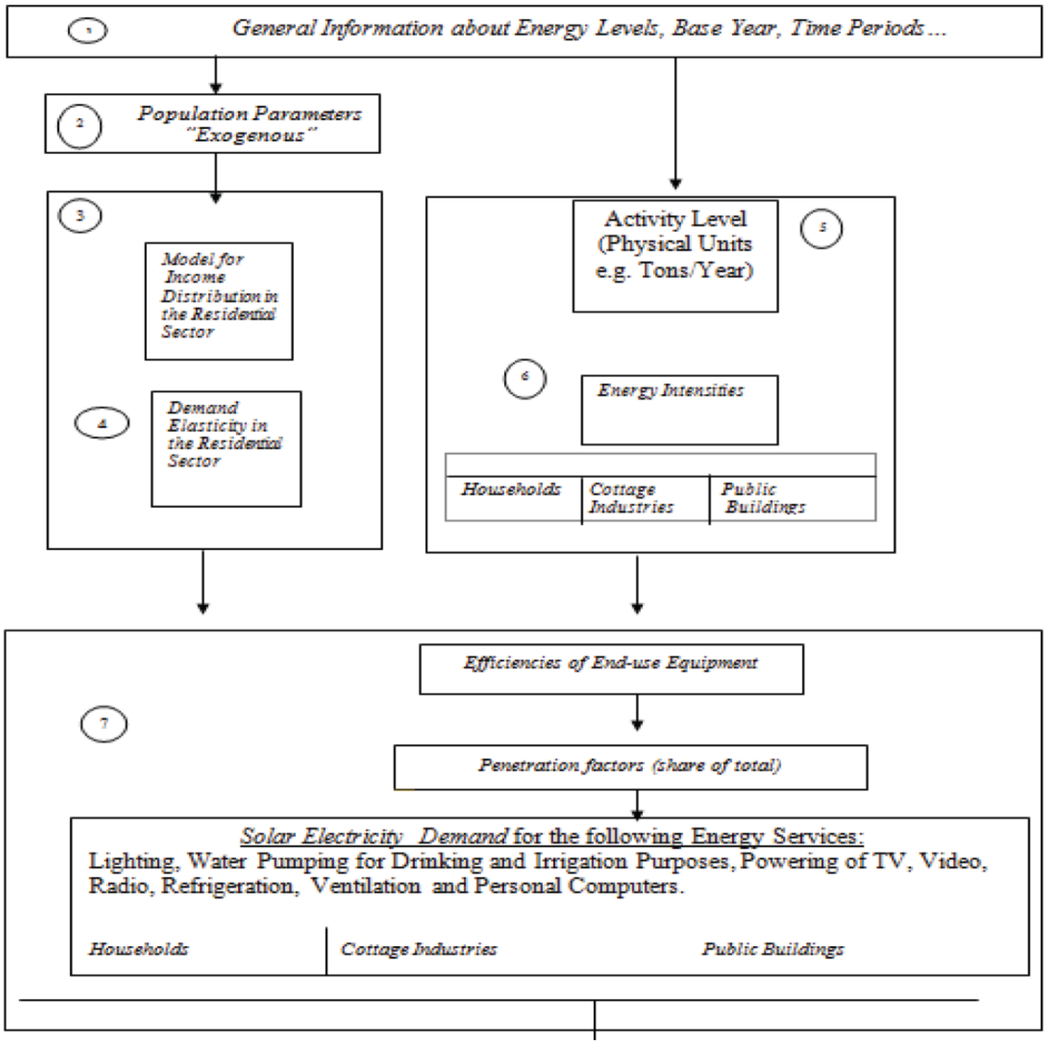

Figure 1. Adapted data flow in model for analysis of demand for energy (MADE –II) From Jesuleye (2020b)

Measurement of Variables for Household Energy Services in the study area

The energy services demand for RSPV was categorised as:

a) Electricity for refrigeration services (Freezers, Fridges)

b) Electricity for entertainment services (Television, Radio, VCD/DVD player)

c) Electricity for Computing services (Computers, Printers, Phones)

JDFEWS 4 (2): 159-177, 2023
ISSN 2709-4529

d) Electricity for Space cooling services (Air conditioner)

e) Electricity for ventilation services (Ceiling fans, Standing fans)

f) Electricity for lighting services (Energy saving bulbs, yellow-Incandescence) bulb.

g) Electricity for cooking services (Electric stove)

h) Electricity for process heat (Shaving kits, pressing iron, microwave oven, blender)

i) Electricity services for water pumping

The total demand for the various energy services was calculated using the data for energy demand collected from the study area with the following formula:

Total Final energy demand from energy mix

$TF_e = EI_{rf} + EI_{et} + EI_{cp} + EI_{sc} + EI_{vt} + EI_{lt} + EI_{ck} + EI_{ph} + EI_{wp}$

Where:

EI_{rf} : Energy Intensity for Refrigeration services

EI_{et} : Energy Intensity for entertainment services

EI_{cp} : Energy Intensity for Computing services

EI_{sc}: Energy Intensity for Space cooling services

EI_{vt} : Energy Intensity for ventilation services

EI_{lt} : Energy Intensity for lighting services

EI_{ck} : Energy Intensity for cooking services

EI_{ph} : Energy Intensity for process heating services

EI_{wp} : Energy Intensity for water pumping services

Variables for Energy Intensity Calculation

Variables used for the calculations include various conversion technologies (end-use appliances) power ratings in watts (technical efficiency), stock and duration of use of the conversion technologies (Household appliances). Essentially energy intensities for the various services were calculated to determine their energy demand with the following equation adapted from Jesuleye et al. (2020b).Energy Intensity ($EI_{j,t}$)= $\frac{(HDSES_{jt})\ Energy\ Input\ (Wp)}{(AL_{jt})populationShare(million)}$

Where,

$HDES_{j,t} = AL_{j,t} * EI_{j,t}$

And,

$EI_{j,t}$: Per Household's Energy Intensity (EI) for Energy Service j (e.g. Lighting) in time period t.

