COMPARATIVE COST ANALYSIS FOR AUTONOMOUS WIRELESS WEATHER STATION PV POWER INSTALLATIONS IN THE SIX GEOPOLITICAL ZONES OF NIGERIA

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Abstract— **In this paper, geospatial photovoltaic (PV) array cost analysis for solar powered autonomous wireless weather station installations across Nigeria is presented. The key sub-units that make up the autonomous wireless weather station are; the sensor unit, the Microcontroller Unit (MCU) and the Lorawan (Long Range Wide Area Network) unit. The absolute maximum of the average electric power demand of the three sub-units that make up the weather station over a 24 hours period are computed and summed and then used to determine the daily energy demand of the autonomous weather station. The computations for the autonomous weather station gave a total of 272.42 mW power consumption and 6.54 Wh/day daily energy demand. The PV array capacity and PV cost for supplying the daily energy need of the autonomous weather station are determined based on the peak sun hour (PSH) data for six selected locations across Nigeria. The available PSH data show that of Katsina State in the North West has the highest annual average Peak Sun Hour (PSH) of 5.94 hours while Akwa Ibom State in the South-South has the lowest annual average Peak Sun Hour (PSH) of 4.21 hours. The results show that Katsina State in the North West requires the lowest PV array capacity of 1.29531 watts while Akwa Ibom State in the South-South requires the highest PV array capacity of 1.82758 watts. Also, Katsina State required the lowest PV array cost of 419.448022 Nara. Generally, the results show that the required PV array capacity and the corresponding PV cost are inversely proportional to the PSH of the location. As such, the higher the PSH of a location, the lower the required PV array capacity to deliver the required daily electric energy demand.**

Keywords— Geospatial , Photovoltaic (PV) , Weather Station PV Array Cost, Daily Energy Demand , Solar Power

1. INTRODUCTION

A weather station is basically a facility installed either onshore or offshore with requisite instruments and equipment that can be used for measuring different atmospheric parameters which are relevant for application like weather forecasts and study of weather and climatic conditions [1,2,3,4,5,6,7,8,9,10,11]. An autonomous wireless weather station (AWWS) is an automatic weather station that has all the facilities and ability to operate without human intervention [12,13,14,15,16,17]. A typical AWWS has a data logger, battery power bank which can be rechargeable, wireless telemetry system for remote communication and requisite weather parameter sensors, all enclosed in a suitable weather-proof compartment and mounted on a mast [18,19,20,21,22,23,24,25,26].

In this paper, the power consumption of an AWWS is estimated along with a statically determined daily energy demand based on the different operating modes of the AWWS, namely, sending mode, idle mode and sleep mode. The PV module sizing is also presented along with the PV module cost analysis. Also, a comparative PV cost analysis is presented for such AWWS installations in the various Nigerian geopolitical regions. The analysis demonstrates the disparity in the minimal cost of PV array required to provide adequate PV power to the AWWS I the various geopolitical regions in Nigeria.

2. METHODOLOGY

2.1 Analysis of the power consumption and daily energy demand of the autonomous weather station

The autonomous weather station can continue to operate as long as the power consumption over a given period of about 24 hours does not exceed the power generated by the power supply unit over the given period. As such, the absolute maximum of the average electric power demand of the various sub-units that make up the weather station over a 24 hours period are computed and summed and then used to determine the daily energy demand of the autonomous weather station. The key sub-units are the sensor unit, the Microcontroller Unit (MCU) and the Lorawan (Long Range Wide Area Network) unit. The power consumption of the sensor unit is given in Table 1. The power consumption of microcontroller unit (MCU) is given in Table 2 while the power consumption of the Lorawan (Long Range Wide Area Network) module is given in Table 3. The daily energy demand of the autonomous weather station is computed using the analytical expressions in Equation 1 to Equation 8 and the results are presented in Table 4.

