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Review

The Trend of Solar Energy Utilization and Its Offshore Assessment in Nigeria

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Abstract: The recent happenings in the world such as flood and wild forest fire were as a result of climate effect as being envisaged by scientists. It is urgent now to adopt a source of energy that will eliminate this effect on our universe. Solar energy is the major energy means that is abundant which could be utilized. In this review, the prospects of solar energy exploration were studied in Nigeria which include assessments, economic viability and hybrid systems. Findings show higher potential in the North as compared to the Southern region. Additionally, potential of offshore solar energy system was simulated by considering 2002, 2003 and 2004 data sets from Era5-land base. Their monthly mean, seasonal changes and annual mean value were estimated. The algebraic annual solar radiance for 2002, 2003 and 2004 were 34,914.732 kWh/m2, 33,898.316 kWh/m2 and 34,338.324 kWh/m2. Suggestions were made due to the present status of solar energy utilization that will enhance its maximum usage and development. One of these is the establishment of a functioning financial scheme and the database for all renewable energy systems. When all these are put in place, the energy supply will increase, climate effect will be reduced, and the economy will be boosted.

Keywords: solar PV system; renewable energy system; solar radiation; net present value; cost of electricity

1. Introduction

The need for Adoption of renewable energy systems is of important based on day-to-day activities that require energy that capable of avert negative effect of global warming and all stakeholders must involve to realize this milestone [1]. The potential of Solar energy systems is of immense benefit in curtailing the effect of climate change and thus aligned with Paris Agreement [2]The advent of Solar energy system as one of renewable energy sources which has capacity to replace fossil fuel that have causes various environmental hazard is a laudable goal [3,4]. Efficiency of a solar energy has been proven to be higher in comparison with other renewable energy means that is economically viable as well as its availability [5]. The continuous utilization of renewable energy power systems has driven their operation and maintenance costs to a lower trend providing room for avoidable, reliable and competitive renewable energy generation techniques [6]. The use of solar energy power from sunlight occur by sun heating the surface of photovoltaics (PVs) cell which resulted into photo- electric emission that can be employed for electricity generation or heating of fluid for industrial purposes [7,8]. Currently, the solar energy serves as foremost reliable renewable energy sources that possess up to 23,000 TW available energy storage on a yearly basis and also adequate to meets the global energy demanded [7]. It had been estimated that the worldwide installation capacity as refer to solar energy PV as at 2016 amounted to hourly deployment of 31,000 panels globally [9]. The solar energy potential available in Nigeria amounted to 3.5–7.5 kWh/m^2 /day with corresponding value of 145.83–312.50 W/ m^2 [10]. Additionally, the mean for yearly estimation was found to be 1770 thousand TWh/ year [11]. The determination to incorporate large solar PV system into Nigeria grid system will pave way for mutual benefits for both ECN (Energy Commission of Nigeria and the IAEA (International Atomic Energy Agency) that target for capacity building in a bid to strategize and plan for energy needs [12]. Although, Nigeria electricity supply is insufficient for electricity demand. The increase in population is very rapid, the pipe vandalism and decaying of existing electricity contributed to present predicament of power sector in Nigeria. The paradigm shifts to renewable energy system like solar, wind, wave, biomass and other renewable energy means will supply the needed energy even in excess. This work dedicated to solar energy system review in Nigeria to depicts the stages of its development in terms assessment of solar radiance, economic effect of solar energy, hybrid configuration. the gaps were enumerated, and recommendations was provided that will pave way for accessing these enormous potentials. Based on gap identify, none of the literatures explore the potential of offshore solar energy system which was assessed on this paper that can serve as hybrid system with wind energy system or standalone.