JDFEWS 4 (2): 159-177, 2023
ISSN 2709-4529

$HDES_{j,t}$: Per Household's Demand D for Energy Service j (e.g. Lighting) in time period t.

Wp: Watt

$AL_{j,t}$**:** Per Household's Activity Level (AL) (Population Share) for Energy Service j (e.g. Lighting)in time period t.

4.0 Results and Discussion

Sociodemographic Characteristics of the Respondents

Table 1. revealed that more than half (58%) of the respondents were male, large percentage (41%) were between age range 31- 40 years, more than two third (68%) were married with about two third (64%) educated to undergraduate level which indicate that the respondents were mature, educated, knowledgeable to understand and interpret the questionnaire and could take decision concerning their households in response to the questionnaire.

Regarding the dwellings, largest percentage (28%) of the households had four (4) members, more than half (54%) own their homes while the largest (27%) live in three (3) bedrooms homes and more than half (56%) dwell in flats (Apartments) and majority (93%) of the homes were connected to the national grid showing that the respondents were households with suitable dwelling place for the study.

The largest percentage (39%) of the household earn within the band of one (1) and three (3) million-naira income per year and the largest percentage (41%) pay between five thousand and ten thousand naira (N5,000 - N10,000) as monthly electricity bill suggesting that the respondents have sources of income and are presently paying for their electricity consumption.

The result shows that (37%) and (39%) of the respondents earn below one million naira (N1,000,000) and between one million and three million naira (N1,000,000 – N3,000,000) respectively annually, with 31% and 41% of the respondents paying below five thousand naira (N5000) and between five thousand and ten thousand naira (N5,000 – N10,000) monthly bills respectively for the poor quality electricity supply from the national grid. The result further revealed that almost all the respondents' dwellings (93%) are connected to the national grid and prospectively intend to shift to the alternative standalone RSPV system for consistent good quality (uninterrupted supply) and quantity (sufficient supply all the time) electricity supply suggesting that consistent good quality electricity supply is indispensable to their daily household activities and one can deduce that the respondents seems to be ready to pay for the services.

Table 1. Sociodemographic Characteristics of the Respondents

Parameters	**Classification**	**F (%**
Gender	Male	190 (58)
	Female	136 (42)
Total		**326 (100)**
Age	21-30yrs	71 (22)
	31-40yrs	135 (41)
	41-50yrs	66 (20)
	Above 50yrs	54 (17)
Total		**326 (100)**
Marital Status	single	73 (22)

JDFEWS 4 (2): 159-177, 2023
ISSN 2709-4529

	married	223 (68)
	Divorced	19 (6)
	Widowed	11 (3)
Total		**326 (100)**
Education	Primary	4 (1)
	Secondary	24 (7)
	Undergraduate	209 (64)
	Postgraduate	89 (27)
Total		**326 (100)**
How many people, including yourself live in your home?	2	32 (10)
	3	53 (16)
	4	91 (28)
	5	74 (23)
	6 and above	76 (23)
Total		**326 (100)**
Do you own your home?	yes	151 (46)
	No	175 (54)
Total		**326 (100)**
How many bedrooms are there in your home?	1	32 (10)
	2	70 (21)
	3	119 (37)
	4	62 (19)
	5	29 (9)
	6 and above	14 (4)
Total		**326 (100)**
Which of these best describes your type of dwelling?	Duplex	40 (12)
	Bungalow	57 (17)
	Detached house	14 (4)
	Semi-detached	8 (2)
	Terraced house	5 (2)
	Flat (Apartments)	184 (56)
	Tenement(face to face)	18 (6)
Total		**326 (100)**
Is your dwelling connected to national grid?	Yes	303 (93)
	No	23 (7)
Total		**326 (100)**
Which of the following bands best represent your approximate total household income per year (N)?	Less than 1m	122 (37)
	1m - 3m	123 (39)
	3m - 5m	51 (16)
	5m - 10m	24 (7)

JDFEWS 4 (2): 159-177, 2023
ISSN 2709-4529

	10m - 20m	5 (2)
	Over 20m	1 (0)
Total		**326 (100)**
What is your average monthly electricity bill (N)?	Below 5,000	102 (31)
	5000 – 10,000	135 (41)
	10000 – 15,000	29 (9)
	15000 - 20000	24 (7)
	Above 20000	36 (11)
Total		**326 (100)**

Table 2. shows the household energy intensity for nine categories of household energy services namely refrigeration services, entertainment services, computing services, space cooling services, ventilation services, lighting services, cooking services, process heating services, and water pumping services demanding RSPV technology generation electricity by potential adopters in the study area. The table indicates that Refrigeration services, has a total appliance wattage of 280watts, total average number of end use appliances in use per household/day is 1.1 and average appliance usage hours per household per day is 8.9 while the energy intensity is 1.06kWh/hh/day.

