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Forecasting Solar PV Demand Split and Fuel Wood Usage Reduction in Eriti and Oke-Agunla Villages in Nigeria

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Author's contribution

The sole author designed, analysed, interpreted and prepared the manuscript.

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ABSTRACT

The study examined solar photovoltaic demand split and fuel wood usage reduction in Eriti and Oke-Agunla villages, that were among the pilot sites for solar electrification programs in the western ecological region of Nigeria. It used questionnaire techniques to elicit information in the local dialect of the respondents, on alternative energy sources for provision of energy services from each of the household's heads, representing solar PV users, in all the 371 households that constitute about 13.4 percent of the 2,778 dwellers in the two villages, for the base year 2020. Specifically, at the rate of the observed 8 dwellers per household, data were obtained from 179 respondents, out of a total of 1,434 dwellers in Eriti village. Likewise, at the rate of the observed 7 dwellers per household, data were also obtained from 192 respondents, out of a total of 1,344 dwellers in Oke-Agunla village. Model for Analysis of Energy Demand (MADE-II) was used for the study. The study showed that the total lighting demand share for solar PV in each of the villages' total energy demand mix in 2020 was insignificantly low at 5.1 percent share in Eriti village and 6.1 percent share in Oke-Agunla village. Contrariwise, firewood demand maintained as high as 94 and 92 percent share for Eriti and Oke-Agunla villages respectively in the total energy demand mix and by 2030, in Oke-Agunla village, 3-stones-firewood stoves demand for cooking fell drastically from 77%

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to 30% share, whereas improved firewood stoves demand for cooking rose astronomically from 11% share in 2020 to 45% share by 2030. Nigerian government should adopt such best policy intervention scenario for all the rural areas in the country.

Keywords: Solar PV demand split; fuelwood usage; cooking; lighting; Eriti village; Oke-Agunla village.

1. INTRODUCTION

The size of demand for energy generally is affected by several factors, prominent among which include population, geographical and economic characteristics of an area [1]. In Nigerian case, the peculiar problems associated with energy use, especially fuel wood usage by larger percentage of the population in three ecological regions of the county are: deforestation in the southwest, desertification in the north generally and soil erosion in the east [2]. Closely connected to this are environmental pollution caused by gas flaring in the fourth ecological southern oil producing region of the country [3,4]. Thus, it is pertinent to give due considerations to the protracted environmental issue of deforestation as a peculiar ecological problem in the southwestern Nigeria, occasioned by the domineering over 85 percent firewood usage in the total energy consumption pattern by the rural dwellers in this region of the country [5,6]. Furthermore, in analyzing factors influencing solar electricity share on energy mix for energy services provision in the region, due considerations should also be given to forest reserve assessment issues [7,8]. Several authors had argued that households income, households stove choice decision and their link with energy ladder hypothesis and energy stacking theories are among issues that are worthy of consideration in rural energy demand analysis [9,10,11]. Moreover, some other authors have even established in one way or the other, the significance of modeling approach and its applications in rural energy demand analysis with their environmental impact [12,13,14,15,16]. The issues revolving around the dependency of fuel type choice and stove adoption choices on a complex interaction between economic, social, cultural and environmental factors, that formed the key findings of the study conducted by Kowsari, 2013, should also be so considered in any rural based energy demand analysis [17]. More so, empirical results generated by several authors had also justified the necessity of appropriate government policy interventions, for mitigating market development barriers of off-grid renewable energy technologies, in addressing the critical subject of rural electrification and solar electricity option for improved access to energy services in Nigeria [18,19,20,21,22,23,17].

As outlined in the 2013 Nigerian National Energy Policy; Draft Revised Edition [24] and the National Renewable Energy and Energy Efficiency Policy [25], provisions were made for the coordinated development, utilization and management of all energy resources. Adequate allowance was particularly given for rural energy supply with conventional (gasolineeum products, gas, coal, electricity) and non-conventional and renewable (solar, wind, small-scale hydro, biomass, fuel wood etc.) alternatives. Emphasis was equally placed on developing and harnessing solar, wind, hydropower and wood biomass energy resources and integrating them into the national energy mix. However, these are yet to be fully integrated into the system. Although, the National Rural Electrification Program started in 1981 with the aim of connecting all the country's local government headquarters and some important towns to the national grid, currently all the 774 Local Government Headquarters in the country have been connected. However, as in many other developing countries even when a town or village is connected to the grid, local distribution networks may be very slow to develop, as is frequently the case in Nigeria, when government funding for the distribution network is unavailable [23]. Deployment of renewable alternatives for electricity offers a viable option for the required expansion nevertheless [26]; several structural constraints faced by the Rural Electrification Program makes these potentials of no effect. The country requires over 26,561 MW of electricity to meet present demand. Current output is around 4,300 MW, much of which is not put to use due to poor power transmission and distribution infrastructure [27]. Secondly, the carried out institutional reforms – which aimed at effective operational functioning of a national regulator, unbundling the of then Power Holding Company of Nigeria (PHCN), and privatizing its business units through the establishment of the distribution companies in various zones of the country is yet to yield the most desirable result. Third, the rural electrification program has been supply driven by political considerations rather than social and economic considerations as demonstrated by the poor performance of such projects years after installations without appropriate sustainable plans [28,29]. This has led to unnecessarily high costs and done little to control mismanagement and corruption. Fourth, funding is a constraint as almost all funding for rural electrification comes from the federal and state budgets. It is clear that grid extension alone will not meet universal rural electrification coverage cost - effectively within a reasonable timeframe, yet off-grid options such as renewable energy technologies to remedy the situation still suffers major barriers to market development, despite the willingness of the villages to adopt the technology [18,30]. The 2019, International Energy Agency's Renewables Market Report [31], estimated 50 percent growth in the global total renewable-based power capacity between 2019 and 2024, with solar PV accounting for 60 percent of the rise. It laid emphasis on the need to surmount policy and regulatory uncertainty, high investment risks and system integration of wind and solar PV to fast track the deployment of renewable. Therefore, in line with this global solar PV penetration forecast, conducting such a study like this which quests to develop appropriate framework for the best policy intervention for solar PV demand split and fuel wood usage reduction in Nigerian villages becomes imperative.

