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Geospatial Assessment and Mapping of Suitable Sites for a Utility-scale Solar PV Farm in Akure South, Ondo State, Nigeria

Abstract: Geospatial and multi-criteria decision-making techniques are applied to process and analyse datasets for determining suitable areas for multiple utility-scale solar photovoltaic farms in the city of Akure, Ondo State, southwestern Nigeria. Data processed include local electric power distribution system data, Shuttle Radar Topographic Mission elevation data, Landsat 8 and solar global horizontal irradiance. Multi-criteria decision-making techniques adopted are the analytical hierarchy process, reclassification, and overlay. These techniques were carried out considering criteria for siting solar photovoltaic farms. Criteria considered in this study are climate, topography, economic, environmental impact operational and technical while sub-criteria are solar global horizontal irradiance, slope, proximity and land cover. The outcome of the study shows that the study area covering a total extent of ~33,200 ha, 15%, 8%, 13% and 64% are highly suitable, suitable, moderately suitable, and unsuitable respectively for siting utility-scale solar photovoltaic farms within the study area. The study reveals the potential of multiple utility-scale solar photovoltaic farms in the study area. However, the proportions of areas suitable for solar photovoltaic farms are quite lower compared to findings from similar studies conducted in northwestern Nigeria. The study recommends solar photovoltaic sources as an alternative energy source in and around the study area.

Keywords: Akure Nigeria, renewable energy, site suitability, solar PV farm, mapping

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1. Introduction

Goal seven of the United Nations (UN) Sustainable Development Goals (SDGs) emphasizes the importance of inexpensive, reliable, sustainable, and clean energy sources for a country's economic development. A continuous and reliable supply of electricity is required for any national socio-economic development, with a more rapidly expanding rural-urban-drifted population [1]. As of 2020, Nigeria recorded an urban population of over 107 million persons, increasing at a rate of 4.18% constituting 51.96% of the country's total population, next to India and Indonesia [1]. According to the Nigerian Gross Domestic Product Report for 2020, the oil and non-oil sectors of the economy contributed to the annual GDP, with the oil sector accounting for 5.87% and the non-oil sector accounting for 94.13% [2]. Although both industries rely on human resources to operate, they also rely substantially on the generation of electrical energy. According to [3] in 2018, 43.5% of Nigerians do not have access to power, and Nigeria ranks high among countries with an electricity access deficit, even though energy access, efficiency, and renewables are on the rise in many developing countries. Access to power reflects citizens' access to safe drinking water, better healthcare facilities, and the expansion and development of many sectors of the national economy, such as communication and industry [3].

According to [4], a review of Nigeria's energy industry reveals that the country has the largest economy in the Sub-Saharan Africa, but power sector constraints impede expansion [4]. Existing sources of power are: oil, gas, hydro, and a few solar power sources, and the present facilities can create 12,522 MW of electricity. However, on most days it can only deploy roughly 4,000 MW, which is insufficient for a country with a population of over 195 million people. Given that power sources are limited in supply, and power demand has been increasing, putting a lot of pressure on these scarce power supplies, this has led to the emergence of environmentally friendly and renewable power sources, bringing about the advent of solar energy exploitation for solar-generated power supply [5]. The sun is the ultimate source of energy because it is a free and renewable energy source. Solar energy is the radiant light and heat from the sun that can be captured using a variety of ever-evolving technologies like solar heating, photovoltaics, solar thermal energy, solar architecture, molten salt power plants, and artificial photosynthesis [5, 6]. Even though the sun is a free source of energy, harnessing it and converting it into usable electricity requires some effort.

A utility-scale solar PV project is a solar farm that produces 10 MW or more of energy and is suitable for metropolises (large cities). Environmental factors (such as irradiance, wind speed, temperature, and so on), land area, solar PV module, and land uses are typically used to determine the energy yields expected from these projects over the life of the proposed power plants [7]. The land area required for a utility solar farm is determined by the projected size and capacity, while the size and capacity of the solar farm are often determined by land availability and uses (human activities). For example, the solar plant located 6 km outside of the town of De Aar in the Northern Cape province of South Africa, has an installed capacity of 95,458 MW, spread across over 100 ha and consists of 167,800 solar PV modules, powering over 19,000 average South African homes [8].

Increased efforts to promote sustainable developments across all fields over the past decade has led to the development of Sustainable Development Goals (SDGs) by the United Nations (UN) and several kinds of research aimed toward sustainable developments. With a growing need to combine goals connected to sustainable development, land use planning has become more difficult. As a result, the modern planning process has evolved into a conflicting and contradictory movement of environmental, economic, and social interests [9]. Approaches to selecting suitable solar sites are emerging as a result of the application of geospatial technologies paired with current breakthroughs in adjacent domains [10]. In recent times, several works have been carried out on the application of geospatial technologies in site assessment for the establishment of utility-solar plants and other related developments.

2. Literature Review

The application of geospatial and multi-criteria decision making (MCDM) technologies in site assessment for the establishment of renewable energy utility plants has become a trend and has been dealt with by several authors. A review on this topic was conducted by [11]. Based on this review, the MCDM has focused on a relatively small number of multicriteria approaches with the analytical hierarchy process (AHP) being the most used technique. Other techniques applied in this review include the weighted linear combination (WLC), ideal points methods, the elimination and choice translating reality (ELECTRE) and technique for order preference by similarity to ideal solution (TOPSIS). The renewable energy sources considered in this review are solar photovoltaic (PV), concentrated solar power (CSP), and wind farms. Considering the global coverage of the reviews carried out by [11] studies have been carried out in the past to determine the feasibilities of the renewable energy sources covering many nations. However, Nigeria considered in this review by [12] helps to determine the optimised electricity generation costs of the future national and regional grids, but fails to consider the geospatial dimension of the energy resources.