The entertainment services have a total appliance wattage of 190watts, total average numbers of appliances in use/household/day of 2.1, total average appliance usage of 10.7 Hours/Household/Day and energy intensity of 0.84kWh/hh/day. The Computing services have a total appliance wattage of 665 watts, 23.3 as average numbers of appliances in use/household/day, 38.8 Hours/Household/day average appliance usage with a total of 0.97kWh/hh/day as the energy intensity. The appliance wattage for space cooling services is 1492 watts, number of appliances in use/household/day is 0.6, Hours/Household/day average appliance usage is 2.9 with 7.59 as the energy intensity. Ventilation services have a total of 155 watts as end use appliance wattage, 2.6 as number of appliance in use/household/day, 9.5 Hours/Household/Day as average appliance usage and energy intensity of 1.46kWh/hh/day. The Lighting services have a total average end use appliance wattage of 75 watts, 5.5 as average numbers of appliances in use/household/day, 9.5 Hours/Household/day average appliance usage with a total of 1.42kWh/hh/day as the energy intensity.

The table further reveals that for cooking services, electric stoves have wattage of 2500 Watts, the average number of the appliance per household is 0.5 while the average appliance usage hours per household per day is 1.7 and the appliance energy usage is 2.77kWh/hh/day in the study area. For process heating services, the total average end use appliance wattage is4670 watts, 2.7is average numbers of appliances in use/household/day, 6.6 Hours/Household/day is average appliance usage with a total of 6.43kWh/hh/day as the energy intensity. For water pumping services, Water pump wattage is 1119 watts, average number of appliance in use/household/day is 0.5, average appliance usage is 1.7 Hours/Household/day, and the energy intensity is 1.89kWh/hh/day.

Furthermore, the result indicates that the numbers of energy consuming appliances namely, washing machine (2,100w), electric stove (2,500w), water pump (1,119w) and Air-conditioner (1492w) are relatively few compared to other appliances with lower wattages. It can be deduced that the respondents are conscious of the quantity of the energy to be consumed by these appliances therefore intend not to use higher energy consuming appliances and seems to seek alternative means as the services of these household appliances are essential.

JDFEWS 4 (2): 159-177, 2023
ISSN 2709-4529

Table 2 **Household Energy Intensity for RSPV Technology**

Energy Services	End use Appliances	End use Appliance wattage	Average no. of end use Appliances in use/Household/day	Average Appliance usage Hours/ Household/Day	Total end use appliance energy usage (kWh/hh/day)
Refrigeration services	Refrigerators	100	0.6	4.6	0.46
	Freezers	180	0.4	4.3	0.60
Total		**280**	**1.1**	**8.9**	**1.06**
Entertainment services	Flat screen TV	100	0.9	5.2	0.64
	Radio	70	0.6	2.7	0.15
	VCD/DVD player	20	0.6	2.8	0.05
Total		**190**	**2.1**	**10.7**	**0.84**
Computing services	charging of Phone	5	2.5	5.7	0.38
	Computer	60	0.7	2.4	0.17
	Printer	600	0.2	0.7	0.42
Total		**665**	**3.3**	**8.8**	**0.97**
Space Cooling services	Air conditioner	1492	0.6	2.9	7.59
Total		**1492**	**0.6**	**2.9**	**7.59**
Ventilation Services	Ceiling fan	85	1.6	5.0	0.98
	Standing fan	70	1.0	4.5	0.48
Total		**155**	**2.6**	**9.5**	**1.46**
Lighting services	Incandescent bulbs	60	1.7	3.5	0.92
	Energy saving bulbs	15	3.8	5.9	0.50
Total		**75**	**5.5**	**9.5**	**1.42**
Cooking services	Electric stove	2500	0.5	1.7	2.77
Total		**2500**	**0.5**	**1.7**	**2.77**
Process heating services	Shaving kits	20	0.5	1.1	0.02
	Pressing iron	1200	0.8	1.5	1.63
	Microwave oven	900	0.4	0.9	0.80
	Blender	450	0.6	1.6	0.60
	Washing machine	2100	0.5	1.6	3.38
Total		**4670**	**2.7**	**6.6**	**6.43**

JDFEWS 4 (2): 159-177, 2023
ISSN 2709-4529

Water pumping services	Water pump	1119	0.5	1.7	1.89
Total		**1119**	**0.5**	**1.7**	**1.89**

Table 3. revealed that the total household energy services electricity demand for RSPV technology by the potential adopters is 24.43 kWh/day. Consistent with the report of [45] that cooling services consumes the bulk of household energy demand in hotter climates, the result indicates that space cooling services have the highest energy intensity, 7.59kWh/hh/day (31.1%) as shown in figure 2.

