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Development of Optimal Site Selection Method for Large Scale Solar Photovoltaic Power Plant

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Abstract

In this paper, method selecting optimal location for large scale photovoltaic (PV) power plant in Imo State is carried out. Ten local government areas (LGAs) in Imo were selected out of the 27 LGAs in the state. Also, five parameters were used for ranking the selected LGAs for their suitability for large scale PV power plant. The five parameters are; (i) Global Irradiation On Horizontal Plane (kWh/m²) (ii) Available Energy (Kwh) (iii) Yearly Unit Cost of Energy (iv) Population (v) Land Mass (Km^2). PVSyst software was used for the simulation of the PV energy generator output and unit cost at each of the selected LGA. The meteorological data used for the simulation was obtained from NASA website. Also, population density and land mass of each of the LGAs were obtained from Nigerian Population Commission publication. In all, Umuapu has the highest PV Site Suitability Factor (PVSSF) of 142 while Oguta has the least with 39. Consequently, the optimal site for large scaled PV power plant among the selected LGAs in Imo State is Umuapu. Accordingly, Umuapu has the PV Site Suitability Rank (PVSSR) of one (1) while Oguta has the poorest PVSSR value of 10.

Keywords: Optimal site, Photovoltaic, Electric Power, Renewable Energy, PVSyst, Global Radiation On Horizontal Plane, Unit Cost of Energy, Site Suitability Factor , Suitability Ranking.

1 Introduction

In recent years, there is increasing global pursuit for both environmental and energy security. In this wise, it has become established fact that the dependence on conventional energy resources has to be reduced and renewable energy resources are one of the promising options available to meet the energy target. Of all the several renewable energy resources solar energy is the most promising option because of its inherent advantages [1]. Furthermore, as the cost of PV devices and systems drop, there is steady increase in the adoption of PV especially at Large Scale Photovoltaic Power (LSPVP) plant. One important aspect for achieving such highly ambitious plan is to identify the promising geographical areas for establishing such SPV plants since with the existing low conversion efficiencies, installation of solar PV power plant requires enormous amount of investment in terms of land, money and man power [2]. Moreover, site selection for large scale PV power plant has a heavy impact, among other factors, on attracting both public and private investments and the overall sustainability of the system [1]. In response to these factors, there is need for a careful and thorough evaluation of potential sites for implementation in order to deliver both social and economic benefits to potential power consumers, as well as boost investment from the public and private sectors [1].

Selection of a suitable site is based on a set of criteria mainly depending on the local conditions of its surrounding environment, availability of solar irradiation within years and even days, as well as some socio-economic criteria such as landmass, the proximity of the selected site to power transmission lines or converting stations and the proximity to main roads or populated areas. There are published works on optimal site selection for PV plants. Some of the notable works that suggested methodologies for selection of optimal site for different kinds of renewable energy systems includes [3, 4, 5]. The potential for wind farm in India was reported in [6] whereas; in [7] the economic potential of different renewable technologies in Karnataka was reported. Also, solar photovoltaic potential and capacity of plant in Patiala was reported in [8]. Detailed work on site selection methodology for large scale PV power plant was reported in [9]. Particularly, Khan and Rathiin [9] presented a decision and methodology to locate potential sites for large-scale Solar PV (SPV) plants focusing on various factors which they classified as “analysis criteria” and “exclusion criteria”. The criteria such as availability of empty land, availability of adequate solar radiation, distance from major roads and distance from existing transmission lines etc. are considered as analysis criteria [3]. Variations of local climate, module soiling, topography of site etc. are exclusion criteria [9]. Another study in Kenya presented a methodology for optimal site selection for PV plant [1]. The study in [1] adopted yet a different approach for classifying and using its criteria for the selection of optimal site for large scaled PV power plant.

