

Estimation and Ranking of the Photovoltaic Energy Potential for Local Government Areas in Akwa Ibom State, Nigeria

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Abstract: In this paper, a comparative assessment and ranking of the solar photovoltaic (PV) generation potential and unit cost of energy in ten Local Government Areas (LGAs) in Akwa Ibom State (AKS), Nigeria is presented. The meteorological data used in this study was obtained from the National Aeronautics and Space Administration Surface meteorology and Solar Energy (NASA SSE) website. Photovoltaic System (PVSyst.) simulation software, (Version 5.06) was used for the simulation and determination of the PV energy generation potential and unit cost of energy in each of the LGAs considered. The unit cost of energy in Naira/kWh and available energy per year (in kWh) are the two major parameters used to rank the LGAs from the top to bottom. A mathematical model relating the unit cost of energy and available energy in AKS is also developed. From the simulation results, Uyo LGA had the highest yearly energy output of 12422 kWh and lowest unit cost of energy of 104 Naira/kWh, while Uruan LGA had the lowest yearly energy output of 10591 kWh and highest unit cost of energy of 114 Naira/kWh. The results from this research are relevant for facilitating investment and adoption of photovoltaic power systems in AKS and to make realistic economic projections.

Keywords: Renewable Energy, Solar Radiation, Unit Cost of Energy, Photovoltaic, Energy Potential, Optimal Tilt Angle

1. Introduction

Renewable energy sources are increasingly becoming significant owing to huge demand for energy and the hazardous effects of fossil fuel [1, 2, 3]. The main advantage of renewable energy sources is that, it is pollution free and this preserves the ecological cycle of the global bio-systems [1, 2, 4, 5]. Also, the fossil fuel-based energy sources are not renewable. While non-renewable sources of energy are harmful to the environment, inadequate and are in short supply, renewable energy will never run out. Accordingly, the depletion of fossil fuel resources on a worldwide basis has necessitated urgent search for alternative energy sources to meet the present day energy demands. Equally, the urgent need to promote alternative and renewable sources of energy across the globe and especially in Nigeria with perennial power

generation shortage cannot be over emphasized. Thus, alternative and renewable energy approach is inevitable, given the fact that the biomass based fuels are increasingly becoming environmentally harmful, and this affects the ecological system. The solar energy resource is therefore one of the best energy alternatives and that is why it has become the focus of this paper [6, 7].

Without doubt, the demand for solar electric power systems has grown steadily over the last few decades. Interestingly, AKS has enormous solar potential but the use of solar power is very insignificant when compared to the use of fossil fuel-based power supply. One reason for this is insufficient knowledge of the solar potential of the state and the cost implication of such systems. As such, the focus of this paper is on the techno-economic analysis and ranking of the PV energy potential of LGAs in AKS.

2. Methodology

The work entailed in this paper includes comparative assessment of the PV electric power generation potential and unit cost of electricity at selected LGAs in AKS. Notably, the energy conversion efficiency of PV modules depends on a number of influences among which include: the temperature of the PV module, which in turn depends on the temperature of the surrounding air, on the light intensity and on the local wind speed. All these effects cause the module efficiency to deviate from the efficiency measured under standard test conditions (stc), which defines the rated or nominal power of a given PV module. The energy production of a given PV module would also vary, due to other none intrinsic factors relating to the details of installation (such as the inclination angle and possible shadows) to the total amount of solar radiation at the site of installation, or the probability of dust or snow deposition.

Consequently, in this paper, PVSyst. software is used to

$$\frac{G(\beta)}{G(\beta_{opt})} = 1 + 4.46 \times (10^{-4})(\beta - \beta_{opt}) - 1.19 \times (10^{-4})(\beta - \beta_{opt})^2 \quad (1)$$

Where: $G(\beta)$ in Wh/m² is the daily global irradiation at an angle β° and β_{opt} the optimal inclination, $G(\beta_{opt})$ in Wh/m² is the global irradiation at an the optimal angle β_{opt} . β and β_{opt} are in degrees. The optimal inclination (β_{opt}) can be calculated with [8, 9, 10]:

$$\beta_{opt} = 3.7 + 0.69|\phi| \quad (2)$$

where: ϕ is the local latitude in degrees.

When global irradiation on horizontal plane is given ($\beta = 0^\circ$) and the optimal tilt angle is also given, then the transposition factor is obtained from equation 3;

$$\text{Transposition Factor} = \frac{G(\beta_{opt})}{G(\beta)} \quad (3)$$

$$\text{where } (\beta = 0^\circ)$$

2.2. Determination of Effective Rooftop Area for Photovoltaic Panel Installation

In this paper, the rooftop PV electric power generation potential of a facility was considered. The facility considered was Zinox-building located at the main campus of the University of Uyo, Uyo. The total rooftop area was calculated based on empirical measurement of the dimensions of the roof of the buildings. There are many factors which influence the fraction of available roof area for PV power installations. The factors include:

- the orientation of pitched roofs;
- the installation and racking of the PV panels;
- the use of roof space for other applications, such as ventilation, heating/air conditioning, dormers or chimneys; and
- shading from other parts of the roof or from neighbouring buildings and trees;

To account for these factors, a reduction in the overall

conduct simulated analysis of the PV electric power generation potential of the selected LGAs in AKS. Thereafter, the LGAs are ranked according to their solar energy potential.