Furthermore, in addressing pertinent research questions that constantly agitate the minds of energy analysts and policy makers, in their quest for optimal solutions to the protracted plaguing Nigerian rural energy challenges, this paper examined the current status of solar PV and other energy sources for provision of energy services and also analyzed the best policy option for the optimal contribution of solar PV and fuel wood usage reduction in the future rural energy mix, in the study area. This was done with a view to stimulate policy debate on policy research framework, required as solution input for widespread and accelerated use of solar PV in the rural areas of the country.

2. MATERIALS AND METHODS

2.1 Materials

2.1.1 Socio-economic parameters for data analysis in the study areas

Since, population data, urbanization rate and disposable income distribution pattern of villagers had widely been adjudged in literature as the key variables for examining the current and future status of solar PV and other energy sources [17,32]. This therefore, explains the reason for the survey of the pilot sites for national and foreign assisted solar electrification programs in the southwestern ecological region of the country with particular focus on Oke-Agunla village in Ondo State and Eriti village in Ogun State as relevant sampled villages for this study because of their peculiarity. Reference was particularly made to user's income distribution pattern and not fuel prices because historical evidence in Nigeria already shows strong correlation between income levels and type of energy use [33]. Which means that low income earners are more disposable to cheaper and inefficient fuel use while the reverse is the case for high income earners who are majorly unbar dwellers. Thus, this study used questionnaire techniques to elicit information in the local dialect of the respondents, on alternative energy sources for provision of energy services from each of the household's heads, representing solar PV users, in all the 371 households that constitute about 13.4 percent of the 2,778 dwellers in the two villages, for the base year 2020. Specifically, at the rate of the observed 8 dwellers per household, data were obtained from 179 respondents, out of a total of 1,434 dwellers in Eriti village. Likewise, at the rate of the observed 7 dwellers per household, data were obtained from 192 respondents, out of a total of 1,344 dwellers in Oke-Agunla village. The questionnaire elicited information on alternative final energy sources (e. g. kerosene, diesel, gasoline, solar panels, fuel wood, charcoal, kerosene, electricity for process heat), for provision of useful energy services (lighting, ventilation, refrigeration, cooking heat, process heat etc.), the energy that is produced after the last conversion [34]. This form of energy is utilized together with other production factors in producing goods and providing services. Whereas, final energy is the content of energy through energy carrier that is available to final consumer. This is the amount of energy that goes into end use technologies as a source of energy [2]. The questionnaire also elicited information on technical, socio-economic and demographic issues as well as key policies impacting on widespread supply and utilization of solar PV to reduce fuel wood usage in the rural areas. Data and information obtained from the questionnaire were analyzed to examine current status and future pattern of the rural energy mix over a 10 year periods from 2020 to 2030.

2.1.2 Eriti village

It is a remote rural village with no access to the national grid. It has an estimated population of 1,120 villagers in 2010 which rose to 1,434 by 2020, whose major occupation is farming and petty trading. It is located in Ward 1, Obafemi Owode Local Government Area, near Abeokuta, Ogun State. It is surrounded by other 52 villages in Ife Parapo Eriti Community. Among which are: Oluwo-Isale, Ajegunle, Arowa, Olubiyi, Akorede and Isiba villages who are not connected to the grid and do not enjoy solar PV access. The next major town to Eriti called Oba is over 12 kilometres away [1]. The solar PV installation in Eriti is part of the FADAMA II Project under the World Bank Assisted project in conjunction with the Power Holding Company of Nigeria (PHCN), Energy Commission of Nigeria (ECN) and the Ogun State Government. The profile of the Solar PV installation presented in Table 1 classifies it as solar home system and solar water pumping systems.

2.1.3 Oke-Agunla village

It is a remote rural village with no access to the national grid. It has a population estimate of 1050 villagers in 2010 which rose to 1,344 by 2020 who are mainly farmers. It is located in Akure north local government area of Ondo State. It is one of the solar electrification pilot projects under the Master Plan Study for Utilization of Solar Energy being jointly coordinated by, Energy Commission of Nigeria, Japan International Cooperation Agency (JICA) and Ondo State Government. Going by the profile of the solar PV installation shown in Table 2, one could typify it as a solar home and solar clinic systems.