In all, most of the published methods for determining the optimal PV plant site are quite complex and the data used are in most cases not readily available, especial in developing countries like Nigeria [10]. In this paper, the focus is to develop and employ a simple optimal PV plant site selection method that is based on readily available data and which is easy to apply to any location. Furthermore, the application of the model is demonstrated by employing it to identify optimum sites for LSPVP plants in Imo State. To achieve this objective, the solar energy potential and eventually, the unit energy cost for a hypothetical PV power plant in the various local government areas in Imo State is used. The suitability of the various LGAs is presented in a sorted list of increasing unit cost of PV generated energy. The optimal site is selected as the site with the lowest unit cost of PV generated energy. PVSyst software is used to conduct the economic analysis and unit cost calculation.

2 Methodology

Normally, in site selection for large scale PV power plant, the first step is review of the site selection parameters and to determine if they are applicable to the sites under assessment [1]. Knowledge on applicability of parameters can be gained through interviews of key area informants, observation, and literature reviews. In this paper, the following three key site selection parameters are obtained from the NASA website [11] and the PVSyst simulation software [12];

1. The Monthly and daily average global solar irradiation on horizontal plane (kWh/m^2)
2. The Available Energy (Kwh/year) output from the PV modules per year
3. The Unit Cost of Energy computed from the annual energy output.

The two additional parameters considered for the site selection are:

1. Population
2. Land Mass (Km^2)

Population density is computed from the data on population and landmass for each of the site considered. The data on the two additional parameters for large scale PV power plant site selection are obtained from the publication by the Nation Population Commission (NPC) of Nigeria [13, 14]. The data on the first three parameters are obtained as follows:

- 22-years average yearly, monthly, or daily solar radiation data, specifically, average hourly global irradiation on horizontal plane (KWh/m^2) and air temperature are downloaded from NASA website for each of the 10 selected LGAs in Imo State studied. Particularly, the data are obtained from the NASA Langley Research Centre Atmospheric Science Data Centre Surface meteorological and Solar Energy (SSE) web portal supported by the NASA LaRC POWER Project [11].
- With the NASA solar radiation data and a common or uniform available PV area (Apv) of $100m^2$, the PVSyst [12] is used to simulate and hence determine the solar energy potential of each of the 10 selected LGAs in Imo State along with the corresponding unit cost of the energy. The yearly solar electric power generation potential of any given area can be estimated as follows [4, 9]:

$$GP = SR \times CA \times AF \times \eta \tag{1}$$

where, GP = Electric power generation potential per year (kWh/day)
SR = Annual solar radiation received per unit horizontal area ($kWh/m^2/day$)
CA = Calculated total area of suitable land (m^2)
AF = the area factor, indicates what fraction of the calculated areas can be covered by solar panels
η = PV system efficiency
Alternatively, the effective available area for PV installation can be represented as Apv, where

$$Apv = CA \text{ x } AF \tag{2}$$

Hence

$$GP = SR \times Apv \times \eta \tag{3}$$

After identifying the site selection parameters, weighting factors are assigned to each parameter based on how much influence the parameter has on the suitability of a site for large scale PV power plant [1]. Let w_i be the weight of parameter *i* where *i*=1, 2, 3, 4, 5.

Table 1: The Weighting Factor for Each of The Five PV Site Selection Parameters

	Unit Cost of Energy	Available Energy (Kwh)	Global Irradiation On Horizontal Plane (kWh/m²)	Population Density	Population
Weighing Factor	5	4	3	2	1

Also, each of the 10 locations is assigned rank for each of the 5 site selection parameters. Let $L_{j,i}$ be the ranking of location j for parameter *i* where *i*=1, 2, 3, 4, 5 and *j*=1, 2, 3,…, 10. Then, the PV Site Suitability Factor (PVSSF) for location *j* is given as;

$$PVSSF_j = \sum_{i=1}^{i=5}\left(\left(L_{j,i}\right)\left(w_i\right)\right) \tag{4}$$

The optimal location for the large scale PV power plant is therefore given as $L_{OPTIMAL}$ where

$$L_{OPTIMAL} = \text{Maximum}\,(PVSSF_j) \quad \text{for } j = 1, 2, 3, \ldots, 10. \tag{5}$$

