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Evaluating the Potential of Large-Scale Photovoltaic Power Generation for Rural Electrification in Makurdi Town, Benue State

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Abstract
The Angstrom-Prescott equation was developed in this research work for Makurdi town over five years from 2012 to 2016 as $H/H_o = 0.126 + 0.644(n/N)$ using Matlab software R2020 for the prediction of global solar radiation incident on the horizontal surface of Makurdi town and other areas with similar geographical weather conditions. The maximum average amount of global solar radiation over Makurdi town was obtained as 20 $MJm^{-2}day^{-1}$ during the dry season and the minimum value of 13 $MJm^{-2}day^{-1}$ during the rainy season which is in agreement with the global annual solar radiation range of 25.2 $MJm^{-2}day^{-1}$ in the far northern part of Nigeria and 12.6 $MJm^{-2}day^{-1}$ in the coastal region respectively. The regression constants for the developed Angstrom-Prescott equation in this work (a=0.126 and b=0.644) showed a significant increment compared with previous work due to the massive use of fossil fuel in Makurdi town which amounted to a high level of global warming in this area. The results obtained were statistically tested with the value of coefficient of determination R^2 as 0.669 (66.9%) and that of RMSE as 0.154% showing the high standard level of correlation of the data used and low percentage error of our methods and equation used in this research work. The high values of "a" and "b" (high global solar radiation and high sunshine hours) obtained in this work show great potential for large-scale photovoltaic power generation for rural electrification in Makurdi town and other areas with similar weather conditions for mitigation of global warming effects

Keywords: Renewable Energy, Solar Radiation, Photovoltaic, Electrification, Global Warming.

Introduction
Due to an excessive reliance on non-renewable energy sources to meet the needs of the globe's expanding population, the world is facing a serious challenge from climate change. This issue prompts scientists to look into alternate energy sources in an effort to lessen the catastrophic effects of climate change on people and other living things on Earth. According to the researchers' findings, using renewable energy sources is the most practical method to stop the catastrophe known as climate change. The term "renewable energy resources" refers to energy sources like tidal, biomass, solar, wind, and other natural forces that can never run out. Solar energy, or the energy that comes from the sun, is the most plentiful form of renewable energy that can be found on Earth. Therefore, if we fully exploit this energy source to end the period of fossil fuels (non-renewable energy resources), which made our planet's environment unsuitable for human habitation as well as plant life, we could address the issue of the world's expanding population. This may be readily accomplished by electrifying both rural and urban areas with photovoltaic power sources.

Mohammadu (2014) worked on solar pumping systems for rural areas' water supply in Nigeria and suggested that solar-powered water pumping should be advocated, supported, invested in, executed, and showcased on a large scale in Nigeria. The feasibility and readiness of the photovoltaic (PV) market in Nigeria, according to Adurodija et al. (1998). They noticed that the most cost-effective decentralized source to support rural development is photovoltaic. It was determined that the country's low level of PV utilization is primarily due to potential purchasers and energy planners not being aware of its widespread application. Growing awareness has led to the installation of PV systems for home lighting, water pumping, and rural electricity [https://www.researchgate.net/title/The market potential of photovoltaic systems in Nigeria] by some industrialists, government organizations, and affluent individuals.

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According to Madougou et al. (February 2013), studied the photovoltaic water pumping with batteries and without batteries in Niger and it was observed that people often used photovoltaic water pumping without batteries, commonly known as "pumping over the sun". Pumping over the sun is simpler and less expensive than with a battery system. Instead of batteries, they use a tank to store water until it is used. Hydraulic storage allows overcoming electrical energy storage thus avoiding the use of batteries which have a limited life (6 years compared with 20 to 30 years of photovoltaic panels) and are polluting. However, the method without batteries has some drawbacks and its main fault is to have a flow of water which depends on the average time of the sunlight (https://www.intechopen.com/books). Tolulope et al. (2014) examined the techno-economic and environmental effects of applying demand-side management (DSM) activities to rural loads. After applying Demand Side Management (DSM) approaches, the total daily consumption, which was initially projected to be 297 kWh/day, fell to 130 kWh/m^2/day, reflecting a decrease of 56.80%. The modelling and optimization processes were carried out using the program Hybrid Optimization Model for Electric Renewable. The impact of the DSM technique was assessed using variables such as the DSM index, net present cost, and emission level. The DSM activities often proved to be more affordable.