Table 1. Profile of solar PV installation in Eriti village, Ogun State

SN	Item	Remark
1	Estimated Population of the Village	1120 (2010), 1434 (2020)
2	Average Number of Households in the village	140 (2010), 179 (2020)
3	Average Number of Persons Per Household	8
4	Number of Households Connected	(i) 20 stand alone 65W panels per household with battery. (ii) 10 stand alone 70W panels for Street Light Poles. (iii) 10 stand alone 70W Panels for water pumping (iv) 3 stand alone 65W panels for a church, a mosque, school
5	Type of Solar PV Installation	Solar Home System and Solar Water Pumping System.
6	Year of Installation of PV System	2006
7	Capacity of the PV (panels) Installed	4.0 KW
8	Major Components of the PV Installation	205 solar panels and accessories, 40 storage batteries (12 volt. & 150 AmH), 4 inverters, 12 battery controllers and 8 ELCB breakers, pumping machine, 1500 litres water tanks.
9	Objective of the PV Installation	Generate Electricity for the village.
10	Sponsors of the PV Installation	World Bank FADAMA II Project, PHCN and ECN.
11	Status of the Installation	Working well but not enough to meet village demand.
12	Monitoring & Evaluation	ECN, PHCN
13	Sustainability	Continuous training of village technicians who work with experts at ECN for maintenance of the installation

Source: [1,35,36,37,38,39,40,41]

Table 2. Profiles of solar PV installation in Oke-Agunla village, Ondo State

SN	Item	Remark
1	Estimated Population of the Village	1050 (2010), 1344 (2020)
2	Average Number of Households in the village	150 (2010), 192 (2020)
3	Average Number of Persons Per Household	7
4	Number of Households Connected	(i) 40 stand alone 70W panels per household with battery. (ii) 10 stand alone 70W panels for Street Light Poles. (iii) 10 stand alone 70W Panels for vaccine refrigeration (iv) 3 stand alone 70W panels for a church, a mosque, a school, a palace
5	Type of Solar PV Installation	Solar Home System and Solar Clinic System.
6	Year of Installation of PV System	June 2006, commissioned by former President Olusegun Obasanjo.
7	Capacity of the PV (panels) Installed	4.5 KW
8	Major Components of the PV Installation	70 solar panels and accessories, 50 storage batteries, 2 inverters, 2 battery controllers and 8 ELCB breakers, 2 big deep freezer, 15 W bulbs, 200 W bulbs.
9	Objective of the PV Installation	Generate Electricity for the village.
10	Sponsors of the PV Installation	*JICA, ECN and Ondo State Government.
11	Status of the Installation	Working well but not enough to meet village demand.
12	Monitoring & Evaluation	ECN, PHCN
13	Sustainability	Continuous training of village technicians who work with experts at ECN for maintenance of the installation

Source: [1,35,36,37,38,39,40,41]

2.2 Methods

2.2.1 Adapted model for analysis of demand for energy made-II as methodology for the study

The adapted methodology for this paper is Model for Analysis of Demand Energy (with the acronyms MADE-II), developed at the Institute for Energy Economics and Rational use of Energy, University of Stuttgart, Germany in 1989. It combines the application of statistical, econometric and engineering process techniques as appropriate for the various sectors of the rural economy. Its flexibility and applicability for demand projection over short or long period and its basic analytical approach premised upon the idea that energy is used together with other production factors to provide goods and services to the society makes it suitable in this paper for demand analysis of solar PV utilization in the study area. [32].

The conceptual framework which showed the general methodological approach of MADE-II adopted for the study is clearly highlighted in Fig. 1. As presented in, Fig. 2, MADE-II is made up of 7 Blocks of data in flow for demand analysis. Block 1 dealt with general information about useful energy level analysis, base year (2020) and future two constant five-year periods (2025, 2030), while information on development of population is presented in Block 2 (see Tables 3a and 3b for further details). Data analysis for useful energy demand in the rural households sector was treated in Block 3 (Tables 6-9 captured the implementation of this block), while Block 4 dealt with activity level in physical units e.g. kWh/Day/Village (Tables 1, 2, 4 and 5 captured the data for block 4).

Block 5 and 6 dealt with the efficiencies and penetration factors for the rural households' energy services, detailed calculations of these were presented in Tables 6 and 7. Block 7 treated the sectoral solar PV demand split for 3-Stones Firewood Stoves Cooking Heat, Improved Firewood Stoves Cooking Heat, Kerosene Stoves Cooking Heat, Incandescent Bulbs Lighting, Fluorescent Bulbs Lighting, Kerosene Lanterns Lighting, Solar Bulbs Lighting, Powering of TV, Video, Radio, Refrigeration, Fan Ventilation and Process Heat (Tables 8 and 9 summarized the implementation of block 7).