2. Assessment of solar irradiance in Nigeria

The establishment of sufficient studies in order to assess the solar radiation in any part of the world is necessary ingredient for successful deployment of efficient solar PV system. Several literatures on assessment of potential solar radiation across Nigeria were scrutinized to reflect the present status of solar renewable energy in different locations and their viability. The estimation of global solar irradiance was carried out ranged 1997-2007 by adopting general circulation model for change in season and annual variation [13]. The trends of concentration solar power potential were reviewed that could be achieved in near time, midterm and long duration. It was suggested that adequate political will could assist in attained the milestone and the existing oil and gas firm should explored this viable renewable energy [14]. Analysis of solar resources in three commercial urban areas (Lagos, Onitsha and Kano) was assessed. The potential in Kano was found to be higher (6.08 Kwh/m^2) compare to Lagos and Onitsha (4.42 Kwh/m^2) [15]. Moreover, the prospect of solar energy policy as enacted in Nigeria renewable energy policy was scrutinized in other to reflect the gaps present. The outcome shows the need to adopt new law that could cater for solar wastes deposit in order to avoid environmental hazards as well as health of people in the communities [10]. The potential of rooftop solar PV system was examined in this research for Ibadan city by reduction factor technique using population census, imagery map and ArcGIS software. Maximum installation capacity obtained was 1734 Mwp covering 7.50 square kilometres at an optimized tilt angle of 11° [9]. Another study expresses the present status of solar application and resources estimation was conducted for Nigeria sites which shows higher radiation in the Northern part compare to Southern areas [8]. The growth in energy demand and global concern about the environment has resulted in the drive towards alternative energy sources and consequently this research concerning solar energy harvesting of radiation received at the earth's surface. In the calculation of solar radiation resources for Portharcourt, Maiduguri and Minna, the larger value depicted in Maiduguri in respect to other two sites; 1219489.32 Wp , 619419.27 Wp, 821142.52 Wp accordingly [16]. Saliu et al describes the installation and designed of micro-grid solar energy in Lajolo rural community as means to boost the economy as well as health status of the occupant of this community [17]. According to scholarly work done on Metropolitan area of Lagos State, result shows lead acid capacity of 2-176 kWh, PV modules ranges 0.3 to 76 Kw and inverter size 0.1 to 13.2kW [18]. These research activities involve review of existing studies which confirmed nearly no literature on artificial intelligent and exploration of artificial neural networks to estimate solar energy in Enugu as pilot study in Nigeria. The system predicts solar potentials using time series technique that shows higher precision than empirical analysis [19]. One of the studies lay emphasis on integrating tracking system on solar energy generation by adopting two-axis tracking in Nigeria. It was asserted that extra energy amounted to 20-40 % could be obtained in regard to non-tracking system when solar irradiation and ambient temperature were employed [20]. A 6 MW solar power grid connected system was examined in North-east region to find the extent of viability in terms of technology, environmental effect as well as economic implication using RETScreen Expert software. The outcome shows that all sites are viable and Yobe state has highest potential (11,385 MWh) annually [21]. Application of neuro-fuzzy inference was tested for solar radiation prediction in Iseyin, Oyo State using Nimets daily data for solar irradiation, sunshine and temperature. When compare the outcome with experimental result, there exist improvement in the performance and root mean square error achieved was 1.7852 on the testing phase [22]. An empirical analysis was employed to calculate mean monthly global solar irradiation in horizontal direction for Makurdi, Benue State with the aid of Angstrom- page model over the range of eighteen years daily data. the mean square error obtained was 1.22 % [23]. Weihao Hu in their study using EnergyPLAN b suggested that hybridization of wind and solar energy in commercial scale will offset inadequacy demand of electricity generation in Nigeria [24]. In order to employ the best modular solar PV system for grid-connected installation in Nigeria, not fewer than fourteen various solar manufacture modules were studied. The result shows the yield to be in the range of 4.0361-4.7972 kWh having performance ratio of 78.96 to 79.96 % [12]. Additionally, research was embarked in Umudike, Niger Delta area for solar energy resources illustration using Sayighr termed Universal Formula. The output obtained was 1.99- 6.75 kWh that in conformity with previous studies [25]. Assessment of solar irradiation was conducted in Aghani urban area having annual mean value of 4.67 kWh/m^2[26]. The possibility of using hybrid energy system for electricity generation in rural and semi-urban areas in the Northern part of Nigeria was investigated in this study. An hybrid of solar energy system was explored in Jos, Plateau State, average annual solar global irradiation observed was 6 kWhm^{-2} which shows solar/ diesel generator/ battery as most effective hybrid integration [27]. A multi-vary objective optimization was employed in 3 rural community area of South-West for solar energy in order to reflect productive utilization in a domestic environment. Spanning period of twenty-five years, energy needed in three localities were obtained to be 28,280 kWh, 28,609 and 29,554 kWh with mean productive use of 0.338, 0.348 and 0.358 respectively [28]. A solar PV system and wind energy were studies as hybrid system in the senate building (University of Ilorin), Kwara State using Energy Analyzer as well as Power Quality. It was observed that daily mean energy required for wet season, dry season and weekend days were 712 kWh, 1520 kWh and 213 kWh accordingly [29]. The estimation of solar radiation in Porth-Harcourt, Sokoto and Ibadan was done for every 4 months in a year using ANOVA (Analysis of Variance). Another study explore phase synchronization in respect to solar radiation data and wind speed in latitude 3-14 degree [30]. An integration of solar PV system into a National grid was analysed with the aim of maintaining stability in the system as well as minimizing the losses by adopting multi-objective optimization algorithm [31]. A related study was considered to ascertain what type of technology could be explored in deploring various renewable energy which reflect their economic value, environmental effect, social influence with the aid of multi-criterial technique. The conclusion made prove that solar PV system is most suitable electrification in Nigeria [32]. Also, smart grid electricity system was evaluated in this study for rural community with a specific design approach. Then battery storage system, solar PV system and diesel generator set was considered that will make use of low-voltage efficient bulb and it was found to save up to 42-76% peak value of electricity demand. When tested with application of light emitting diode bulbs, it saves around 56-81 % net present cost compare with diesel generating set having incandescent lighting [33]. Ikejemba et al adopted multi—step technique to design network for solar energy pack and wind energy pack in South-East region taking Anambra State as hub site for the study [34]. Assessment of life cycle impact for solar PV system having rating of 1.5kWpaper was studied in all six region of Nigeria. The following factors were considered, global warming, emission rate, energy payback time cumulative energy demand as well as net energy ratio. The outcome show less global warming and energy payback time at a site with higher solar irradiance whereas larger in location of lower solar irradiance [35]. Evaluation of a hybrid flat plate solar collector system and nocturnal radiator in respect to water heating was simulated in selected five urban areas. It was suggested that ambient energy depicts enormous potential to reduce energy security issues and still provide friendly environmental condition [36]. As for estimation of back temperature for solar modules, it was tilted at different angles of 26.80°, 16.80 ° and 6.70 ° was explored in Lagos State. The analysis shows energy gain amount to 19.49 %, 20.84 % and 8.74 % as the angle decrease respectively [37]. Importantly, this research described the influence of solar eclipse (97 %) that occurred in Oyo State in March 2006 [38]. The grid-connected solar PV system was examined in Northern region of Nigeria by explored HOMER software optimization tool. Global solar daily radiation observed was 6.0 kWh/m per day having annual electricity generation of 331,536 kWh [39].The preference for solar charger in household was observed using a random parameter model with an outcome showing the respondents voted for high quality charger [40]. In order to estimate the mean monthly solar radiation in Makurdi, Benue State, artificial neural network was explored which include radial basis function neural network, generalized regression method and feedforward neural network. It was concluded that all the neural networks perform maximally with mean square error of 0.0142 and square error of 0.998 on average basis [41]. Additionally, the deployment of solar pumping system was studied in Ibadan city for abattoirs which depicts economic benefits [42]. Another studies examine applicability of concentration solar power by adopting DESERTEC model for Nigeria solar radiation as it reflect beneficial to European countries [43]. This work utilized user- oriented software application for solar/hydrogen energy production. It encloses hydrogen cooking based load devices. The outcome suggested that solar PV module of 2.420 Kw, 3.70 kWh battery storage with 0.6 Kw electrolyser is sufficient for daily demand amounted to 2.2 kWh in a rural community [44]. Modelling the assessment of solar PV system in some designated cities was conducted by adopting six tracking system (single axis), inclined as well as dual base- axis tracking surfaces. Still Perez anisotropic and Koronakis isotropic technique were employed for component diffuse prior to combination of tracking system. The yearly solar potential for fixed inclination give 1621-2279 kWh/m^2 while that of solar tracking system shows 1664-2983 kWh/m^2 which are adequate in impacting on energy supply to the populace [45]. An assessment of solar PV system in combination with small hydro system was enumerated in Federal university of technology Owerri (FUTO) using twelve years solar data sets. The system give 98521098 Ah as capacity for battery bank with 3025 PV module covering area of 3248 m^2 would be most suitable configuration for site location [46]. In order to formulate empirical model for global solar radiation in Ibadan city, three different models were explored which include Garcial, Angstrom-Prescott and Hargreaves- Sammani model. It was observed that Garcial quadratic technique serve as the best model which could forecast mean daily global solar radiance having root mean square error of 2.70 MJ/m^2 per day, mean absolute error amounted to 1.86 MJ//m^2 per day, coefficient of determination 0.68 and 9.34 % mean absolute percentage error [47]. The rural communities in the coastal area of Niger- Delta area was simulated for solar PV system using hybrid optimization model software (HOMER) within a period of twenty-two years. Result depicted future electric energy demand of 8.83 kWh having cost of energy 0.653 $ per kWh, existing energy demand amounted to 5.640 kWh with cost of energy 0.651$ per kWh which also include future energy based demand of 7.233 kWh consist of 0.674 $ per kWh cost of energy that all seem to be accurate, reliable clean energy system [48]. More importantly, this study describe solar energy research in terms coordinated finance for investment that was systematic in deploring solar energy system in Nigeria [49]. Oduola et al evaluate the acceptance of solar PV system in Port Harcourt, River State by used AHC (Agglomerative Hierarchy Cluster) and logistic regression technique. An acceptance rate of 40.51 % was obtained which is centred on unawareness level of 99 % while rejection rate was 59.49 % [50]. Similar study was done in Lagos State by considering medium and small enterprises by questionnaire method with the use of descriptive statistic and regression model. It was observed that inadequate accessibility to electricity, poor customer care as well as power outage from electricity distribution were not serve as main causes of the use of solar energy [51]. Likewise, in South-West preference for use of solar PV system was illustrated based on respondents from available users and non-user with the aid statistic and regression analysis. Respondents admitted that solar energy was preferred alternative means of energy having mean score of 3.83 [52]. Also, a qualitative analysis was explored based on interview in form of semi-structured one-on- one to access barrier in the use of solar PV system in Nigeria. This study suggested that barriers related to politics, technology, social factors and finance contributed to low solar utilization and development [53]. A household reflection on the installation of solar PV system was conducted via interview in Kano metropolitan area. Respondent were found to adopt solar energy for recharging purposes, cooling system and lighting [54]. Then, a questionnaire was administered in Ibadan to show usage of solar PV system in Oyo State by considering schools, households and industries. The survey revealed that households and schools used solar for electronic devices while offices employing it for lighting and powering equipment with

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the exemption of air condition device. It must be emphasize that awareness is low for solar energy utilization [55]. Study was conducted on solar PV rooftop system in the primary health care facilities using analytical expression across 6 geopolitical zones. Annual available energy at the inverter output recorded highest in Kano State (6654.4 kWh) with the lowest value of 5363.1kWh in Akwa Ibom. Summarily, Northern part possess higher solar radiance compare to Southern region [56]. A geospatial analysis of solar PV system was conducted in eastern part of Nigeria by adopting multi-criteria decision analysis. Result show that 5900 hectares were appropriate for solar energy system [57]. In this study, an experiment procedure was followed to measure solar radiance on a daily base with the aid of light meter (LX101A) in North central part of Nigeria. It was realized that 29168.29 MW of solar energy spread over 0.1 % of total mass land is available while mean minimum and maximum values were 2.70 kWh/m^2 and 7.50 kWh/m^2 respectively [58]. Analysis of daily solar radiance was done by means of Artificial Neural Network (ANN) spanned twenty-year data set. The RMSE (Root mean square error) observed was 0.470 and 0.480 as regard training and testing the network while their square error was 0.78 [59]. In the other hand, mathematical modelling of off-grid solar PV system was examined in Jos, Plateau State on a residential building. Result depicted that battery capacity of 500 Ah each of 100 Ah, ten PV modules each value 275 Wp will meet yearly electricity demand of nearly 3132 kWh [60]. Availability of solar energy was studied in 25 sites across Nigeria based on solar PV system rating 100-MW by applying RETScreen application. It was deduced that Gusau possess highest annual electricity generation of 167,307 MWh with the least value of 108,309 MWh in Port Harcourt [61]. Okoye et al researched the solar energy PV system resources by means of Hargreaves and Samani technique in selected six sites in Nigeria for period of 10 years temperature data. The outcome depicts average global solar irradiation to be 19.83$\pm$ 0.60 MJ/m^2, 18.55 $\pm$ 0.54 MJ/m^2 and 17.80 $\pm$0.30 MJ/m^2 for Maiduguri, Sokoto and Markurdi respectively compare to southern part namely; Awka, Ibadan and Port Harcourt that have 17.68 $\pm$0.28 MJ/m^2, 16.68 $\pm$0.36 MJ/m^2 and 17.46 $\pm$0.19 MJ/m^2 accordingly [62]. Generally, the Northern section of the country shows larger solar radiation as compared to Southern part as enumerated in the above studies. It should be noted that there is absence of comprehensive Data based repository for global solar irradiance assessment in all cities and locations. This might be of immense benefits to scholars, government as well as investors on how best they can explore the abundant solar energy in Nigeria. It will in turns avert incessant power supply when adequately utilized. Additionally, over reliance on fossil fuel that has cause various hazards to the climate and the occupant of the earth can be easily reduced to minimum level. The government policy needs to be aligned to sustainable, adequate and clean energy for enhancement of renewable energy systems. Lack of political will had been the bottle neck for attained goals as highlighted in the millennium plans. Though Nigeria government partner with Worlds Bank on solar energy PV system that has brought tremendous developments and advantages compare to other renewable energy. On the part of higher institution of learning. Their programs should incorporate renewable energy studies as part of general courses, partner with various private company for projects in the communities, educate the populace about the benefits of renewable sources and incentives could be offered to scholars that contributed their knowledge to development of renewable energy. Therefore, needs for stakeholders involves in renewable energy to work together on achieving the stated recommendations.