Table 1 The power consumption of the sensor unit [27]

Weather Conditions	Dry period	Precipitation period
Power draw by the sensor [mW]	19	181

Table 2 The power consumption of microcontroller unit (MCU) [27]

Conditions	Active	Idle
Power draw by the MCU [mW]	90	0.66

Table 3 The power consumption of the Lorawan (Long Range Wide Area Network) module

LoRa Module State	**Sending**	**Idle**	**Sleep**	
Typical power drawn in each state [mW]	132	9.24	0.0053	A
Percentage of Time in the given state (%)	1	1	98	B
Actual power drawn in each state for the given percentage of time [mW]	1.32	0.0924	0.005194	C= A (B/100)
Total Power drawn by the LoRa module [mW]	1.32+ 0.0924+0.005194 = 1.417594			

Let $P_{LoRaSend}$, $P_{LoRaSleep}$ and $P_{LoRaIdle}$ be the power drawn by the LoRa module when sending data, in sleep mode and in idle mode respectively. Let $T_{LoRaPtSend}$, $T_{LoRaPtSleep}$ and $T_{LoRaPtIdle}$ be the be the percentage of time the LoRa module spent in sending data, in sleep mode and in idle mode respectively. Also, let $P_{LoRaASend}$, $P_{LoRaAvSleep}$ and $P_{LoRaSAvIdle}$ be the average power drawn by the LoRa module when sending data for time $P_{LoRaAvSend}$, in sleep mode for time period $P_{LoRaAvSleep}$ and in idle mode for time period $P_{LoRaAvIdle}$ respectively. Then,

$$P_{LoRaAvSend} = \frac{T_{LoRaPtSend}}{100}(P_{LoRaSend}) \quad (1)$$

$$P_{LoRaAvSleep} = \frac{T_{LoRaPtSleep}}{100}(P_{LoRaSleep}) \quad (2)$$

$$P_{LoRaAvIdle} = \frac{T_{LoRaPtIdle}}{100}(P_{LoRaIdle}) \quad (3)$$

Again, let $P_{LoRaTTL}$ be total power drawn by the LoRa module [mW], then,

$$P_{LoRaTTL} = P_{LoRaAvSend} + P_{LoRaAvSleep} + P_{LoRaAvIdle} \quad (4)$$

$$P_{LoRaAvSend} = \frac{1}{100}(132) = 1.32 \quad (5)$$

$$P_{LoRaAvSleep} = \frac{1}{100}(9.24) = 0.0924 \quad (6)$$

$$P_{LoRaAvIdle} = \frac{98}{100}(0.0053) = 0.005194 \quad (7)$$

$$P_{LoRaTTL} = 1.32 + 0.0924 + 0.005194 = 1.417594 \quad (8)$$

Table 4 The daily energy demand of the autonomous weather station

S/N	Sub-Unit Name	**Power Consumption [mW]**	**Energy Demand per day (24 hours) Wh/day**
1	**Sensor Unit**	181	24(181/1000) → 4.34
2	**Microcontroller Unit (MCU)**	90	24(90 /1000) → 2.16
3	**LoRa Module**	1.42	24(1.42/1000) → 0.03
	Total	272.42	6.54

2.2 Sizing of the Battery

The system uses lithium ion battery and has a daily electric energy consumption of 6.54Wh. Let depth of discharge be denoted as DoD, which in this case is taken as 10%. Let the state of charge be denoted as SoC, which in this case is 90% . Also, let state of charge (SoC) factor be denoted as SoCFactor, the daily energy demand be denoted as E_{Daily} and the number of days of autonomy be denoted as N_{Days} and the battery bank capacity be denoted as E_{Bat} , hence,

$$\text{SoCFactor} = \frac{100}{\text{SoC} - \text{DoD}} \quad (9)$$

$$E_{Bat} = \text{SoCFactor}\left(E_{Daily}\right)\left(N_{Days}\right) \quad (10)$$

Where $E_{Daily} = 6.54$ Wh/day , SoC = 90% and DoD = 10%, hence

$$\text{SoCFactor} = \frac{100}{90-10} = 1.25 \text{ and } E_{Bat} = 1.25r(6.54)\left(N_{Days}\right) = 8.175 \ N_{Days}.$$