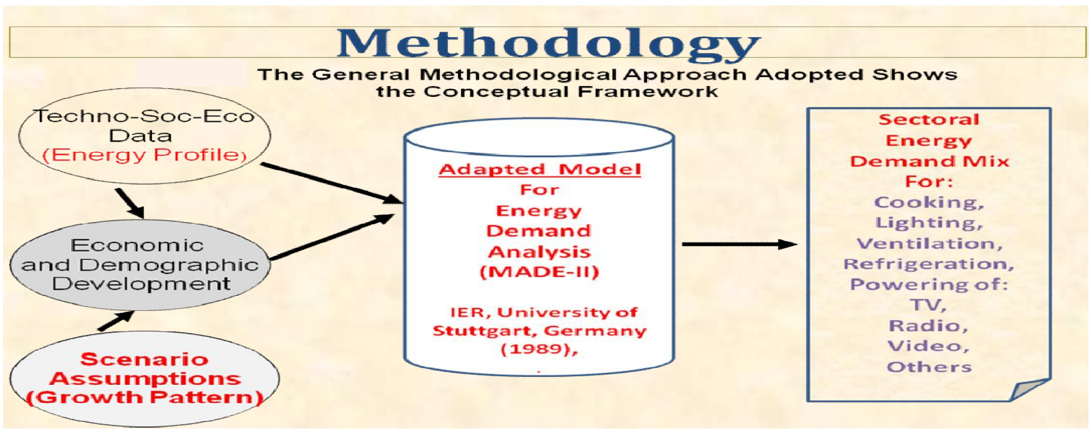

Fig. 1. The general methodological approach adopted shows the conceptual framework

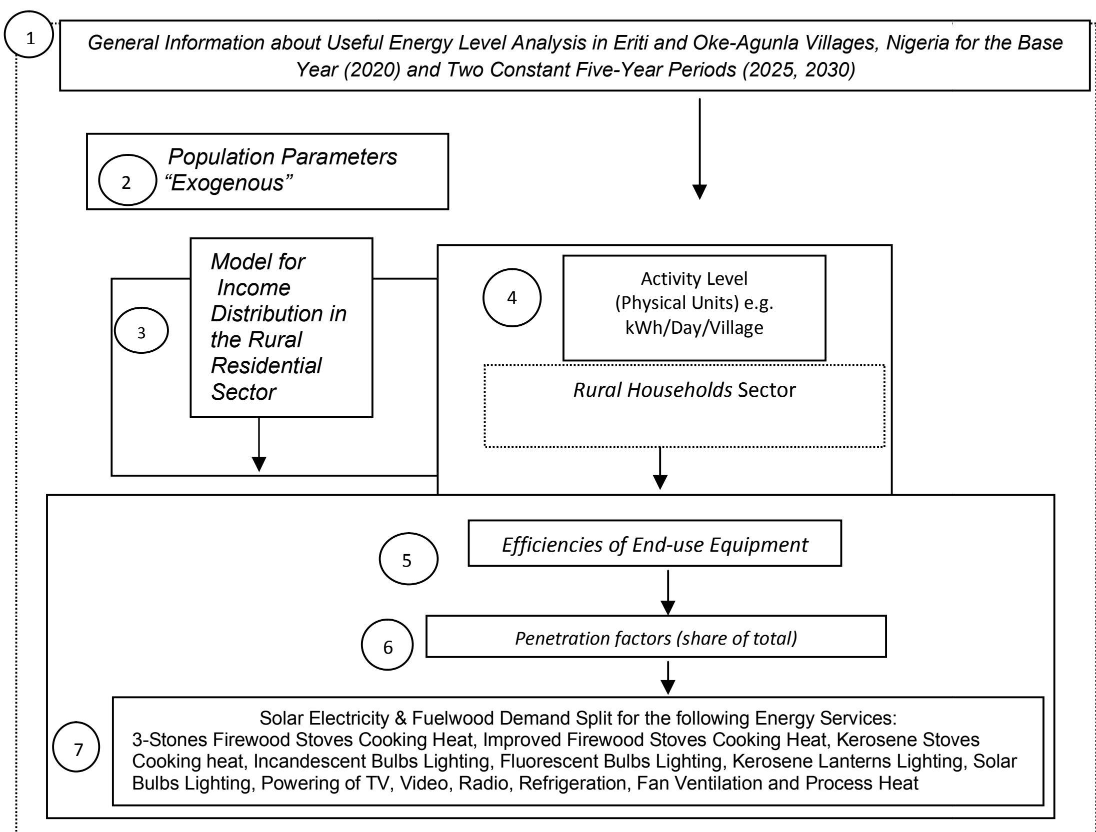

Fig. 2. Schematic diagram adapted from model for analysis of demand for energy (MADE-II), IER, University of Stuttgart, Germany, 1989

To quantify total demand for energy services in Eriti and Oke-Agunla villages, the energy consumption data obtained from conducted survey in each village were used. This involves the calculation of energy intensities as represented in equation 1 as follows:

$$\text{Energy Intensity } (EI_{j,t}) = \frac{(HDL_{j,t})\text{Energy Input (Wp)}}{(AL_{j,t})\text{Population Share (Million)}}$$

Where,

$$HDL_{j,t} = AL_{j,t} \times EI_{j,t} \qquad (1)$$

And

$HDL_{j,t}$ = Per Household's Demand D for Lighting j in time period t.
$AL_{j,t}$ = Per Household's Activity Level (AL) (Population Share & Stock of End-Use Appliances) for Lighting j in time period t.
$EI_{j,t}$ = Per Household's Energy Intensity for Lighting j in time period t
W_P = Watt

2.2.2 The study variables and measurement for quantifying sectoral demand for energy services

Transformation in the social, demographic, economical, technological and environmental issues had been empirically found to be the key forces driving the Nigerian energy system [33]. This therefore provides the basis for households' survey of each village in the study areas, thereby providing suitable means for analyzing the effect of socio-economic development and structural changes in the demand for energy services on household per household basis to achieve objective one of the study. For instance, the total solar electricity demand to provide (energy service like) lighting, for each household in each village is driving by socio-economic activities and energy intensity of that particular household. Detailed information on the household population share and size, village population and growth rate, persons per household, fuel types and consumption rate per household per day, stock of end use appliances per household and the technical efficiencies of end use appliances are used for the analysis are presented in Tables 1-7.