Table 3. Household Energy Services Electricity Demand for RSPV Technology

Energy Services	**Household Energy Intensity (kWh/hh/day)**	**(%)**
Refrigeration services	1.06	4.3
Entertainment services	0.84	3.4
Computing services	0.97	4.0
Space Cooling services	7.59	31.1
Ventilation services	1.46	6.0
Lighting services	1.42	5.8
Cooking services	2.77	11.3
Process heating services	6.43	26.3
Water pumping services	1.89	7.7
Total	**24.43**	**100.0**

JDFEWS 4 (2): 159-177, 2023
ISSN 2709-4529

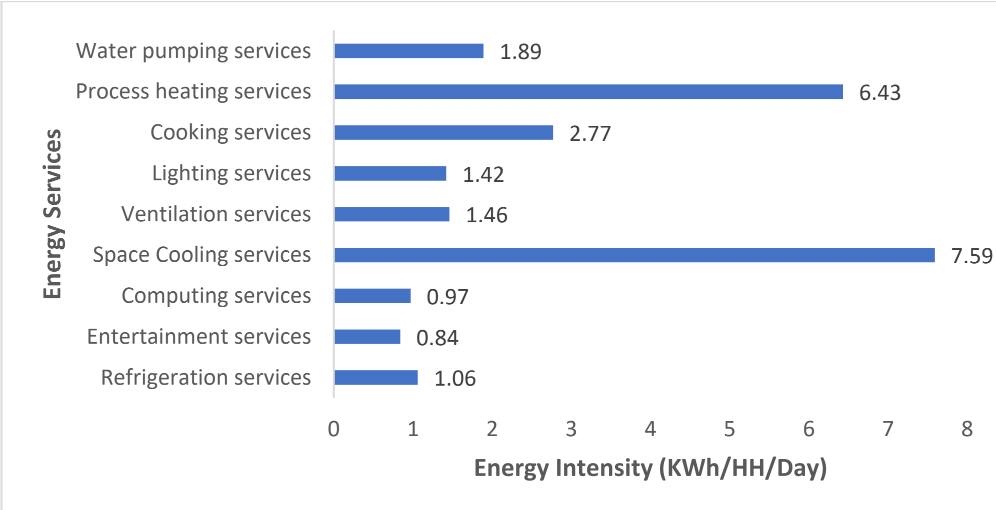

Figure 2 Household energy intensity for RSVP Technology

The total electricity demand from the solar modules is calculated thus:

The total household electricity demand from the PV modules = Total household electricity demand x 1.3

The total household electricity demand from the PV modules = 24.43 x 1.3 = 31.59kWh/day

And the total PV panel capacity per household is:

$$\text{Total wattage of PV panel capacity required} = \frac{\text{Total household electricity demand from the PV modules}}{\text{Panel Generation Factor for Nigeria}}$$

$$= \frac{31.59\text{kWh/day}}{3.41} = 9.2639 \text{ kW}$$

***Note**: 1.3 is the multiplying factor to cater for the energy lost from the solar modules and Panel generator factor (PGF), 3.41 for Nigeria is the varying factor used to calculate the size of the solar PV cells (modules) which depend upon the global geographic location, specifically the climate of the solar PV system, site location. [46,47]*

This aligns with the findings of [42] who simulate the size of PV system in three local government areas in the metropolitan area of Lagos state. The base case scenario in their study indicates that the PV panel capacity ranges from 0.3 to 76 kW for different building types in the study area.
In addition, the rooftop area needed for the capacity required is calculated as follows:

PV power rating per module = 400 W

The number of solar panels required for the capacity required = 9.2639 kW/400 W

= 23.16 ≈ 24 panels

JDFEWS 4 (2): 159-177, 2023
ISSN 2709-4529

The rooftop area needed for the capacity required = number of solar panels x area of one solar panel.

$$= 24 \times 2.32 = 55.68 \text{ m}^2$$

The study of [48] and [42] in the Southwest geopolitical zone of Nigeriaindicated that the rooftop area of typical buildings is: Tenement(Face-me-I-face-you) -156.78 m^2;traditional court - 282.24 m^2; flat apartment - 280.72 m^2; single family bungalow - 332.12 m^2 and duplex - 218.3 m^2.The result indicates that the required solar panel sizes can be accommodated by the rooftop areas of buildings in south west Nigeria according to literature.For dwellings such as flat (apartments) and Tenement(Face-me-I-face-you)occupied by 56% and 6% of the respondents respectively which are multi-occupancy in nature, there may be roof space limitation to accommodate the solar module panels for all the occupant households. Hence the energy intensities can be improved in order to reduce the capacity and the number of PV panels per household in order to accommodate all the occupant households while simultaneously maintaining or increasing the output level of the energy services [42].

The Pareto analysis in figure 3. shows that the energy intensities for space cooling services (31.1%), process heating services (26.3%) and cooking services (11.3%) constitute more than two third (68.7%) of the total household energy demand suggesting the potential for improvement and concentration of improvement efforts and resources on the energy intensities of these services in descending order.