Oyedepo et al. (2019) investigated the hybrid energy system for generating power in rural Nigeria's six geopolitical zones. Using hourly mean, global solar radiation, and wind speed data for these sites, 500 rural houses with an electric load of 493 kWh per day over the course of 21 years (1992-2012) were chosen for this study. Between 2.31 m/s in Warri and 3.52 m/s in Maiduguri, as well as 4.53 kWh/m^2 in Warri and 5.92 kWh/m^2 in Maiduguri, respectively, were the mean annual wind speed and solar radiation for these localities. With the HOMER software's Micro-Power Optimization Model, these meteorological data were simulated. Warri has the highest NPC and COE, at $2,441,222 and $0.721/kWh, respectively, according to the statistics, while Maiduguri has the lowest. The feasibility of creating a standalone hybrid renewable energy system (RES) combining sun and wind for Giri village (Nigeria) was investigated by Sani et al. in 2019. The hybrid optimization model for the electric renewable (HOMER) simulation program was used to investigate the sustainability study. The best configuration was chosen based on the cost of electricity (COE), net present cost (NPC), renewable fraction (RF), and greenhouse gas emissions (GHG). According to the results of sensitivity analysis, the ideal configuration has an operating cost of $4723, an NPC of $1.01 m and a COE of $0.110/kWh. With a 98.3% renewable percentage and annual GHG emissions of 2889.36 kg, the system is environmentally friendly [https://www.sciencedirect.com].

Using four typical locations, Ogunjo et al. (2021) evaluated the solar energy potentials at various climatic zones in Nigeria. In order to determine the potential power production from solar power systems, surface temperature and solar radiation measurements that were received from the study areas were examined. It was established that seasonal variations had an impact on the solar power systems' monthly mean output power for the four study locations. Additionally, we came to the conclusion that the rising temperature is a significant factor restricting PV output in Nigeria. Using a simple linear relationship between energy generation potential, E/Pk, (kWh/kWp) and insulation (kWh/m^2/day) and data of monthly mean daily insolation incidents on horizontal surfaces obtained from the online open-access NASA Surface meteorology and Solar Energy (NASA-SSE) database. [https://www.researchgate.net.Solar energy potentials in different climatic zones of Nigeria]. Njoku (2014) estimated Photovoltaic electricity generation potentials for Nigeria on a 1° by 1° grid. For horizontal and optimally inclined PV collectors, the estimates are displayed as charts of seasonal and yearly E/Pk isoclines and tables of annual E/P for important urban centres in Nigeria. The seasons with the greatest expected E/Pk values were December-January-February and March-April-May, whereas the season with the lowest values was June-July-August. The yearly E/Pk ranged for horizontal (optimally slanted) collectors from 1150 (1200) kWh/kWp to 1750 (1800) kWh/kWp.

The feasibility analysis of load data and simulation of a standalone photovoltaic power system that met a household's electrical needs were explored by Ani., (2015). Studying and modelling the household's load consumption patterns was appropriate for simulation. The simulation conducted shows that the 520W solar PV array, 2312Ah nominal capacity battery, and 1 kW DC/AC inverter are capable of meeting the energy requirements to produce electricity, which is equivalent to a 650VA generator for domestic usage in Nigeria. This would work well for the deployment of 100% clean energy for long-term environmental sustainability and reliable, uninterrupted power in the home. The findings demonstrated that a single family may completely satisfy its annual electricity needs using only low-power using items. The potential of solar PV systems in residential structures in Nigeria's Lagos Metropolitan Area was evaluated by Enongene et al. (2019). To gather information on electric load, they used a survey of 150 residential buildings across three local government areas (LGAs) in Lagos State. In order to size the PV systems and calculate the level cost of energy (LCOE), HOMER Pro was employed. The PV array, lead acid battery, and converter (inverter) of the PV systems were found to be in the following ranges, according to the study's computed energy results for the base case scenario: 0.3 to 76 kW to 176kWh; and 0.1 to 13.2 kW, respectively. According to economic research, the systems' LCOE ranged from 0.398 USD/kWh to 0.743 USD/kWh. The potential exists for using electricity produced by PV systems in homes.

The use of large-scale solar photovoltaic (SPV) systems for improving the voltage stability of weakened national grids was studied by Adetokun et al. (2021). In order to improve voltage stability and as a feasible replacement for the outdated shunt reactors now utilized in the Nigerian national grid to alleviate overvoltage problems in Northern Nigeria, large-scale SPV integration has been researched in the Nigerian power system. We looked at two options for enhancing SPV penetration level (PL), namely distributed large-scale SPV throughout weak buses and concentrated large-scale SPV at the essential bus. The active power margin (APM), also known as the megawatt margin (MWM), reactive power margin (RPM), and associated critical voltage-reactive power ratio (CVQR) were used to assess the voltage stability of the system. In order to help reduce the impact of global warming caused by the burning of wood and to advance the sustainable technological development of the region, which was hindered by the Boko Haram insurgency, Owolabi et al., (2019), developed a solar energy road map to attract solar energy investors to invest in clean energy technology from the underutilized and abundant solar energy in North Eastern Nigeria. To confirm the technological, economic, and environmental viability of putting up a grid-connected solar PV system in the area, they employed RETScreen Expert software. The assessment was conducted using financial metrics and climatic information provided by the National Aeronautics and Space Administration (NASA) for the various locations. All of the chosen locations were recommended for solar photovoltaic projects.

