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Determination Of The Optimal Location For The Installation Of Solar Farm In Akwa Ibom State

IkpongAkaninyene Asuquo[1], Udofia, Kufre[2], Okon Smart Essang[3]
[1,2,3]Department of Electrical/Electronic & Computer Engineering, University of Uyo, AkwaIbom, Nigeria
([2]kmudofiaa@yahoo.com)

***Abstract*—In this paper, the optimal location for the installation of solar photovoltaic (PV) farm in AwkaIbom State is determined based on multiple criteria analysis conducted on 29 local government areas (LGAs) in AkwaIbom State. The parameters used for the analysis include meteorological parameters (temperature and insolation on horizontal surfaces), distance from the national grid, population and landmass. The meteorological data for each location was obtained from the AkwaIbom State Bureau of Statistics. Available landmass for solar farm installation and weights of the atmospheric parameters were calculated. Finally, the cost per unit of energy for the PV array installation in the 29 LGAs in AkwaIbom State was computed and then used to determine the optimal location for the installation of the solar farm in AkwaIbom State. From the results obtained, IkotAbasi had the least energy cost per unit energy of 100.6256 N /kWh, thus, making it the most preferred location for the installation and operation of the solar farm in AkwaIbom . On the other hand Ini LGA had the highest cost per unit energy of 266.9466 N /kWh.**

Keywords—Solar Power, Multiple Criteria Analysis, Optimal Location, Solar Farm, Unit Cost Of Energy, Solar Potential, Renewable Energy

I. INTRODUCTION

In Nigeria, the power supply challenge is ever-increasing [1,2]. For decades now, electricity provision remained a herculean task. Tripartite issues of energy generation, transmission and distribution remain unsolved despite the huge sums that have been committed to the same project. For a country with an estimated population of over 185 million as at 2016, the highest ever recorded power output was 5320 MW in the same year indicating a meager density of 0.30 kW of electricity per person [3,4,5,6,7]. This has led to the high level of dependence on gasoline and diesel generator set across the country. It is therefore needless to emphasize that the country needs to diversify its sources of energy generation particularly by taking advantage of the readily available solar and wind energy in the country [8].

Fortunately, the advancement in the solar photovoltaic (PV) technology continues to drive the price down and thereby makes solar PV more viable for domestic and industrial applications [9,10,11,12]. In this paper, the optimal location of solar farm installation is determined for AkwaIbom State based on multiple criteria data analysis conducted on 29 local government areas in the state. The multiple criteria include land mass, solar radiation intensity, accessibility to the grid, population and temperature. The multiple parameters were used to determine the cost per unit of energy for all the selected LGAs and the LGA with the lowest unit cost is selected as the optimum location. The idea presented in this paper is relevant for policy and investment decision regarding the adoption of large scale solar PV power plant in AkwaIbom State.

II. METHODOLOGY

The methodology used in the study is shown in Figure 1. In this study, 29 local government areas (LGAs) of AkwaIbom State are considered in the determination of the optimal location of a solar farm. The parameters needed to determine the optimal location of the solar farm are temperature, insolation on horizontal surface, population, distances of each location from the national grid and the land mass area of each of the location. The LGAs and their geo-coordinates are given in Table 1. From Table 1, the distance from the national grid data was mapped out according to the national grid closest to the local government area under consideration. The coordinates of each of the power stations are obtained and haversine formula was used to calculate the distance between the power grid and LGAs as follows;.

$$d = 2r\arcsin\left(\sqrt{\sin^2\left(\frac{\varphi_2 - \varphi_1}{2}\right) + \cos(\varphi_1)\cos(\varphi_2)\sin^2\left(\frac{\theta_2 - \theta_1}{2}\right)}\right) \quad (1)$$

Where d is the distance between two points, φ_1 is the latitude of point one in radians, φ_2 is the latitude of point two in radians, θ_1 is longitude of point 1 in radians, θ_2 is longitude of point 2 in radians and r is the radius of the earth.