2.1. Solar Radiation, Ambient Temperature and Wind Speed Data

The data were obtained from the NASA Langley Research Center Atmospheric Science Data Center Surface meteorological and Solar Energy (SSE) web portal supported by the NASA LaRC power project. The data consist of 22-year NASA SSE monthly average global radiation horizontal plane, ambient temperature and wind speed.

The global solar radiation horizontal plane is the sum of both the direct and diffuse radiation components as measured incident on a flat horizontal plane. When global irradiation at an angle β° is given, then the irradiation on the inclined plane is given as [8, 9];

suitable rooftop area was applied. The reduction process for this analysis was determined as follows;

Let r_{flat} be the proportion of flat rooftops in the set of buildings considered.

Let r_{peak} be the proportion of pitched rooftops in the set of buildings considered.

Let f_{flat} be the reduction factor for flat rooftops. All flat rooftops are assumed to be unaffected by their rooftop orientation. More simply, because they have a flat rooftop, it does not matter which direction the building is facing to receive optimal sun exposure. As such,

$$f_{flat} = 1 \text{ or } 100\%.$$

Let f_{peak} be the reduction factor for pitched rooftops. For pitched rooftops however, half of all peaked rooftops are assumed to have suitable northern exposure. This assumption meant that;

$$f_{peak} = 0.5 \text{ or } 50\%.$$

AKS is located in the Southern part of Nigeria. In this case, the PV-appropriate roof space orientation is that which faces North. Also, the set of roofs considered in this paper possess pitched roofs. Let f_o be the fraction of properly oriented roof area, [11, 12];

$$f_o = (f_{flat} \times r_{flat}) + (f_{peak} \times r_{peak}) \quad (4)$$

For instance, if $f_{flat} = 100\%$; $r_{flat} = 25\%$; $f_{peak} = 50\%$ and $r_{peak} = 95$, then $f_o = (1 \times 0.25) + (0.5 \times 0.95) = 0.625$

The rooftop area is further reduced by another factor, f_s which accounts for other unknowns such as shadow from trees, and areas needed for other kinds of installations on the roof, as well as the installations of the solar panels themselves and other barriers to construction. The reduction fractions

used for this formula are taken directly from available literature [12]. According to Wiginton, et al., [11], a fraction of 0.30 formulated by Ghosh and Vale [13] was used and represented as f_s . Unlike Wiginton, et al., [11], the purpose of this paper was to show a range in estimation from best to worst case scenario. As such, the more liberal estimation of 0.90 from [12] was taken. Each value was multiplied to the result of f_o in order to find the total roof area available for PV installations. The formula for this estimation is presented below.

$$A_{pv} = A_{pvroof} = A_{roof} \times f_o \times f_s \quad (5)$$

Where:

A_{roof} = the total available rooftop area

A_{pvroof} = the effective rooftop area available for the PV installations

The worst case scenario $f_s = 0.3$ that is 30% whereas, the best case scenario,

$f_s = 0.9$ that is 90%.

In this paper, $f_o = 50\% = 0.5$ and $f_s = 90\% = 0.9$

$A_{pv} = A_{pvroof} = A_{roof} \times 0.5 \times 0.9 = 0.45 A_{roof}$

The roof area $A_{roof} = 92.4 \text{ m}^2$, such that,

$$A_{pv} = 0.45 A_{roof} = 0.45 \times 92.4 = 41.57 \text{ m}^2$$

2.3. Determination of the Photovoltaic Electric Power Generation Potential for A

Given Available Rooftop Area

For any given daily load demand (E_L) kWh/day, the PV size in terms of area (A_{pv}) required to meet the daily load demand is given as:

$$A_{pv} = \frac{E_L}{G_d \times \eta_{pv}} \quad (6)$$

The size of the PV array used in this study can be calculated by using equation 6.

Where: E_L is the daily load demand, G_d is solar energy input per day on PV panels in kW/m²/day and η_{pv} is the PV efficiency. Conversely, for any given PV size in terms of area (A_{pv}), the daily energy output (E) of the PV is given as [14];

$$E = G_d \times \eta_{pv} \times A_{pv} \quad (7)$$

In order to allow for other system losses a safety factor (Sf) is introduced as follows.

$$E = (G_d \times \eta_{pv} \times A_{pv}) \text{Sf} \quad (8)$$

The total annual energy output is calculated as [14];

$$E = (G_d \times 365 \times \eta_{pv} \times A_{pv}) \text{Sf} \quad (9)$$

$A_{pv} = 41.57 \text{ m}^2$, $\eta_{pv} = 14.5\%$, $G_d = 5.887419 \text{ kWh/m}^2/\text{day}$ and $\text{Sf} = 1.2$

Thus, using equation 9, $E = 15517.264198635 \text{ kWh}$ per year.

3. Results and Discussions

The results presented in the paper shows the solar energy potential for selected LGAs in AKS.

3.1. The Co-ordinates of the Local Government Areas in Akwa Ibom State

In order to assess and estimate the solar energy potential of AKS, ten LGAs in AKS were selected out of the 31 LGAs in AKS. The coordinates of the 10 selected LGAs in AKS, is as given in Table 1.

Table 1. The coordinates of the 10 Local Government Areas in Akwa Ibom State.