Critical Solar PV Meteorological and Performance Parameters of a Roof-Mounted Crystalline Solar PV System in Berea, Durban, South Africa, were examined by Williams et al., in 2022. There were four software programs used for solar PV assessment, design, and simulation (PV*SOL, SOLARGIS Prospect and pv Planner, and PV system). The global tilted irradiation GTI, (1890 kWh/m2), global horizontal irradiation, GHI (1684 kWh/m2), diffuse horizontal irradiation DIF, (694 kWh/m^2), and ambient temperature (19 °C) are based on simulation reports collected from the four software applications employed. The produced energy (13.06 MWh/year), specific production (1511 kWh/kWp/year), performance ratio (PR) (79%), and solar fraction (SF) (36.92%) performance metrics were also reported [https://doi.org]. Gongsin et al. (2020) used energy characteristics of the monthly solar radiation data from Yola, a town in north-eastern Nigeria, to assess solar energy potentials in Adamawa state. The Weibull distribution offered the best fit for each month of the year out of the five distributions that were used to match the data. Standard home (1.626 m^2) and standard commercial (1.935 m^2) solar panels were exposed to solar radiation and their energy outputs were calculated using the Weibull distribution for each month. In August, radiation levels were at their lowest. This resulted in a realizable energy output for conventional residential and commercial panels of 1.514 kWh and 2.216 kWh, respectively. In Kano State Nigeria, Madugu et al. (2020) investigated the statistical analysis and energy output for the solar energy potential. The analysis's results might be utilized to realistically size and build sustainable energy solutions in the area. The Nigeria Meteorological Agency provided daily average sun radiation statistics going back 46 years. In order to determine the area's monthly energy potential, statistical analyses of the data were carried out with the aid of probability density functions. The findings indicated that August had the lowest solar energy at 227.05 W/m^2, while the month of March had the greatest at 291.75 W/m^2. These findings demonstrated that Kano's solar energy potential may be used to generate solar electricity at a reasonable cost, according to [https://www.researchgate.net]. In Makurdi, Audu, (2014) used meteorological characteristics to evaluate the viability of solar energy use. Angstrom-type correlation equations were created to estimate the amount of solar radiation that the world receives using data from Makurdi collected over a ten-year period (2000–2010) on solar radiation, relative sunshine hours, air temperature, and relative humidity measurements. The model equation that may be utilized to estimate the global solar radiation the most, with an R2 of 84.3%, MBE of 1.079 x 10-1, and RMSE of 2.466 x 10-2, was found. In comparison to the measured value of 15.690 MJm-2day-1 for the same period, this equation estimated the dry season to have the most global solar radiation at 15.702 MJm-2day-1, and the wet season to have the lowest.

Methodology

The Angstrom-Prescott equation is an equation that gives the direct correlation of sunshine hours and solar radiation amount incident on a particular location.

$$\frac{H}{Ho} = a + b \left(\frac{n}{N}\right) \qquad 1$$

Where

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In this research work, "a" and "b" are the regression coefficients that must be obtained using a graphical method. H_0 is the monthly average daily extraterrestrial solar radiation ($MJm^{-2}day^{-1}$), which is calculated using the formula below. H is the monthly average daily global solar radiation ($MJm^{-2}day^{-1}$), which is measured on the surface of the earth of the study location (Makurdi). "n" is the sunshine hours of the study area (Makurdi). N is the monthly average daily maximum number of hours of possible sunshine (or day length).

$$H_o = \frac{24(60)}{\pi} I_{sc} d_r (W_s Sin(\varphi) Sin(\delta) + Cos(\varphi) Cos(\delta) Sin(W_s)) \qquad 2$$

Where the light beams from the Sun and the Earth's equator are represented by the declination angle of solar radiation, δ. The angle of declination varies throughout the year due to the Earth's annual rotation and tilt. The solar declination varies annually between -23.44 and +23.44 degrees in accordance with the Earth's seasons. The formula for the declination angle of solar radiation is

$$\delta = 0.409 Sin(\frac{2\pi}{365} J - 1.39) \qquad 3$$

Where J is the total number of days in a year, counting from 1 (January 1) to 365 or 366 (December 31). Equation (3) above is used to obtain the solar declination angle values, which are then tabulated as indicated below for a period of five years.

Table 1. The average monthly values of δ in degrees and radians

Month	δ in degrees(^{0})	δ in radians
January	-17.7	-0.3090
February	-8.6	-0.1496
March	3.3	0.0579
April	14.3	0.2503
May	21.8	0.3800
June	23.2	0.4051
July	18.3	0.3202
August	8.4	0.1463
September	-3.1	-0.0544
October	-14.5	-0.2531
November	-21.7	-0.3787
December	-23.2	-0.4046

dr is **the inverse** relative distance of Earth-Sun. It is calculated using the formula below as;

$$d_r = 1 + 0.033 Cos(\frac{2\pi}{365} J) \qquad 4$$

Equation 4 was used for all the twelve months for the five years and the values are shown in the table below.