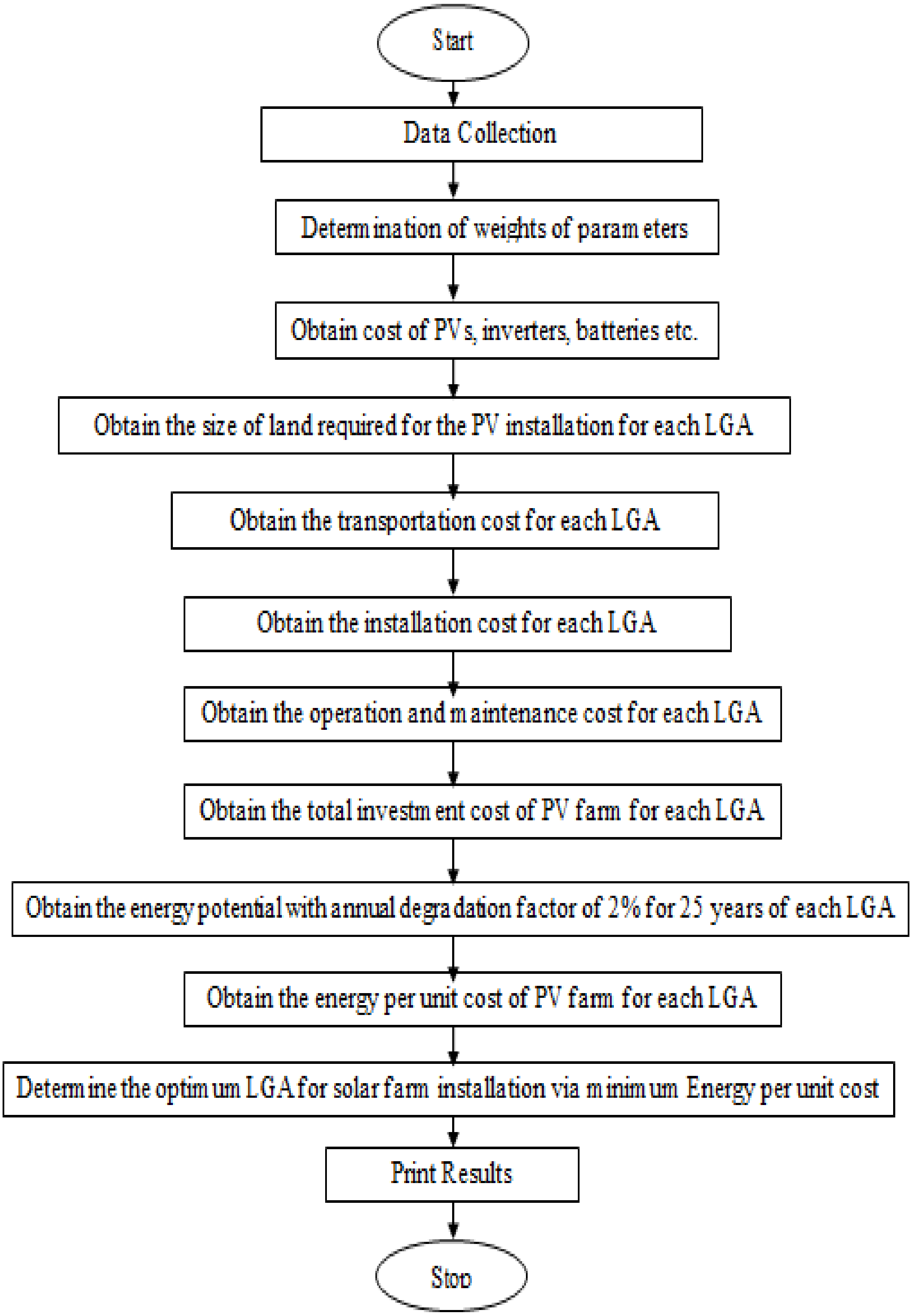

Figure 1: Process flow diagram

Table 1: AkwaIbom State Local Government Areas and their geographical coordinates

S/N	Local Government Areas	Coordinates (latitude, longitude)
1	Abak	4.982872, 7.789049
2	Eket	4.647519, 7.945733
3	EssienUdim	5.103988, 7.648969
4	Etim-Ekpo	4.970464, 7.595459
5	Etinan	4.843397, 7.853122
6	Ibeno	4.563492, 8.002249
7	Ibesikpo-Asutan	4.920408, 7.961355
8	Ibiono-Ibom	5.192260, 7.893264
9	Ika	5.014204, 7.536962
10	Ikono	5.221387, 7.785191
11	Ikot-Ekpene	7.785191, 7.713990
12	IkotAbasi	4.603045, 7.647532
13	Ini	5.403893, 7.775760
14	Itu	5.177936 8.074267
15	Mbo	4.646260, 8.256208
16	Mkpatenin	4.703229, 7.764415
17	Nsit-Atai	4.832348, 8.019751
18	Nsit-Ibom	4.909535, 7.891262
19	Nsit-Ubium	4.731341, 7.968516
20	ObotAkara	5.262528, 7.620896
21	Okobo	4.842366, 8.136626
22	Onna	4.629928, 7.858612
23	Oron	4.804825, 8.230948
24	OrukAnam	4.773362, 7.634080
25	UdungUko	4.757650, 8.246045
26	Ukanafun	4.890958, 7.606100
27	Utuan	5.024641, 8.071518
28	UrueOffong/Oruko	4.716733, 8.177152
29	Uyo	5.033484, 7.927577