2.2.3 Scenario analysis techniques for model runs and future solar PV demand split and fuel wood usage reduction in the study area

The study also adopted scenario analysis techniques widely used as scientific method for dealing with the basic inherent uncertainty about future evolution of various variables driving the energy demand. This becomes essential in evaluating available policy options for optimal future contribution of solar PV and fuel wood usage reduction in the energy mix for the study areas to achieve the second study objective. Thus, in order to bring out the basic issues relating to population growth, rural socio-economic development levels and household growth rate in the study, three scenarios namely Business-As-Usual (BAU), Moderate (MOD) and Best Policy Option (BPO) were used. The basic assumptions behind the three scenarios used pertaining to this study variables are described below.

2.2.3.1 The Business-As-Usual (BAU) scenario

This is characterized by low economic development in the future. Hence, the study assumes a high population growth rate. The underlying assumption is that the economy's dependence on crude oil export will increase while government population policy will be ineffective. The share of fuel wood will be high, followed by fossil fuel and the rate of solar electric powered services in the rural energy mix will be lowest compared with other two scenarios. The villages will remain unconnected to the national grid. The income distribution expected to be more or less the same as at now (i.e. the share of population in the low income group will be reduced very slowly). Government support for provision of solar infrastructural equipment will remain the same. This scenario is more or less a pessimistic view of the Nigerian future but it is structured to demonstrate what could happen if the negative trend in the socio-economic parameters are not reversed.

2.2.3.2 The Moderate (MOD) scenario

This represents the middle of the road case to compare the pessimistic case as represented by BAU scenario and the very optimistic assumption about the future as represented by the BPO scenario. The underlying assumption is that policies to turn the economy around work but moderately. The villages will still remain unconnected to the national grid. Despite the positive development, there will be improved government support for infrastructural development and very little subsidies for increase solar appliances acquisition by the villagers for improved access to low wattage energy services such as lighting, entertainment, refrigeration and ventilation. This will be complemented by support for use of improved fuel wood stoves for cooking and commensurate reduction in 3-stones-stoves for cooking.

2.2.3.3 The Best Policy Option (BPO) scenario

This scenario assumes a successful population and solar energy policies leading to reduced population growth rate, and minimal increase in solar electric powered energy services in the energy mix for the rural areas. The economy is expected to expand very fast while the income distribution is much better with share of low income groups decreasing substantially. In spite of this, the study areas will still not be connected to the national grid even by 2030. Table 3a and 3b shows the rural population growth assumption for BAU, Moderate and BPO Scenarios for the two villages respectively.

2.2.4 Technical data and socio-economic parameters used as input for model runs for the study

It could be observed from the stock of end-use appliances and energy intensity for energy services analysis in Eriti Village (2020-2030)

Table 3a. Historical and future population growth assumption for BAU, Moderate and BPO Scenarios for Eriti Villages 2010 – 2030

	(8 Persons Per Household)					
Scenarios	**Parameters**	**2010**	**2015**	**2020**	**2025**	**2030**
BAU	**Population at 3.0% Annual Growth Rate**	1120	1298	1505	1550	1797
	Average Households per Village	140	163	188	194	225
MOD	**Population at 2.7% Annual Growth Rate**	1120	1280	1462	1670	1908
	Average Households per Village	140	160	183	209	238
BPO	**Population at 2.5% Annual Growth Rate**	1120	1267	1434	1712	1937
	Average Households per Village	140	158	179	214	242

Table 3b. Historical and future population growth assumption for BAU, Moderate and BPO Scenarios for Oke-Agunla Village 2010 – 2030

	(7 Persons Per Household)					
Scenarios	**Parameters**	**2010**	**2015**	**2020**	**2025**	**2030**
BAU	**Population at 3.0% Annual Growth Rate**	1050	1217	1411	1453	1685
	Average Households per Village	150	174	202	208	241
MOD	**Population at 2.7% Annual Growth Rate**	1050	1200	1371	1566	1789
	Average Households per Village	150	172	196	224	256
BPO	**Population at 2.5% Annual Growth Rate**	1050	1188	1344	1605	1816
	Average Households per Village	150	170	192	229	259