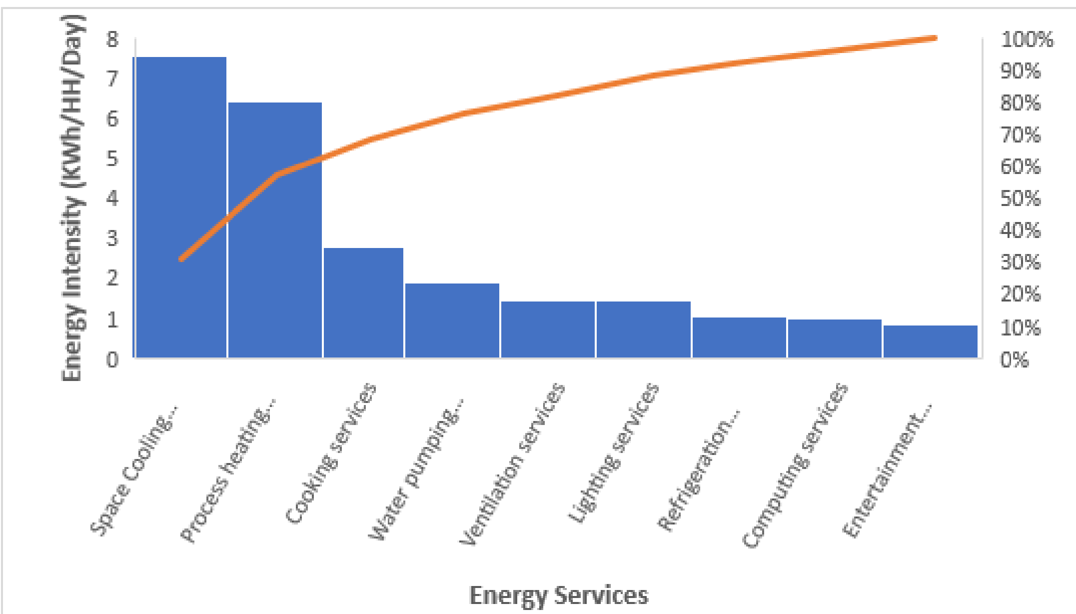

Figure 3. Pareto Analysis of Household Energy Intensity for RSPV Technology

Figure 4. shows the analysis of the household energy conversion technologies (Household appliances) with air conditioner in the space cooling services having the highest energy consumption value of 7.59 kWh/hh/day and shaving kits having the lowest energy consumption value of 0.02 kWh/hh/day. The Pareto analysis in Figure 5. indicates that the most important few energy conversion technologies (household appliances) that needs urgent improvement attention are four items namely, air conditioner (7.59kWh/hh/day) in space cooling services, washing

JDFEWS 4 (2): 159-177, 2023
ISSN 2709-4529

machine (3.38kWh/hh/day) in process heating services, electric stove(2.77kWh/hh/day) in cooking services and water pump (1.89kWh/hh/day) in water pumping services demanding 15.63kWh/hh/day out of the twenty appliances that demands a total of 24.43kWh/hh/day from RSPV.