Table 2. The average monthly values of Inverse relative distance Earth-sun (dr) in radians and in degrees

Month	**dr in radians**	**dr in degrees(^{0})**
January	1.0284	58.9
February	1.0174	58.3
March	1.0013	57.4
April	0.9848	56.4
May	0.9720	55.7
June	0.9670	55.4
July	0.9709	55.6
August	0.9828	56.3
September	0.9984	57.2
October	1.0154	58.2
November	1.0278	58.9
December	1.0330	59.2

W_s is the Sunset angle. It is calculated using the formula given as;

$$W_s = Cos^{-1}(-\tan(\varphi)\tan(\delta)) \quad 5$$

The sunset angle values are calculated using equation (3.5) and presented in the table below.

Table 3 shows values of sunset angles (W_s)

Month	W_s in radians	W_s in degrees (^{0})
January	1.5277	87.5
February	1.5505	88.8
March	1.5786	90.4
April	1.6053	92.0
May	1.6247	93.1
June	1.6286	93.3
July	1.6155	92.5
August	1.5907	91.1
September	1.5635	89.6
October	1.5359	88.0
November	1.5171	86.9
December	1.5130	86.7

I_{sc} is a Solar constant. The value of the solar constant is 1367 W/m^2. This value is converted to mega-joules per meter square per day as; $(1367 \times 60)/10^6 = 0.0820\ MJm^{-2}\ day^{-1}$ and φ is the latitude angle of the location (Makurdi at $7^0 41^1$), which is 0.134 in radians.

Extraterrestrial Radiation Values (H_o)

The values of extraterrestrial radiation are calculated using equation (2) above as

$$H_o = \frac{24(60)}{\pi} I_{sc} d_r (W_s \operatorname{Sin}(\varphi)\operatorname{Sin}(\delta) + \operatorname{Cos}(\varphi)\operatorname{Cos}(\delta)\operatorname{Sin}(W_s))$$

The values of extraterrestrial solar radiation obtained are presented in the table below.

Table 4. The average monthly values of extraterrestrial radiation (H_o) in $MJm^{-2}day^{-1}$

Month	H_o ($MJm^{-2}day^{-1}$)
January	34.0596
February	36.2856
March	37.6932
April	37.4850
May	36.5159
June	36.1659
July	36.7717
August	37.3546
September	35.9720
October	34.6344
November	32.6259
December	32.2231

The Global Solar Radiation Values

The following table presents the values of global solar radiation, expressed in $MJm^{-2}day^{-1}$, that were gathered at the Nigerian Meteorological Agency's Nnamdi Azikiwe International Airport in Abuja.

Table 5 Monthly mean solar radiation values in $MJm^{-2}day^{-1}$ for five years

Month/Year	**2012**	**2013**	**2014**	**2015**	**2016**
January	20.272	19.994	18.334	19.197	21.949
February	18.794	20.171	18.421	18.779	19.765
March	18.230	18.521	18.025	18.174	18.617
April	17.837	17.688	17.734	17.609	18.432
May	15.746	16.252	16.466	15.927	16.419
June	14.056	13.871	14.403	14.101	15.157
July	13.507	12.537	13.272	13.868	14.594
August	14.293	15.146	14.198	14.019	14.224
September	15.884	15.073	15.048	15.200	15.033
October	17.315	17.121	17.509	17.231	17.004
November	17.163	17.597	18.882	21.224	20.958
December	19.021	18.295	21.448	22.542	20.530

The ratios of global solar radiation to extraterrestrial solar radiation are presented in the table below.

Table 6. The ratios of global solar radiation to extraterrestrial solar radiation (H/Ho) for five years

Month/Year	2012	2013	2014	2015	2016
January	0.595	0.587	0.538	0.564	0.644
February	0.528	0.556	0.508	0.518	0.545
March	0.484	0.491	0.478	0.482	0.494
April	0.476	0.472	0.473	0.470	0.492
May	0.431	0.445	0.451	0.436	0.450
June	0.389	0.384	0.398	0.390	0.419
July	0.367	0.341	0.361	0.377	0.397
August	0.383	0.405	0.380	0.375	0.381
September	0.442	0.419	0.418	0.423	0.418
October	0.500	0.494	0.506	0.498	0.491
November	0.526	0.540	0.579	0.651	0.643
December	0.590	0.568	0.666	0.700	0.637

Sunshine Hour values

The values of sunshine hours in hours were collected during a five-year period at the Nigerian Meteorological Agency (NIMET), Nnamdi Azikiwe International Airport in Abuja, and were tabulated for presentation.

Table 7 The average monthly values of sunshine hours for five years.

Month/Year	**2012**	**2013**	**2014**	**2015**	**2016**
January	7.5	7.3	7.7	7.6	7.7
February	7.2	8.0	7.3	7.0	7.2
March	6.8	6.3	6.3	6.3	6.2
April	6.2	6.4	7.3	7.3	7.7
May	7.1	7.0	6.7	6.7	6.5
June	6.9	7.2	6.9	6.8	6.7
July	5.1	5.3	5.2	5.0	5.1
August	4.1	4.6	4.5	4.3	4.5
September	4.9	4.9	4.8	4.7	4.7
October	6.6	7.0	7.0	6.9	7.2
November	8.7	8.6	8.5	8.4	8.6
December	7.9	7.9	7.9	7.9	7.9

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Day Light Hours (N)
This is the number of hours the sun shines on the earth. It is calculated using the formula below.

$$N = \frac{2}{15}W_s \quad (6)$$

The obtained values are presented below.

