Mathematical Modeling and Analysis for Solar Power Generation for Ado-Ekiti Climate zone, Ekiti State, Nigeria

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Abstract

Every climate zone in Nigeria requires adequate, reliable and clean power supply for domestic, commercial and industrial convenience of the citizens. However, the present energy state depicts a huge gap between the power generation and demand. Hence, the need to boost power generation through solar energy cannot be overemphasized. A ten year solar irradiance and temperature data were collected from National aeronautic space administration. The least square regression modeling was applied to the obtained data to determine the power generation for the Ekiti climate zone. Bayelsian criterion and Akaike information criterion were applied were used as the validation to choose the best probabilistic approach in the determination of the power generation among Weibull, Lognormal and Beta probability distributions. The goodness of fit for the least square regression model for power generation of solar energy for the climate zone were 0.94, 0.98 and 0.99 for root mean square error, mean average error and root square respectively. The lognormal probabilistic distribution proved to the best with the highest values of Akaike of 820.45 and Bayelsian information criterion of 930 when compared to both Weibull and Beta distribution. The generated solar power estimation for the period of ten range from 3709.03 kWh to 4126.81kWh.. Efforts should be geared towards using complex regression to further estimate the power generation. Comparative analysis of more probabilistic approaches should be employed to carry out solar power generation.

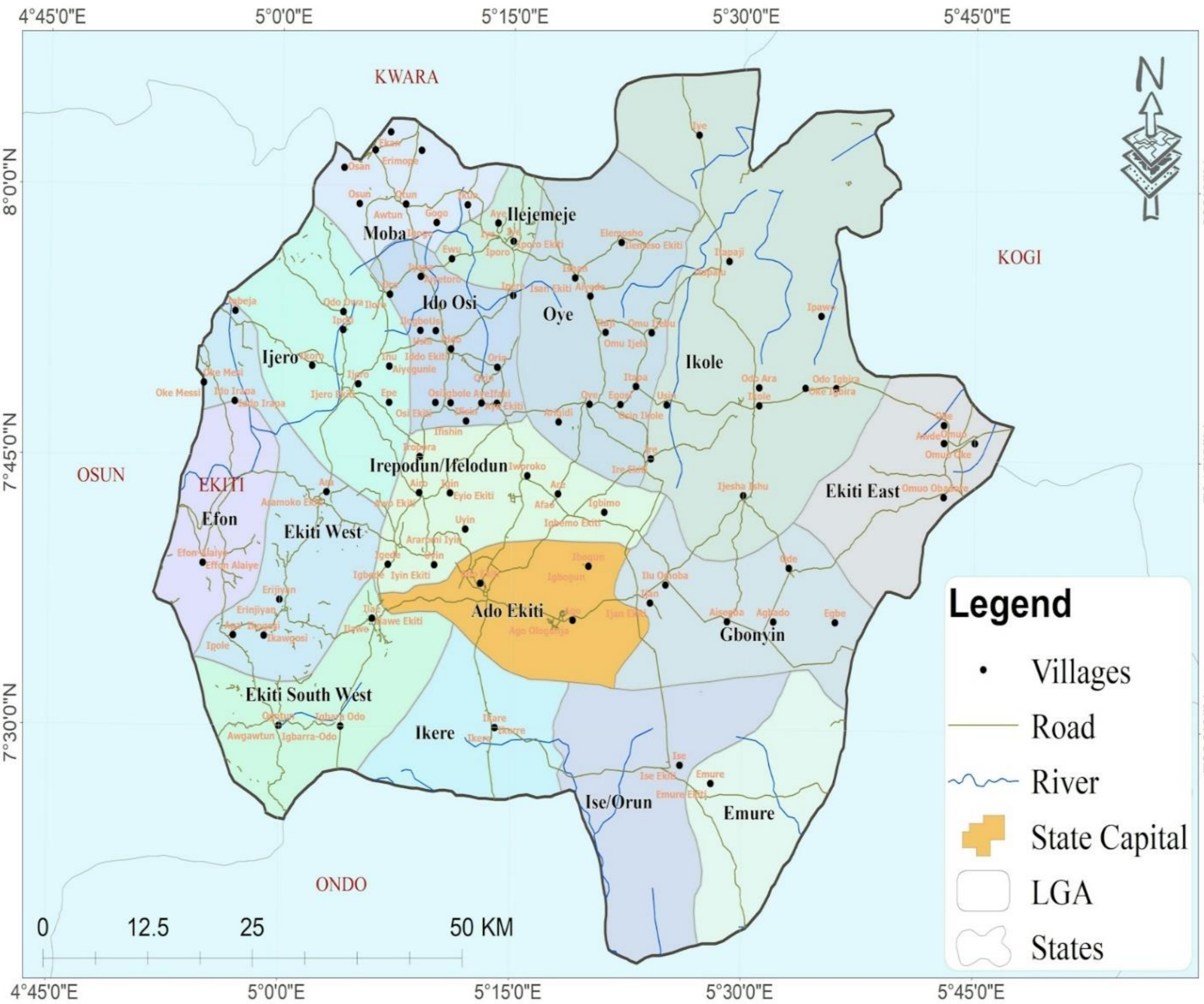
***Keyword**: climate, generation, model, solar, zone*