2.3 Sizing and cost Analysis of the PV Array

If the daily Peak Sun Hour is PSH and a derating factor, f_{der} is applied, then, the PV array watt-peak capacity, denoted as E_{PVwp} is given as;

$$E_{PVwp} = \frac{E_{Daily}}{\text{PSH}\,(f_{der})} \quad (11)$$

In this paper, a simple PV cost analysis is used to compare the cost of PV array that will be required to power the autonomous weather station in various locations across Nigeria. The cost analysis is based on the PV cost per watt peak rating denoted as C_{PVwp}. Then, for the required PV array watt-peak capacity $\left(E_{PVwp}\right)$, the total PV cost, denoted as C_{PV} is given as;

$$C_{PV} = C_{PVwp}\left(E_{PVwp}\right) \quad (12)$$

Since the PSH varies for the different locations, the C_{PV} and C_{PVwp} are determined and used to compare the relative cost of powering the autonomous weather station in various locations across Nigeria.

2.4 The Selected Case Study Sites Across Nigeria

Six locations are selected, one from each of the six geo-political zones in Nigeria. The location name, geo-coordinates and annual average peak sun hour (PSH) solar radiation data of the selected locations across Nigeria are presented in Table 5. The map plot for visualizing the spatial distribution of the location across Nigeria is shown in Figure 1. The detailed monthly and annual average peak sun hour (PSH) solar radiation data of the selected six locations across Nigeria are presented in Table 6.

Table 5 The solar radiation data of the selected locations across Nigeria

S/N	Location	Latitude	Longitude	Annual Average Peak Sun Hour (PSH)
1	**Abuja (North Central)**	8.981451	7.180485	**5.35**
2	Katsina state (North West)	12.889119	7.573117	**5.94**
3	Adamawa State (North East)	10.280311	13.277301	**5.74**
4	**Enugu State (South East)**	6.503748	7.503978	**4.92**
5	**Akwa Ibom State (South South)**	4.647675	7.763166	**4.21**
6	**Osun State (South West)**	7.761545	4.601301	**4.89**