S/N	LGA	Latitude (°)	Longitude (°E)
1	Abak	5.003394	7.774887
2	Eket	4.651073	7.932042
3	Ibendo	4.571247	7.982284
4	Ika	5.030528	7.5513
5	IkotAbasi	4.580055	7.539742
6	Ini	5.327954	7.71939
7	Itu	5.203613	7.968864
8	Oron	4.806522,	8.233081
9	Uruan	5.129222	7.980461
10	Uyo	5.031486	7.910069

3.2. Solar Radiation Data Representation and Analysis

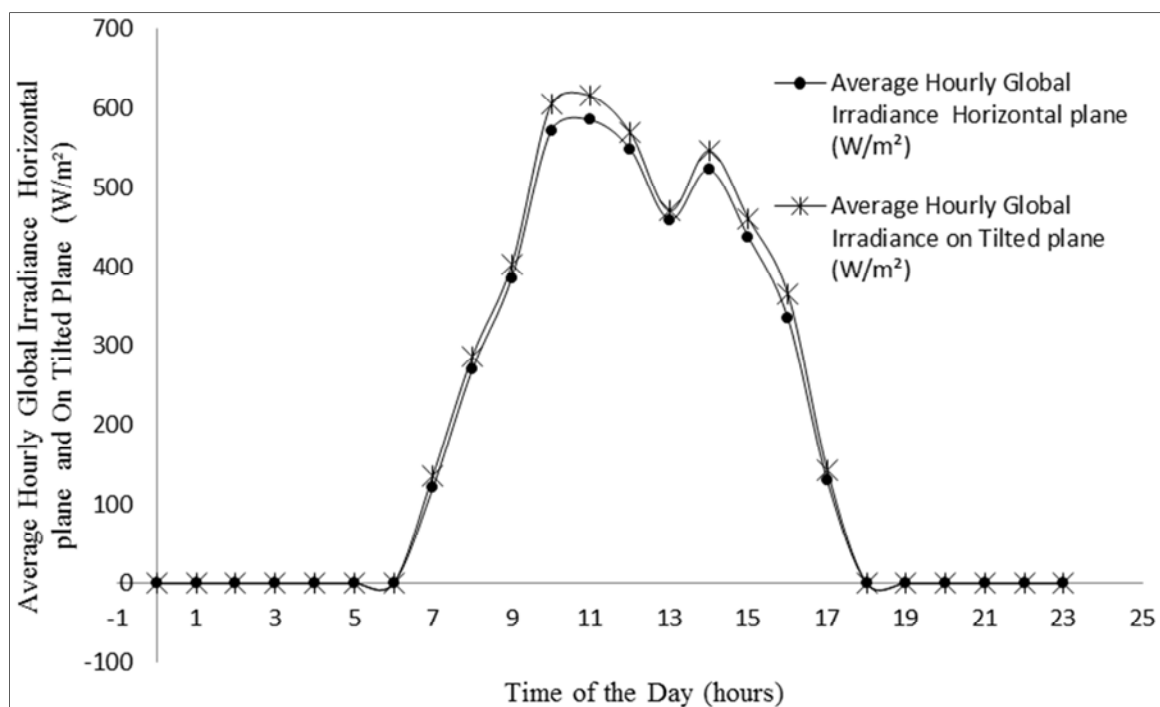
The meteorological data for the selected LGAs are downloaded directly into PVSyst. from NASA SSE website. After downloading the 22-years average solar radiation data from NASA website, PVSyst generates the average hourly global irradiance and temperature data with which it performed the simulation of PV systems. The PVSysts-generated hourly solar data of Table 2 and Figure 1 for Uyo are used to present typical average hourly global irradiance on horizontal plane in (W/m²) and on tilted plane in (W/m²) for the month of January.

In addition, PVSyst. also generates the average daily and average monthly solar radiation data. Table 3 and Figure 2 are the average daily global irradiation on horizontal plane and on tilted plane in (kWh/m²) for the month of January in Uyo LGA. Similarly, Table 4 and Figure 3 shows monthly global irradiation on horizontal plane and on tilted plane (kWh/m²) and the monthly transposition factors for Uyo LGA.

According to Table 2 and Figure 1, the hourly global irradiance (in W/m²) is non-zero for the hours of 7am to 6pm. The peak value of occurred between the hours of 11 am to 12 noon. The peak value for the average hourly global irradiance on horizontal plane is 584.67 W/m² whereas, the peak value for the average hourly global irradiance on tilted plane is 615.33 W/m².

Table 2. Average hourly global irradiance on horizontal plane and on tilted plane (W/m^2) for the first day in the month of January in Uyo LGA.

Time of the Day (hours)	Average Hourly Global Irradiance Horizontal plane (W/m^2)	Average Hourly Global Irradiance on Tilted plane (W/m^2)	Time of the Day (hours)	Average Hourly Global Irradiance Horizontal plane (W/m^2)	Average Hourly Global Irradiance on Tilted plane (W/m^2)
0	0	0	12	548.33	569.33
1	0	0	13	459	470
2	0	0	14	522	546
3	0	0	15	437	460.33
4	0	0	16	334.33	365
5	0	0	17	129	142.67
6	0	0	18	0	0
7	120.33	135.67	19	0	0
8	269.33	286	20	0	0
9	385.33	402	21	0	0
10	571.33	604.67	22	0	0
11	584.67	615.33	23	0	0

**Figure 1.** Average hourly global irradiance on horizontal plane and on tilted plane (W/m^2) for the 1st day in the month of January in Uyo LGA.**Table 3.** Average daily global irradiation on horizontal plane and on tilted plane (kWh/m^2) for the month of January in Uyo LGA.