Introduction

Electricity plays an important role in human life and it is one of the indices to measure the standard of living for the people of a country. Conventional and non-conventional energy sources are used for electrical power generation. Due to the continuous use of conventional sources they are going to vanish from the earth and the main draw backs are the contribution to air pollution and global warming, the search for the other sources of energy ends with non-conventional sources of energy (RaviKumar & Vennila, 2017). Growing energy demand, depleting fossil fuel reserves and the global concern for increasing greenhouse gas emissions have encouraged the use of renewable energy sources such as solar photovoltaic (PV) and wind for electricity production. The falling price of PVs and its suitability for residential application have made it the prime choice as green energy solution. Globally, PV systems are the fastest growing power generation source (Dong et al., 2018; Mukherjee et al., 2019; Sharma et al., 2020). Renewable energy resources (RES) like solar and wind are going to become alternative for future energy needs (Manikanta et al., 2020; Patel & Singh, 2014; Sahu et al., 2020). Electricity generation based on renewable resources, mainly wind and solar, has highlighted additional challenges in the management of the electricity system, primarily due to the dispersion of this type of generators, the energy of changing output, and the inefficient coordination of the conditions of the electrical grid. These complications have created technical obstacles such as energy management, architecture design of electrical systems, voltage, and frequency support, means of protection and low voltage aspects (López-meraz et al., 2021). Solar PV power generation is not only important but also the proper matching of supply with the demand is vital for optimum use of energy systems (Barkavi, 2019). The PV energy as an alternative energy source has been extensively employed since it is pollution free, plentiful, and largely accessible. The PV power generation applications can be splitted into two categories, stand-alone systems and grid connected systems (Ehimen Airoboman, 2015). Solar energy is one of the most important sources of sustainable energy due to its wide availability and complete free of cost. Due to the environmentally friendly energy solutions, solar energy has received a very great attention and they have demonstrated a step forward in their performance in the past decades. In general, Renewable Energy Sources (RES) technologies are considered as a solution to reduce CO2 emission globally as they are non-pollutant sources. The environmental and technical problems of the conventional plants, which use fossil fuel, led to the increase of dependency of the distribution networks on the RES for generating electrical power (Moukhtar et al., 2018). Solar PV has the potential to help meeting the high load demand and at the same time present itself as an excellent energy source alternative that is environmentally friendly. In recent years, it becomes very cost competitive and competes with other fossil fuel-based generation cost. The solar PV capacity has increased by 40 GW during the period 2013–2014 (Alquthami et al., 2020). The importance of solar energy is marked by the fact that the current global installed capacity of solar PV generation is around 505 GW (Afzaal et al., 2020). The electricity supply to Ekiti State is sporadic, erratic and could be classified as the worst in the civilised world. The power line winds its way through 268 km of roads, probably one of the longest of such in the world. The State has over one hundred towns and villages with electricity served with 33 kV lines. The power supply sources to Ekiti State are Omu-aran, Isanle Mokutu, Akure and Ilesa with 12.7 MW, 4 MW, 10.8 MW and 10 MW respectively (Adeoye & Okereke, 2018; Adeoye & Oladimeji, 2016; Adeoye, 2021; Adeoye et al., 2021). The country has a population of over 170 million citizens with the government targeting 10,000MW generating capacity. However, the power generation is fluctuating from time to time based on gas pipeline vandalism and other environmental factors with low values of 1,508.6MW, 2,800 MW and high values of 4,387 MW and 5,000 MW (Adeoye et al., 2023; Adeoye & Adebayo, 2018). Power supply in Nigeria is characterized with incessant power outages due to internal and external faults, inadequate power generation, un-necessary long span, inadequate power design, wrong sizing of cables and conductors and other obvious factors affecting power supply effectiveness and this had ravaged the country with slow pace of development. Electricity is used for lightning, household purposes and allows for mechanization of farm operations (Adeoye et al., 2023; Adeoye & Adebayo, 2018). At least a billion people worldwide still lack house hold electric power (Adeoye & Oladimeji, 2016.). Electrical power balance is the mathematical difference between the injected powers and the (power demand) load on the busses (Adeoye,& Titiloye 2014).