Source: Projected from Field Survey 2010 and 2020 presented in Table 4 obtained from the base year survey result, that 23 percent of the households' population had access to solar panels as a source of energy generation with solar bulbs as the end-use appliances to provide lighting for the required energy services for them. It also showed that 68 percent of the villagers still depended on fuel wood usage for instance, as a source of energy generation with 3-stones open air firewood stoves end-use appliances to provide cooking heat services for them. This cooking option is projected to reduce drastically to 30 percent by 2030 under the BPO Scenario. Likewise, the case of Oke-Agunla village presented in Table 5 followed the same trend with 25 percent of the households' population in possession of solar panels as a source of energy generation, using solar bulbs as the end-use appliances to provide lighting for their required energy services. 70 percent of these villagers still heavily rely on fuel wood as a source of energy generation, with 3-stones firewood stoves as the end-use appliances to provide cooking services for them. Table 6 revealed the survey data for energy intensity calculation (kWh/Household/Day) per village to be 0.72, 0.48, 0.24 and 1.98, for gasoline powered incandescent bulbs, gasoline powered florescent tubes, solar bulbs and kerosene powered lantern for lighting respectively. The energy intensity calculation (kWh/Household/Day) per village for entertainment is also 0.48, 0.9, 0.78 Radio, TV and Video respectively. Tables 7 also presented the calculated intensity for Ventilation, Refrigeration, Process Heat and Cooking 0.36, 3.6, 0.009, 7.9, and 25.6 respectively.

3. RESULTS AND DISCUSSION

3.1 Analysis of Total Energy Demand Split by Various Energy Services in the Two Villages

The results obtained from the model runs and critical issues emanating from the analysis were also pointed out as presented in Tables 8 and 9. In Table 8, it showed that Eriti village had the largest total energy demand of 3,773 kWh per day for the based year 2020. It rose to 4,366 kWh per day by 2025 and declined slightly to 4,075.2 kWh per day by 2030. The total energy demand for energy services in Oke-Agunla village as presented in Table 9, were 3,256.3 kWh per day, 4,729.8 kWh per day and 3,870.3 kWh per day in 2020, 2025 and 2030 respectively. Out of this, total energy demand for cooking maintained a domineering share of 94 percent and 92 percent share for Eriti and Oke-Agunla villages respectively. This is far higher than 87 percent recorded cooking share in the findings of Solar Cooking Archive (2011). If this were to be taken as a reflection of the general trend in the Nigerian rural villages, it means that government efforts over the years to reduce incessant dependency of the rural populace on fuel wood usage have not yielded much result. It then calls for drastic review of existing government policy over this and the need for quick action to reverse the trend.

In the total energy demand profile per village, lighting is next to cooking with 5.1 percent share in Eriti village and 6.1 percent share in

Table 4. Stock of end-use appliances for energy services analysis in Eriti Village (2020-2030)

Energy services	2020	2025	2030
Incandescent Bulbs Lighting	12	5	0
Florescent Bulbs & Other Lighting	10	5	0
Solar Bulbs Lighting	23	25	40
Kerosene Lighting	55	65	60
Total Lighting	100	100	100
3-Stones Firewood Cooking	68	45	30
Kerosene Cooking	12	15	18
Improved Firewood Cooking	20	45	52
Total Cooking	100	100	100
Radio Entertainment	8	10	15
TV Entertainment	6	13	15
Video Entertainment	6	13	15
Refrigeration	3	10	15
Process Heat	8	15	20
Ventilation	10	20	25

Note: As at 2020 no additional stock in the solar technical equipment recorded from 2010 Profile

Table 5. Stock of end-use appliances for energy services analysis in Oke-Agunla Village (2020-2030)

Energy services	2020	2025	2030
Incandescent Bulbs Lighting	10	5	0
Florescent Bulbs Lighting	11	5	0
Solar Bulbs Lighting	25	25	40
Kerosene Lighting	56	65	60
Total Lighting	100	100	100
3-Stones Firewood Cooking	70	45	30
Kerosene Cooking	12	15	18
Improved Firewood Cooking	18	45	52
Total Cooking	100	100	100
Radio Entertainment	15	18	20
TV Entertainment	7	13	15
Video Entertainment	7	13	15
Refrigeration	5	10	15
Process Heat	15	20	25
Ventilation	10	20	25

Note: As at 2020 no additional stock in the solar technical equipment recorded from 2010 Profile

Oke-Agunla village. The daily energy demand share for entertainment was 0.5 percent and 8.7 percent in Eriti and Oke-Agunla respectively, while the share for refrigeration and ventilation energy services were also less than 1 percent shares in each of the villages. Further analysis showed that, although kerosene powered lighting for the two villages was just about 5 percent share, an insignificant amount of only lest than 0.3 percent of this total lighting for the two villages were powered by solar bulbs, whereas the shares of inefficient florescent lamps was as high as 0.5 percent of the total lighting demand for Oke-Agula village in particular. This connotes a level of ignorance on the part of the villagers on financial and energy savings accruable by substituting energy efficient bulbs with florescent and incandescent bulbs. Thus, there is a need to raise the level of awareness of the villagers on this and subsequently enforce the required energy efficient measures for the village. Policy to move rural dwellers away from domineering use of kerosene for lighting to solar bulbs usage should be adopted. This should be complemented with policy that supports use of kerosene for cooking.