Days of the Month	Average Daily Global Irradiation Horizontal Plane (Kwh/M^2)	Average Daily Global Irradiation On Tilted Plane (Kwh/M^2)	Days Of The Month	Average Daily Global Irradiation Horizontal Plane (Kwh/M^2)	Average Daily Global Irradiation On Tilted Plane (Kwh/M^2)
1	3.215	3.273	17	5.97	6.394
2	5.339	5.72	18	5.631	5.995
3	4.528	4.798	19	6.012	6.446
4	5.881	6.325	20	5.957	6.349
5	5.488	5.889	21	4.922	5.168
6	5.629	6.044	22	3.115	3.147
7	6.686	7.236	23	4.179	4.306
8	5.376	5.756	24	6.746	7.226
9	6.087	6.558	25	6.203	6.603
10	6.2	6.707	26	5.63	5.981
11	5.497	5.878	27	4.867	5.102
12	6.574	7.093	28	5.823	6.144
13	6.065	6.524	29	4.728	4.914
14	4.017	4.17	30	5.937	6.29
15	6.526	7.033	31	6.295	6.669
16	6.303	6.772	Daily Average	5.529871	5.887419

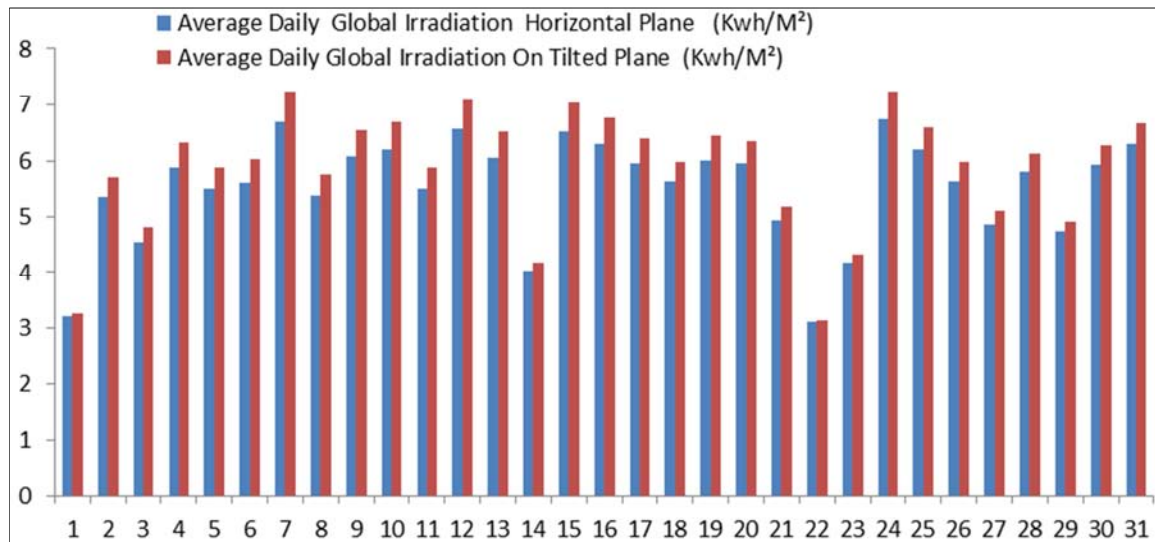


Figure 2. Average daily global irradiation on horizontal plane and on tilted plane (kWh/m^2) for the month of January in Uyo LGA. Table 4 and Figure 3, show the average monthly global irradiation on horizontal plane and on tilted plane in Uyo. According to Table 4 and Figure 3, the yearly average global irradiation on horizontal plane is 1545.8 kWh/m , the yearly average global irradiation on tilted plane is 1553.1 kWh/m , and the yearly average of the transposition factor is 1.01. Essentially, there is about 1% gain in irradiation by tilting the PV array to the 8 degrees optimal tilt angle.

Generally, in PVSyst. simulation, two seasons are identified in a year, namely; summer (April to September) and winter (October to March). These two seasons are similar to the dry and wet seasons in Nigeria. The PV array optimal tilt angle

can be set with respect to the summer and winter on the yearly average. In any case, the summer season has much lower solar potential than the winter as indicated by the data in Table 5.

Table 4. Monthly global irradiation on horizontal plane and on tilted plane (kWh/m^2) and the monthly transposition factors for Uyo LGA.

Months	Global Irradiation On Horizontal Plane (kWh/m^2)	Global Irradiation On Tilted Plane (kWh/m^2)	Transposition Factor
August	116.9	114	0.98
September	118.2	117.8	1.00
July	119.4	114.7	0.96
June	129.3	123.2	0.95
October	132.4	135.2	1.02
November	145.2	152.7	1.05
May	146.3	140.9	0.96
April	152.7	149.8	0.98
February	156.5	162.8	1.04
December	164	175.4	1.07
March	164.9	166.6	1.01
January	171.4	182.5	1.06
Yearly Average	1545.8	1553.1	1.01