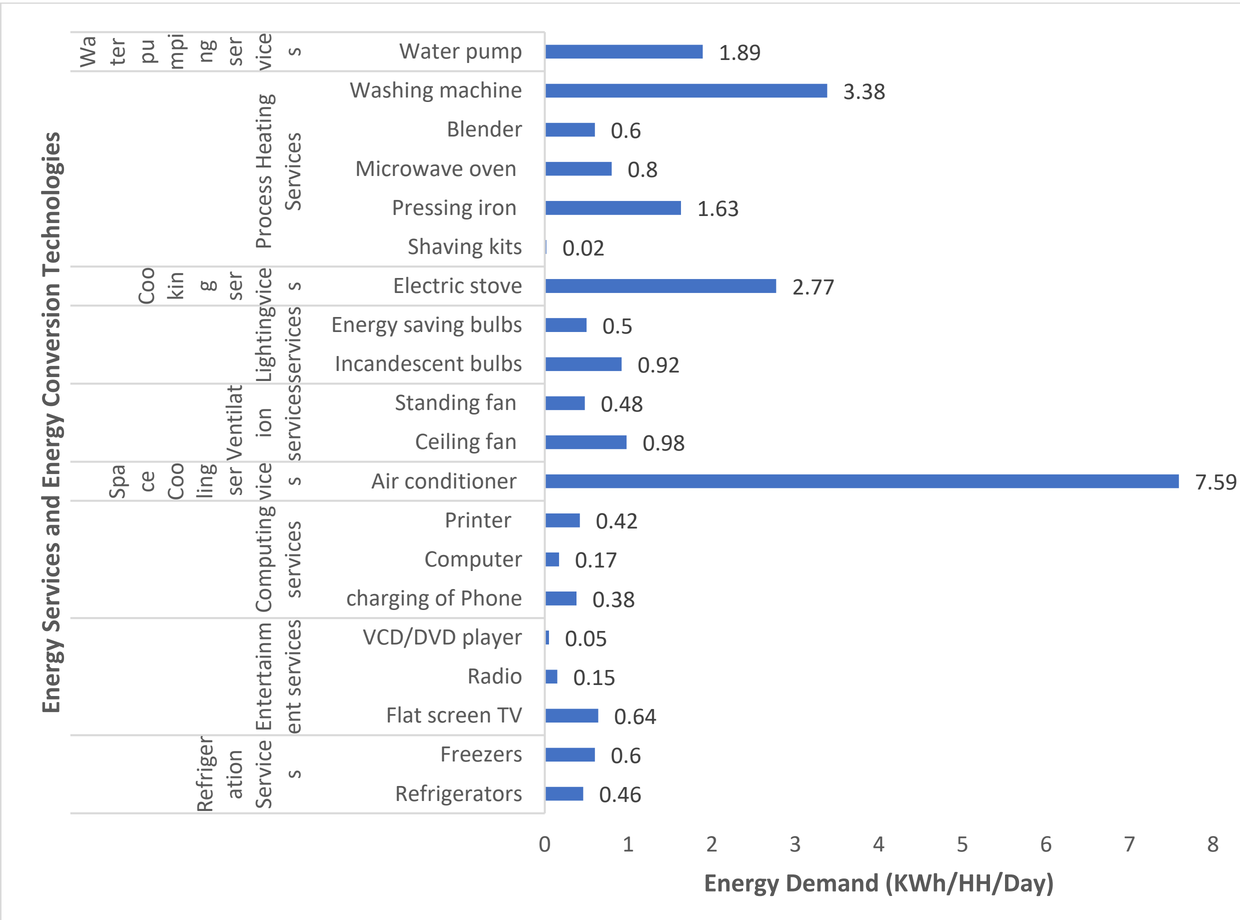

Figure 4. Household Energy Conversion Technologies Electricity Demand

Journal of Digital Food, Energy & Water Systems [JD-FEWS]

JDFEWS 4 (2): 159-177, 2023
ISSN 2709-4529

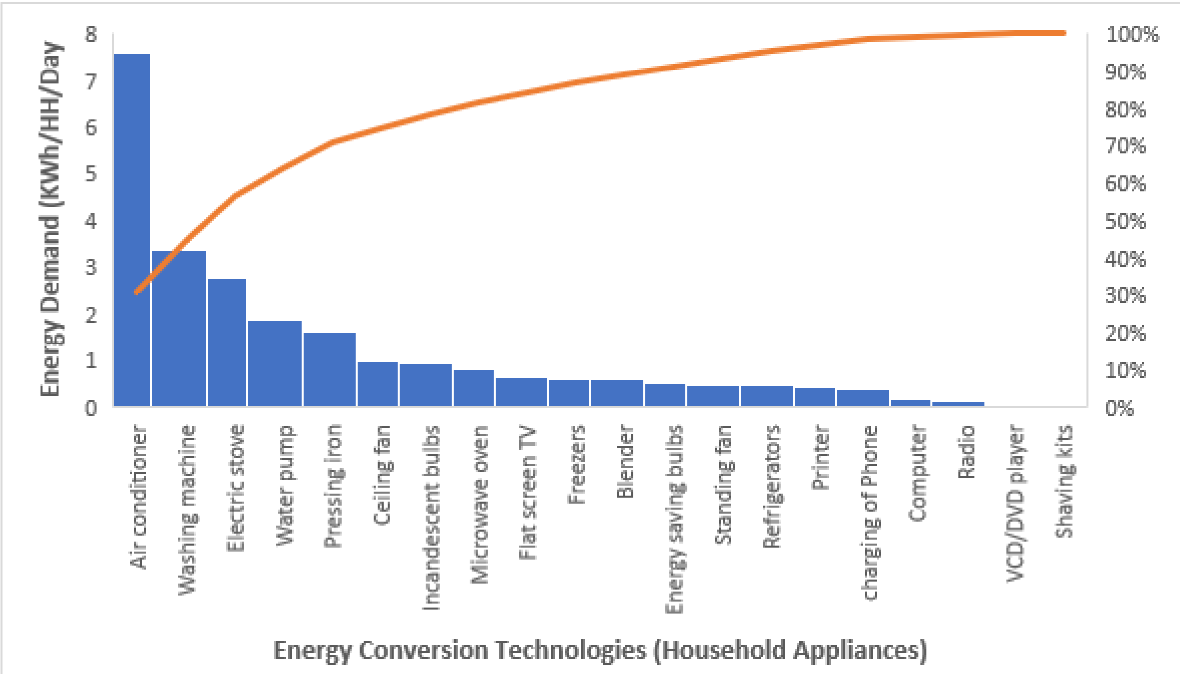

Figure 5 Pareto Analysis of Electricity Demand of Energy Conversion Technologies

The implication is that replacing these conversion technologies (Air conditioner, washing machine, electric stove and water pump) in descending order with higher energy efficient conversion technologies will significantly reduce the energy intensity of the energy services (electric load), the capacity and numbers of the PV panels while the system delivers the same or increase output level of energy services.

5.0 Conclusion and Recommendations

The study evaluates the prospective energy services demand for RSPV technology generated electricity by potential household RSPV adopters to effectively plan the deployment of RSPV technology in Lagos state, Nigeria plagued with endemic epileptic supply of grid electricity. The study provided information on the proposed electricity consumption by household appliances for energy services and concludes that each household demands 24.43kWh/hh/day of electricity to meet their energy services with the total demand of 31.59kWh/hh/day from the solar module panel. However, the result shows that the respondents seems to be conscious of the energy consumption and carefully select household appliances based on the energy requirements of the appliances suggesting that the daily energy demand should be planned, monitored and controlled to minimize the demand.The study recommend that the energy intensity for the energy services could be improved by increasing the efficiency and effectively monitor the performance of the household appliances vis-a-viz the operation and performance of the stand-alone RSPV system to minimise the energy demand and optimize the energy services output. The study further recommends government intervention with dedicated policy to guide adoption of high efficiency standard for household appliances and appropriate financial schemes to support replacement of inefficient household appliances with highly efficient ones.