Table 6. Energy use data (kWh/household/day) for energy intensity calculation for lighting and entertainment in for Eriti & Oke-Agunla Villages (2020)

End-Use Appliances	Lighting				Entertainment		
	Incandescent bulbs	Florescent bulbs	Solar bulbs	Kerosene	Radio	TV.	Video
Average Usage Hours per Household per Day	6	6	6	6	6	6	6
Appliance Energy Efficiency (%)	100	100	100	*37	100	100	100
Appliance Wattage	60	40	20	0.25 litre	80	150	130
Average No of Appliances in Use per Household per Day	2	2	2	19.8	1	1	1
Daily Per Household Energy Use in Kilowatt Hours	0.72	0.48	0.24	1.98	0.48	0.9	0.78

*Source: *(Adegbulugbe et. al., 1995), Energy Efficiency of 25% is also adopted for Improved Firewood stove*

Table 7. Energy use data (kWh/Household/Day) for energy intensity calculation for ventilation, refrigeration, process heat and cooking for Eriti & Oke-Agunla Villages (2020)

Various End-Use Appliances	Fans for ventilation	Fridge for refrigeration	Grinders for process heat	Cooking		
				Kerosene stoves cooking	3-Stones firewood stoves cooking	Improved firewood stoves cooking
Average Usage Hours per Household per Day	6	6	3	4	3	3
Appliance Energy Efficiency (%)	100	100	100	*37	*12	25
Appliance Wattage	60	600	3	1.0 Litre	10kg	5kg
Average No of Appliances in Use per Household per Day	1	1	1	1	1	1
Daily Per Household Energy Use in Kilowatt Hours	0.36	3.6	0.009	7.9	25.6	12.8

Note: (i) 10 kg of hard firewood is equivalent of 0.01 Ton and 0.0022 Tons of OilEquivalent (TOE). This translates to 25.58 KWh. (Source: E/DI Energy Card, USA).

*Source: *(Adegbulugbe et. al., 1995), Energy Efficiency of 25% is also adopted for Improved Firewood Stove*

3.2 Analysis of Energy Demand Split for Entertainment, Refrigeration, Process Heat and Ventilation in the Two Villages

The distribution of energy demand for entertainment by various end-use-appliances used to provide the service is presented in Tables 8 and 9. The specific daily energy demand by TV for Eriti and stood at 6.6 kWh (0.2% share), 25.0 kWh (0.57% share) and 32.7 kWh (0.8% share) 2020, 2025 and 2030 respectively. Following the same pattern, the daily energy demand by TV in Oke-Agunla were 9.5 kWh (0.29% share), 26.8 kWh (0.57% share), 35.0 (0.90% share) in 2020, 2025 and 2030 respectively. The daily energy demand by both video and radio appliances also recorded less than 1 percent share each in the two villages. The generally low total energy demand shares of

Table 8. Energy demand pattern for energy services in Eriti Village (2020-2030)

Energy services	Best policy option scenario 2020 -2030					
	kWh/Day (2020)	Share (2020)	kWh/Day (2025)	Share (2025)	kWh/Day (2030)	Share (2030)
Incandescent Bulbs Lighting	10.1	0.3%	7.7	0.2%	0.0	0.0%
Florescent Bulbs Lighting	16.8	0.4%	5.1	0.1%	0.0	0.0%
Solar Bulbs Lighting	8.4	0.2%	11.8	0.27%	13.4	0.33%
Kerosene Lighting	152.5	4.0%	233.0	5.3%	263.5	6.5%
Total Lighting	187.7	5.0%	257.7	5.9%	276.9	6.8%
3-Stones Firewood Cooking	2437.1	64.6%	2465.3	56.5%	1858.6	45.6%
Kerosene Cooking	752.1	19.9%	253.6	5.8%	304.3	7.5%
Improved Firewood Cooking	358.4	9.5%	1232.6	28.2%	1424.4	35.0%
Total Cooking	3,547.6	94.0%	3,951.5	90.5%	3,587.3	88.0%
Radio	5.4	0.1%	10.3	0.2%	17.4	0.4%
TV	6.6	0.2%	25.0	0.57%	32.7	0.8%
Video	5.3	0.1%	25.0	0.6%%	8.1	0.2%
Total Entertainment	17.2	0.5%	60.3	1.4%	58.2	1.4%
Refrigeration	15.1	0.4%	77.0	1.8%	130.7	3.2%
Process Heat	0.3	0.01%	0.2	0.004%	0.4	0.011%
Ventilation	5.0	0.1%	19.3	0.4%	21.8	0.5%
Grand Total	3,773.0	100%	4,366.0	100.0%	4,075.2	100.0%

Table 9. Energy demand pattern for energy services in Oke-Agunla Village (2020-2030)