3 Results and Discussion

The values for each of the site selection parameter for the 10 selected local government areas (LGAs) in Imo State are shown in Table 2. Column 2 of Table 2 shows the Global Irradiation on Horizontal Plane (kWh/m²) obtained from NASA website [11]. Column 3 and column 4 of Table 2 contain the Unit Cost of Energy (Naira/KWh) and Available Energy (Kwh) respectively. The Unit Cost of Energy (Naira/KWh) and Available Energy (Kwh) are obtained from PVSyst simulation of the PV potential and economic analysis of PV system for each of the selected 10 LGAs in Imo state. Column 5 and column 6 contain data on population density and population respectively.

The data on population density and population are obtained from the published bulletin of Nation Population Commission (NPC) of Nigeria [13, 14]. Table 3 shows the ranking of each LGA for each of the five parameters listed in Table 2 as well as the computed Site Suitability Ranking Factor (SSRF) and Site Suitability Rank (SSR) for each of the 10 LGAs.

Table 2: The Values for Each of the Site Selection Parameters for the 10 LGAs in Imo State

	Global Irradiation On Horizontal Plane (kWh/m²)	Unit Cost of Energy (Naira /Kwh)	Available Energy (Kwh)	Population Density	Population
DIKENAFAI	1717.2	106	12256	812.4668	156,161
IDEATO NORTH	1650.2	108	11692	812.4668	156,161
IHIAGWA	1558.4	110	11066	342.4596	101,754
ISINWEKE	1717.2	105	12328	1137.508	119,419
NEKEDE	1558.4	111	10906	881.6876	176,334
OGUTA	1535.3	114	10591	291.6546	142,340
OKIGWE	1717.2	104	12422	409.9797	132,701
OWERRI	1535.3	112	10692	2143.356	125,337
UMUAKA	1535.3	113	10653	1692.679	143,485
UMUAKPU	1717.2	105	12418	203.6657	182,891

Site suitability is directly proportional to Global Irradiation on Horizontal Plane (kWh/m²). With respect to Global Irradiation on Horizontal Plane (kWh/m²), Fig. 1 shows that Umuakpu has the highest value and hence is the most preferred site if only Global Irradiation on Horizontal Plane (kWh/m²) is considered. On the other hand, Oguta is the worst location with respect to Global Irradiation on Horizontal Plane (kWh/m²).

Table 3: The Site Suitability Factor and Suitability Ranking Computation for the 10 LGAs in Imo State

	Global Irradiation On Horizontal Plane (kWh/m²) (W_i = 3)	Unit Cost of energy (W_i =5)	Available Energy (Kwh) (W_i = 4)	Population Density (W_i = 2)	Population (W_i =1)	PV Site Suitability Factor (PVSSF)	PV Site Suitability Rank (PVSSR)
DIKENAFAI	7	7	7	6	8	105	3
IDEATO NORTH	6	6	6	5	7	90	5
IHIAGWA	4	5	5	8	1	75	6
ISINWEKE	8	8	8	3	2	105	4
NEKEDE	5	4	4	4	9	69	7
OGUTA	1	1	1	9	5	36	10
OKIGWE	9	10	10	7	4	136	2
OWERRI	2	3	3	1	3	39	8
UMUAKA	3	2	2	2	6	38	9
UMUAKPU	10	9	9	10	10	142	1

