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# Site Suitability Analysis for Solar Energy Farms in Enugu State, Using GIS and Remote Sensing

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## ABSTRACT

*Identifying suitable sites for renewable energy deployment poses a technical challenge, demanding an approach considering various factors; technical, physical, economic, social, environmental, and political. Leveraging tools like Geographic Information System (GIS) and Multi-Criteria Decision Making (MCDM) becomes imperative for site selection, offering a comprehensive framework integrating high-resolution remote sensing data. GIS, a potent technological ally, empowers decision-makers with geospatial insights critical for renewable energy development. Therefore, the study aimed at a site suitability analysis for solar energy farms in Enugu State, Nigeria, with a view to identify suitable locations for harvesting renewable energy such as Solar energy. Its objectives were to: establish the factors needed for mapping Solar Energy potential in the study area; classify the established factors according to their level of suitability; calculate the reliability index of the classified factors and to determine the Solar Energy potential areas using analytical hierarchical process and weighted linear combination. The results were classified according to their levels of suitability. The high suitable areas for solar development in Enugu State covered 1000.4 km<sup>2</sup>, with a percentage coverage of 13.39%. the moderate suitability for solar development covered 2605.50km<sup>2</sup> with a percentage coverage of 33.82%. lastly, the low suitable areas for solar development covered 4066.6km<sup>2</sup> with a percentage coverage of 52.79%, the study area. The study's approach is recommended to serve as a basis for making location suitability decisions for siting similar renewable energy sources in other regions of Nigeria.*

**Keywords: Site Suitability Analysis, Solar Energy Farms, Enugu State, GIS, Remote Sensing**

## 1. INTRODUCTION

Energy stands as the cornerstone of any economy, serving as a pivotal factor in national development across economic, social, and political dimensions [1] Amidst its various forms, energy delineates into renewable and non-renewable sources, with the latter, albeit widely utilized, raising environmental concerns due to emissions and by-products [2, 3]. Notably, coal, fossil fuels, and nuclear reactors, while prevalent, exhibit depletability and inadequacies in consistent power provision, exacerbating maintenance costs, particularly burdensome for developing nations. Nigeria, endowed with abundant energy resources, grapples with significant challenges in energy provision, evidenced by the disparity between resource richness and electricity accessibility, affecting a mere 40% of its populace [4]. Furthermore, even those connected to the grid experience erratic supply. This disparity underscores the imperative to harness renewable energy sources like wind and solar, offering vast, largely untapped potential to meet

energy demands sustainably, without compromising the environment.

Diversification is key in energy generation, evident even in regions like the US and Europe, where despite stable power systems, demand for standby generators and backup solutions persists. Wind power adoption, for instance, has seen commercial traction in eighty countries globally, with Europe leading the charge, followed by North America and Asia [5]. However, regions like Africa, including Nigeria, lag behind, despite significant wind power potential. Nigeria's over-reliance on gas turbines and seasonal hydroelectricity exacerbates power inconsistency, with adverse economic ramifications, necessitating a shift towards complementary renewable energy sources like wind, renowned for its cost-effectiveness and minimal maintenance requirements [6].

Identifying suitable sites for renewable energy deployment poses a technical challenge, demanding a nuanced approach considering various factors—

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technical, physical, economic, social, environmental, and political. Leveraging tools like Geographic Information System (GIS) and Multi-Criteria Decision Making (MCDM) becomes imperative for site selection, offering a comprehensive framework integrating high-resolution remote sensing data. GIS, a potent technological ally, empowers decision-makers with geospatial insights critical for renewable energy development.

Against this backdrop, this study endeavours to unravel the complexities of site suitability analysis for solar energy farms in Enugu State, employing GIS and remote sensing techniques. By synthesizing a diverse array of factors and conditions, this study aims to furnish a robust framework facilitating informed decision-making in renewable energy site selection, thereby contributing to Nigeria's energy diversification and sustainability agenda.

Despite the abundant renewable energy potential in Enugu State, Nigeria, there remains a significant gap in harnessing this renewable resource to address the region's energy needs. The current reliance on non-renewable energy sources, coupled with inconsistent power supply from conventional sources, poses challenges to sustainable development and economic growth in the state. This situation exacerbates environmental concerns associated with fossil fuel usage and underscores the urgency to transition towards cleaner, renewable energy alternatives.

Furthermore, the lack of comprehensive spatial analysis tools and methodologies tailored to Enugu State's unique geographical and socio-economic context hampers effective site selection for solar energy farms. This deficiency in decision support mechanisms restricts the identification of optimal locations for solar infrastructure deployment, hindering the realization of Enugu State's solar energy potential and impeding progress towards energy security and sustainability.