Table 1. Summary of literatures on assessment of solar energy resources.

LOCATION	DESIGNATION	SOURCE
Nigeria	General circulation model	[13]
Nigeria	Concentration solar power	[14]
Lasgos, Onisha, Kano	Analysis	[15]
Nigeria	Policy	[10]
Ibadan	Roof top PV	[9]
Nigeria	Analysis	[8]
Porth Harcourt, Maiduguri, Minna	Analysis	[16]
Lajola rural community	Micro-grid	[17]

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Lagos State	Analysis	[18]
Nigeria	Review/ Analydsis	[19]
Nigeria	Tracking/ Analysis	[20]
North-East	Analysis	[21]
Iseyin, Oyo State	Analysis	[22]
Markurdi, Benue State	Analysis	[23]
Nigeria	Hybrid analysis	[24]
Nigeria	Analysis	[12]
Umudike, Niger-Delta	Analysis	[25]
Agbani	Analysis	[26]
Jos, Plateu State	Analysis /Mathematical modelling	[27,60]
University Ilorin, Kwara State	Analysis	[28]
Porth Harcourt, Sokoto, Ibadan	Analysis	[29]
Nigeria	Analysis	[30]
Nigeria	Analysis	[31]
Nigeria	Analysis	[32]
Nigeria	Hybrid analysis	[33]
South- East	Energy pack	[34]
Nigeria	Analysis	[35]
Nigeria	Solar heating	[33]
Lagos State	Analysis	[37]
Oyo State	Solar eclipse	[38]
Northern Nigeria	Analysis	[39]
	Questionnaire	[40]
Markurdi, Benue State	Analysis	[41]
Ibadan	Solar pumping	[42]
Nigeria	Concentration solar power	[43]
Rural community	Solar/Hydrogen	[44]
Major cities	Tracking/ Analysis	[45]
FUTO, Owerri	Solar/Hydro	[46]
Ibadan	Analysis	[47]
Niger- Delta	Analysis	[48]
Nigeria	Solar investment	[49]
Porth Harcourt	Solar Acceptance	[50]
Lagos State	Questionnaire	[51]
South-West	Questionnaire	[52]
Nigeria	Interview/ Qualitative	[53]
Kano	Questionnaire	[54]
Oyo State	Questionnaire	[55]
Nigeria	PV rooftop	[56]
Eastern Region	Geospatial analysis	[57]
North Cenral	Solar experiment base analysis	[58]
Nigeria	ANN analysis	[59]
Nigeria	Analysis	[61]
Selected Sites	Analysis	[62]

3. Economic evaluation of solar energy

Analysis of economic viability and applicability of solar PV system is a pivot for development of appropriate technology in different sites. So researchers decided to explore this platform in Nigeria context as outlined in this section. This paper conducted the economic effect of standalone solar PV system for off-grid rural areas using HOMER software up to twenty- four years' meteorological data for 40 sites. The result shows that for 15 MW PV system, the levelized cost fall on $ 0.01/kWh to $

0.17/kWh in twenty-nine sites [63]. A cost-effective way to install solar PV system was done for Lagos State by removing the adoption of diesel generation sets. Base on financial technique, a cost reduction of 60% was obtained for PV system in respect to usual diesel generator application [64]. Similar studies explore the hybrid of solar PV/ diesel generator sets as regard its cost effectiveness for private company. It was asserted that cost reduction of about € 0.002 with 0.009/kWh was observed [65]. The estimated values of PV capacity with their cost of electricity generation in three commercial cities (Lagos, Onitsha and Kano were ranged from 1.26 kWp-2.92Kwp and 0.206-0.502 USD /kWh [15]. Assumed energy demand of 1.1 MWh was simulated for the cost viability of solar energy in three States capital in Nigeria. An incremental value cost of $460,984.72 was detected in both Porth-Harcourt and Minna for the life span of the project compare to Maiduguri [16]. The economic evaluation of solar PV systems with the use of levelized cost was deduced to be 0.398-0.743 USD per kWh in Lagos Metropolitan area [18]. The cost implication deduced for 14 different locations in Nigeria was found to be 0.0524-0.0607 $/kWh with payback period of 10.18 to 10.42 years [12]. Economic viability of Agbani city as well as its technology was simulated by adopting HOMER Pro software. Model of direct current via grid PV system aligned with Surrette S-260 battery valued at 35.67 Kw serve as cheapest configuration with cost of 0.11 $/kWh having 0.048 million dollars as Net Present Cost [26] . Analysis of hybrid system in rural areas and towns of Northern Nigeria with the aid levilsed cost depicts $0.3480-0.3780 per kWh and $0.378/kWh regarding interest rate. This value is lower compare to standalone diesel generating set [27]. Similar study was done in Giri village base on hybrid of wind/ solar energy system. The operational expenses incurred was $4723 having cost of electricity of 0.11dollar per kWh at net present cost of one million dollars [66]. The usage of hybrid in health facility in Norther region was thoroughly assessed for optimum financial viability. Simulation outcome prove that solar/ diesel generator/ battery that have the following capacity; 2 kilowatt generator set, solar PV of 5.43 Kw, ten pieces of battery and 3.06 Kw converter give optimum values for cost of electricity ($0.259 per kWh) and net present cost ($16457) [67]. An hybrid analysis of wind/solar energy costing in University of Ilorin depicted $0.283 per kWh which is comparatively higher than the present electricity in Nigeria [29]. This study investigates the economics potential in remote community of Nigeria for three sources of electricity namely diesel generating set, solar energy as well as electric connection to power grid and the outcome shows solar renewable energy is most economically viable system [68]. The impact of climatic difference on the performance ratio and economic buoyance of solar PV system was conducted. It was emphasized that larger value of performance ratio had been identified in tropical savanna and monsoon compared to warm semi-arid and warm desert. As for the economic potentiality, the levelized cost of energy across climatic variation to be 0.21 Dollar per kWh lesser than 0.25 dollar per kWh for national grid tariff whereas mean net present value was 31,164 dollar [69]. Arowolo et al stressed the need to provide centralized solar PV system that fitted to market design as well as effective regulatory framework [70] Moreover, an installation of solar PV system by applying energy partitioning technique in regard to status of quality of life was scrutinized. At the end of research, life cycle cost using 20 years horizon was 10600 dollars for highest influence on life quality while the cos of energy was 033341 dollar per kWh [71]. The levelized cost of energy obtained in Northern part of Nigeria was $0.103/kW h using HOMER software which is economically buoyant. This work illustrated the application of solar energy in rural community name as Vandeikya local council, Benue State for their hospital using HOMER software Pro version 3.13.8. the yearly mean insolation is 4.92 kWh per meter square and the outcome give NPC (Net Present Cost) amounted to 718308000 Naira. It was suggested that hybrid application will be economically viable [41]. By evaluating through costing and benefit technique, an affordable solar energy was studied in Abuja base micro-grid system. The net present value obtained was 320,897841 Naira while internal rate of return was estimated to be 17.5%. so it was affirmed that solar PV system was viable and could reduce emission effect on the climate changes [72]. Assessment on economic viability of incorporating roof-top PV system based on nine- hour per day energy consumption for 3 building types in Nigeria was simulated using NREL's system advisor model application. It was estimated that 3.30, 7.00, and 15.25 kW give NPV values of 2330, 7947 and 8075 Dollars respectively while their equivalent payback period were 12.3, 12.3 and 18.2 years accordingly. Their levelized cost