Source: Google earth map

A. CALCULATION OF THE WEIGHTS FOR EACH PARAMETER

The weights of temperature, insolation and relative humidity are necessary for determining the energy per unit of the PV cell radiation. The formula for calculating the weights of temperature, insolation and relative humidity is given as;

$$\text{Weights of parameters} = \frac{\text{actual values ofparameters}}{\text{maximum allowable values to obtain maximum radiation}} \quad (2)$$

The weights of population and distance from national grid are necessary for obtaining the installation cost. The formula for calculating the weights for population and distance from the national grid is given as;

$$\text{Weights for parameter} = \frac{\text{actual parameter for each LGA}}{\text{minimum parameter value}} \quad (3)$$

It is assumed that each person in the populace occupies about 0.585 km^2 of land. Then, the land available for PV installation is given as;

$$Land\ avalaible\ for\ PV\ installation = (land\ mass\ area) - (population \times 0.585) \quad (4)$$

B. DETERMINATION OF THE ENERGY PER UNIT COST OF THE INSTALLED PV PANELS

In order to determine the energy per unit cost of installation, we have to determine the installation cost of a single solar panel. Sanyo hit-300W PV module was selected for the solar farm and the dimension of each of the Sanyo hit-300W PV module is1.57x 0.798m which amounts to an area of $1.2529m^2$. If $1m^2$ is the area of the space between a PV panel and its adjacent panels, then, the area occupied by each of the PV panel becomes 2.2529 m^2. The total number of panels required for each location is given as;

$$Number\ of\ PV\ panels = \frac{Land\ available\ for\ PV\ installation\ for\ each\ LGA\ in\ km^2 * 10^6}{2.2529} \quad (5)$$

$$\text{Investment cost} = \text{installation cost} + \text{operation and maintenance cost} \quad (6)$$

The energy output of the PV module is affected by the cell temperature and solar radiation, as well as other factors. The PV cell temperate, T_c (in °C) is given as;

$$T_c = T_a + \left(\frac{T_{NOC} - 20}{0.8kW/m^2}\right) G_T \quad (7)$$

Where T_a is the ambient temperature, T_{NOC} is theNominal Operating Cell Temperature (NOCT), G_T is the solar radiation flux/irradiance. The PV output power or energy is normally de0rated due to temperature and other factors. In this study, the temperature effect is considered in the de-rating factor. The temperature de-rating factor, $f_{temp}$for PV panel is given as;

$$f_{temp} = 1 - (\gamma(T_c - T_{STC})) \quad (8)$$

Where γ is the power temperature co-efficient, per degree C (typically 0.005 for crystalline silicon), T_c is the average daily effective cell temperature, in degrees Celsius and T_{STC} is the cell temperature at standard test conditions, in degrees Celsius.

The electric energy, Epv generated in output of a photovoltaic system is:

$$Epv = A * r * H * f_{derate} \quad (9)$$

Where Epv is the Energy (kWh) , A is the total solar panel Area (m2) , r is the solar panel yield or efficiency(%) , G_T is the annual average solar radiation on tilted panels plane and f_{derate} is the PV output de-rating factor which in this case, the temperature de-rating factor, f_{temp} is considered.

In this paper, the energy generated by the PV panel is affected by the solar insolation incident on the PV surface and the ambient temperature of the location. These factors are used to estimate the energy , Epv generated by the PV array as follows;

$$\text{Epv (kWh)} = \text{power rating of solar panel} \times \text{weights of temperature} \times \text{weights of insolation} \times \text{No of PV} \quad (10)$$

For the operational cost and maintenance cost (O & M cost),

$$O\ \&\ M = solar\ panel\ cleaning\ cost + (\text{inverter replacement}\ \&\ maintenance\ cost) + (\text{battery replacement}\ \&\ maintenance\ cost) \quad (11)$$

$$\text{Total investment cost} = \text{installation cost} + \text{operation and maintenance cost} \quad (12)$$

Therefore, cost per unit energy of the PV power system in kWh/₦ is given as;

$$\text{Cost per unit energy} = \frac{\text{total investment throughout the life span of the solar PV}}{\text{energy generated throughout the life span of the solar PV}} \quad (13)$$

The location with the least cost per unit energy is taken as the best location for installing the solar farm.