Moreover, the existing literature on solar energy site suitability analysis in Enugu State is limited, with few studies providing comprehensive insights into the multifaceted factors influencing site selection. This knowledge gap underscores the need for a rigorous

investigation into the spatial, technical, economic, and environmental considerations shaping the viability of solar energy projects in the region.

Therefore, this research aims to address the following key issues:

1. To assess the suitability of potential sites for solar energy farms in Enugu State using advanced Geographic Information System (GIS) and remote sensing techniques.
2. To identify the key spatial, technical, economic, and environmental factors influencing the suitability of sites for solar energy development in the region.
3. To develop a comprehensive framework for site suitability analysis that integrates multiple criteria and facilitates informed decision-making by stakeholders.
4. To evaluate the implications of adopting renewable energy solutions, particularly solar power, for Enugu State's energy landscape, economic development, and environmental sustainability.

The study aimed at a site suitability analysis for solar energy farms in Enugu State, Nigeria, with a view to identify suitable locations for harvesting renewable energy such as Solar energy with the following outlined objectives:

1. To establish the factors needed for mapping Solar Energy potential in the study area
2. To classify the established factors according to their level of suitability
3. To calculate the reliability index of the classified factors
4. To determine the Solar Energy potential areas using analytical hierarchical process and weighted linear combination

All over the world conventional and alternative power generation systems are not fail-proof and are therefore integrated with each other to provide stable and uninterrupted power supply to consumers. When one power source goes down a backup source is activated to cover the shortfall. Nations should not depend on only one or two sources of power to

generate power supply no matter how abundant. Most nations like USA and Europe have a very stable and highly integrated variety of power supply systems and that is why the market for standby generators and back-up UPS/ batteries is still huge. Nigeria's over-dependence on gas powered turbines and a few hydro power plants without other alternative to power supply is the reason for her inability to generate enough power for her domestic needs as well as meet her international obligations to her neighbours. Compared to the environmental effects of traditional energy source (use of fossil fuel), the environment effects of wind are minor. Wind power consumes no fuel and emits no air pollution, unlike fossil fuel power sources. Nigeria should diversify and integrate her power sources with a mix of gas, wind, solar, nuclear, hydro, biomass etc with each contributing to the national grid.

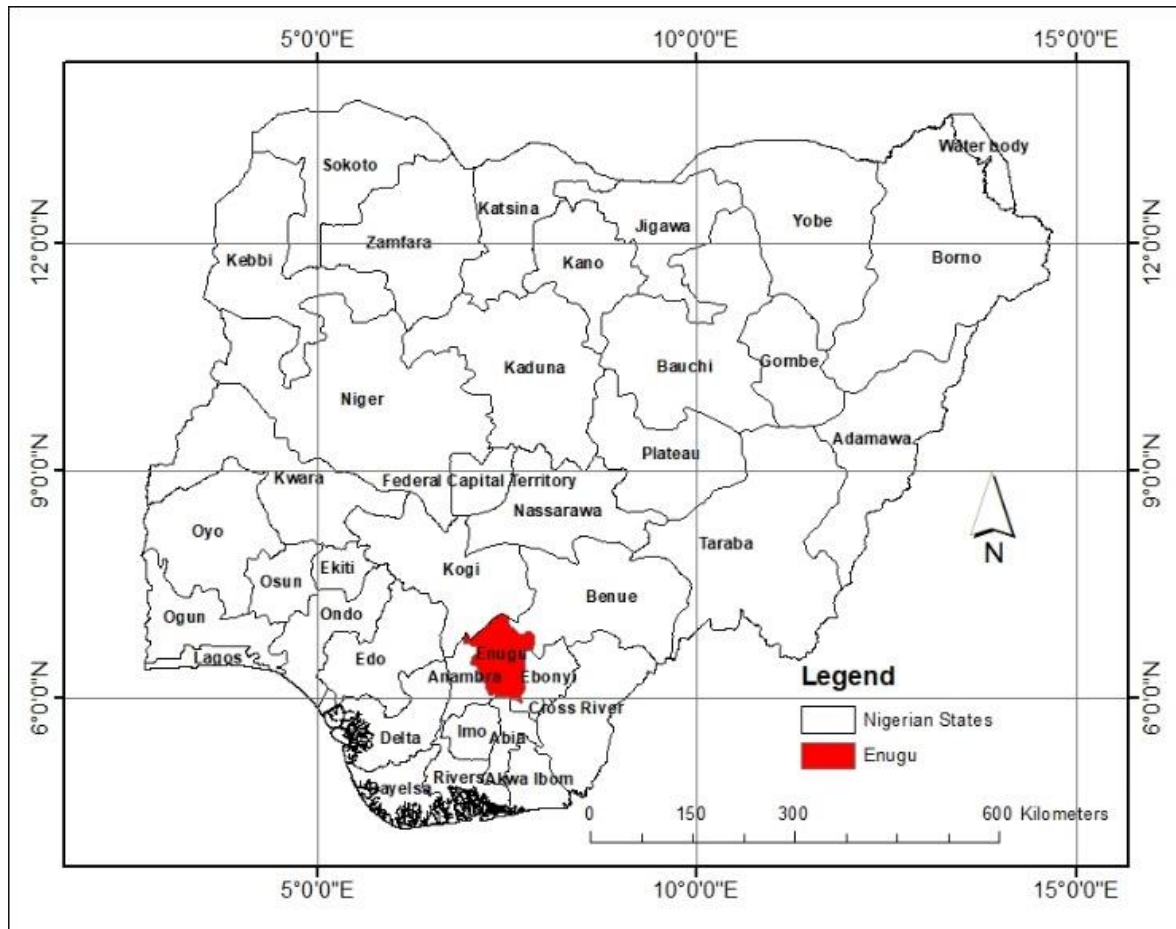
Nigeria is yet to fully embrace renewable energy, however, the desire to seek for a long-lasting solution to energy situation in Nigeria has prompted the government as well as independent researchers to assess the nation's potentials for energy. Renewable energy sources are clean alternative energy solutions that may overcome most of the challenges of fossil fuel. Hence, this study is important and justified as it can provide solutions to energy problems in Delta and Edo State Nigeria as well as Nigeria as a whole by providing a framework to locating suitable areas for harnessing renewable energy.