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of electricity were 8, 3 and 3cent per kWh respectively [73]. The cost of adopting off-grid solar PV system was simulated in Jos. The cost of electricity estimated was 0.18 Dollar per kWh (COE), yearly life cycle cost assessment was 593.75 Dollar (ALCC) having life cycle cost of 101110.9 Dollars (LCC) [60]. In the analysis of economic viability of solar PV system using RTScreen software, those sites fall on higher latitude appear to be more profitable compared to low latitude sites. The cash flow cumulative obtained (CCF) in Gusau was 795.30 million in US Dollar with the cost of energy production worthy 66.74 US Dollars per MWh while NPV was 215 million US Dollar. Likewise, in Port Harcourt, CCF was 389.7 million US Dollar with NPV of 40 million US Dollar and the cost of energy production was 103.10 US Dollar per MWh [61]. By critically examine the studies above, none of the study use Feed-in- Tariff system (FiT) due to unavailability of effective tariff system and other financial incentive that could boost the deployment of renewable energy systems. As stated by scholars that FiT had been most valuable renewable energy policy that promotes the utilization of renewable energy systems [74]. Then this gap needs to be filled by adopting efficient financial scheme that will encourage the umpires in renewable energy business. Researchers should assist in designed the required scheme that in line with economic reality of our communities. As time pass, we shall reach the milestone for avoidable, dependable and sustainable energy system when all stakeholders did their part.

Table 2. Summary of literatures on economic analysis.

LOCATION	METHOD	SOURCE
Nigeria	HOMER	[63]
Lagos State	Financial technique	[64]
Nigeria	Hybrid	[65]
Lagos, Onisha, Kano		[15]
Maiduguri, Porth –Harcourt. Minna	Value cost	[16]
Lagos metropoly	Levilized cost	[18]
Nigeria	Levilized cost	[12]
Agbani City	HOMER Pro	[26]
Nortern Nigeria	Levilized cost	[27]
Giri village	NPV	[66]
Northern region	NPC	[67]
University of Ilorin	Levilized cost	[29]
Nigeria	Costing	[68]
Nigeria	Levilized cost	[69]
Nigeria	Life cycle cost	[68]
Vandeika LG, Benue State	HOMER	[41]
Abuja	NPV	[72]
Nigeria	NPV	[72]
Jos, Plateu State	ALCC, LCC,COE	[60]
Nigeria	CCF, NPV	[61]

4. Assessment of offshore solar energy resources

The potential of solar radiance was simulated to reflect monthly, seasonal and yearly variation as a platform to explore this enormous renewable energy source. The coastal part of Nigeria has a total area of 13000KM^2. Its longitude falls on 2° 45' to 8° 35' E and the latitudes lies on 4°10' to 6° 20′ this coastline experiences south westerly's. The map is depicted in Figure 1 with the blue portion indicate coastal part of Nigeria.

Figure 1. Map of the study area [75].

The ERA5-Land grided at 0.1° by 0.1° at a resolution of 9 Km was employed in this study by considered 2002, 2003 and 2004 hourly data sets for solar energy in offshore part of Nigeria as depicted in the blue colour section in map 1. Data obtained was processed in ARCGIS 10.3 by converting NETCDF file into raster map. Thereafter, actual solar irradiance values were extracted in joules which then converted to kilowatt-hour per meter square. Moreover, the mean monthly solar radiance was calculated for 2002, 2003 and 2004 and the mean seasonal changes from rainy season (March-September) to dry season (October- February as well as annual mean solar radiance for the three years considered in this work as depicted in Tables 3–5. The least monthly mean solar radiance occurred in August for 2002 and 2003 were 2.3803 kWh/m^2 and 1.8594 kWh/m^2 respectively while in 2004 the least value was 2.3171 kWh/m^2 2 in June.

Maximum mean monthly solar radiance recorded in February for 2002 was 5.5278 kWh/m^2 and the maximum value for 2003 (June) was 5.116 kWh/m^2 having 4.6983 kWh/m^2 in 2004 (December). The result for seasonal changes depicts the dry season higher than wet season as expected. Their mean solar radiance for dry season is 4.0272, 4.1958 and 4.1421 kWh/m^2 accordingly for 2002, 2003 and 2004 as well as their mean solar radiance for wet season give 3.8046, 3.6409 and 3.6518 kWh/m^2 respectively for 2002, 2003 and 2004. Moreover, the annual mean solar radiance for 2002, 2003 and 2004 were 3.9857, 3.8691 and 3.9199 kWh/m^2. The algebraic annual solar radiance for 2002, 2003 and 2004 were 34,914.732 kWh/m^2, 33,898.316 kWh/m^2 and 34,338.324 kWh/m^2. The Figures 2–4 show the distribution of mean monthly solar radiance occurred based on highest and lowest value across the coast of Nigeria economy zone as indicated in blue portion of map (Figure 1). These huge resources could be harnessed to cater for epileptic power supply being experience in the country as well as mitigate the effect of global warming as enshrined in the pact signed by the government. The hybrid of solar and wind energy can be deplored near offshore.

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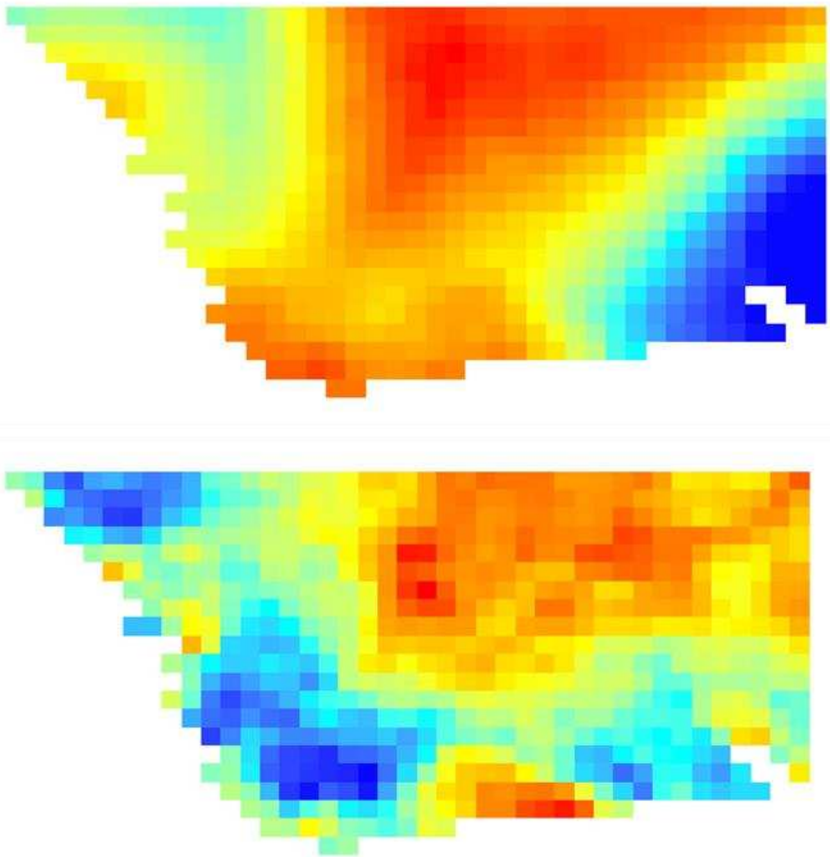

Figure 2. Distribution of solar energy for August and february 2002 respectively.

Table 3. Analysis of solar radiance for 2002.