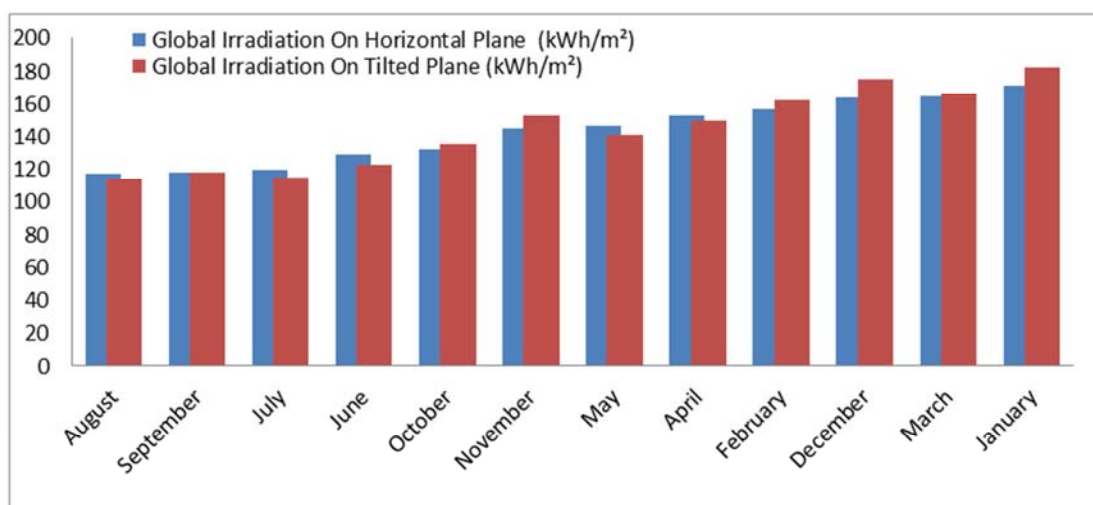


Figure 3. Monthly global irradiation on horizontal plane and on tilted plane (kWh/m^2).

Table 5. Seasonal (summer and winter) solar radiation data for Uyo LGA.

Solar radiation parameters	summer (April to September)	winter (October to March)	Percentage of winter to summer Parameters
Global Irradiation On Horizontal Plane (kWh/m ²)	782.80	934.40	19.37
Global Irradiation On Tilted Plane (kWh/m ²)	760.40	975.20	28.25
Transposition Factor	0.97	1.04	7.34
Ambient Temperature (°C)	24.72	25.12	1.62
Wind Velocity (m/s)	2.24	2.03	-9.02
Array (Cell) Temperature	37.07	39.81	7.40
Available Energy (kWh)	5193.00	7228.00	39.19
Thermal Loss (kWh)	555.20	916.30	65.04
Thermal Loss (%) of Available Energy	10.54	12.62	19.76
Monthly Unit Cost of Energy	121.04	86.95	-28.16

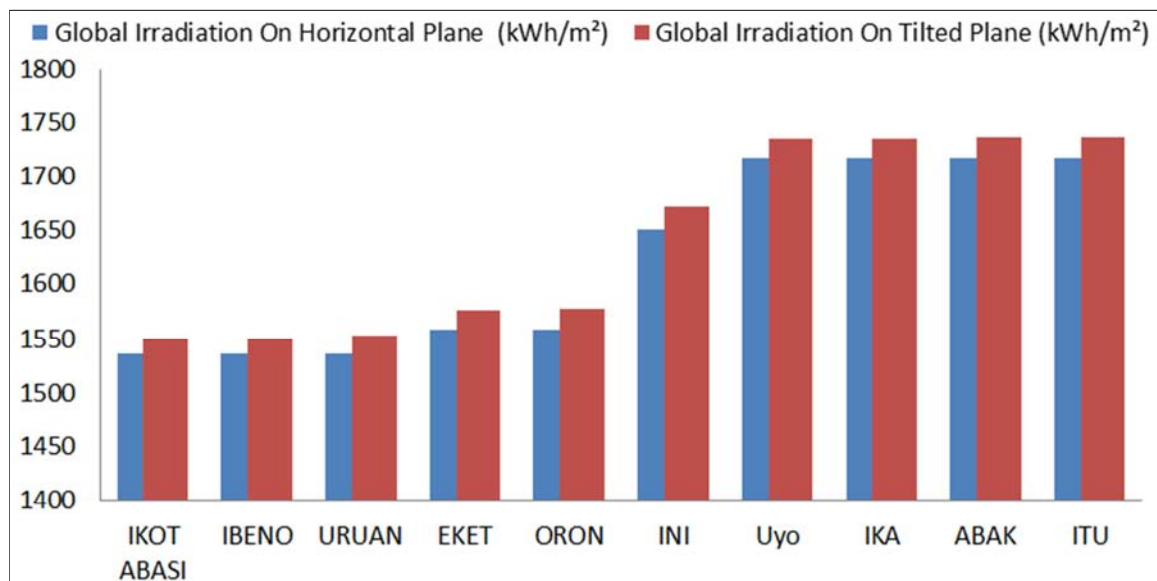
Tilting the PV array with respect to the summer season gives lower solar potential and higher unit cost for the energy but it ensures that the load demand is satisfied most of the times in the year. Using the yearly average or winter season gives higher solar potential but in this case, the load demand is not satisfied in most cases, especially those summer months with poor solar irradiance values. For this reason, the yearly average is used for the analysis in this paper.

According to Table 6 and Figure 4, the peak value of 1717.2

kWh/m² for the average yearly global irradiation on horizontal plane occurred in Uyo, Ika, Itu and Abak whereas, the lowest value of 1535.3 kWh/m² for the average yearly global irradiation on horizontal plane occurred in Ikot Abasi and Ibeno. Similarly, value of 1737.3 kWh/m² for the average yearly global irradiation on tilted plane occurred in Itu whereas, the lowest value of 1550.1 kWh/m² for the average yearly global irradiation on tilted plane occurred in IkotAbasi.

Table 6. Yearly global irradiation on horizontal plane and on tilted plane (kWh/m²) and transposition factor for the 10 LGAs in AKS.