The scope of the study covers the identification and evaluation of potential sites for Solar energy in Enugu State. The study focuses on solar Energy as the primary sources of renewable energy, and employs

GIS technology and multicriteria evaluation techniques to assess the suitability of potential sites. The scope of the study includes the following key components:

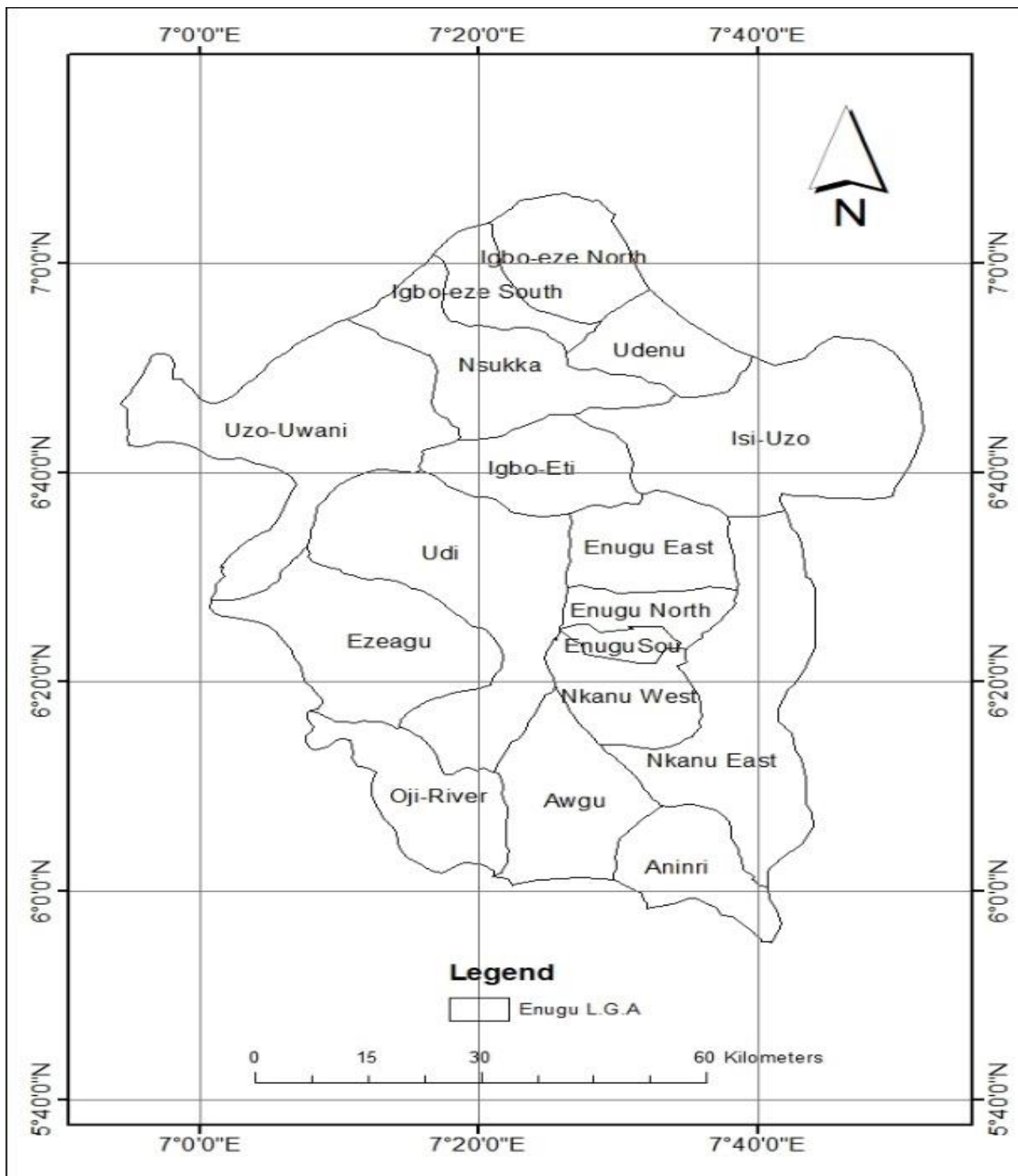
1. Collection and analysis of geographical data related to topography, solar radiation in Enugu State.
2. Development of a set of criteria for evaluating the suitability of potential sites for Solar energy development, including accessibility, land-use suitability, and environmental impact.
3. Use of GIS technology and multicriteria evaluation techniques to rank and compare the different potential sites and determine the most suitable locations for Solar energy development.
4. Presentation of the results of the study in a clear and concise manner, highlighting the most suitable locations for Solar energy development in Enugu State.