Items	Mean	Maximum	Minimum	Standard deviation	Variance
January	4.4166	4.8701	3.4553	0.25207	0.06354
February	5.5278	5.7548	5.2445	0.12137	0.01473
March	4.8732	5.4426	4.1839	0.27273	0.07438
April	4.4468	5.0362	4.0784	0.19847	0.039391
May	4.0174	4.6169	3.3221	0.27214	0.074058
June	3.7400	4.5156	3.2807	0.20953	0.04390
July	3.3388	4.1735	2.9391	0.23046	0.05311
August	2.3808	3.0056	0.9434	0.47174	0.22254
September	3.8549	4.7792	3.1757	0.38294	0.14664
October	3.3326	4.2356	2.5089	0.33041	0.10917
November	2.9086	4.2907	2.0765	0.46246	0.21387
December	4.0040	4.6571	3.4823	0.26701	0.07130
Rainy season	3.8046	5.4426	0.9434	0.80274	0.64439
Dry season	4.0272	5.7548	2.0765	0.95724	0.91631
Annual value	3.9857	5.4426	0.9434	0.65057	0.42324

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Table 4. Analysis of solar radiance for 2003.

Items	Mean kWh/m²)	Maximum kWh/m²)	Minimum kWh/m²)	Standard deviation	Variance
January	4.4166	4.8701	3.4553	0.25207	0.06354
February	5.5278	5.7548	5.2445	0.12137	0.01473
March	4.8732	5.4426	4.1839	0.27273	0.074382
April	4.4468	5.0362	4.0784	0.19847	0.039391
May	4.0174	4.6169	3.3221	0.27214	0.074058
June	3.7400	4.5156	3.2807	0.20953	0.043901
July	3.3388	4.1735	2.9391	0.23046	0.053112
August	2.3803	3.0056	0.94343	0.47174	0.22254
September	3.8549	4.7792	3.1757	0.38294	0.14664
October	3.3326	4.2356	2.5089	0.33041	0.10917
November	2.9086	4.2907	2.0765	0.46246	0.21387
December	4.004	4.6571	3.4823	0.26701	0.071295
Rainy season	3.8046	5.4426	0.94343	0.80274	0.64439
Dry season	4.0272	5.7548	2.0765	0.95724	0.91631
Annual value	3.9857	5.4426	0.94343	0.65057	0.42324

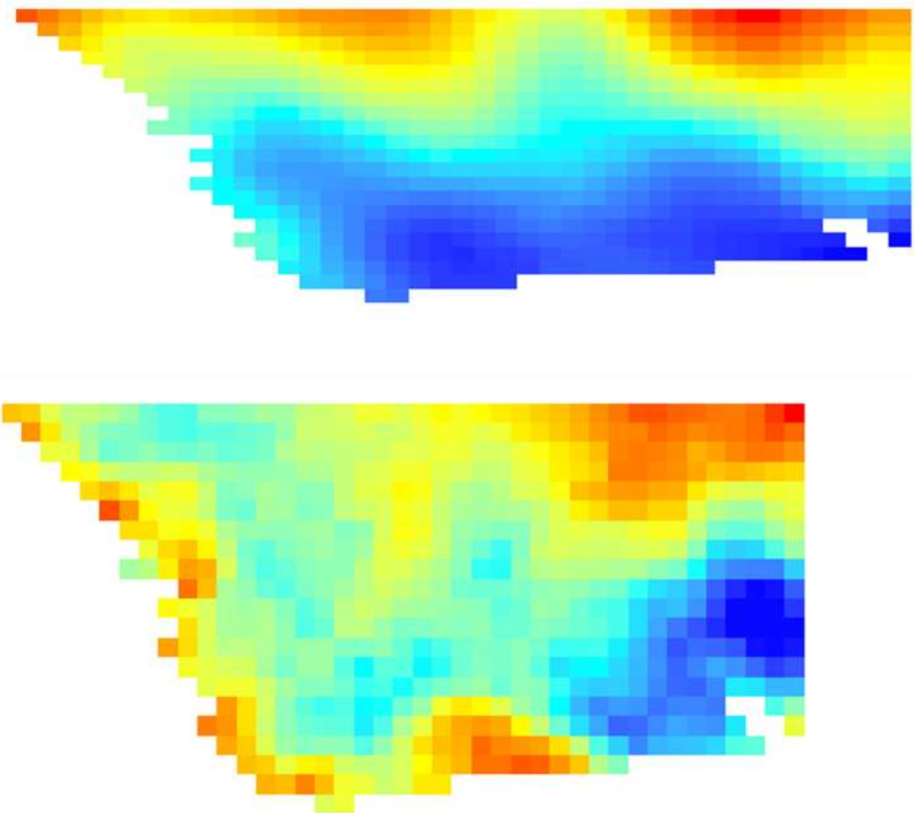

Figure 3. Distribution of solar energy for August and January 2003 respectively.

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Table 5. Analysis of solar radiance for 2004.

Items	Mean (kWh/m^2)	Maximum (kWh/m^2)	Minimum (kWh/m^2)	Standard deviation	Variance
January	4.3000	4.9072	3.7378	0.25338	0.064201
February	4.4440	5.3242	3.8155	0.31389	0.098525
March	4.3190	5.0137	3.6318	0.27281	0.074428
April	3.8033	4.4814	3.3680	0.21063	0.044363
May	4.4863	5.0087	3.9788	0.19986	0.039944
June	2.3171	3.5861	1.4975	0.46454	0.21580
July	3.4492	3.9663	2.6382	0.27212	0.07405
August	3.6343	4.7182	2.7112	0.38142	0.14548
September	3.5588	4.6634	2.7145	0.38051	0.14479
October	3.1743	4.7466	1.4766	0.85378	0.72894
November	4.1200	4.6728	3.7079	0.21210	0.044985
December	4.6983	5.2486	4.4032	0.13805	0.019059
Rainy season	3.6518	5.0137	1.4748	0.73437	0.5393
Dry season	4.1421	5.3242	1.4766	0.68404	0.46791
Annual value	3.9199	4.6634	2.7145	0.22494	0.050596

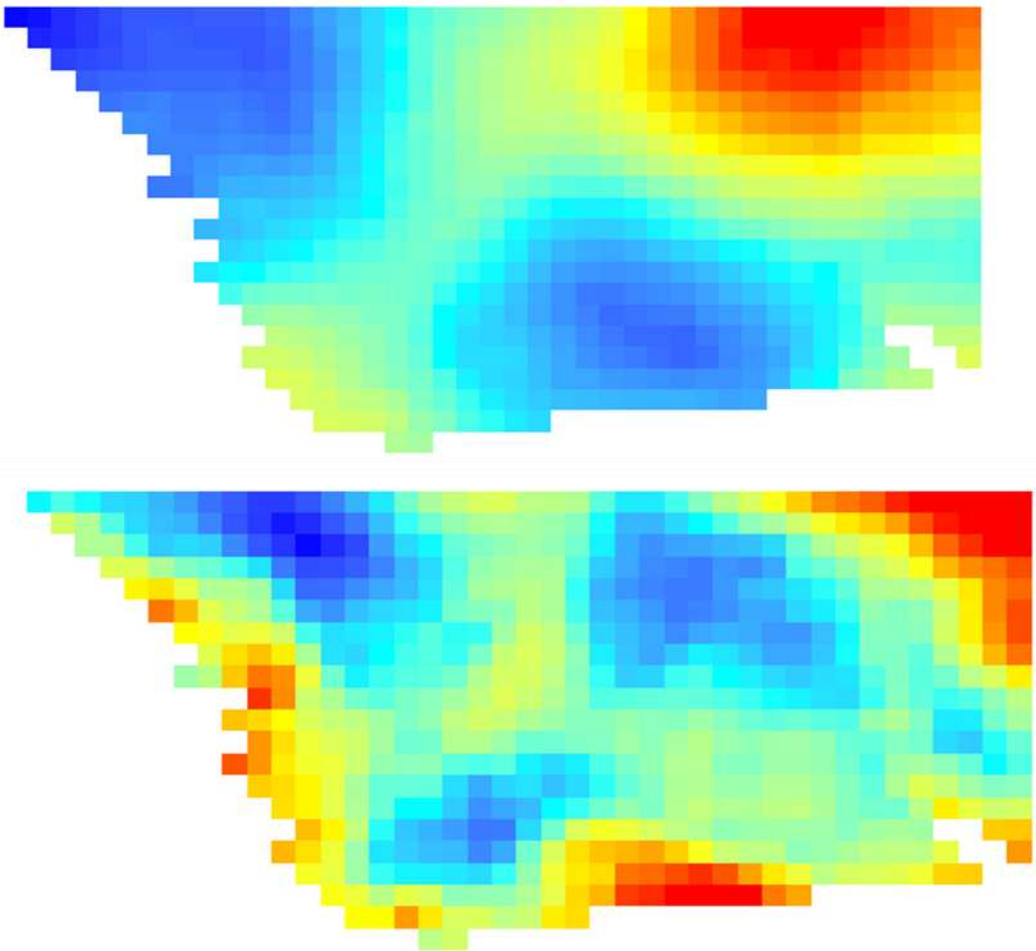

Figure 4. Distribution of solar energy in June and December 2004 respectively.