LGAs	Global Irradiation On Horizontal Plane (kWh/m ²)	Global Irradiation On Tilted Plane (kWh/m ²)	Transposition Factor
IkotAbasi	1535.3	1550.1	1.01
Ibeno	1535.3	1550.3	1.01
Uruan	1535.3	1553.1	1.012
Eket	1558.4	1576.4	1.012
Oron	1558.4	1578	1.013
Ini	1650.2	1671.6	1.013
Uyo	1717.2	1735.6	1.011
Ika	1717.2	1735.6	1.011
Abak	1717.2	1736.3	1.011
Itu	1717.2	1737.3	1.012

**Figure 4.** Yearly global irradiation on horizontal plane and on tilted plane (kWh/m²) for the 10 LGAs in AKS.

The rooftop of the Zinox laboratory at the faculty of Engineering University of Uyo main campus was used as a

sample facility to determine the solar energy potential of typical rooftop area in Akwa Ibom state. The Zinox laboratory

has rooftop area $A_{\text{roof}} = 92.4 \text{ m}^2$, then;

$$A_{\text{pv}} = 0.45 A_{\text{roof}} = 0.45 \times 92.4 = 41.57 \text{ m}^2$$

The same effective PV rooftop area $A_{\text{pv}} = 41.57 \text{ m}^2$ is used in the PVSyst to simulate for the solar energy potential in the 10 LGAs considered.

Table 7 and Figure 5, show the ambient temperature ($^{\circ}\text{C}$), wind speed (m/s) and cell temperature ($^{\circ}\text{C}$) for the 10 LGAs in AKS. According to Table 7 and Figure 5, the peak value of array (cell) temperature (of 40.43°C) occurred in Ini whereas,

the lowest value of array (cell) temperature of 36.5°C occurred in Oron. Accordingly, in Table 8 and Figure 6, the peak value of thermal loss of 1606.7 kWh occurred in Ini whereas, the lowest value of thermal loss of 1220.9 kWh occurred in Oron.

According to Table 8 and Figure 6, the peak value of solar energy generated by the PV array is 12422 kWh and it occurred in Uyo whereas, the lowest value of solar energy generated by the PV array is 10591 kWh and it occurred in Uruan.

Table 7. Ambient Temperature ($^{\circ}\text{C}$), Wind Speed (m/s) and Cell Temperature ($^{\circ}\text{C}$).

LGAs	Ambient Temperature ($^{\circ}\text{C}$)	Wind Velocity (m/s)	Array (Cell) Temperature ($^{\circ}\text{C}$)
Oron	24.66	2.17	36.5
Uyo	24.91	2.13	38.28
Abak	24.91	2.13	38.28
Itu	24.91	2.13	38.33
Eket	24.66	2.77	38.4
Ika	24.91	2.13	38.46
Ibendo	25.33	2.77	39.11
IkotAbasi	25.33	2.77	39.11
Uruan	25.33	2.77	39.13
Ini	25.59	2.13	40.43

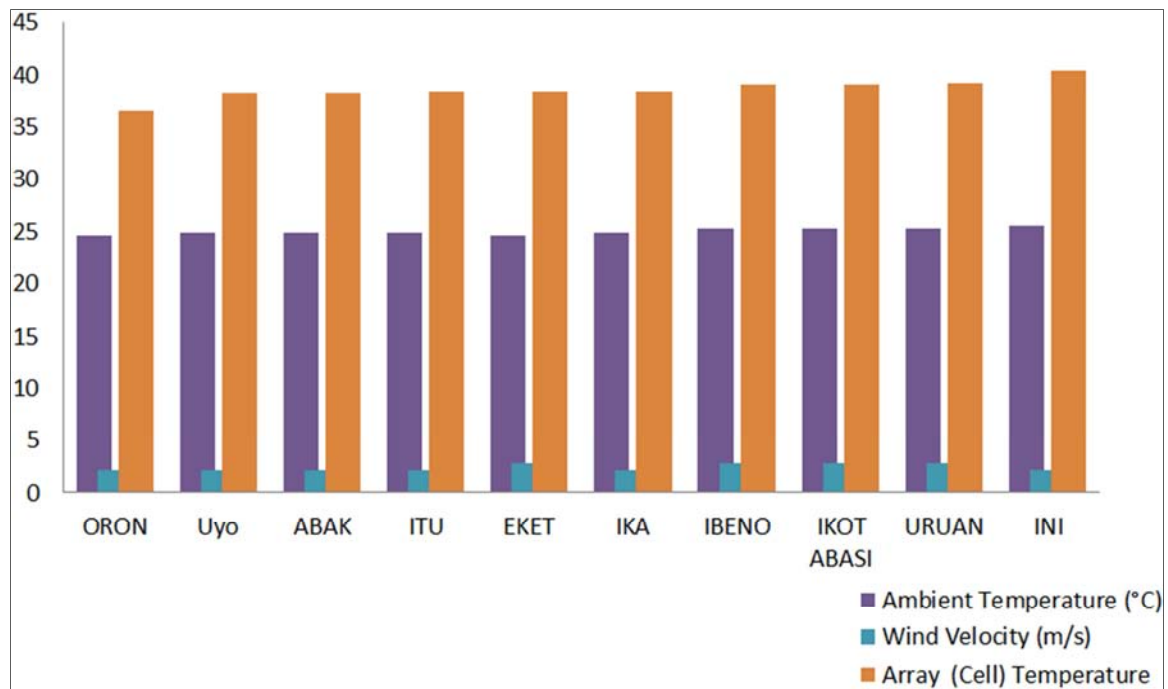


Figure 5. Ambient temperature ($^{\circ}\text{C}$), wind speed (m/s) and cell temperature ($^{\circ}\text{C}$).