JDFEWS 4 (2): 159-177, 2023
ISSN 2709-4529

Further study could investigate the integration and interaction of the household appliances with the stand alone RSPV system to measure and track the real time household energy consumption, schedule and balance the operation time of the appliances, identify and isolate high energy consuming appliances to minimise the energy consumption and optimise the performance of both the supply and demand system The study could be conducted in other regions of Nigeria for comparism and to have a national understanding of energy services demand for electricity from RSPV technology. Additionally, economic feasibility and behavioural acceptability of RSPV technology could be investigated for effective planning of the energy system transformation.

References

[1] F. Arroyo, L. Miguel, the trends of the energy intensity and CO_2 emissions related to final energy consumption in Ecuador: Scenarios of national and worldwide strategies, Sustainability, December (2019) DOI: 10.3390/su12010020.

[2] REN21 Renewables 2023 global Status report collection, global overview (Paris: REN21 Secretariat) (2023) ISBN 978-3-948393-11-3

[3] E. Amoako, J. T. Wilson, Environmental behavior factors influencing the outlook of Chinese college students on the domestic adoption of solar photovoltaic technology, Undergraduate Review 13 (2017) 7-30. Available at: http://vc.bridgew.edu

[4] O. A. Jesuleye, A. O. Adepoju, O. F. Arigbede, Status of solar PV utilization for energy services in the Nigerian housing estate, International Journal of Engineering, Applied Sciences and Technology 4(10) (2020) 386-394

[5] S. Ahmad, R. Tahar, M. Bin, J. K. Cheng, & L. Yao, Public acceptance of residential solar photovoltaic technology in Malaysia, Environment Behaviour. 34 (2017) 740–756

[6] O. A. Jesuleye, O. F. Arigbede, A. O. Adepoju, Factors influencing solar photovoltaic utilization for energy services among residential in Akure, Nigeria Journal of Energy Research and Reviews 4(3) (2020) 14-28. /undergrad_rev/vol13/iss1/5

[7] A. Adepoju, O. Jesuleye, O. Arigbede, Solar photovoltaics contribution to energy mix in selected Nigerian estates, Archives of Business Research 8(3) (2020) 131-164

[8] O. Olabisi, Forecasting Nigeria's electricity demand and energy efficiency potential under climate uncertainty. PhD dissertation, University of Tennessee. (2021) https://trace.tennessee.edu/utk_graddiss/7012

[9] A. Adepoju, K. J. Ekundayo, A. K. Oladiipo, Household energy conservation behaviour: A Socio-economic perspective, Journal of Digital Food Energy & Water Systems 4(1) (2023) 1-24, ISSN 2709-4529

[10] E. O. Diemuodeke, A. Addo, I. Dabipi-Kalio, C. O. C. Oko, Y. Mulugetta, Domestic energy demand assessment of coastline rural communities with solar electrification, Energy and Policy Research, 4:1(2017) 1-9, DOI: 10.1080/23815639.2017.1280431

[11] K. Muchiri, J. N. Kamau, D. W. Wekesa, C. O. Saoke, J. N. Mutuku, J. K. Gathua, Energy demand and its implication on wind/pv system sizing in Machakos, Kenya. International Journal of Sustainable and Green Energy. 10(3) (2021) 92-98. doi: 10.11648/j.ijrse.20211003.12

[12] A. I. Ugulu, C. Aigbavboa, Assessing Urban Households' Willingness to Pay for Standalone Solar Photovoltaic Systems: A Case Study of Lagos, Nigeria, Journal of sustainable development Energy Water Environmental System, 7(3) (2019) 553-56.

[13] K. Olaniyan, B. C McLellan, S. Ogata, T. Tezuka, Estimating residential electricity consumption in Nigeria to support energy transitions, Sustainability 10, (2018)1440 doi:10.3390 /su10051440

[14] C. L. Azimoh, P. Klintenberg, C. Mbohwa, F. Wallin, Replicability and scalability of mini-grid solution to rural electrification programs in sub-Saharan Africa, Renew. Energy, (June 2017) 222e231, https://doi.org/10.1016/j.

[15] O. A. Jesuleye, Solar PV demand for lighting in nigerian remote villages International Journal of Management and Applied Science 3 (2017) 10ISSN: 2394-7926

[17] A. J. Njoh, S. Etta, I. B. Ngyah-Etchutambe, L.E.D. Enomah, H. T. Tabrey, U. Essia, Opportunities and challenges to rural renewable energy projects in Africa: Lessons from the Esaghem Village, Cameroon solar electrification project, Renew. Energy 131 (Feb 2019) 1013e1021, https://doi.org/10.1016/ j.renene.

[18] B. K. Sovacool, Conceptualising urban household energy use: climbing the "Energy Services Ladder", Energy Policy 39 (2011).1659–1668.