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4. Hybrid of solar energy system

There are several studies that embarked on hybrid of solar PV system and other renewable energy source as explained in the study done by Idris et al [76]. It is my hope that efficient configurations of hybrid will enhance the development of solar PV system and will be of utmost benefits to communities especially in rural areas as various projects had been achieved and still ongoing.

5. Recommendation and suggestion

Data repository for solar energy assessment in Nigeria should be developed and deployed for easy access for government, scholars, developers and investors. The universities, colleges, monotechnics and polytechnics should design their curriculum with incorporation of renewable energy as part of their general studies. Community sensitization and awareness should be programmed by the relevant agencies. An extensive tariff system should be designed by Energy Commission of Nigeria. Existing policy need to be tailored towards achieving rapid development on renewable energy system.

6. Conclusion

Several literatures were extensively studied the assessment of solar energy PV system, analysis of cost implication of solar energy and the hybrid system. Their works was reviewed to lay emphasis on what to be done to improve, enhance, and utilize solar energy in Nigeria. These was discussed at the end of each section. It should be reiterated all six geo-political zones in Nigeria possess adequate solar irradiance for solar energy PV system generation with larger values in the Northern region. Summarily, improvement on present renewable energy policy, formulation of appropriate financial system, collaboration on research and development and the willingness of government to explore renewable energy means are necessary steps to actualize our dreams on renewable deployment.

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References

1. J. Luo, C. Zhuang, J. Liu, and K. hung Lai, "A comprehensive assessment approach to quantify the energy and economic performance of small-scale solar homestay hotel systems," *Energy Build.*, vol. 279, p. 112675, 2023, doi: 10.1016/j.enbuild.2022.112675.
2. S. C. Nwokolo, J. C. Ogbulezie, and O. J. Ushie, "A multi-model ensemble-based CMIP6 assessment of future solar radiation and PV potential under various climate warming scenarios," *Optik (Stuttg).*, vol. 285, no. July 2021, p. 170956, 2023, doi: 10.1016/j.ijleo.2023.170956.
3. R. Liu, M. Liu, Y. Zhao, Y. Ma, and J. Yan, "Thermodynamic study of a novel lignite poly-generation system driven by solar energy," *Energy*, vol. 214, p. 119075, 2021, doi: 10.1016/j.energy.2020.119075.
4. M. K. Abdelrazik, S. E. Abdelaziz, M. F. Hassan, and T. M. Hatem, "Climate action: Prospects of solar energy in Africa," *Energy Reports*, vol. 8, pp. 11363–11377, 2022, doi: 10.1016/j.egyr.2022.08.252.
5. J. Wang, Z. Han, Y. Liu, X. Zhang, and Z. Cui, "Thermodynamic analysis of a combined cooling, heating, and power system integrated with full-spectrum hybrid solar energy device," *Energy Convers. Manag.*, vol. 228, no. November 2020, p. 113596, 2021, doi: 10.1016/j.enconman.2020.113596.

6. A. Abu-Rayash and I. Dincer, "Development and analysis of an integrated solar energy system for smart cities," *Sustain. Energy Technol. Assessments*, vol. 46, no. November 2020, p. 101170, 2021, doi: 10.1016/j.seta.2021.101170.
7. Y. Wu, C. Li, Z. Tian, and J. Sun, "Solar-driven integrated energy systems: State of the art and challenges," *J. Power Sources*, vol. 478, no. May, p. 228762, 2020, doi: 10.1016/j.jpowsour.2020.228762.
8. E. P. Agbo, C. O. Edet, T. O. Magu, A. O. Njok, C. M. Ekpo, and H. Louis, "Solar energy: A panacea for the electricity generation crisis in Nigeria," *Heliyon*, vol. 7, no. 5, p. e07016, 2021, doi: 10.1016/j.heliyon.2021.e07016.
9. T. R. Ayodele, A. S. O. Ogunjuyigbe, and K. C. Nwakanma, "Solar energy harvesting on building's rooftops: A case of a Nigeria cosmopolitan city," *Renew. Energy Focus*, vol. 38, pp. 57–70, 2021, doi: 10.1016/j.ref.2021.06.001.
10. C. G. Ozoegwu and P. U. obong Akpan, "Solar energy policy directions for safer and cleaner development in Nigeria," *Energy Policy*, vol. 150, no. June 2020, p. 112141, 2021, doi: 10.1016/j.enpol.2021.112141.
11. O. S. Ohunakin, M. S. Adaramola, O. M. Oyewola, and R. O. Fagbenle, "Solar energy applications and development in Nigeria: Drivers and barriers," *Renew. Sustain. Energy Rev.*, vol. 32, pp. 294–301, 2014, doi: 10.1016/j.rser.2014.01.014.
12. O. R. O, O. A. S. O, A. T. R, A. A. Yusuff, and T. C. Mosetlhe, "An assessment of proposed grid integrated solar photovoltaic in different locations of Nigeria: Technical and economic perspective," *Clean. Eng. Technol.*, vol. 4, p. 100149, 2021, doi: 10.1016/j.clet.2021.100149.
13. O. S. Ohunakin, M. S. Adaramola, O. M. Oyewola, and R. O. Fagbenle, "Solar radiation variability in Nigeria based on multiyear RegCM3 simulations," *Renew. Energy*, vol. 74, pp. 195–207, 2015, doi: 10.1016/j.renene.2014.07.057.
14. O. Ogunmodimu and E. C. Okoroigwe, "Solar thermal electricity in Nigeria: Prospects and challenges," *Energy Policy*, vol. 128, no. February 2018, pp. 440–448, 2019, doi: 10.1016/j.enpol.2019.01.013.
15. C. O. Okoye, O. Taylan, and D. K. Baker, "Solar energy potentials in strategically located cities in Nigeria: Review, resource assessment and PV system design," *Renew. Sustain. Energy Rev.*, vol. 55, pp. 550–566, 2016, doi: 10.1016/j.rser.2015.10.154.
16. H. T. Abdulkarim, C. L. Sansom, K. Patchigolla, and P. King, "Statistical and economic analysis of solar radiation and climatic data for the development of solar PV system in Nigeria," *Energy Reports*, vol. 6, pp. 309–316, 2020, doi: 10.1016/j.egyr.2019.08.061.
17. T. Y. Salihu, M. F. Akorede, A. Abdulkarim, and A. I. Abdullateef, "Off-grid photovoltaic microgrid development for rural electrification in Nigeria," *Electr. J.*, vol. 33, no. 5, p. 106765, 2020, doi: 10.1016/j.tej.2020.106765.
18. K. E. Enongene, F. H. Abanda, I. J. J. Otene, S. I. Obi, and C. Okafor, "The potential of solar photovoltaic systems for residential homes in Lagos city of Nigeria," *J. Environ. Manage.*, vol. 244, no. December 2018, pp. 247–256, 2019, doi: 10.1016/j.jenvman.2019.04.039.
19. C. G. Ozoegwu, "The solar energy assessment methods for Nigeria: The current status, the future directions and a neural time series method," *Renew. Sustain. Energy Rev.*, vol. 92, no. November 2017, pp. 146–159, 2018, doi: 10.1016/j.rser.2018.04.050.
20. H. O. Njoku, "Upper-limit solar photovoltaic power generation: Estimates for 2-axis tracking collectors in Nigeria," *Energy*, vol. 95, pp. 504–516, 2016, doi: 10.1016/j.energy.2015.11.078.
21. A. B. Owolabi, B. E. K. Nsafon, and J. S. Huh, "Validating the techno-economic and environmental sustainability of solar PV technology in Nigeria using RETScreen Experts to assess its viability," *Sustain. Energy Technol. Assessments*, vol. 36, no. July, p. 100542, 2019, doi: 10.1016/j.seta.2019.100542.
22. L. Olatomiwa, S. Mekhilef, S. Shamshirband, and D. Petković, "Adaptive neuro-fuzzy approach for solar radiation prediction in Nigeria," *Renew. Sustain. Energy Rev.*, vol. 51, pp. 1784–1791, 2015, doi: 10.1016/j.rser.2015.05.068.
23. J. K. Yohanna, I. N. Itodo, and V. I. Umogbai, "A model for determining the global solar radiation for Makurdi, Nigeria," *Renew. Energy*, vol. 36, no. 7, pp. 1989–1992, 2011, doi: 10.1016/j.renene.2010.12.028.
24. O. Bamisile *et al.*, "An approach for sustainable energy planning towards 100 % electri fi cation of Nigeria by 2030," *Energy*, vol. 197, p. 117172, 2020, doi: 10.1016/j.energy.2020.117172.
25. T. C. Chineke and U. K. Okoro, "Application of Sayigh 'Universal Formula' for global solar radiation estimation in the Niger Delta region of Nigeria," *Renew. Energy*, vol. 35, no. 3, pp. 734–739, 2010, doi: 10.1016/j.renene.2009.08.010.
26. P. C. Ene, C. C. Okoh, P. A. Okoro, S. V. Egoigwe, and K. C. Chike, "Application of smart DC-Grid for efficient use of solar photovoltaic system in driving separately excited DC motor: Dynamic performance and techno-economic assessments," *Clean. Eng. Technol.*, vol. 4, p. 100136, 2021, doi: 10.1016/j.clet.2021.100136.
27. M. S. Adaramola, S. S. Paul, and O. M. Oyewola, "Assessment of decentralized hybrid PV solar-diesel power system for applications in Northern part of Nigeria," *Energy Sustain. Dev.*, vol. 19, no. 1, pp. 72–82, 2014, doi: 10.1016/j.esd.2013.12.007.