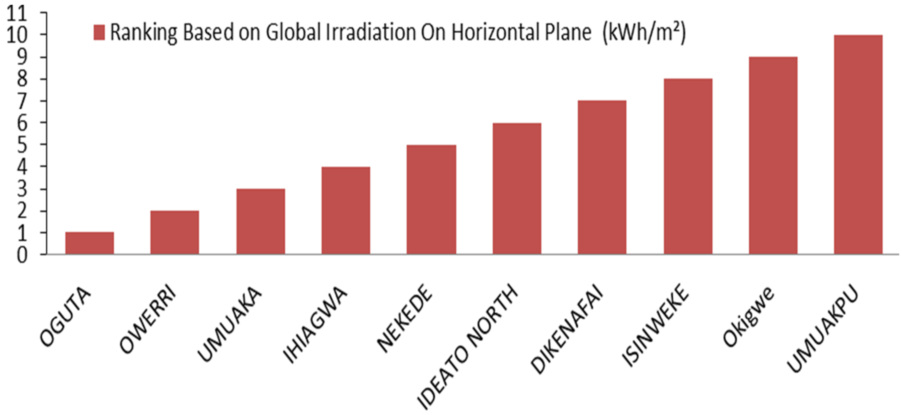

Figure 1: Site Ranking Based on global Irradiation On Horizontal Plane (KWh/m^2)

With respect to population density, Fig. 2 shows that Umuakpu has the lowest value and hence is the most preferred site if only population density is considered. On the other hand, Owerri with the highest population density is the worst location with respect to population density.

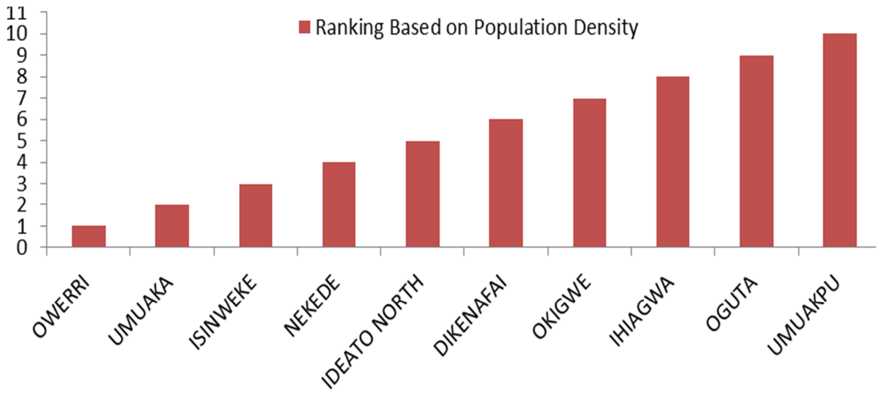

Figure 2: Site Ranking Based on Population Density

Actually, site suitability is inversely proportional to population density, consequently, in Table 2, Owerri has the highest population density, and so, Owerri is the most unsuitable because it will require evacuation of more people and payment of more compensation if the large scale PV power plant is to be sited in Owerri. Umuakpu, on the other hand, has the lowest population density.

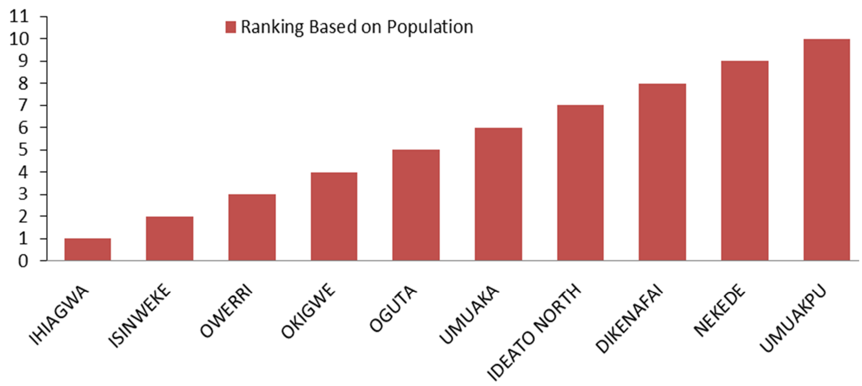

Figure 3: Site Ranking Based on Population Density

Site suitability is directly proportional to population, the higher the population, the higher the number of potential customers for the PV power plant. With respect to population, Table 2 shows that Umuakpu has the highest value and hence in Fig. 3 Umuakpu is the most preferred site if only population density is considered. On the other hand, Ihiagwa is the worst location with respect to population. Actually, in Table 2, Umuakpu has the highest population density. As such it is the most suitable because it will have more customers who will pay for the investment if the large scale PV power plant is to be sited in Umuakpu.