For this study, a more recent review is made which presents an update on the already existing reviews. A summary of the recent literature studies is presented in Table 1. One key new feature seen based on the recent review is in the techniques adopted for the MCDM. The MCDM techniques adopted in the studies reviewed are: AHP, TOPSIS, WLC, choosing by advantage (CBA), maximum entropy (MaxEnt) model, versatile participatory planning technique (VPPT), interval type-2 fuzzy sets (IT-2FS), spatial model with GIS multi-criteria decision analysis (MCDA), weighted sum average (WSA), additive ratio assessment (ARAS), operational competitive rating assessment (OCRA), preference selection index (PSI), simple multi-attribute rating technique (SMART), weighted superposition (WS), VIKOR method, and binary overlay (BO). Most of these techniques were seen to be implemented in conjunction with Geographic Information System (GIS) and remote sensing (RS) techniques.

Given the recent literature reviews in Table 1, the AHP technique is seen to be the most popular MCDM technique, this may be due to the ease of adaptability and reliability of the technique in solving a variety of site suitability problems as seen in past and recent studies. Consequently, the AHP MCDM, in combination with GIS techniques, were adopted in this study.

The recent literature review reveals that not much work has been conducted on spatial suitability for solar and other renewable energies in Nigeria, even with its tremendous solar PV electricity generation potential, with all locations within Nigeria capable of annually producing above 1,000 kWh/kWp [37]. The study of [32] on suitable sites for wind energy farms in Nigeria reveals that a vast majority of the northern parts of Nigeria are suitable for wind energy farms, while a majority of southern Nigeria are unsuitable, which include Akure, Ondo state which is the study area adopted in this research. The study [38] examines the need for policy statements to take care of the adverse impacts of solar derived wastes on the environmental and human health based on the Nigerian Solar Energy Policy (NSEP), as contained in the National Renewable Energy and Energy Efficiency Policy (NREEEP). They suggested that one of the ways to control hazards posed by the solar PV derived waste is by identifying suitable sites for the solar PV plants. For this reason, environmental impacts were considered among factors in this study, by ensuring appropriate distances of potential sites to residential areas were maintained. The works of [17] were carried out in northwestern Nigeria on locating suitable sites for solar PV plants and identifying suitability indices for the study area. One of the setbacks identified in Raji's study is the failure to consider the proximity to existing grid connections which may imply additional costs incurred in connecting the solar energy source to prospective consumers. The proximity to existing grid connections was evaluated in this study. Again, the findings in the work of Raji are limited to the northern region of Nigeria, ruling out information on the feasibilities of solar PV energy completely in the southern region of Nigeria. The map in Figure 1a is a map of Nigeria showing the distribution of solar global horizontal irradiance (GHI) over Nigeria. This map shows the distribution of the solar GHI over Nigeria, varying from ~2,200 kWh/m^2 (northern Nigeria) to ~1,200 kWh/m^2 (southern Nigeria). Variations in other factors considered in locating suitable sites for solar PV such as climate (Fig. 1b), topography (Fig. 1c) and land cover (Fig. 1d) over Nigeria are also evident. Consequently, there is a need to understand the feasibility of solar PV energy, in terms of factors associated with the spatial dimension, especially within southern Nigeria.

Table 1. Summary of recent studies on site suitability assessment for renewable energy

No.	Reference	Technique applied	Type of renewable energy	Region/Country	Year
1	[13]	AHP	PV and CSP	West Africa	2018
2	[14]	AHP-GIS	solar PV	Kahramanmaraş, Turkey	2021
3	[15]	AHP-GIS	large-scale solar PV	Peru	2021
4	[16]	AHP-GIS	PV	Amhara region, Ethiopia	2020
5	[17]	AHP-GIS	PV	Northwest, Nigeria	2017
6	[18]	AHP-GIS-TOPSIS	offshore wind farm	Aegean, Greece	2018
7	[19]	GIS-AHP with VPPT	wind and PV farm	Israel	2021
8	[20]	AHP	CSP and PV	Morocco	2018
9	[21]	GIS- MaxEnt model	solar and wind	Turkey	2021
10	[22]	spatial model with GIS-MCDA	solar PV	New York State, USA	2021
11	[23]	IT-2FS	offshore wind farm	Ireland	2020
12	[24]	AHP	wind and solar	South Gondar, Ethiopia	2020
13	[25]	AHP	floating solar PV on dams	Ethiopia	2020
14	[26]	GIS, RS and AHP	solar PV	Northwest Coast, Egypt	2020
15	[27]	GIS-AHP	CSP	Algeria	2020
16	[28]	AHP and WSA	solar PV and CSP	Ghana	2022
17	[29]	CBA	solar plant	California, USA	2022
18	[30]	GIS-AHP	CSP with dry and wet colling	Eastern Morocco	2018
19	[31]	ARAS, OCRA, PSI, WS, TOPSI SMART and VIKOR	solar PV	Ecuador	2022
20	[32]	IT-2FS and AHP	wind	Nigeria	2018
21	[33]	GIS-AHP	wind powerd hydrogen plant	Algeria	2019
22	[34]	AHP, WLC and BO	hybrid solar-wind	Assiut Governorate, Egypt	2022
23	[35]	GIS-AHP	solar plant	Turkey	2022
24	[36]	GIS-AHP	solar PV	Egypt	2022