28. D. Akinyele, L. Olatomiwa, D. E. Ighravwe, M. O. Babatunde, C. Monyei, and D. Aikhuele, "Optimal planning and electricity sharing strategy of hybrid energy system for remote communities in Nigeria," *Sci. African*, vol. 10, p. e00589, 2020, doi: 10.1016/j.sciaf.2020.e00589.
29. B. O. Ariyo, M. F. Akorede, I. O. A. Omeiza, S. A. Y. Amuda, and S. A. Oladeji, "Optimisation analysis of a stand-alone hybrid energy system for the senate building, university of Ilorin, Nigeria," *J. Build. Eng.*, vol. 19, no. August 2017, pp. 285–294, 2018, doi: 10.1016/j.jobe.2018.05.015.
30. A. E. Adeniji, A. N. Njah, and O. I. Olusola, "Phase synchronization between solar radiation and wind speed data from some locations across Nigeria via nonlinear recurrence measures," *Chinese J. Phys.*, vol. 61, no. August, pp. 274–282, 2019, doi: 10.1016/j.cjph.2019.08.015.
31. O. B. Adewuyi, R. Shigenobu, T. Senjyu, M. E. Lotfy, and A. M. Howlader, "Multiobjective mix generation planning considering utility-scale solar PV system and voltage stability: Nigerian case study," *Electr. Power Syst. Res.*, vol. 168, no. December 2018, pp. 269–282, 2019, doi: 10.1016/j.epsr.2018.12.010.
32. M. Juanpera, P. Blechinger, L. Ferrer-Martí, M. M. Hoffmann, and R. Pastor, "Multicriteria-based methodology for the design of rural electrification systems. A case study in Nigeria," *Renew. Sustain. Energy Rev.*, vol. 133, no. April, p. 110243, 2020, doi: 10.1016/j.rser.2020.110243.
33. E. C. Nnaji, D. Adgidzi, M. O. Dioha, D. R. E. Ewim, and Z. Huan, "Modelling and management of smart microgrid for rural electrification in sub-saharan Africa: The case of Nigeria," *Electr. J.*, vol. 32, no. 10, 2019, doi: 10.1016/j.tej.2019.106672.
34. E. C. X. Ikejemba and P. Schuur, "Locating solar and wind parks in South-Eastern Nigeria for maximum population coverage: A multi-step approach," *Renew. Energy*, 2016, doi: 10.1016/j.renene.2015.12.024.
35. D. O. Akinyele, R. K. Rayudu, and N. K. C. Nair, "Life cycle impact assessment of photovoltaic power generation from crystalline silicon-based solar modules in Nigeria," *Renew. Energy*, vol. 101, pp. 537–549, 2017, doi: 10.1016/j.renene.2016.09.017.
36. G. N. Nwaji, C. A. Okoronkwo, N. V. Ogueke, and E. E. Anyanwu, "Investigation of a hybrid solar collector/nocturnal radiator for water heating/cooling in selected Nigerian cities," *Renew. Energy*, vol. 145, pp. 2561–2574, 2020, doi: 10.1016/j.renene.2019.07.144.
37. A. U. Obiwulu, M. A. C. Chendo, N. Erusiafe, and S. C. Nwokolo, "Implicit meteorological parameter-based empirical models for estimating back temperature solar modules under varying tilt-angles in Lagos, Nigeria," *Renew. Energy*, vol. 145, pp. 442–457, 2020, doi: 10.1016/j.renene.2019.05.136.
38. E. F. Nymphas, T. A. Otunla, M. O. Adeniyi, and E. O. Oladiran, "Impact of the total solar eclipse of 29 March 2006 on the surface energy fluxes at Ibadan, Nigeria," *J. Atmos. Solar-Terrestrial Phys.*, vol. 80, no. May 1919, pp. 28–36, 2012, doi: 10.1016/j.jastp.2012.02.024.
39. M. S. Adaramola, "Viability of grid-connected solar PV energy system in Jos, Nigeria," *Int. J. Electr. Power Energy Syst.*, vol. 61, pp. 64–69, 2014, doi: 10.1016/j.ijepes.2014.03.015.
40. O. Elegbede, J. Kerr, R. Richardson, and A. Sanou, "Using a choice experiment to understand preferences in off-grid solar electricity attributes: The case of Nigerian households," *Energy Sustain. Dev.*, vol. 60, pp. 33–39, 2021, doi: 10.1016/j.esd.2020.12.001.
41. A. Kuhe, V. T. Achirgbenda, and M. Agada, "Global solar radiation prediction for Makurdi, Nigeria, using neural networks ensemble," *Energy Sources, Part A Recover. Util. Environ. Eff.*, vol. 43, no. 11, pp. 1373–1385, 2021, doi: 10.1080/15567036.2019.1637481.
42. T. R. Ayodele, A. S. O. Ogunjuyigbe, and O. A. Adeniran, "Evaluation of solar powered water pumping system: the case study of three selected Abattoirs in Ibadan, Nigeria," *Int. J. Sustain. Eng.*, vol. 12, no. 1, pp. 58–69, 2019, doi: 10.1080/19397038.2018.1482967.
43. U. B. Akuru, O. I. Okoro, and C. F. Maduko, "Harnessing Nigeria's abundant solar energy potential using the DESERTEC model," *J. Energy South. Africa*, vol. 26, no. 3, pp. 105–110, 2015, doi: 10.17159/2413-3051/2016/v26i3a2148.
44. C. A. Onwe, D. Rodley, and S. Reynolds, "Modelling and simulation tool for off-grid PV-hydrogen energy system," *Int. J. Sustain. Energy*, vol. 39, no. 1, pp. 1–20, 2020, doi: 10.1080/14786451.2019.1617711.
45. C. O. Okoye, A. Bahrami, and U. Atikol, "Evaluating the solar resource potential on different tracking surfaces in Nigeria," *Renew. Sustain. Energy Rev.*, vol. 81, no. June 2017, pp. 1569–1581, 2018, doi: 10.1016/j.rser.2017.05.235.
46. N. V. Ogueke, I. I. Ikpamezie, and E. E. Anyanwu, "The potential of a small hydro/photovoltaic hybrid system for electricity generation in FUTO, Nigeria," *Int. J. Ambient Energy*, vol. 37, no. 3, pp. 256–265, 2016, doi: 10.1080/01430750.2014.952841.
47. T. R. Ayodele and A. S. O. Ogunjuyigbe, "Performance assessment of empirical models for prediction of daily and monthly average global solar radiation: the case study of Ibadan, Nigeria," *Int. J. Ambient Energy*, vol. 38, no. 8, pp. 803–813, 2017, doi: 10.1080/01430750.2016.1222961.
48. E. O. Diemuodeke, A. Addo, I. Dabipi-Kalio, C. O. C. Oko, and Y. Mulugetta, "Domestic energy demand assessment of coastline rural communities with solar electrification," *Energy Policy Res.*, vol. 4, no. 1, pp. 1–9, 2017, doi: 10.1080/23815639.2017.1280431.