Study Area

A small quantity of about 3 to 4 MW was released by the Akure injection substation at night periods, when the entire state depended on 132/33kV injection substation at Akure. The zone substation has been supplied from a long transmission from Oshogho axis. . It was noted that low load allocation on most of the 33kV feeders varied and particularly more pronounced on the Akure—Ado-Ekiti feeder. Variations occur in other injection substations within the state and that connecting to adjoining states with maximum injected power ranging from 4MW to 12.7MW (Adeoye, 2014). In Ado-Ekiti metropolis, the residents have not been enjoying constant power supply and good power quality because, the power authority (Benin Electricity Distribution Company) inherited problems from Power Holding Company of Nigeria (PHCN) ranging from Planning, inadequate kVA rating of transformers, illegal connections, in-adequate cross sectional areas of aluminum conductors, unnecessary long span of conductors, insufficient injected power from the authority to the community(Olulope& Adeoye 2018). The administrative map of Ekiti State is shown in fig.1.



Source: spatialnode.net/projects/Ekiti/state/map posted on 18th May, 2022 and retrieved on 31st May, 2024.

Fig.1: Administrative map of Ekiti Climate zone

Methodology

A ten year solar irradiance and temperature data were collected from National aeronautic space administration. The least square regression modeling was applied to the obtained data to determine the power generation for the Ekiti climate. The samples of the obtained data from solar were presented. The mathematical model for the solar power generation was stated. Bayelsian criterion and Akaike information criterion were applied were used as the validation to choose the best probabilistic approach in the determination of the power g3neration among Weibull, Lognormal and Beta probability distributions. Goodness of fit for the selected probabilistic distribution were applied to determine the best based on mean average error, root mean square error and root square. Table 1 represents the solar irradiance, relative humidity and temperature data for one decades.

The Mathematical model for solar power generation is denoted as:

$$Solar\ Power\ Generation = 32.3\,\alpha + 5\beta + 2.84\gamma + 0.01\delta \quad (1)$$

Where α is the solar irradiance

β is the temperature in degree celcius

γ is the dew

δ is the relative humidity

Weibull model for solar system

$$p(\alpha) = \frac{k}{c}\frac{v}{c}^{k-1} exp - \frac{v}{c}^{k} \quad (2)$$

k represents the shape parameter

c represents scale parameter

The cumulative distribution function is:

$$p(\alpha) = \int_0^\infty p(\alpha)d\alpha \ = 1 - \exp\{-(\frac{v}{c})^k \quad (3)$$

Lognormal model for solar system

$$f(\alpha, \gamma, \beta, \partial : \mu, \delta = \frac{1}{\alpha\delta\sqrt{2\pi}} \exp[-\frac{1}{2}[\frac{ln - \mu]}{\delta}^2 \quad (4)$$

$\alpha > 0, \partial > 0, \delta < \mu\delta$ (Lawan et al, 2015)

For Beta model of solar system,

$$PDF(S) = \frac{\Gamma(\alpha+\beta)}{\Gamma(\alpha)+\Gamma(\beta)} \times S^{\alpha-1} \times 1 - S^{\beta-1} \quad (5)$$

If $0 \leq s \leq 1, 0 \leq \alpha, \beta$

S is the solar irradiance kW/m2, α, β *are parameters of Beta probability distribution function* (Soroudi et al, 2012)

Table 1 : Collected Solar data from NASA

Day	Temperature (0C)	Dew (C)	Relative Humidity (%)	Solar irradiance (kWh/m2/day
1	22.1	13.32	58.36	13.32
2	22.4	14.81	58.6	14.81
3	24	16.15	58.47	16.15
4	23.2	17.33	63.26	17.33
5	22.8	18.86	70.63	18.86
6	23.4	17	63.33	17
7	24	16.83	64.87	16.83
8	23.9	13.97	59.26	13.97
9	22.8	12.12	56.14	12.12
10	22.7	12.19	55.05	12.19
11	23.8	12.35	56.02	12.35
12	23.4	11.86	56.02	11.86
13	23.6	14.98	58.49	14.98
14	24	16.62	61.45	16.62
15	24.3	13.98	59.06	13.59
16	22.7	14.09	54.08	14.87
17	23.0	15.80	54.09	15.21
18	22.5	14.00	56.09	15.0

Results and Discussion

Table 2 shows the estimated solar power generated for a period of ten years from 2014 to 2023. The result shows that the months of April and December have the highest solar power generation while the months of August and September for the period verified the lowest solar power generation. These were not far-fetched from the fact that the geographical location of an area determines the solar irradiance, dew, relative humidity and temperature. The application of Akaike and Bayelsian Criterion to the probabilistic distribution of Beta, Lognormal and Weibull. The Akaike information criteria were 817.13, 820.45 and 815.67 for Beta, lognormal and Weibull distribution. The Bayelsian information criteria for Beta, lognormal and Weibull were 912.24, 930.63 and 915.67 respectively. The goodness of fit for the least square regression model showed that RMSE, MAE and R2 were 0.94, 0.98 and 0.99 respectively. Table 2 and fig.2 show the behavioural pattern of the solar power generation in Ekiti Climate zone with the highest power generation in 2023 with 4126.81 kWh and the least in 2014 with 3709.3 kWh.