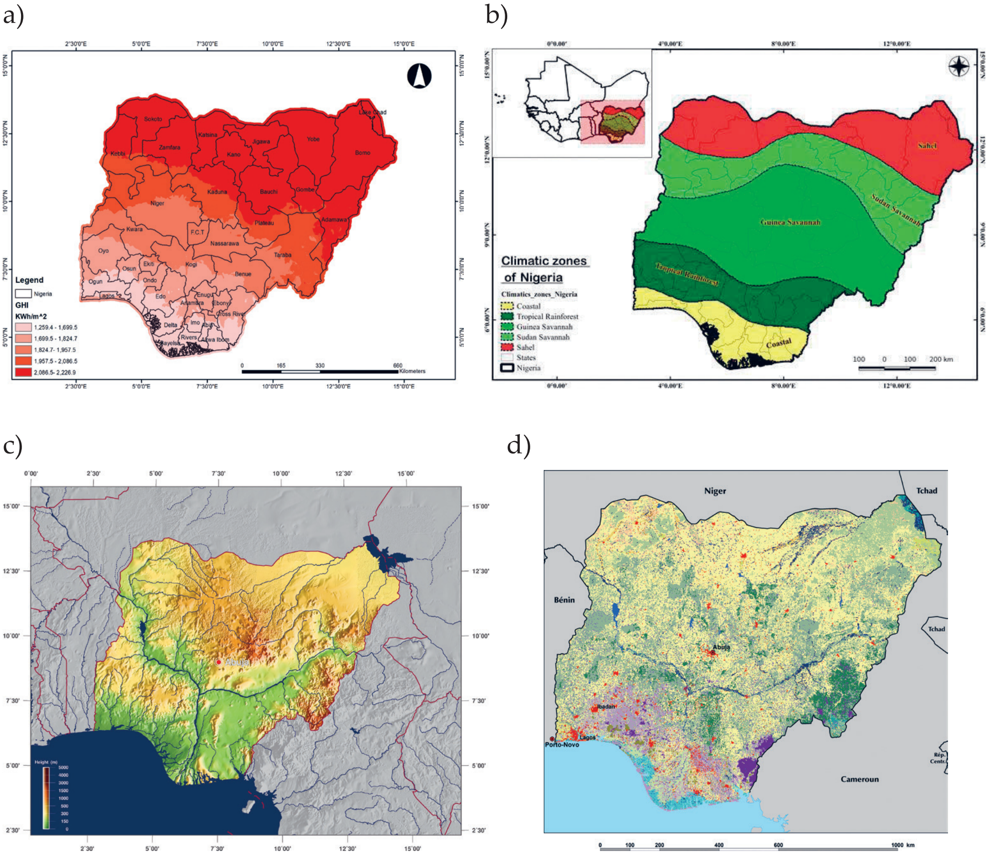

Fig. 1. Map of Nigeria:
a) solar GHI; b) climatic zones of Nigeria;
c) shaded height and relief; d) land cover

Source: adapted from [39] (a), [40] (b), [41] (c), [42] (d)

This study is aimed at conducting a geospatial assessment to determine the feasibility of multiple utility-scale solar PV plants in the city of Akure, Ondo State, southwestern Nigeria. Figure 1 shows variations in some factors considered to locate suitable sites for solar PV in Nigeria.

3. Study Area

The study area is Akure South Local Government Area, Ondo State, Nigeria. Akure is a city in southwestern Nigeria and the largest city and capital of Ondo state. It has an area of 332 km^2 and a population of 484,798 according to the 2006 census and according to the world population [43], projected to be 803,062 in 2025.

The study area lies between latitudes 7°5′0″N and 7°22′0″N and longitudes 5°5′0″E and 5°22′30″E. Akure has a major land use of residential areas and is home to a lot of commercial activities as well. Ondo state is known to be Nigeria's chief cocoa-producing state. Ondo State, with the slogan of the "Sunshine State" still has many communities yet to be connected to the national grid and large deficiencies existing in the national grid system. Considering the aforesaid, a new electricity bill was proposed to the Ondo State House of Assembly to repeal the old Ondo State Electricity board law. This new bill was proposed and approved to provide enabling laws to ensure private sector participation in power generation, transmission, and distribution in Ondo State, as well as a legal framework for investors to participate in electricity provision in areas not served by the national grid system [44]. Mini-grid systems, mostly utility-scale solar farms, have been brought in as a result of the new law, which will provide job opportunities in the electricity sector in the state, as well as improving the economy and standard of living of the people within the state. Figure 2 is a satellite image map of the study area (Akure South) in the context of Ondo State and Nigeria.

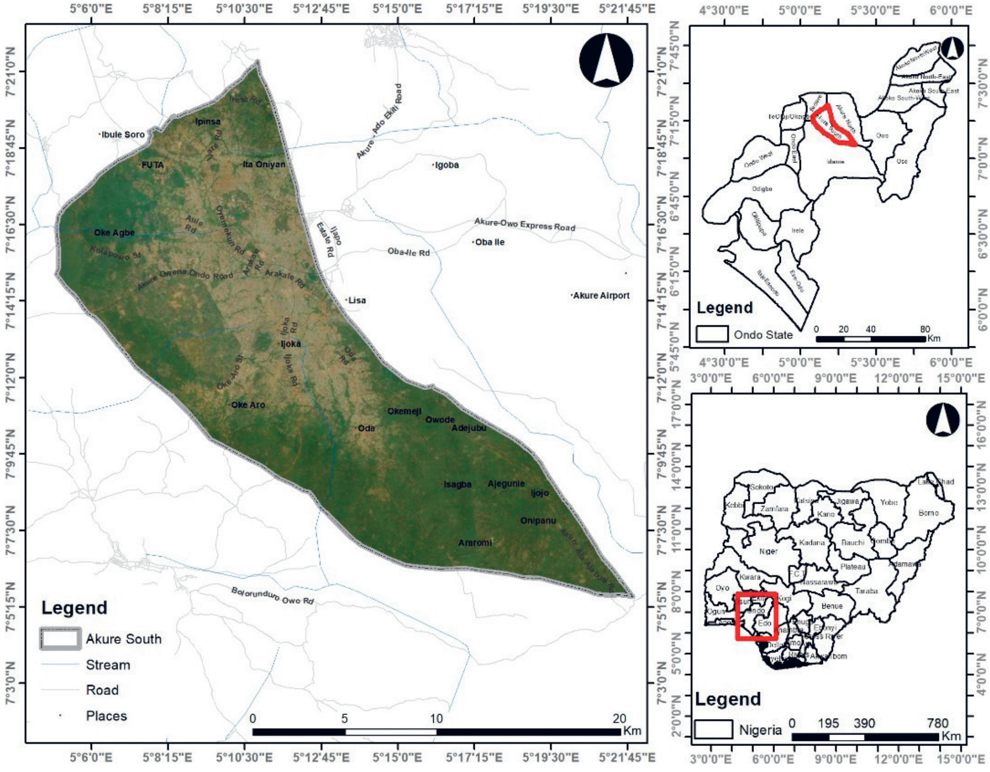

Fig. 2. Satellite image map of the study area (Akure South) in the context of Ondo State and Nigeria

4. Materials and Methods

4.1. Data Collection and Derivation

Considering the peculiarity of this study, site-specific factors or criteria considered in this research, adapted from past studies that either promote or inhibit effective use of solar energy are: climate, topography, economic, environmental impact, technical and operational. These criteria were further categorised into sub-criteria as solar resources, land cover, slope and elevations, distance to agricultural lands (restricted areas), residential, industrial areas and proximity to grid connection. Water bodies were not considered a major issue in the study, because only a few small streams were found in the study area (Fig. 2), insignificant to the analysis. Details of the datasets used in this research are presented in Table 2. Data derivations for the MCDM were achieved by developing spatial data layers, using GIS techniques with ArcGIS 10.7 software. The AHP analysis was implemented based on data derived from spatial data layers, bearing in mind the criteria that influence the site selection for solar PV plants.