Table 8. Available energy (kWh), thermal loss (kWh) and percentage of thermal loss to the available energy.

LGAs	Available Energy (kWh)	Thermal Loss (kWh)	Thermal Loss (%) of Available Energy
Uruan	10591	1356.9	12.81182136
Ibendo	10653	1384.4	12.99540036
IkotAbasi	10692	1373.7	12.84792368
Eket	10906	1375	12.60774
Oron	11066	1220.9	11.03289355
Ini	11692	1606.7	13.74187
Abak	12256	1410.7	11.51028
Ika	12328	1479.7	12.00275795
Itu	12418	1467.4	11.81671767
Uyo	12422	1471.4	11.84511351

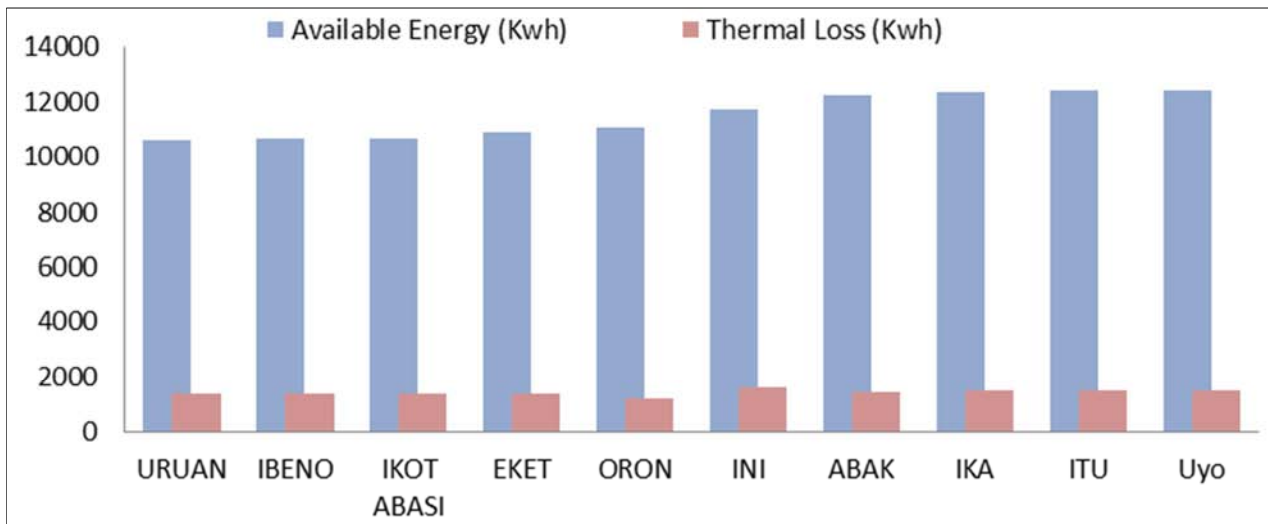


Figure 6. Available energy (kW/h) and thermal loss (kW/h).

Table 9. Unit cost (Naira/kWh) and normalized available energy (%).

LGAs	Yearly Unit Cost of Energy (Naira/kWh)	Normalised Available Energy in Percentage of the Largest Available Energy (%)
Uyo	104	100
Ika	105	99.24
Itu	105	99.97
Abak	106	98.66
Ini	108	94.12
Oron	110	89.08
Eket	111	87.8
IkotAbasi	112	86.07
Ibeno	113	85.76
Uruan	114	85.26

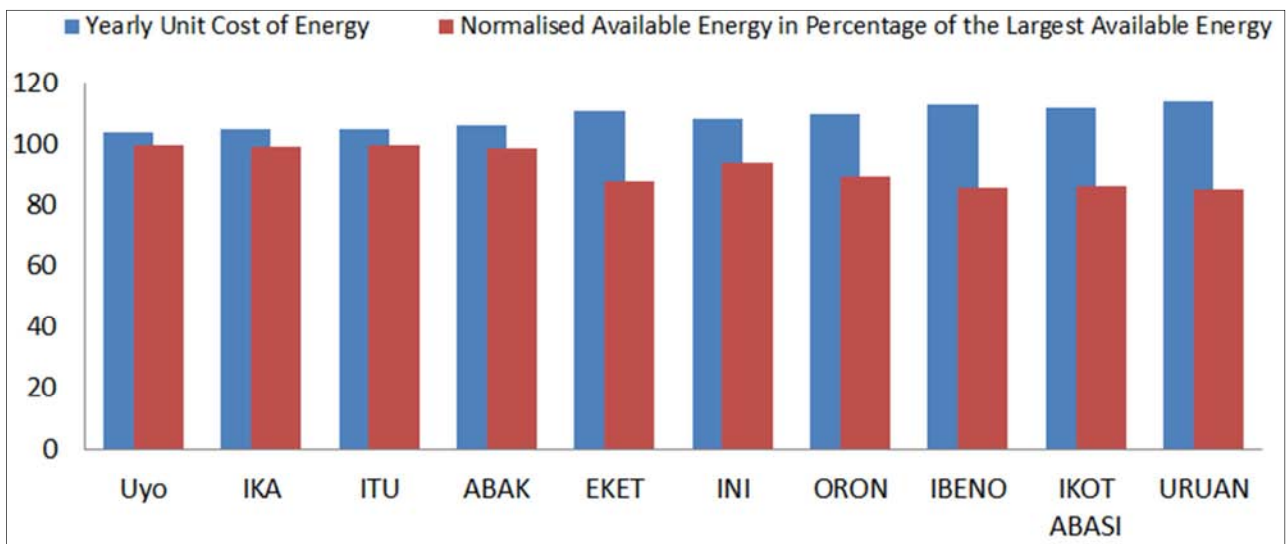


Figure 7. Unit cost (Naira/ kWh) and normalised available energy (%).