49. O. I. Okoro and T. C. Madueme, "Solar energy: A necessary investment in a developing economy," *Int. J. Sustain. Energy*, vol. 25, no. 1, pp. 23–31, 2006, doi: 10.1080/14786450600593147.
50. Koyejo Oduola and Zorbarile Atukomi, "Application of agglomerative hierarchical clustering and logistic model development for assessing solar energy acceptability as an alternate energy option," *Glob. J. Eng. Technol. Adv.*, vol. 7, no. 1, pp. 103–112, 2021, doi: 10.30574/gjeta.2021.7.1.0055.
51. S. A. Anaba and O. E. Olubusoye, "Determinants of use of solar energy as an alternative means of energy by small and medium enterprises in Lagos State, Nigeria," *Discov. Sustain.*, vol. 2, no. 1, 2021, doi: 10.1007/s43621-021-00038-7.
52. O. A. Thompson, B. O. Ajiboye, A. D. Oluwamide, and O. O. Oyenike, "Analysis of factors influencing households' preference level for solar energy in urban areas of southwest Nigeria," *Int. J. Energy Econ. Policy*, vol. 11, no. 3, pp. 468–476, 2021, doi: 10.32479/ijeep.10001.
53. D. Abdullahi, S. Renukappa, S. Suresh, and D. Oloke, "Barriers for implementing solar energy initiatives in Nigeria: an empirical study," *Smart Sustain. Built Environ.*, vol. ahead-of-p, no. ahead-of-print, 2021, doi: 10.1108/sasbe-06-2020-0094.
54. A. S. Barau, A. H. Abubakar, and A. H. I. Kiyawa, "Not there yet: Mapping inhibitions to solar energy utilisation by households in african informal urban neighbourhoods," *Sustain.*, vol. 12, no. 3, 2020, doi: 10.3390/su12030840.
55. A. . Ilori, W. . Mufutau, O. . Idowu, and J. . Babawale, "Analysis of Solar Energy Utilization Pattern in Ibadan , Oyo State , Nigeria," vol. 3, no. 1, pp. 27–35, 2020.
56. U. Chikwado *et al.*, "PRIMARY HEALTH CENTRE ROOF-TOP SOLAR ENERGY SYSTEM," vol. 8, no. 5, pp. 14205–14214, 2021.
57. N. E. Chiemelu, O. C. D. Anejionu, R. I. Ndukwu, and F. I. Okeke, "Assessing the potentials of largescale generation of solar energy in Eastern Nigeria with geospatial technologies," *Sci. African*, vol. 12, p. e00771, 2021, doi: 10.1016/j.sciaf.2021.e00771.
58. M. B. Ndanusa, "Harnessing Solar Energy Potential As an Alternative Source," vol. 3, no. 4, pp. 86–94, 2020.
59. S. Aliyu, A. S. Zakari, M. Ismail, and M. A. Ahmed, "An Artificial Neural Network Model for Estimating Daily Solar Radiation in Northwest Nigeria," *FUOYE J. Eng. Technol.*, vol. 5, no. 2, pp. 1–5, 2020, doi: 10.46792/fuoyejet.v5i2.563.
60. O. C. Akinsipe, D. Moya, and P. Kaparaju, "Design and economic analysis of off-grid solar PV system in Jos-Nigeria," *J. Clean. Prod.*, vol. 287, p. 125055, 2021, doi: 10.1016/j.jclepro.2020.125055.
61. H. O. Njoku and O. M. Omeke, "Potentials and financial viability of solar photovoltaic power generation in Nigeria for greenhouse gas emissions mitigation," *Clean Technol. Environ. Policy*, vol. 22, no. 2, pp. 481–492, 2020, doi: 10.1007/s10098-019-01797-8.
62. A. . Okoye, I. Ofang, G. . Nwaji, and E. . Anyawu, "Analysis of Solar Energy Resource Potential to Supplement Grid Power in Nigeria," vol. 17, no. 3, pp. 49–55, 2020, doi: 10.9790/1684-1703054955.
63. O. D. Ohijeagbon and O. O. Ajayi, "Solar regime and LVOE of PV embedded generation systems in Nigeria," *Renew. Energy*, vol. 78, no. 2015, pp. 226–235, 2015, doi: 10.1016/j.renene.2015.01.014.
64. A. Babajide and M. C. Brito, "Solar PV systems to eliminate or reduce the use of diesel generators at no additional cost: A case study of Lagos, Nigeria," *Renew. Energy*, vol. 172, pp. 209–218, 2021, doi: 10.1016/j.renene.2021.02.088.
65. A. A. Adesanya and C. Schelly, "Solar PV-diesel hybrid systems for the Nigerian private sector: An impact assessment," *Energy Policy*, vol. 132, no. April, pp. 196–207, 2019, doi: 10.1016/j.enpol.2019.05.038.
66. S. Salisu, M. W. Mustafa, L. Olatomiwa, and O. O. Mohammed, "Assessment of technical and economic feasibility for a hybrid PV-wind-diesel-battery energy system in a remote community of north central Nigeria," *Alexandria Eng. J.*, vol. 58, no. 4, pp. 1103–1118, 2019, doi: 10.1016/j.aej.2019.09.013.
67. J. O. Oladigbolu, Y. A. Al-Turki, and L. Olatomiwa, "Comparative study and sensitivity analysis of a standalone hybrid energy system for electrification of rural healthcare facility in Nigeria," *Alexandria Eng. J.*, vol. 60, no. 6, pp. 5547–5565, 2021, doi: 10.1016/j.aej.2021.04.042.
68. I. M. Bugaje, "Remote area power supply in Nigeria: The prospects of solar energy," *Renew. Energy*, vol. 18, no. 4, pp. 491–500, 1999, doi: 10.1016/S0960-1481(98)00814-3.
69. N. Hamisu Umar, B. Bora, C. Banerjee, P. Gupta, and N. Anjum, "Performance and economic viability of the PV system in different climatic zones of Nigeria," *Sustain. Energy Technol. Assessments*, vol. 43, no. November 2020, p. 100987, 2021, doi: 10.1016/j.seta.2020.100987.
70. W. Arowolo and Y. Perez, "Market reform in the Nigeria power sector: A review of the issues and potential solutions," *Energy Policy*, vol. 144, no. June 2017, p. 111580, 2020, doi: 10.1016/j.enpol.2020.111580.
71. T. R. Ayodele and A. S. O. Ogunjuyigbe, "Increasing household solar energy penetration through load partitioning based on quality of life: The case study of Nigeria," *Sustain. Cities Soc.*, vol. 18, pp. 21–31, 2015, doi: 10.1016/j.scs.2015.05.005.
72. O.-O. Izuchukwu and A. E. Peace, "Design of Affordable Solar Photovoltaic Systems in Nigeria: A Cost Implication Analysis," *South Asian J. Soc. Stud. Econ.*, vol. 10, no. 3, pp. 27–37, 2021, doi: 10.9734/sajsse/2021/v10i330264.

 doi:10.20944/preprints202307.0803.v1

73. U. K. Elinwa, J. E. Ogbeba, and O. P. Agboola, "Cleaner energy in Nigeria residential housing," *Results Eng.*, vol. 9, no. February 2020, p. 100103, 2021, doi: 10.1016/j.rineng.2020.100103.
74. M. S. Shahmohammadi, R. Mohd. Yusuff, S. Keyhanian, and H. Shakouri, "A decision support system for evaluating effects of Feed-in Tariff mechanism: Dynamic modeling of Malaysia's electricity generation mix," *Appl. Energy*, vol. 146, pp. 217–229, 2015, doi: 10.1016/j.apenergy.2015.01.076.
75. P. C. Nwilo, O. T. Badejo Badejo, and O. T. Badejo, "Impacts and Management of Oil Spill Pollution along the Nigerian Coastal Areas Geoid Modelling View project Current Modelling and Prediction View project Impacts and Management of Oil Spill Pollution along the Nigerian Coastal Areas." [Online]. Available: https://www.researchgate.net/publication/242327944
76. W. O. Idris, M. Z. Ibrahim, and A. Albani, "The Status of the Development of Wind Energy in Nigeria," *Energies*, vol. 13, no. 23, p. 6219, Nov. 2020, doi: 10.3390/en13236219.