Table 2. Details of datasets used for this research

Datasets	Source	Resolution	Period of data collection	Description	Application in the study
Global horizontal irradiance (GHI)	SolarGIS (originator) The World Bank (owner)	Distance: 9.0 arcsec (250 m)	1994–2018	The long-term yearly average of global horizontal irradiation (GHI) [kWh/m^2]	Solar irradiance data
Landsat 8 satellite imagery	United States Geological Survey (USGS)	30 m spatial resolution except band 8 (panchromatic) with 15 m resolution	2020-11-12	11 bands of multispectral images were collected with both operational land imager (OLI) and thermal infrared sensor (TIRS) onboard the Landsat 8 satellite	Land cover mapping
SRTM	NASA Servers via dwtkns	30 m spatial resolution	–	Raster digital elevation model (DEM) with global coverage	Surface analysis: slope and hill shade
Power grid data	Energy Data The World Bank	–	2018-08-03	Information on the transmission line and substations within the study area	Proximity to grid connection
Farmlands built-up areas	Grid3 Nigeria https//grid3.gov.ng/	–	2020-12-22	Polygon shapefiles WGS84	Identification of farmlands and built-up/ assessment of land cover classification

4.2. Implementation of MCDM (AHP)

The MCDM technique adopted for the decision-making process in the study is AHP. This is because of the reliability and flexibility of the technique described in past and recent studies, which has gained the approach popularity in site suitability assessment. In implementing the AHP, the scale of importance for each factor considered was determined by developing an Eigen weight value which was employed for implementing the AHP as a decision rule for the suitability assessment and final mapping of suitable areas for the installation of a utility-scale solar PV farm within the study area.

The fundamental scale of the pairwise comparison adapted from [16, 45] is presented in Table 3. This scale is used to evaluate the relative importance of each criterion/factor considered in locating a suitable area for solar PV farms in the study area. Pairwise comparisons are used to reveal experts' preferences on these four criteria when selecting areas fit for a solar farm.

Table 3. Fundamental scale of pairwise comparison

Degree of importance	Definition	Explanation
1	Equal importance	Criterion equally important to the objective
3	Moderate importance	One criterion is slightly more important than another
5	Strong importance	One criterion is strongly more important than another
7	Very strong importance	One criterion is very strongly more important than another
9	Extreme importance	One criterion is extremely more important than another
2, 4, 6, and 8	Intermediate values	A compromise is needed

Source: adapted from [16, 45]

Table 4 presents the list of experts involved in this study, while Table 5 presents the decision-maker matrix for solar PV farms. This matrix was derived by comparing each criterion with the next to determine which is more important, based on the opinion of each expert involved [16] for example, deciding a high GHI is more important than having the site close to the national grid connection within the study area and ultimately their decision collectively held a number 9 on the scale of preference meaning that the solar resource is of extreme importance compared to proximity to grid connection.

Table 4. Experts involved in the decision-making process

Role	Qualification	Organization
Co-founder	MSc	Lightsup Energy Solutions
BTHO	MSc	Benin Electrical Distribution Corporation
Professor	PhD	Electrical and Information Engineering Department, Landmark University
Professor	PhD	Electrical and Electronics Department, The Federal University of Technology, Akure
Senior Lecturer	PhD	Department of Physics (electronics), The Federal University of Technology, Akure

Table 5. Decision-maker matrix of a solar PV farm

0	1 Solar irradiance	2 Slope	3 Land cover	4 Grid connection
1 Solar irradiance	1	8	9	9
2 Slope	1/8	1	3	2
3 Land cover	1/9	1/3	1	2
4 Grid connection	1/9	1/2	1/2	1

The next step is to estimate the principal eigenvector of the pairwise matrix [16, 45]. Here, the first step in normalizing the decision-maker matrix for a solar PV farm is presented in Table 6, this is obtained by summing up each column of the matrix and dividing it by the column elements i.e., for the first column the elements are 1, 1/8, 1/9, 1/9 and the sum of the first column of the matrix is 1.3472222. This was calculated using Equation (1) [16]:

$$N = \frac{c}{\sum j} \tag{1}$$

where N is the normalized value, j is the column of the matrix in Table 5, c is each column element.

Table 6. Normalized decision matrix of a solar PV farm

Criteria	1 Solar irradiance	2 Slope	3 Land cover	4 Grid connection
1 Solar irradiance	0.74	0.81	0.67	0.64
2 Slope	0.09	0.10	0.22	0.14
3 Land cover	0.08	0.03	0.07	0.14
4 Grid connection	0.08	0.05	0.04	0.07

Source: the normalized decision matrix is calculated acc. to Equation (1) traced to [16]

Through further calculation, the eigenvector of the pairwise comparison was obtained. This serves as the vector of priorities and gives the weighting for criteria considered in locating a suitable area for siting a solar PV farm. The weights of the criteria presented in Table 7, were calculated from a normalized matrix in Table 6 using Equation (2) [16]. The eigenvector is the sum of the row matrix i.e., for solar irradiance 0.74, 0.81, 0.67, 0.64 and the sum of the row matrix is 2.86, this is further divided by the number of criteria for the suitability analysis.

$$W = \frac{\sum n}{X} \tag{2}$$

where W is the weight of the criteria, n is the row value of the normalized matrix, and X is the number of criteria for suitability analysis, is the eigenvector.