JDFEWS 4 (2): 159-177, 2023
ISSN 2709-4529

[19] J. Cravioto, E. Yamasue, H. Okumura, K. N. Ishihara, Energy service satisfaction in two Mexican communities: a study on demographic, household, equipment and energy related predictors, Energy Policy 73 (2014) 110–126, https://doi.org/10. 016/j.enpol.
[20] G. Kalt, D. Wiedenhofer, C. Görg, H. Haberl, Conceptualizing energy services: A review of energy and well-being along the Energy Service Cascade. Energy Research & Social Science 53 (2019) 47-58. 10.1016/j.erss
[21] M. A. Pedrasa, T. Spooner, I. MacGill, An energy service decision-support tool for optimal energy services acquisition Centre for Energy and Environmental Markets University of New South wales (2010).
[22] M. J. Fell, Energy services: a conceptual review. Energy Research and Social. Science. 27 (2017) 129–140 https://doi.org/10.1016/j.erss.
[23] L. C. Hunt, D. L. Ryan, Economic modelling of energy services: Rectifying mis specified energy demand functions, surrey energy Economics Centre, University of Surrey, Guildford, UK (2014) Available at http://www.seec.surrey.ac.uk/research/SEEDS/SEEDS147.pdf
[24] M. G. Oladokun I. A. Odesola, Household energy consumption and carbon emissions for sustainable cities – A critical review of modelling approaches, International Journal of Sustainable Built Environment 4 (2015) 231–247
[25] M. Hart, R. de Dear, Weather sensitivity in household appliance energy end-use. Energy Build. 36 (2004)161–174.
[26] Ruffell, An econometric analysis of the household demand for electricity in Great Britain by R.J., Ruffell. Scottish Academic Press (1977).
[27] I. Ajzen, The theory of planned behaviour. Organ. Behav. Human Decis. Processes 50 (2) (1991) 179–211.
[28] J. Keirstead, Evaluating the applicability of integrated domestic energy consumption frameworks in the UK. Energy Policy 34 (17) (2006)3065–3077.
[29] S. Natarajan, J. Padget, L. Elliott, Modelling UK domestic energy and carbon emissions: an agent-based approach. Energy Build. 43 (2011) 2602–2612.
[30] L. Lutzenhiser, A cultural model of household energy consumption. Energy 17 (1) (1992) 47–60.
[31] G. Hitchcock, An integrated framework for energy use and behaviour in the domestic sector. Energy Build. 20 (1993) 151–157.
[32] M. Kavgic, A. Mavrogianni, D. Mumovic, A. Summerfield, Z. Stevanovic, M. Djurovic-Petrovic, A review of bottom-up building stock models for energy consumption in the residential sector. Build. Environ. 45 (2010) 1683–1697.
[33] S. Kelly, Do homes that are more energy efficient consume less energy? a structural equation model for England's residential sector, EPRG Working Paper, Electricity Policy Research Group, University of Cambridge (2011).
[34] Lagos state government official website, www.lagosstate.gov.ng/aboutlagos, Accessed 14/07/2023.
[35] Lagos State Government, Lagos state electricity policy (2021).
[36] Y. O. Akinwale, A. O. Adepoju, Factors influencing willingness to adopt renewable energy technologies among micro and small enterprises in Lagos State Nigeria. International Journal of Sustainable Energy Planning and Management 19 (2019) 69–82
[37] N. Nomura, M. Akai, Willingness to pay for green electricity in Japan as estimated through contingent valuation method, Applied Energy 78(4) (2004) 453-463.
[38] S. Komatsu, S. Kaneko, P. Ghosh, A. Morinaga, Determinants of user satisfaction with solar home systems in rural Bangladesh, Energy 61 (2013) 52-58.
[39] X. Guo, H. Liu, X. Mao, J. Jin, D. Chen, S. Cheng, Willingness to pay for renewable electricity: A contingent valuation study in Beijing, China, Energy Policy, 68 (2014) 340-347.
[40] T. Arega, T. Tadesse, Household willingness to pay for green electricity inassessment and evaluation in higher education 33 (2017) 301–14.
[41] S. Abdullah, P. Mariel, Choice experiment study on the willingness to pay to improve electricity services, Energy Policy 38(8) (2010) 4570-4581.
[42] K. E. Enongene, F. H. Abanda, I. J. J. Otene, S. I. Obi, C. Okafor, The potential of solar photovoltaic systems for residential homes in Lagos city of Nigeria. Journal of environmental management, 244 (2019) 247–256. ttps://doi.org/10.1016/j.jenvman.2019.04. 039
[43] R. Jacobs, Sampling a population in educational research. Villanova University: Department of Public Administration (2016).
[44] T. Yamane, Statistics: An Introductory analysis, 2nd Edition, New York: Harper and Row (1967).
[45] IEA, Market report series: Energy Efficiency (2018) – Analysis [WWW Document]. URL. IEA, 1.4.21. https://www.iea.org/reports/energy-efficiency-2018.
[46] A. A. Adewale, A. I. Adekitan, O. J. Idoko, F. I. Agbetuyi, I. A. Samuel, Energy audit and optimal power supply for a commercial building in Nigeria, Cogent Engineering, 5:1 (2018) 1546658.

JDFEWS 4 (2): 159-177, 2023
ISSN 2709-4529

[47] T. Somefun, C. Awosope, A. Abdulkareem, J. Ojo, E. Amuta, T. Sanni, Cost implications analysis of grid supplied electricity and solar source of electricity in Nigeria, TELKOMNIKA Telecommunication, Computing, Electronics and Control 18(6) (2020) 3258~3265 .DOI: 10.12928/.v18i6.13558

[48] A. O. Eruola, G. C. Ufoegbune, A. O. Eruola, J. A. Awomeso, C. O. Adeofun, O. A. Idowu, A. Sowunmi, Qualitative and quantitative assessment of rainwater harvesting from rooftop catchments: case study of oke-lantoro community in Abeokuta, Southwest Nigeria Journal of Agricultural Science and Environment 10(2) (2010).