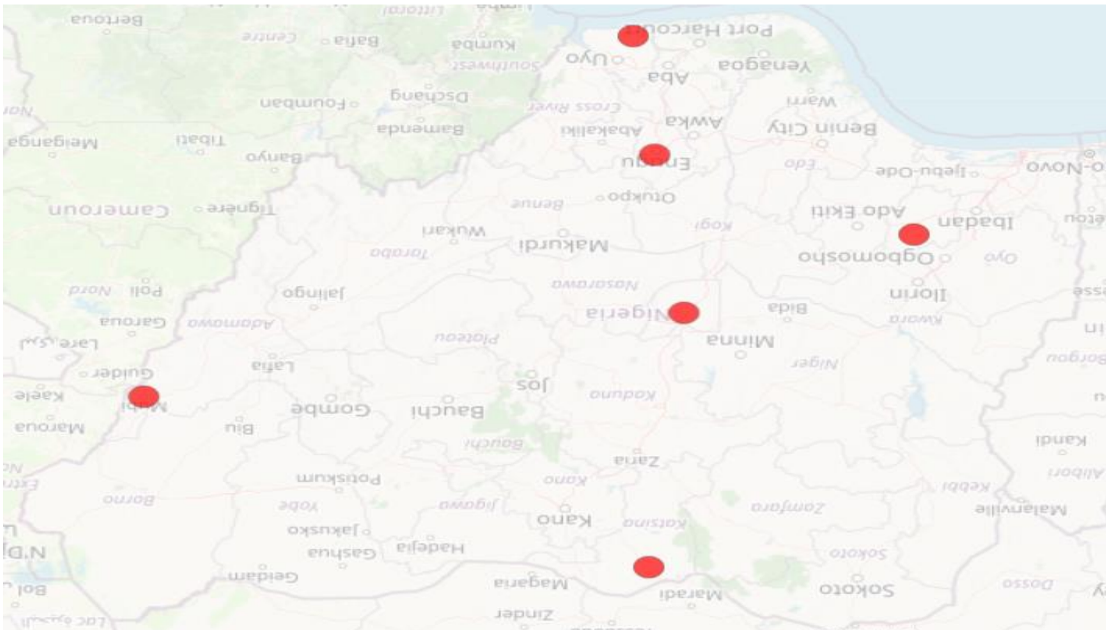
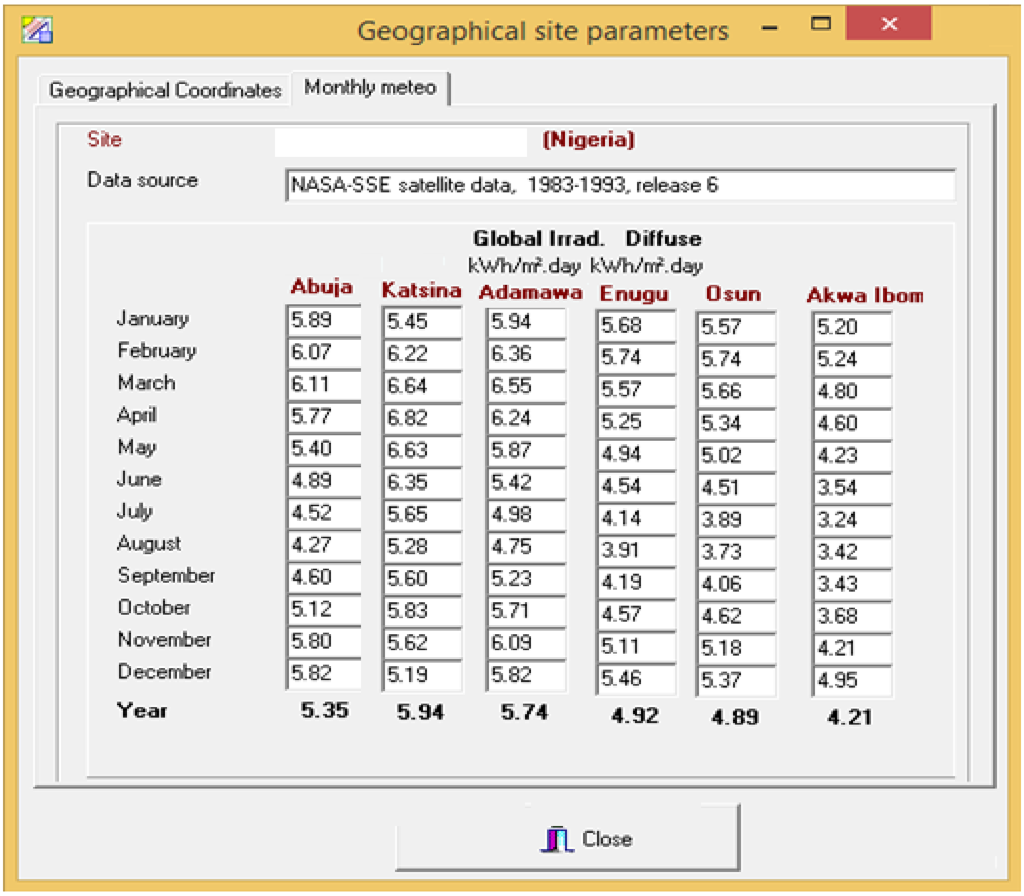


Figure 1 The map plot for visualizing the spatial distribution of the location across Nigeria.

Table 6 The detailed monthly and annual average peak sun hour (PSH) solar radiation data of the selected six locations across Nigeria.