Table 7. Eigenvector and weights of criteria solar attributes

Criteria for suitability analysis	Eigenvector	Weight
1 Solar irradiance	2.86	0.72
2 Slope	0.55	0.14
3 Land cover	0.32	0.08
4 Grid connection	0.24	0.06

Source: the eigenvector and weight are calculated acc. to Equation (2) traced to [16]

To analyze and map areas suitable for installing solar PV plants, the study area was assessed based on criteria adapted from standards recommended by expert studies. For this study, the suitability indices: highly suitable, suitable, moderately suitable and unsuitable are designated as S1, S2, S3 and N respectively. Solar-GHI is a high average annual GHI or total radiation received on the Earth's surface, which is the most basic criterion for developing a solar PV plant. The higher the demand for the solar PV, the more energy is required [7].

Standards adopted for the classification of the suitability of the study area in terms of the amount of solar energy received on its surface, proximity to grid connections, topography and slope, and land cover are provided in Table 8. Topography and slope stability are considered because the location should be relatively flat or on a little south-facing slope in the northern hemisphere or a north-facing slope in the southern hemisphere. Such a topography simplifies installation and lowers the cost of technical changes required to compensate for ground undulations [7]. Areas with a slope of less than 5% were considered highly suitable. Given the environmental impact of a solar PV farm, land cover is a necessary factor. The land cover provides information on the physical surface of the Earth such as bare lands, vegetation cover, built-up areas, water bodies, rock outcrops etc. Consequently, information relating to areas to be excluded, as well as the level of suitability of other areas for locating solar PV farms are also included in Table 8, based on standards adopted. Proximity to the grid connection within the study area is both an economic and operational factor, in that it determines the distribution line and its phases or sites within close range to the distribution line. Selecting sites in proximity to the grid connection will result in a reduced cost of the proposed project. The proximity of agricultural sites (food security) and worksites (e.g., mine site) were also considered. Distance from built-up areas is considered a factor due to hazardous materials used during the PV cell manufacturing process and stages involved in resource extraction, manufacturing, transportation, installation, maintenance, decommissioning and dismantling. This consideration was made in conformance to the Nigerian Solar Energy Policy (NSEP) and recommendations in [38]. Table 8 presents the standards guiding classification for factors considered, while Figure 3 is a workflow of research framework in site suitability assessment for installation of utility solar PV plants.

Table 8. Standards guiding classification for factors considered in site suitability assessment for solar PV plants

Standard	GHI [kWh/m²]	Grid connection [m]	Slope [%]	Land cover
S1	>700	<2000	<5	Barren lands > 200 m away from built up
S2	500–700	2000–2500	5–7	Bare lands
S3	300–500	2500–3000	7–10	Lands > 100 m away from thick vegetation
N	<300	>3000	>10	Lands > 10% slope (rock outcrops), farms lands on light vegetation, lands < 100 m away from thick vegetation

Source: adapted from [7, 16, 45]

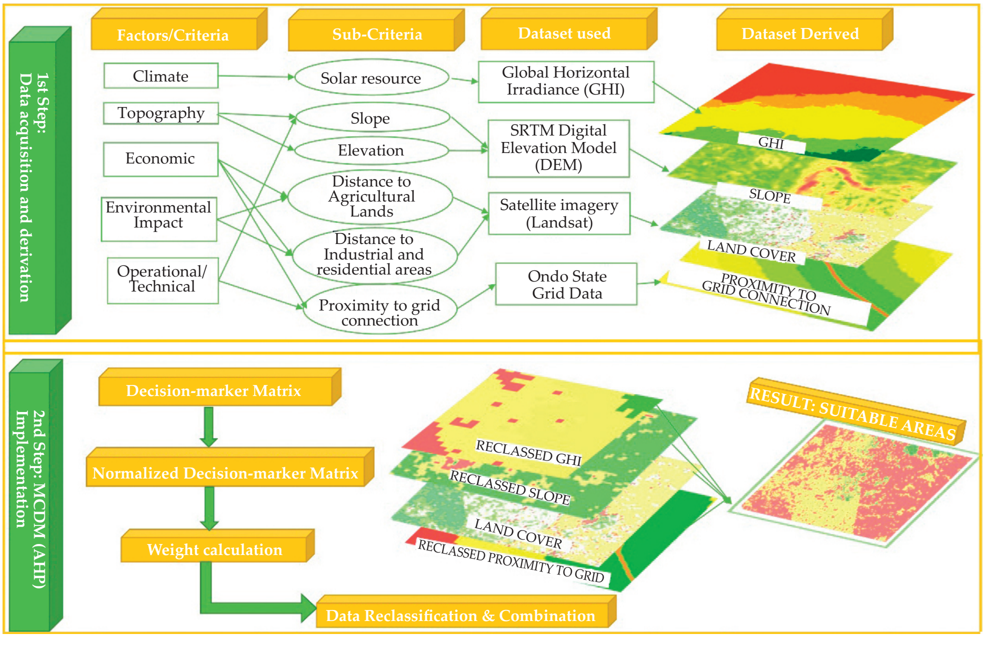

Fig. 3. The framework of the methodology

5. Results

The adopted methodology involved the weighted overlay that took reclassified spatial data layers and the weight obtained from the AHP as inputs for the analysis, this presented the key finding for this study. Suitability indices as used in the reclassified maps on Figures 4–7 are given in Table 9. The categorization of the study area based on Solar-GHI is presented based on the reclassified map in Figure 4 which is based on the standards and the suitability index of the solar resource of the study area. Surface analysis was performed on the elevation data of the study area to derive the slope within the study. One of the environmental factors considered in the site selection process is the slope on which the solar PV modules would be installed. The reclassification of the slope is shown in Figure 5. The land cover analysis is necessary for accessing the environmental impact and further site consideration for a solar PV farm. Figure 6 shows pictorial information on the land cover of the study area and the areas and percentages of each land cover class is presented in Table 10. Euclidean distance showing the straight-line distance from the grid connection transmission line, cutting across the entire study area was performed. Figure 7 shows the reclassed proximity to the grid, with seven (7) classes within the straight-line of 0–8,970 m. Based on standards adopted shown in Table 8, areas within a distance less than 2,000 m are considered highly suitable and more than 3,000 m unsuitable. The suitability of the study area for the installation of solar PV is mapped in Figure 8 and represented as a pie chart in Figure 9.