Energy services	**Best policy option scenario 2020 2030**					
	kWh/Day (2020)	**Share (2020)**	**kWh/Day (2025)**	**Share (2025)**	**kWh/Day (2030)**	**Share (2030)**
Incandescent Bulbs Lighting	10.8	0.33%	8.2	0.17%	0.0	0.00%
Florescent Bulbs Lighting	16.6	0.51%	5.5	0.12%	0.0	0.00%
Solar Bulbs Lighting	8.3	0.25%	12.6	0.27%	24.9	0.64%
Kerosene Lighting	163.4	5.02%	294.7	6.23%	307.7	7.95%
Total Lighting	199.0	6.11%	321.1	6.79%	332.6	8.59%
3-Stones Firewood Cooking	2508.8	77.05%	2638.1	55.78%	1193.5	30.84%
Kerosene Cooking	142.2	4.37%	271.4	5.74%	368.3	9.52%
Improved Firewood Cooking	345.6	10.61%	1319.0	27.89%	1723.9	44.54%
Total Cooking	2996.6	92.03%	4228.5	89.40%	3285.7	84.89%
Radio	10.8	0.33%	19.8	0.42%	23.2	0.60%
TV	9.5	0.29%	26.8	0.57%	35.0	0.90%
Video	8.2	0.25%	26.8	0.57%	30.3	0.78%
Total Entertainment	28.4	0.87%	73.4	1.55%	88.5	2.29%
Refrigeration	27.0	0.83%	87.1	1.84%	139.9	3.61%
Process Heat	0.2	0.006%	0.4	0.009%	0.4	0.011%
Ventilation	5.0	0.15%	19.3	0.41%	23.3	0.60%
Grand Total	3256.3	100.%	4729.8	100.%	3870.3	100.%

less than 1 percent for both entertainment and ventilation services, about 2.5 percent and 3.6 percent shares each for process heat and refrigeration services respectively, in the overall energy demand split for all energy services, even by 2030, in the two villages, were attributable to poor access to electricity, due to high incident of poverty experience by the Villagers.

Secondly, it is also occasioned by poor stock of these appliances such as fridges food preservation and vaccine refrigeration, fans for ventilation, electric pepper grinders for food processing and process heat by the villagers. Government intervention through solar PV deployment will be a good avenue for increasing their living standard. The study observed that over 95 percent of the food stuff grinding activities by the villagers in all the study areas were catered for using grinding stones, mortars and pestles which proves to be grossly inefficient, cumbersome and time consuming. The same is the case for ventilation. Hand fans are commonly use by over 90 percent of the villagers population. It was also discovered that frequent cooking and incessant use of firewood persists due to lack of electricity based food refrigeration appliances that could preserve the food for a longer time and minimize rate of cooking for the usually large households families. Thus, lack of refrigerating facilities also impact negatively on the health of the villagers. Therefore, provision of solar PVs to the rural areas of Nigeria for food and vaccine refrigeration has strong positive effects on policy of firewood usage reduction and environmental mitigation.

4. CONCLUSION

The study showed that the total lighting demand share for solar PV in each of the villages' total energy demand mix in 2020 was insignificantly low at 5.1 percent share in Eriti village and 6.1 percent share in Oke-Agunla village. Contrariwise, firewood demand maintained as high as 94 and 92 percent share for Eriti and Oke-Agunla villages respectively in the total energy demand mix and by 2030, in Oke-Agunla village, 3-stones-firewood stoves demand for cooking fell drastically from 77% to 30% share, whereas improved firewood stoves demand for cooking rose astronomically from 11% share in 2020 to 45% share by 2030. Nigerian government should adopt such best policy intervention scenario for all the rural areas in the country. It also revealed that high incidents of poverty experience by these villagers accounted generally for the less than 4 share each in the total energy demand for entertainment, ventilation, process heat and refrigeration services in the overall energy demand split for all energy services, even by 2030, in the two villages. It further showed that these village dwellers possessed low financial capability for electricity access and acquisition of the stock of end use appliances, such as fridges food preservation and vaccine refrigeration, fans for ventilation, electric pepper grinders for food processing and process heat in their energy consumption profiles. They could not consume beyond the solar PV intervention access granted them by the government supply, which was found to be grossly inadequate for the two village populace. Thus, the best policy intervention scenario analysis for the future energy demand in the study area could be considered in the review of the existing rural energy policy of the nation. The study highlighted the need for increased government interventions through solar PV deployment, which will be a good avenue for increasing their living standard. It will afford them the opportunities for food and vaccine refrigeration, increased solar bulbs usage for lighting, less kerosene usage for lighting, increased kerosene usage for cooking, reduction in the domineering 3 stones firewood stoves usage for cooking, increased improved firewood stoves usage for cooking and improved environmental mitigation.

5. RECOMMENDATION

i. Government support for solar PV intervention to the rural areas is appropriate and should be further encouraged. However, its effectiveness rest squarely on its utilization for low wattage appliances for lighting, radio, television and video entertainment; food and vaccine preservation through refrigeration; ventilation and water pumping for provision of portable water and farm irrigation.
ii. Due to the continued domineering share of fuel wood in energy mix of the study areas, there is an urgent need for a review of government forest reserve policy as it affects desertification, deforestation and soil erosion problems in the northern, western and eastern parts of the country respectively.
iii. Due to remoteness of the study areas, and higher cost of connecting them to the national grid, government policy of providing the rural dwellers with stand alone solar PV system is commendable. However, more of such villages should be identified and provided with solar PV systems.
iv. Fuel substitution policy for displacement of kerosene usage for lighting with solar PVs should be aggressively pursued.
v. Fuel switches policy in favour of kerosene to displace firewood for cooking should also be pursued.
vi. Policy that promotes drastic reduction of firewood usage for cooking should also be adopted through substitution of 3-stone firewood stoves with improved firewood stoves.

CONSENT

As per international standard or university standard, respondents' written consent has been collected and preserved by the author(s).

COMPETING INTERESTS

Author has declared that no competing interests exist.

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