III. RESULTS AND DISCUSSION

The plot of the population of different LGAs in AkwaIbom State is shown in Figure 2. The results in Figure 2 shows that the 29th point (Uyo LGA) of the line plot is densely populated (with 314,520 residents) when compared with any other LGA in the State. The line plot of the temperature of the different LGAs of the State is given in Figure 3. According to Figure 3, point 13 (Ini LGA) has the highest temperature. Ini LGA also has the highest solar insolation, as shown in Figure 4. Figure 5 shows the line plot of the distance from national grid for each of the LGAs. Point 28 (Urueoffong/ Oruko has the longest distance from national grid with a distance of 60km. Figure 6 shown the line plots of the land mass area of each local government area of AkwaIbom State. Uyo LGA has the highest land mass area with a value of 362 km^2.

However, being the State capital with the largest population in the State Uyo has the largest occupied landmass in the State, as shown in Figure 7.

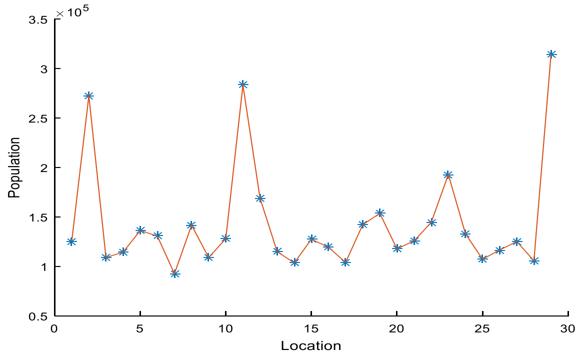

Figure 2: Line plot of Population

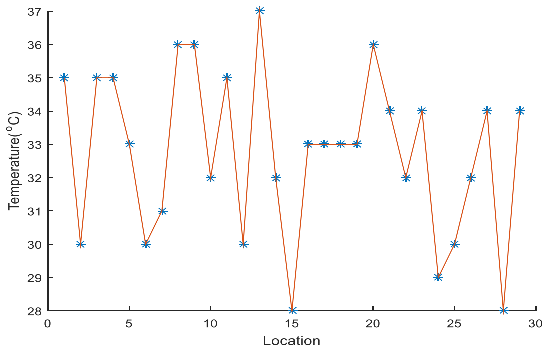

Figure 3: Line plot of Temperature

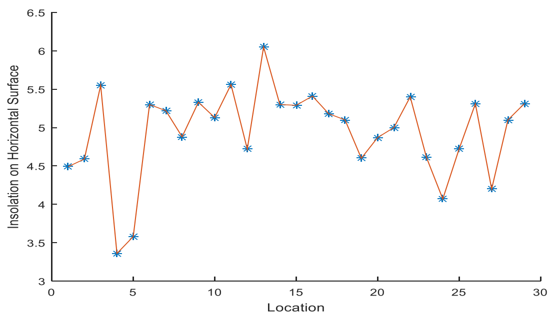

Figure 4: Line plot of Insolation on Horizontal Surface

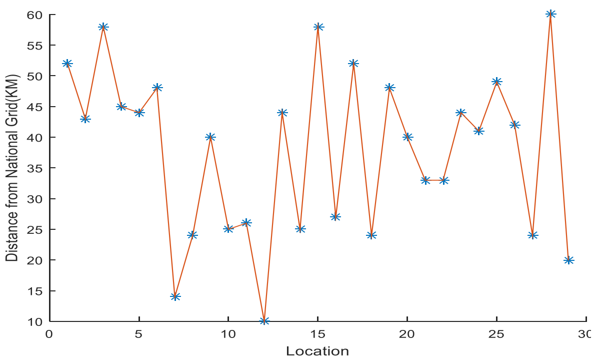

Figure 5: Line plot of Distance from National Grid

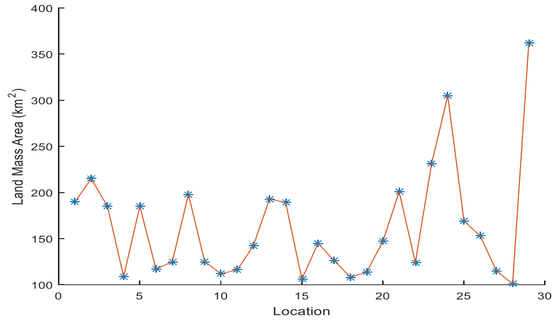

Figure 6: Line plot of Land Mass Area (km^2)