Table 9. Solar PV farm suitability index

Definition	Class	Weighting Rate/Index
Unsuitable	N	1
Moderately suitable	S3	2
Suitable	S2	3
Highly suitable	S1	4

Table 10. Area occupied by each land cover

Land cover	Area [ha]	Percentage [%]
Thick vegetation	11,364.53	34.23
Light vegetation	7,994.16	24.08
Built-up	7,480.46	22.53
Baren land	4,018.91	12.10
Rock outcrop	2,346.23	7.07

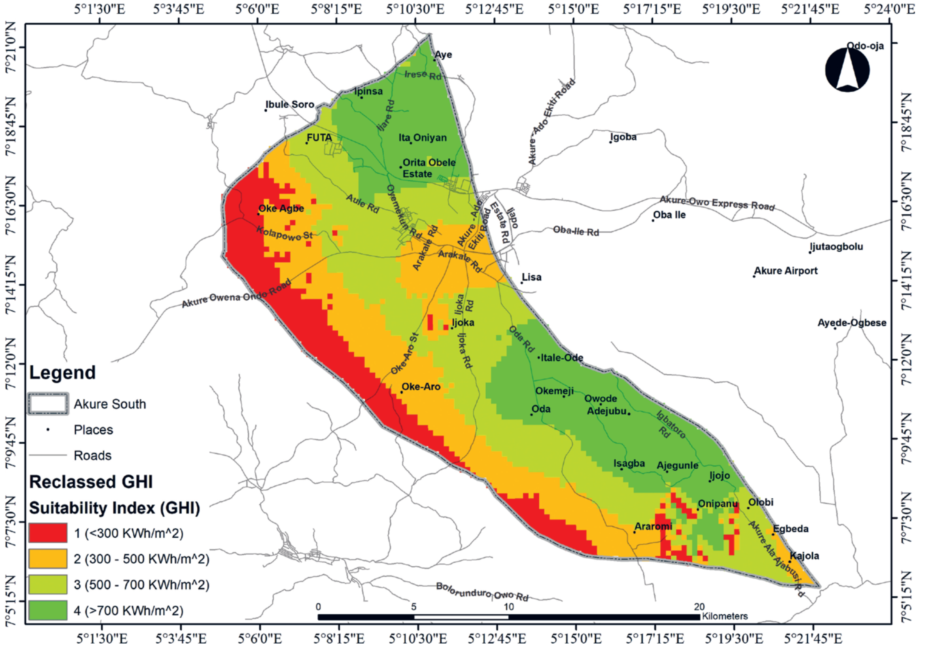

Fig. 4. Reclassed global horizontal irradiance (GHI)