With respect to potential available yearly energy output from the PV plant, Fig. 4 shows that Okigwe has the highest value and so it is the most preferred site if only available yearly energy output from the PV plant is considered. On the other hand, Oguta is the worst location with respect to available yearly energy output from the PV plant. Essentially, site suitability is directly proportional to potential available yearly energy output.

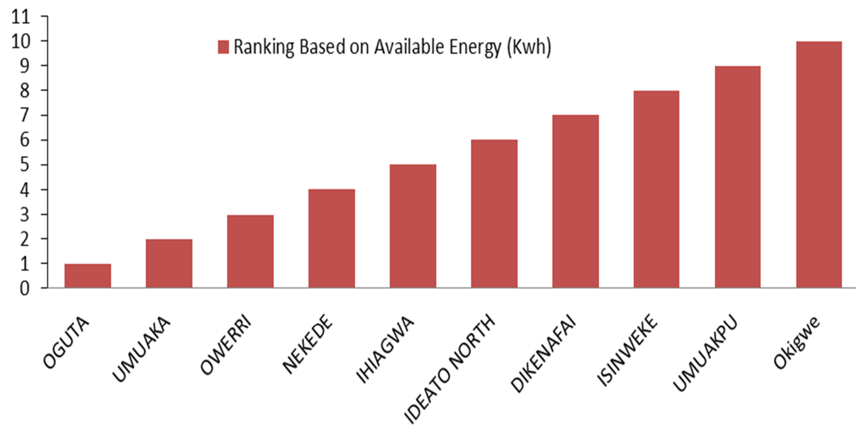

Figure 4: Site Ranking Based on Available Energy (KWh)

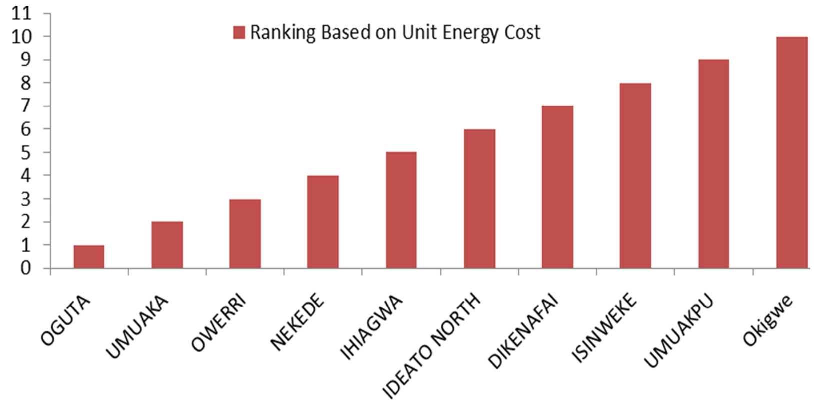

Figure 5: Site Ranking Based on Uint Cost Of Energy

Obviously, site suitability is inversely proportional to unit cost of energy, the smaller the unit cost of energy the more suitable the site is for large scaled PV power plant. With respect to unit cost of energy (naira/KWh) from the PV plant, Table 2 and Fig. 5 show that Okigwe has the lowest value and so it is the most preferred site if only unit cost of energy (naira/KWh) from the PV plant is considered. On the other hand, Oguta is the worst location with respect to unit cost of energy (naira/KWh) from the PV plant.

When the five optimal site selection parameters are simultaneously considered using Eq. (4) and Eq. (5), a single value is obtained for ranking the different sites. Table 3 and Fig. 6 show the collective PV Site Suitability Factor (PVSSF) which is computed from the five site selection parameters. With respect to PVSSF, Table 3 and Fig. 6 show that Umuakpu has the highest value and so it is the most preferred site if all the five site selection parameters are simultaneously considered. On the other hand, Oguta is the worst location if all the five site selection parameters are simultaneously considered. Figure 7 shows the actual ranking of the 10 LGAs based on the PVSSF. Again, Umuakpu is ranked number 1 based on the PVSSF in Fig. 6 whereas Oguta is ranked number 10. In all, Umuakpu is the most suitable site for large scaled PV power plant in Imo state.