Table 8 Average values of daylight hours for the five years

Month	**N** in hours
January	11.7
February	11.8
March	12.0
April	12.3
May	12.4
June	12.4
July	12.3
August	12.1
September	11.9
October	11.7
November	11.6
December	11.6

Ratios of Sunshine Hours to Daylight Hours (n/N)
The ratios of sunshine hours to daylight hours for five years were calculated and tabulated below.

Table 9. The average monthly mean ratios of sunshine hours to daylight hours (n/N) for five years.

Month/Year	2012	2013	2014	2015	2016
January	0.641	0.624	0.658	0.650	0.658
February	0.602	0.678	0.619	0.593	0.610
March	0.567	0.525	0.525	0.525	0.517
April	0.564	0.520	0.593	0.593	0.626
May	0.573	0.565	0.540	0.540	0.524
June	0.556	0.581	0.556	0.548	0.540
July	0.415	0.431	0.423	0.407	0.415
August	0.339	0.380	0.372	0.355	0.372
September	0.412	0.412	0.403	0.395	0.395
October	0.564	0.598	0.598	0.590	0.615
November	0.750	0.741	0.733	0.724	0.741
December	0.681	0.681	0.681	0.681	0.681

Results
The findings pertaining to the methodology are presented for examination and discourse. Graphs and charts are essentially used in this research to represent all of the data collected according to the technique.

Global Solar Radiation
The bar chart below compares the monthly global solar radiation values for five years using the data from Table "5" above.

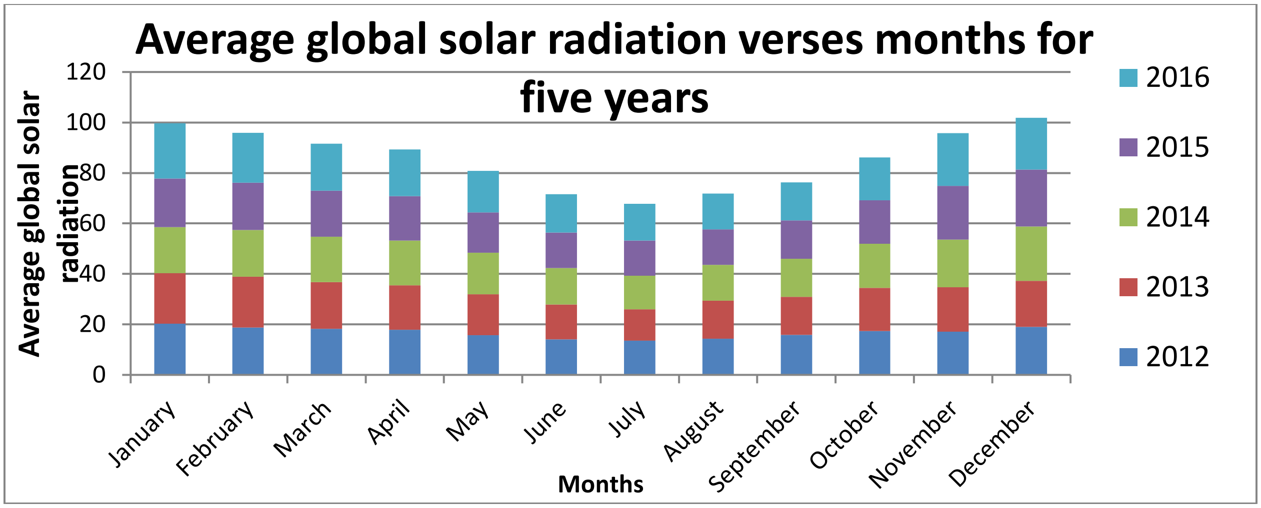

Figure 1: Average global solar radiation versus months for five years

The solar radiation incident in Makurdi town is shown in Figure "1" to be highest in December (20 $MJm^{-2}day^{-1}$) during the dry season due to the clear skies during this season and to be lowest during the rainy season (13 $MJm^{-2}day^{-1}$), especially in July due to the high amount of clouds covering the atmosphere during this season. This conclusion was in line with Audu's earlier findings, which showed that the lowest during the rainy season is 12 $MJm^{-2}day^{-1}$ and the highest during the dry season is 16 $MJm^{-2}day^{-1}$.

Average Sunshine hours

The collected data for sunshine hours for five years in Table "7" above is analyzed using the bar chart as shown in Figure 2 below.