Geographical site parameters

Geographical Coordinates | Monthly meteo

Site (Nigeria)

Data source: NASA-SSE satellite data, 1983-1993, release 6

Global Irrad. Diffuse
kWh/m².day kWh/m².day

	Abuja	Katsina	Adamawa	Enugu	Osun	Akwa Ibom
January	5.89	5.45	5.94	5.68	5.57	5.20
February	6.07	6.22	6.36	5.74	5.74	5.24
March	6.11	6.64	6.55	5.57	5.66	4.80
April	5.77	6.82	6.24	5.25	5.34	4.60
May	5.40	6.63	5.87	4.94	5.02	4.23
June	4.89	6.35	5.42	4.54	4.51	3.54
July	4.52	5.65	4.98	4.14	3.89	3.24
August	4.27	5.28	4.75	3.91	3.73	3.42
September	4.60	5.60	5.23	4.19	4.06	3.43
October	5.12	5.83	5.71	4.57	4.62	3.68
November	5.80	5.62	6.09	5.11	5.18	4.21
December	5.82	5.19	5.82	5.46	5.37	4.95
Year	5.35	5.94	5.74	4.92	4.89	4.21

Close

3 Results and Discussion

Based on the daily Peak Sun Hour (PSH) (presented in Table 5 and Table 6), the daily energy demand of the autonomous weather station (presented in Table 4 as 6.54 Wh/day) and a derating factor, f_{der} of 0.85 , the PV array watt-peak capacity, (E_{PVwp}) and total PV cost, (Cpv) in Naira are computed for the six selected locations and the results are presented in Table 7, Table 8, Table 9 and Table 10.

The results in Table 7, Table 8, Table 10, Figure 2 and Figure 4 show that Katsina State in the North West requires the lowest PV array capacity of 1.29531 watts while Akwa Ibom State in the South-South requires the highest PV array capacity of 1.82758 watts. Also, the results in Table 7, Table 9, Table 10, Figure 3 and Figure 4 show that Katsina State in the North West requires the lowest PV array cost of 419.448022 Nara while Akwa Ibom State in the South-South requires the highest PV array cost of 591.810274 Naira . Similarly, the results in Table 7, Table 10 and Figure 4 show that Katsina State in the North West has the highest annual average Peak Sun Hour (PSH) of 5.94 hours while Akwa Ibom State in the South-South has the lowest annual average Peak Sun Hour (PSH) of 4.21 hours.

Generally, the results show that the required PV array capacity and the corresponding PV cost are inversely proportional to the PSH of the location. As such the higher the PSH of a location, the lower the required PV array capacity to deliver a given daily energy demand.

Table 7 The input data and results of the computation of the PV array watt-peak capacity, (E_{PVwp}) and total PV cost, (Cpv) in Naira for the six selected locations

S/N	Location	Latitude	Longitude	Annual Average Peak Sun Hour (PSH) in hours/day	Edaily (Wh/day)	fder	PV Array watt-peak Capacity, Epvwp (watts)	Cpvwp (Naira /wp)	Total PV Cost, Cpv (Naira)
1	Abuja (North Central)	8.981451	7.180485	5.35	6.54	0.85	1.43815	323.8216	465.704907

2	Katsina state (North West)	12.889119	7.573117	5.94	6.54	0.85	1.29531	323.8216	419.448022
3	Adamawa State (North East)	10.280311	13.277301	5.74	6.54	0.85	1.34044	323.8216	434.062936
4	Enugu State (South East)	6.503748	7.503978	4.92	6.54	0.85	1.56385	323.8216	506.406758
5	Akwa Ibom State (South South)	4.647675	7.763166	4.21	6.54	0.85	1.82758	323.8216	591.810274
6	Osun State (South West)	7.761545	4.601301	4.89	6.54	0.85	1.57344	323.8216	509.513548

Table 8 The results of the PV Array watt-peak Capacity, Epvwp (watts) sorted in ascending order

Location	PV Array watt-peak Capacity, Epvwp (watts)
Katsina state (North West)	1.29531
Adamawa State (North East)	1.34044
Abuja (North Central)	1.43815
Enugu State (South East)	1.56385
Osun State (South West)	1.57344
Akwa Ibom State (South South)	1.82758