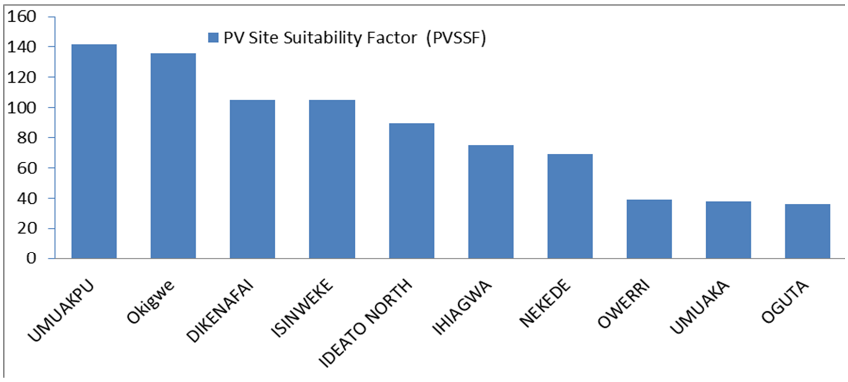

Figure 6: PV Site Suitability Factor (PVSSF)

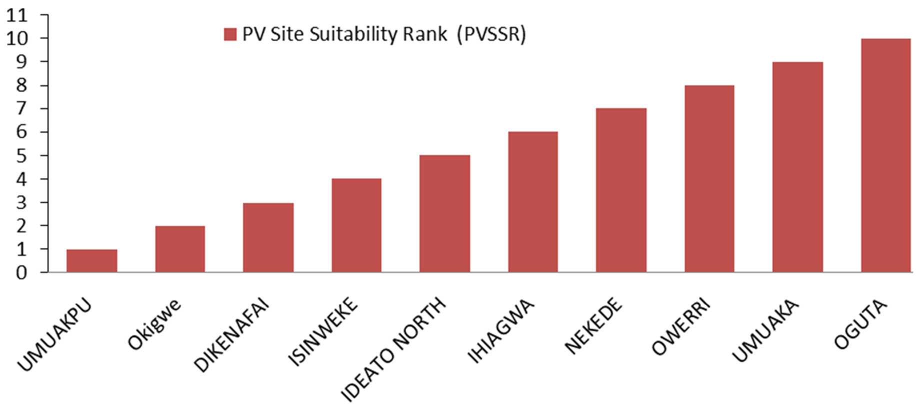

Figure 7: PV Site Suitability Ranking (PVSSR)

4 Conclusion and Recommendations

4.1 Conclusion

In this paper, comparative assessment of the various parameters that are essential for the selection of optimal location for siting large scale photovoltaic electric power generation plant in Imo State is carried out. In order to determine the optimal location for siting large scale PV power plant in Imo State, 10 local government areas (LGAs) in Imo are selected out of the 27 LGAs in Imo State. Also, five key parameters are used for the ranking of the selected LGAs for their suitability for large scale PV power plant. The five parameters are:

1. Global Irradiation On Horizontal Plane (kWh/m^2)
2. Available Energy (Kwh)
3. Yearly Unit Cost of Energy
4. Population
5. Land Mass (in Km^2)

In all, Umuapu has the highest PV Site Suitability Factor (PVSSF) of 142 while Oguta has the least with 39. Consequently, the optimal site for large scaled PV power plant among the selected LGAs in Imo State is Umuapu. Accordingly, Umuapu has the PV Site Suitability Rank (PVSSR) of one (1) while Oguta has the poorest PVSSR value of 10.

4.2 Recommendations

The study so far covered only 10 LGAs in Imo State. Further works are required to conduct the study for the whole LGAs in Imo State. Also, the data used for the study are obtained from NASA SSE website. It is always recommended that locally measured data should be used.

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