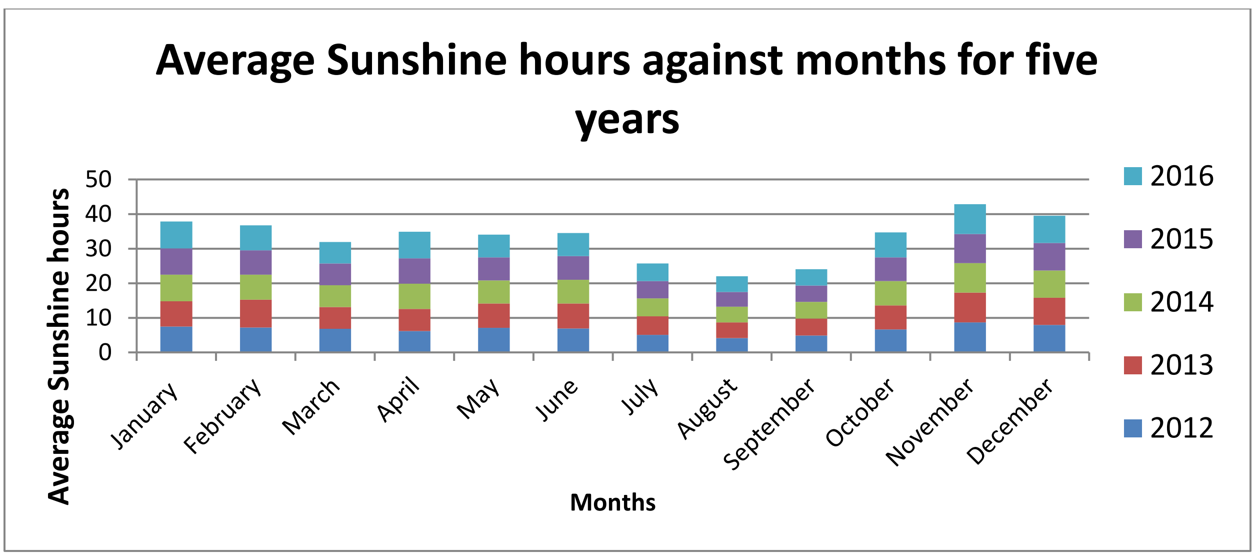

Figure 2: Average sunshine hours against months for five years

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The graph's conclusion indicates that because of the clear atmosphere, dense cloud cover, and sun's position during these seasons, the sun shines more during the dry season, particularly in November and less in August during the rainy one. This outcome was consistent with Audu's ten years of prior research in this field from 2000 to 2010.

Angstrom-Prescott Equation

Using Mat lab software R2020, the Angstrom-Prescott equation for this research is created by averaging data from five years' worth of ratios between sunshine hours and daylight hours and between global solar radiation and alien solar radiation.