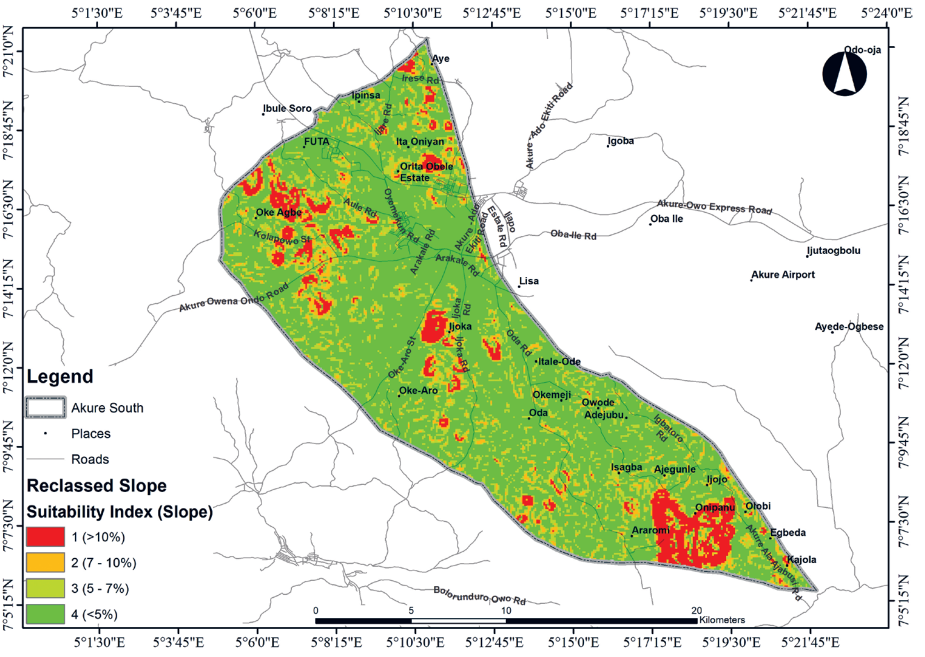

Fig. 5. Reclassed slope

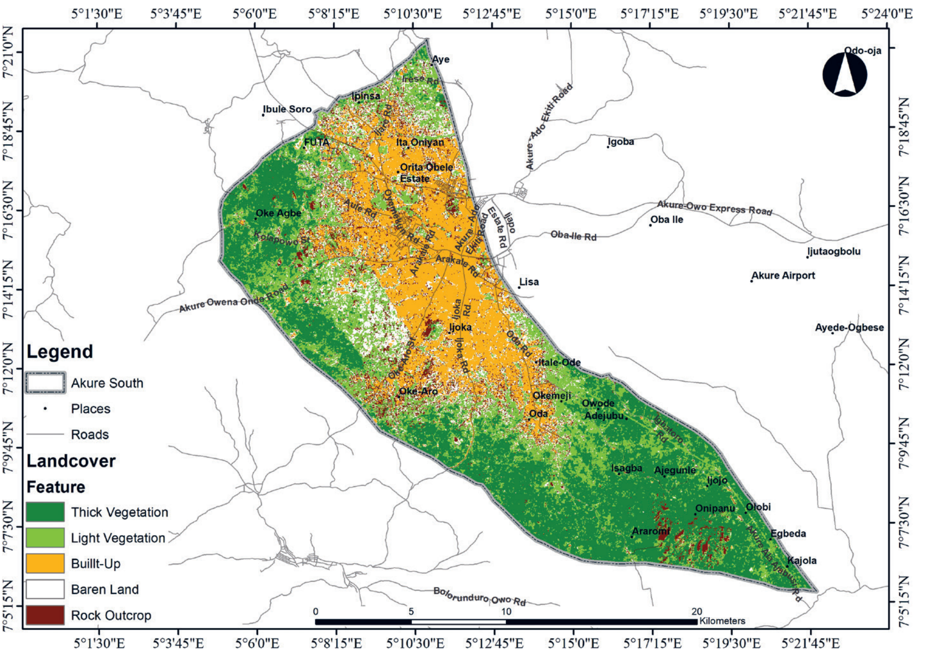

Fig. 6. Land cover

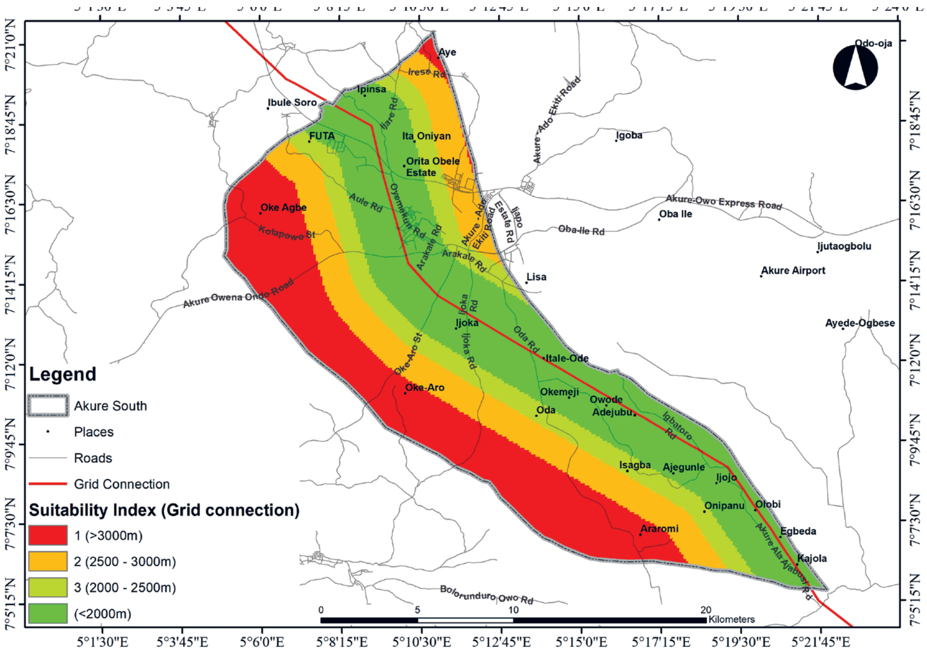

Fig. 7. Reclassed proximity to grid connection

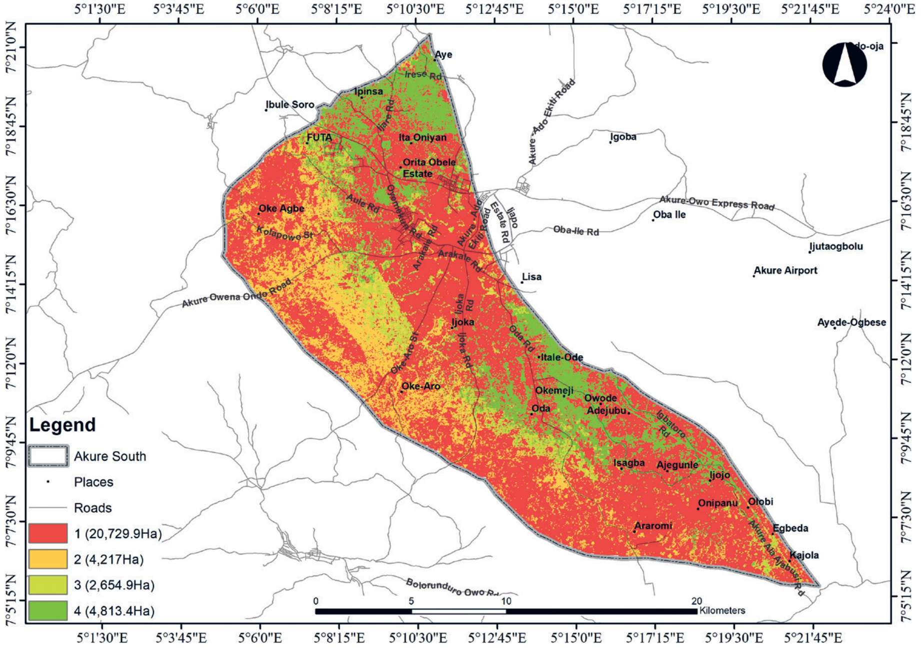

Fig. 8. Site suitability map for a solar photovoltaic farm in the study area

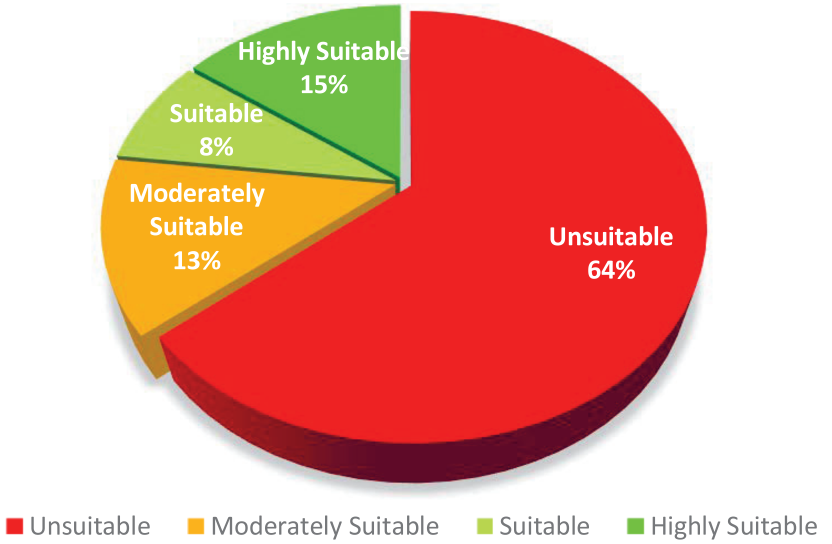

Fig. 9. Pie chart showing solar PV site suitability index

6. Discussion

Solar PV farm projects, in general, necessitate the selection of a suitable site first; this was usually done based on political considerations or traditional decision-making procedures. More appropriate approaches to understanding suitable solar sites have begun to emerge, as can be seen in recent studies. With a growing need to combine goals connected to sustainable development, land use planning has become more difficult. As a result, the modern planning process has evolved into a conflicting and contradictory movement of environmental, economic, and social interests [9]. This study has taken clues from several authors and their research [16, 46] who have considered myriads of constraints to make an intelligent decision on the suitable site for a solar PV farm installation. The AHP technique, coupled with the GIS technology adopted in the study, is used worldwide for analyzing criteria for spatial choices [47]. This study presents the first attempt in Ondo State, bearing in mind the power deficiencies existing in the state and considering the state's slogan of "Sunshine State".

Solar energy is considered as providing customers and end-users with a better and healthier power source that is free of greenhouse gas emissions and other contaminants. Based on this perspective on solar technology, cutting trees to build a solar PV farm defeats this very advantage. As a result, areas with dense vegetation (forests) account for about 34.23% (11,363.13 ha) of the research area are unsuitable. Also, considering the environmental impact on food security, this latter factor (agriculture) must not be compromised when locating sites for solar PV farms, and the installation must not obstruct the flow of activities, rendering such areas unsuitable, approximately 24% (7,994.16 ha) of land covered by light vegetation confirmed to have a heavy presence of farmlands unsuitable. Also, steep slopes and rock outcrops are inappropriate for a solar PV farm; yet, rock outcrops occur in around 7% of the research area. Based on technical standards, a relatively flat area simplifies installation and lowers technical changes required to compensate for ground undulation. However, a large portion of the study area falls within the standards (shown in Table 8), indicating a slope less than 5% is considered highly suitable for the installation of solar PV plants.

The suitability of the study area for the installation of a solar PV plant was mapped. For the suitability map, the entire study area was categorized into four classes for suitability for solar PV installations, with the range of solar PV suitability based on criteria standards classed from one (1) to four (4). The results of the analysis indicated approximately 15% (4,813.38 ha), 8% (2,654.91 ha), 13% (4,216.95 ha) and 64% (20,729.88 ha) of the study area are considered highly suitable, suitable, moderately suitable, and unsuitable respectively for installation of solar PV farm. Most suitable and suitable classes represent areas with high solar irradiance, a gentle slope, high proximity to the grid connection, are far from farmlands (hence preserving food security), restricted from the forest and thick vegetation (keeping the environment healthy and green), far from major built-up areas, and restricted from rock outcrops (hence on level ground). The suitable areas can be found