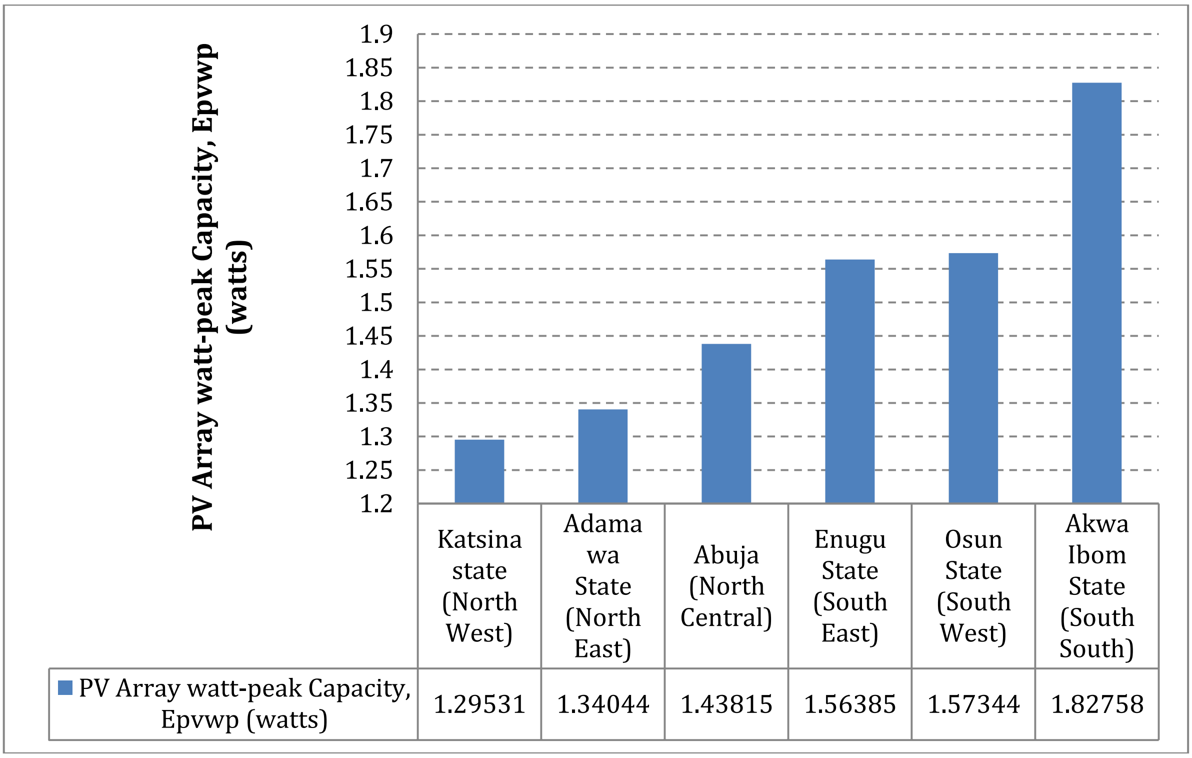


Figure 2 Bar chart of the PV Array watt-peak Capacity, Epvwp (watts) for the six selected locations

Table 9 The results of the Total PV Cost, Cpv (Naira) sorted in ascending order

Location	Total PV Cost, Cpv (Naira)
Katsina state (North West)	419.448022
Adamawa State (North East)	434.062936
Abuja (North Central)	465.704907
Enugu State (South East)	506.406758
Osun State (South West)	509.513548
Akwa Ibom State (South South)	591.810274