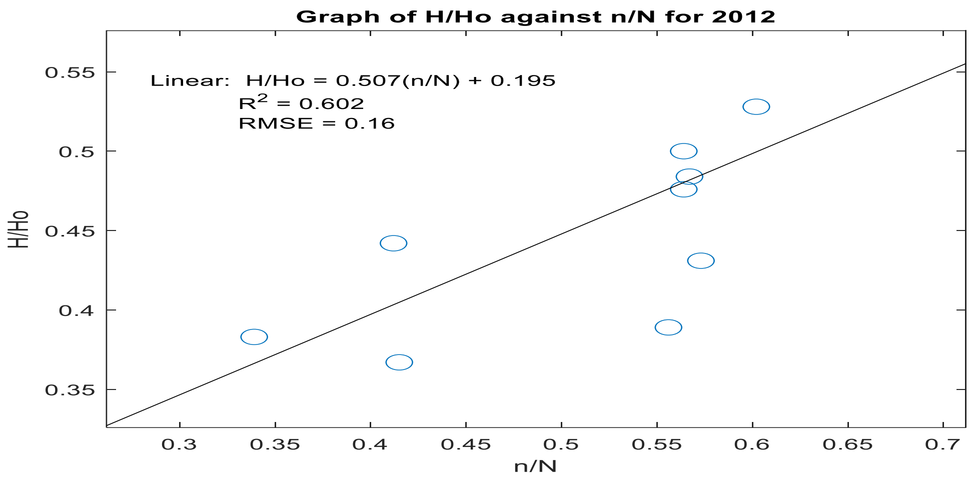

Figure 3: Graph of H/Ho against n/N for 2012

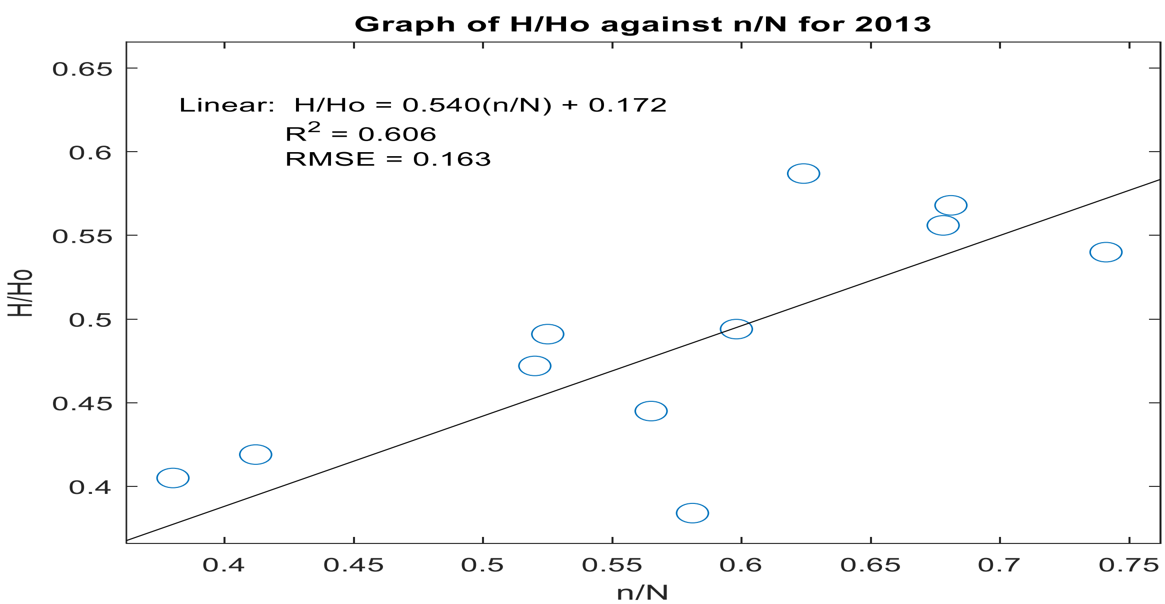

Figure 4: Graph of H/Ho against n/N for 2013

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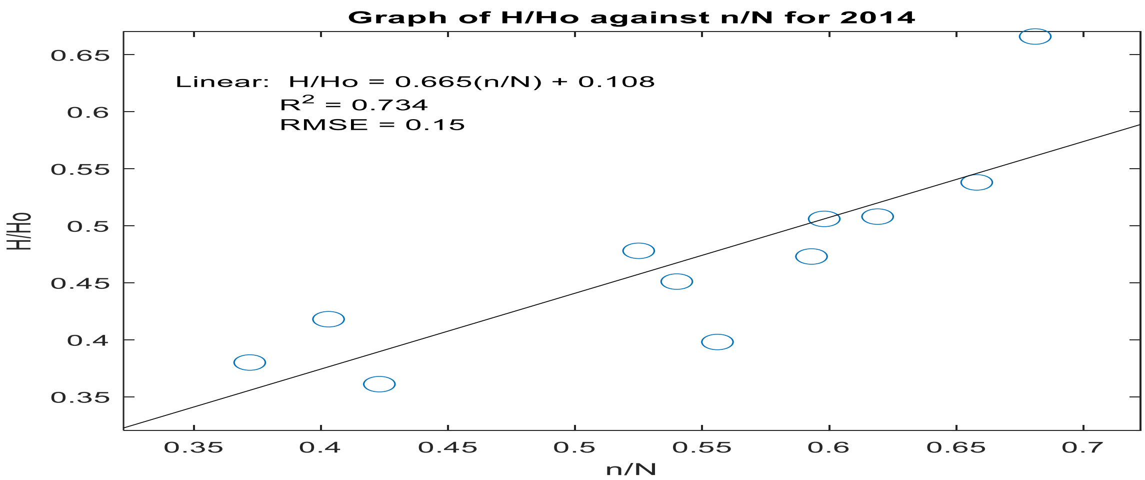