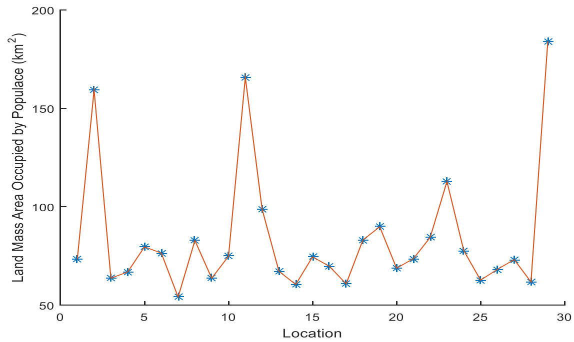

Figure 7: Line plot of land mass area occupied by populace (km^2)

The line plot for energy potential of the PV cells for each LGA is given in Figure 8. Accordingly, Ini LGA (point 13) with the highest solar radiation and temperature has the highest PV energy output.

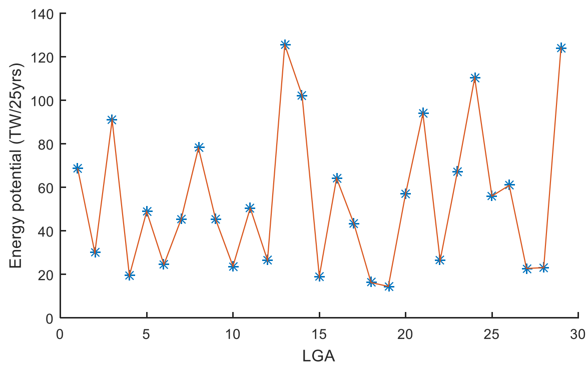

Figure 8: Line plot for energy potential of the PV cells for each LGA

According to Figure 9, the line plot of the installation cost for the different LGAs for a period of 25 years, Nsit-Ubium LGA (point 19) has the least installation cost while Uyo has the highest installation cost. Similarly, the results in Figure 10 shows that, Nsit-Ubium LGA (point 19) has the least operations and maintenance cost while OrukAnam LGA (point 24) has the highest operations and maintenance cost and the highest investment cost (Figure 11).

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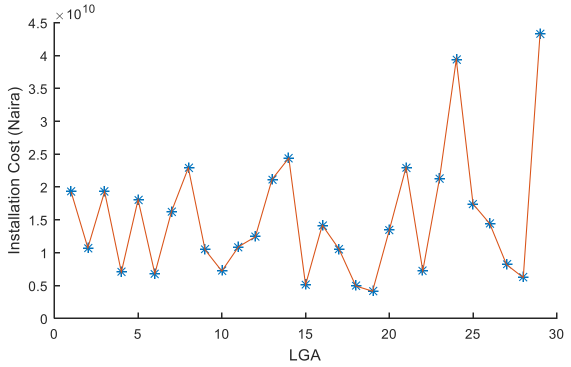