around Ipinsa, the FUTA area, hinterlands of Oda, Okemeji and Italepode. While moderately suitable areas are bordered between Oke-aro and Ondo roads. Results from the studies of [17] in northwestern Nigeria have revealed that 22.8%, 37.79%, 27.92% and 7.86% of the land area depict excellently suitable, moderately suitable, suitable and marginally suitable respectively. This has shown that the proportion of land suitable for solar PV farms in Akure, southwestern Nigeria is quite less compared to northwestern Nigeria. This may be attributed to variations in some factors considered in locating suitable sites for solar farms in Nigeria (Fig. 1).

7. Conclusion and Recommendations

Recent reviews on the potential of renewable energies conducted in this studyhave revealed various techniques in MCDM. Focusing on studies in Nigeria, reviews have shown that wind energy has poor potential within the vast part of southern Nigeria, including the study area. This has left the region with the alternative being solar renewable energy. This review has also shown the need to understand the feasibility of solar PV energy, in terms of factors associated with spatial dimension, especially within southern zones in Nigeria. In a bid to achieve this, a study has been conducted involving a geospatial assessment to determine the feasibility of multiple utility-scale solar PV plants in the city of Akure, Ondo State, southwestern

Nigeria. Factors considered in this study are climate, topography, economy, environmental impact, technical and operational. These factors were further assessed in terms of the following sub-criteria as solar resources, land cover, slope and elevations, distance to agricultural lands (restricted areas), residential, industrial areas and proximity to grid connection. Impacts of solar derived wastes on the environmental and human health recommended in the National Renewable Energy and Energy Efficiency Policy (NREEEP) were also considered. The task of identifying land suitability classes for solar PV farms within the study area was carried out using GIS and AHP techniques.

The study has revealed the potential of multiple utility-scale solar PV farms within the study area. The study area has a total extent of about 33,200 ha, approximately 23% of the research area met the suitability analysis criteria, 13% moderately met the criteria and 64% were identified as completely unsuitable. Comparing findings from similar past studies conducted in northwestern Nigeria reveals that the proportions of land suitable for solar PV farms in this study are quite a lot less compared to those in northwestern Nigeria.

Considering the potential of solar PV in the state as an alternative renewable energy, multiple utility-scale solar PV farms are therefore recommended to bridge the energy gap and ensure energy security for the commercial and industrial sectors in the state. The findings of this study have provided the necessary information on the feasibility of multiple utility-scale solar plants that will assist in advancing sustainable land development policy and investment opportunities in renewable energy in the state. Further studies are also recommended in other parts of Nigeria and using the other MCDM technique identified in the review to provide a wider spatial understanding of the feasibility of solar PV in Nigeria.

Author Contribution

Author 1: conceptualization, methodology, software, analysis, investigation, resources, data curation, writing – original draft preparation, writing – review and editing, visualization, supervision, project administration. Author 2: methodology, software, formal analysis, investigation, resources, data curation, writing – review and editing. Author 3: writing – review and editing

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