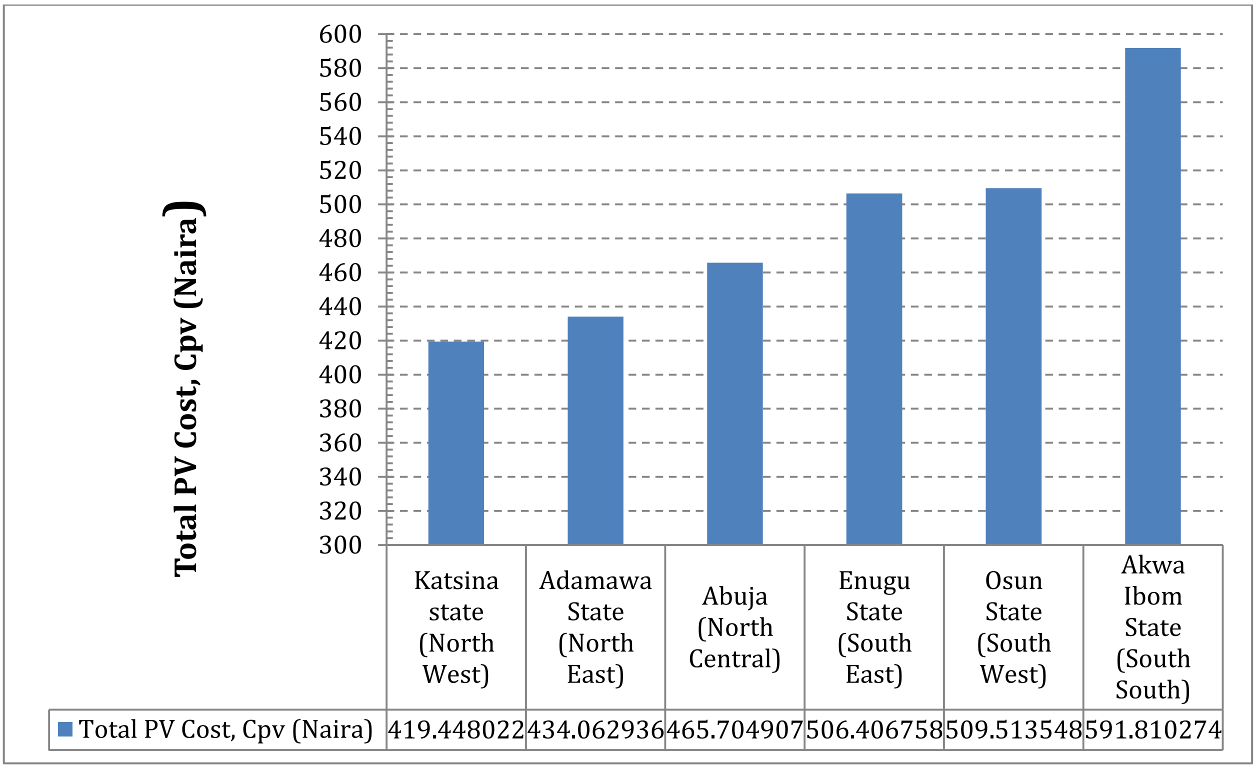


Figure 3 Bar chart of the Total PV Cost, Cpv (Naira) for the six selected locations

Table 10 PV Array watt-peak Capacity, Epvwp (watts) and Total PV Cost, Cpv (Naira) versus Annual Average Peak Sun Hour (PSH) in hours/day sorted in ascending order based on the value of PSH

Location	Latitude	Longitude	Annual Average Peak Sun Hour (PSH) in hours/day	PV Array watt-peak Capacity, Epvwp (watts)	Total PV Cost, Cpv (Naira)
Akwa Ibom State (South South)	4.647675	7.763166	4.21	1.82758	591.81027
Osun State (South West)	7.761545	4.601301	4.89	1.57344	509.51355
Enugu State (South East)	6.503748	7.503978	4.92	1.56385	506.40676
Abuja (North Central)	8.981451	7.180485	5.35	1.43815	465.70491
Adamawa State (North East)	10.280311	13.277301	5.74	1.34044	434.06294
Katsina state (North West)	12.889119	7.573117	5.94	1.29531	419.44802