Conversely, in Table 9 and Figure 7, the peak value of unit cost of energy is 114 Naira/kWh and it occurred in Uruan whereas, the lowest value of unit cost of energy is 104 Naira/kWh and it occurred in Uyo. A difference of 10 Naira/kWh is observed between the highest and the lowest unit cost of energy among the selected LGAs in Akwa Ibom state.

3.3. Model for the Unit Cost of Energy

According to Table 8 and Figure 6, the peak value of solar energy generated by the PV array is 12422 kWh and it occurred in Uyo whereas, the lowest value of solar energy generated by the PV array is 10591 kWh and it occurred in Uruan. Conversely, in Table 9 and Figure 7, the peak value of

unit cost of energy is 114 Naira/kWh and it occurred in Uruan whereas, the lowest value of unit cost of energy is 104 Naira/kWh and it occurred in Uyo. A difference of 10 Naira/kWh is observed between the highest and the lowest unit cost of energy among the selected LGAs in Akwa Ibom

state.

Finally, from Table 10 and Figure 8, the trend line model (equation) relating the unit cost to the available energy per year is given as:

$$\text{Yearly unit cost of energy (Naira/kWh)} = \frac{73.23 (\text{Available Energy per year in kWh})}{(\text{Available Energy Per Year in kWh} - 3736.271278)}$$

$$U (\text{Naira/kWh}) = \frac{73.23 (E)}{(E - 3736.271278)}$$

Where:

U is the unit cost of energy in Naira/kWh and E is the available energy in kWh per year

The unit cost model has a correlation value of 97.7% which shows very strong correlation between the available energy

per year and the unit cost. It means that the available energy per year is accurately predicts about 97.7% of the unit cost of energy. The implication is that, the unit cost depends strongly on the energy that is available at the output of the PV array.

Table 10. Yearly unit cost of energy (Naira/kWh) versus available energy (kWh).

LGAs	Available Energy (kWh) per year	Yearly Unit Cost of Energy (Naira/kWh)
Uyo	12422	104
Itu	12418	105
Ika	12328	105
Abak	12256	106
Ini	11692	108
Oron	11066	110
Eket	10906	111
IkotAbasi	10692	112
Ibena	10653	113
Uruan	10591	114

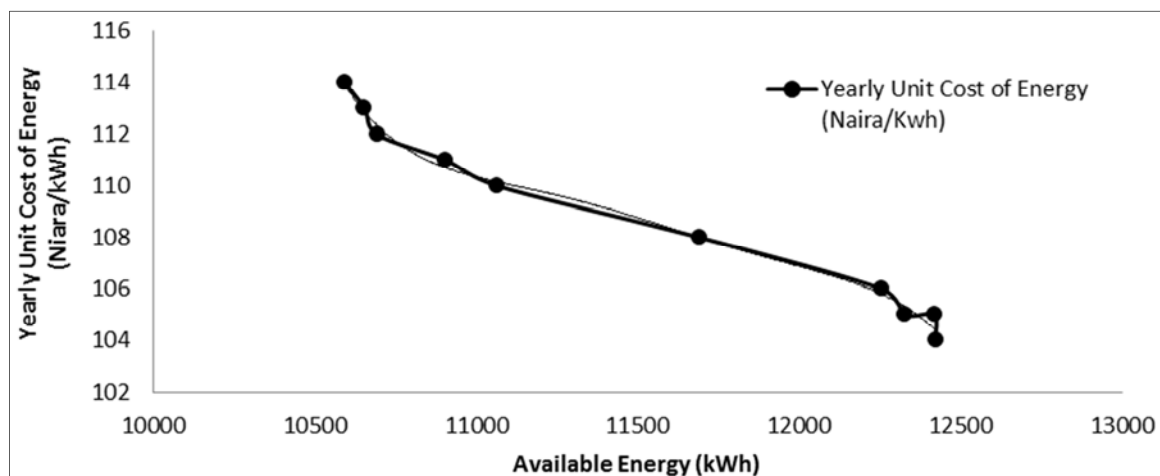


Figure 8. Yearly unit cost of energy (Naira/kWh) versus available energy (kWh).

4. Conclusion

It can be concluded that Akwa Ibom state has the solar potential to generate electricity for both domestic and commercial purposes. Uyo LGA was ranked topmost. Uyo LGA has the highest yearly energy output of 12422 kWh and lowest unit cost of energy of 104 Naira/kWh. Uruan LGA was ranked lowest. Uruan LGA has the lowest yearly energy output of 10591 kWh and highest unit cost of energy of 114 Naira/kWh. This shows that solar energy is spatiotemporal because it varies with time and location. It also shows that the

amount of solar irradiance in a particular location determines the output of the PV module. From the results obtained in this paper it is clearly seen that cell temperature which is a function of ambient temperature and wind speed contributes to the thermal loss of the PV module. This affects the power output of the PV module and the unit cost of energy.

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