Figure 9: Line plot of installation cost

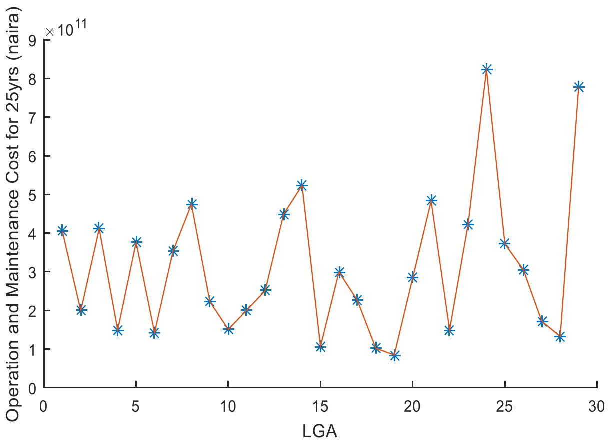

Figure 10: Line plot of operations and maintenance cost for 25 years

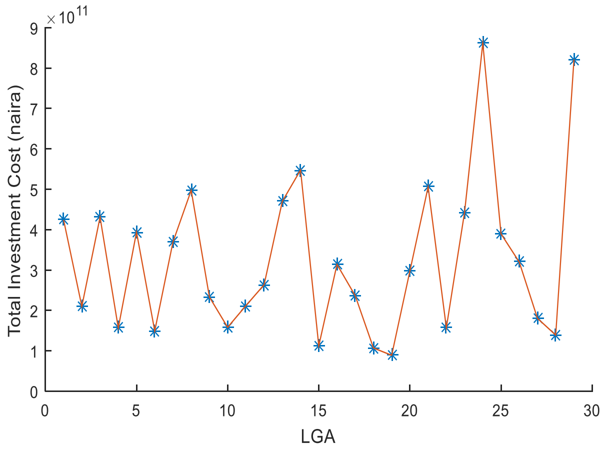

Figure 11: Line plot on total investment cost.

Table 2 and Figure 12 present the cost per unit of energy of each LGA. The location with the least cost per unit of energy is considered as the optimum point for the location of the solar farm. Accordingly, IkotAbasi LGA (point 12) has the lowest cost per unit of energy of 100 ₦/kWh. Therefore, IkotAbasi LGA is the optimum location for siting the solar farm in AkwaIbom State.

Table 2: Energy per unit cost of the PV cell installation for a life cycle of 25 years

S/N	Location	Cost per unit of energy (₦/kWh)
1	Abak	162.3397
2	Eket	142.7685
3	Essienudim	211.1906
4	Etim-Ekpo	124.3305
5	Etinan	124.1557
6	Ibeno	164.5697
7	Ibesikpo-Asutan	123.0433
8	Ibiono-Ibom	157.0850
9	Ika	193.9433
10	Ikono	150.4056
11	Ikot-Ekpene	238.6048
12	IkotAbasi	100.6256
13	Ini	266.9466
14	Itu	187.0694
15	Mbo	170.0343
16	Mkpatenin	204.5950
17	Nsit-Atai	183.8422
18	Nsit-Ibom	151.7901
19	Nsit-Ubium	163.3473
20	ObotAkara	191.9633
21	Okobo	185.7517
22	Onna	168.6833
23	Oron	151.8345
24	OrukAnam	128.0531
25	Udunguko	143.7791
26	Ukanafun	190.5821
27	Uruan	126.2014
28	Urueoffong/Oruko	166.2896
29	Uyo	151.4912

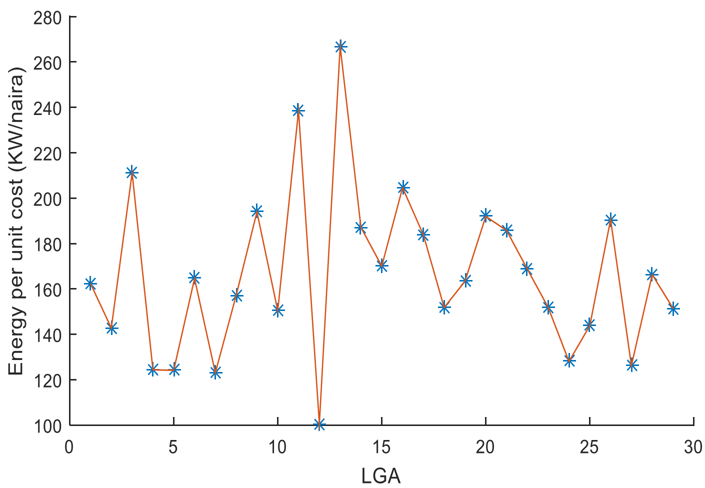

Figure 12: Line plot of the cost per unit of energy (kW/N).

IV. CONCLUSION

The essence of this paper is to determine the optimal location for installation and operation of solar farm. The meteorological parameters (temperature and insolation on horizontal surfaces), distance from the national grid, population and landmass area were the variables considered in the course of this research. The meteorological data for each location was obtained from the AkwaIbom State Bureau of Statistics. Available landmass for solar farm installation and weights of the atmospheric parameters were also calculated. The values obtained played a major role in obtaining the installation cost, operation and maintenance cost and energy unit cost for each location.

Specifically, the cost per unit of energy for PV array installation in 29 LGAs in AkwaIbom State was computed and then used to determine the optimal location for the installation of solar farm in AkwaIbom State. From the results obtained, IkotAbasi had the least energy cost per unit of energy, thus, making it the most preferred location for the installation and operation of the solar farm in AkwaIbom State since it is feasible and profitable.

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