Figure 5: Graph of H/Ho against n/N for 2014

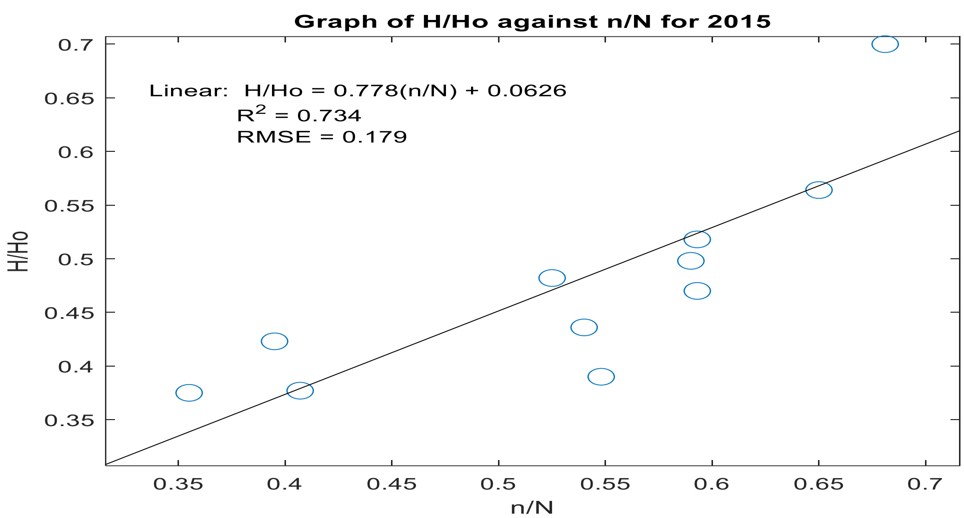

Figure 6: Graph of H/Ho against n/N for 2015

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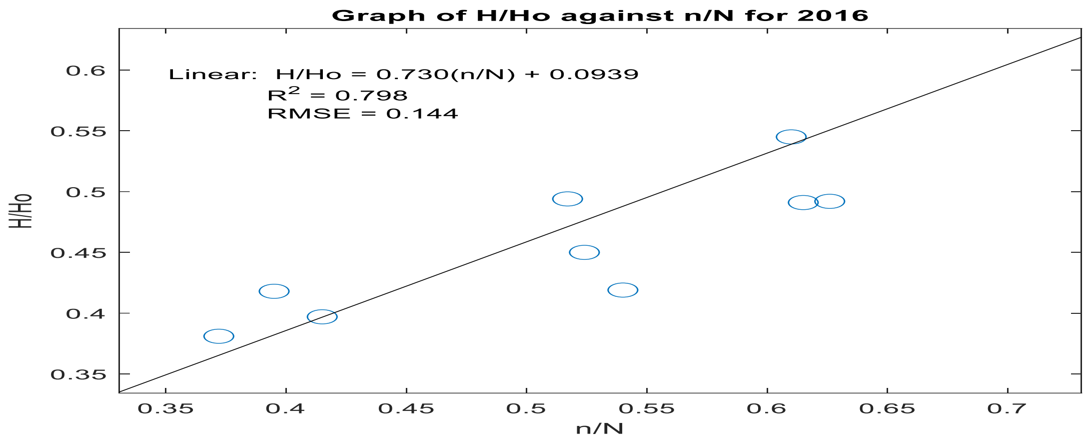

Figure 7: Graph of H/Ho against n/N for 2015

From the five plotted graphs of H/H_o against n/N, the five Angstrom-Prescott equations are obtained and presented in a tabular form as shown below.

Table 10 Angstrom-Prescott equations for five years (2012-2016)

Year	Values of "a"	Values of "b"	Angstrom-Prescott equation
2012	0.195	0.507	$H/H_o = 0.195 + 0.507(n/N)$
2013	0.172	0.540	$H/ H_o = 0.172 + 0.540(n/N)$
2014	0.108	0.665	$H/ H_o = 0.108 + 0.665(n/N)$
2015	0.0626	0.778	$H/ H_o = 0.0626 + 0.778(n/N)$
2016	0.0939	0.730	$H/ H_o = 0.0939 + 0.730(n/N)$
Mean	0.126	0.644	$H/ H_o = 0.126 + 0.644(n/N)$

$$H/ H_o = 0.126 + 0.644(n/N) \quad (7)$$

The established equation for Makurdi Town's research project is Equation 7. The root mean square error (RMSE) of the equation is 0.159(15.9%), while the coefficient of determination (R) is 0.695 (69.5%). This equation is contrasted, as indicated below, with the earlier modelled equation in Makurdi town created by Audu between 2000 and 2010.

Table 11 Comparison of Angstrom-Prescott Equations in Makurdi Town

Period	"a"	"b"	Developed equation
Current (2012—2016)	0.126	0.644	$H/H_o = 0.126 + 0.644(n/N)$
Previous (2000—2010)	0.138	0.455	$H/H_o = 0.138 + 0.455(n/N)$

Discussion

According to this finding, Makurdi Town saw more incidents of global solar radiation throughout the five years (2012–2016) than in previous years. However, the atmospheric reflection and absorption during these years was low. Due to the area's excessive use of fossil fuels and other non-renewable energy sources, Makurdi Town has seen high levels of solar radiation over the past five years. In order to lessen the effects of global warming on Makurdi town and other places with comparable geographical features, this has shown the area's high level of global warming and its tremendous potential for photovoltaic power generation for rural electrification. With the help of this work, we were able to create a model (H/Ho = 0.126 + 0.644(n/N)) that makes it simple to estimate the incidence of solar radiation in Makurdi Town and other places with comparable geographic weather. Additionally, we discovered significant potential for the production of photovoltaic power systems for ruler electrification in Makurdi in place of fossil fuel (non-renewable energy resources) in order to lessen the dangerous effects of global warming on this area due to the high levels of solar radiation in this region (Makurdi town).

Conclusion

This work allowed us to develop a model (H/Ho = 0.126 + 0.644(n/N)) that facilitates the estimation of solar radiation incidence in Makurdi Town and other locations with similar geographic conditions. Additionally, we discovered that there is a great deal of potential for the production of photovoltaic power in Makurdi Town due to the high levels of solar radiation in the area.

Recommendations

The following recommendations were made.

1. Other methods/equations should be used to evaluate solar radiation values in this area to compare with the methods and equations we used in this research work.
2. Governments, individuals and NGOs should embark on total migration from non-renewable energy power systems to photovoltaic power generation systems (renewable energy systems) to drastically reduce global warming effect on our planet Earth.
3. Government agencies and Non-governmental organizations should always use the models developed in this area whenever they are to execute any renewable energy project.

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