Table 2: Estimated Solar Power Generated (kWh) from 2014 to 2023 in Ekiti Climate zone

Month/ Year	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
January	303.96	307.17	310.24	315.47	321.08	318.14	316.77	318.14	320.34	324.14
February	337.96	340.41	338.22	341.22	330.10	313.89	319.20	342.44	338	338.12
March	395.47	396.19	398.24	401.24	400.4	398.1	390.10	402.11	396	398.11
April	430.39	440.71	420.29	401.24	430.84	401.26	440.11	401.22	390	391.56
May	387.94	384.77	385.66	401.17	396.24	398.11	401	402.11	400	396
June	384.06	383.11	382.11	400.11	380.46	381.6	382	392.17	401	402.44
July	318.80	301.22	305.2	390.24	317.91	315	320	321	318	321
August	276.58	270	272.4	316.11	276.2	280	268	266.4	264	275.2
September	274.10	271.2	272.1	275.11	271	265.11	266	272.2	275	278.11
October	280.11	281.1	280.2	270.06	281.4	282.4	281	284	280	283.8
November	303.96	307.1	308.9	280.5	308.14	309.1	307.2	306.4	307.2	308.22
December	400.1	401.2	400.6	309.11	407.11	408.44	400	408.2	409.5	410.11
Total	3709.37	4085.26	3801.75	3859.67	4120.58	4071.15	4091.38	4116.39	4009.04	4126.81
Mean	309.11	340.44	316.81	321.64	343.38	339.26	340.95	343.03	341.59	343.9

Table 3: Information Criterion for probabilistic distribution

Probabilistic Distribution	AIC	BIC
Beta	817.13	912.24
Lognormal	820.45	930.63
Weibull	815. 67	915.67

Table 4: Goodness of Fit Test for Least Square Regression

RMSE	MAE	R2
0.94	0.98	0.99

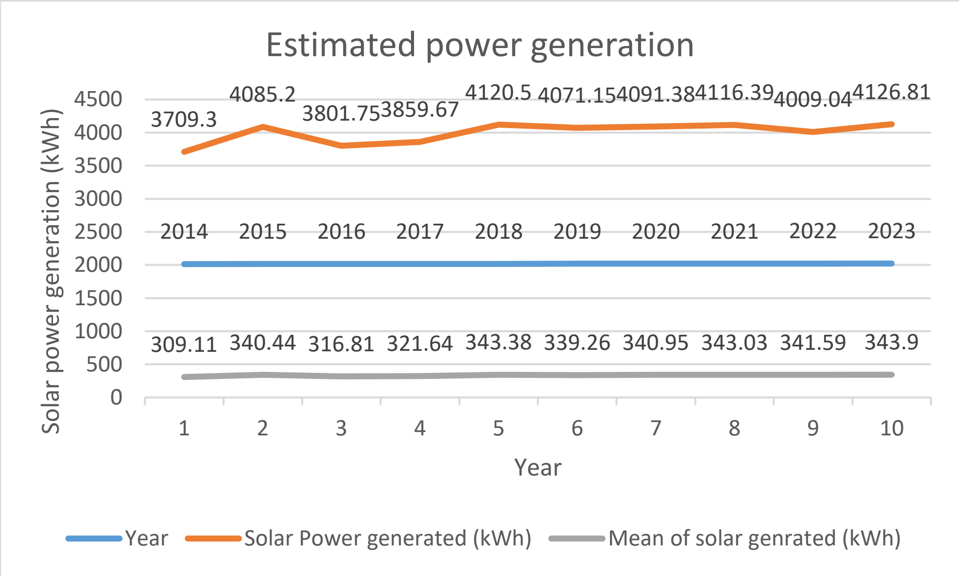


Fig. 2: plot of estimated solar power generation for Ekiti Climate zone from 2014 to 2023

Conclusion

The paper set up a mathematical model to estimate the solar power generation for Ado-Ekiti climate zone and analyzed that the potential for solar energy in the climate zone should be vigorously harnessed to minimize the incessant power supply and improve the supply to the zone. The estimated soalr power generation for the climate zone ranges from 3709.3 kwh to 4126.81kWh. The need to harness the solar energy potentials in the zone should be intensified to provide adequate power supply to the citizens at the level of domestication and the commercialization.

Recommendations

Further research should be carried out by utilizing various probabilistic distribution approaches to evaluate the solar power generation for more than two decades and select the best statistical approach.

Solar measuring tools to capture real time irradiance, temperature, dew and relative humidity to compare and contrast the measured and the result of this research.

Complex regression approach and neural network applications should be applied to the real time solar data to determine the power generation.

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