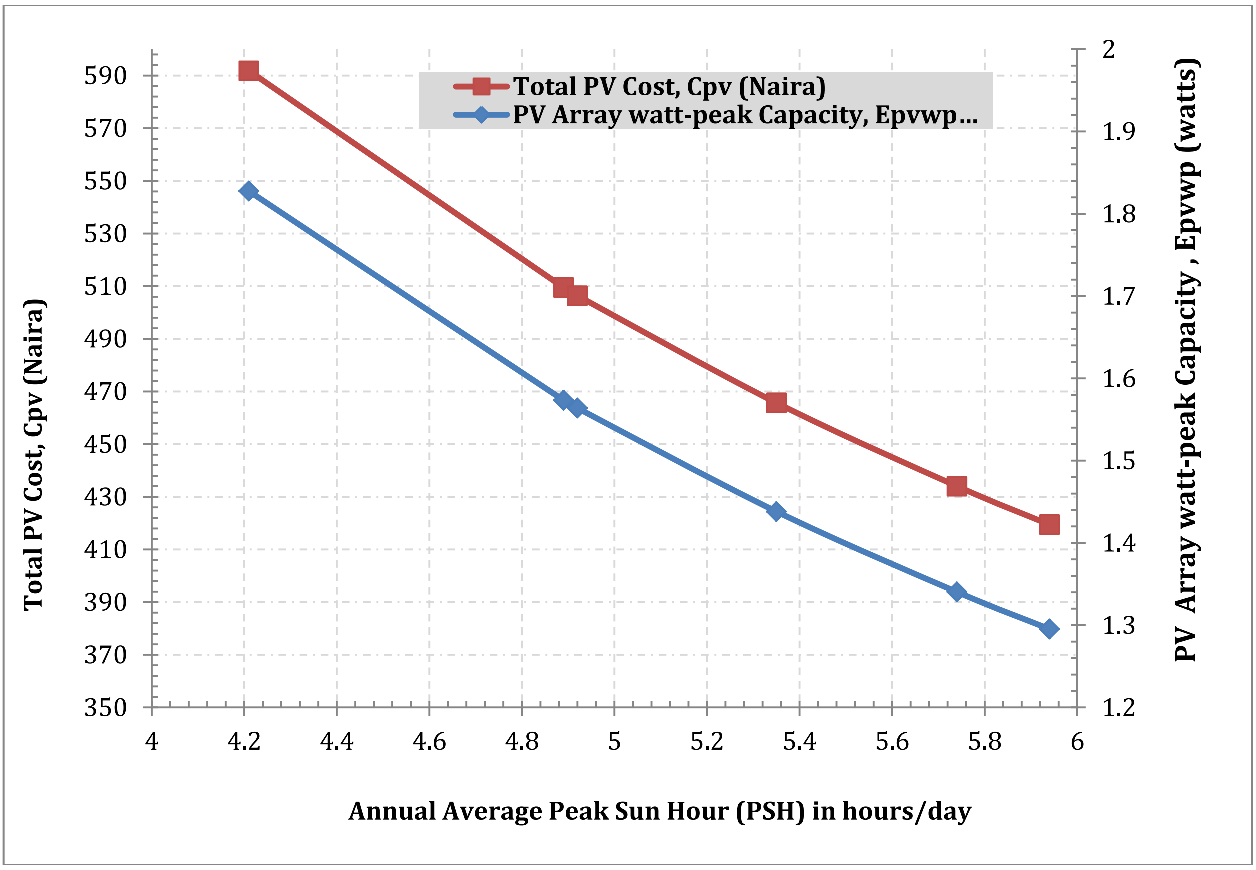


Figure 4 The graph of PV Array watt-peak Capacity, Epvwp (watts) and Total PV Cost, Cpv (Naira) versus Annual Average Peak Sun Hour (PSH) in hours/day

4. Conclusion

The power consumption and daily energy demand of an autonomous weather station is presented. Also, PV array capacity and PV cost for supplying the daily energy need of the autonomous weather station are determined based on the peak sun hour data for six selected locations across Nigeria. The results the required PV array capacity and the corresponding PV cost are inversely proportional to the PSH of the location. As such the higher the PSH of a location, the lower the required PV array capacity to deliver a given daily energy demand.

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