Enugu State, the study area is one of the thirty-six states of the Federal Republic of Nigeria; it's a mainland state in South-Eastern Nigeria, created in 1991 from the old Anambra State (figure 1.1). Enugu state is located between latitudes  $5^{\circ} 40''$  N to  $7^{\circ} 0''$  N of the equator and longitude  $7^{\circ} 0''$  E and  $7^{\circ} 40''$  E of the Greenwich meridian and the state has an area of 7,702.20km<sup>2</sup> (Figure 1.2). The state Enugu is bordered in the north, east, south, and west by Benue & Kogi, Ebonyi, Abia Imo and Anambra states respectively. The state has 17 local government areas. The ethnicity of Enugu people is Igbo and is tied with a history of discovery of coal in 1909 within Udi Hills.



*Figure 1.1: Map of Nigeria showing Enugu State*  
 Source: (Department of Geoinformatics and Surveying, NAU)





*Figure 1.2: Map of Enugu State (Study Area)*

Source: (Department of Geoinformatics and Surveying, NAU)

Enugu, often referred to as the "Coal City," is known for its rich cultural heritage and vibrant communities. The city is predominantly inhabited by the Igbo people, one of the largest ethnic groups in Nigeria. The Igbo culture is characterized by its deep-rooted traditions, including colourful festivals, music, dance, and art. The New Yam Festival (Iri Ji) is a significant cultural event celebrated with great enthusiasm. Enugu is also a hub for Igbo highlife music and has produced notable musicians in this genre. The city's culture emphasizes community, respect for elders, and a strong sense of identity.

Enugu is located in a tropical rain forest zone with a derived savannah. The city has a tropical savanna climate. Enugu's climate is humid and this humidity is at its highest between March and November, For the whole of Enugu State the mean daily temperature is 26.7 °C (80.1 °F), as in the rest of West Africa ([www.enugu.gov.ng](http://www.enugu.gov.ng)), the rainy season and dry season are the only weather periods that recur in Enugu. The average annual rainfall in Enugu is around 2,000 millimetres (79 in), which arrives intermittently and becomes very heavy during the rainy season. Other weather conditions affecting the city include Harmattan, a dusty trade wind lasting a few weeks of December and January Like the rest of Nigeria, Enugu is humid all year round.

Enugu is characterized by the presence of many tree species of the rainforest interspersed by tall grasses. Vegetation therefore consists of wooded shrub lands and varying pockets of forest.

The major water resources in the state are Ebonyi River basin to the east and the Oji-River basin to the west; these river valleys support the growth of dense vegetation. The basic crops within the area are grown as subsistence or market garden crops, thus the

farmland are mostly outfield. A fallow system is practiced in the area and major crops are yam, maize, cassava, cocoyam, Vegetables and fruits. Other crop trees include palms, cashew, mango, rubber, oranges and pear.

Enugu experiences a tropical savannah climate, characterized by two distinct seasons: the wet and dry seasons. The temperature in Enugu is relatively consistent throughout the year, with average daytime temperatures ranging from 26°C (79°F) to 30°C (86°F). The hottest months are typically February and March, with temperatures occasionally rising above 30°C (86°F). The cooler months are between November and January, during the Harmattan season, when temperatures can drop to around 19°C (66°F) at night.

Enugu receives substantial rainfall, particularly during the wet season, which spans from April to October. The heaviest rainfall occurs between June and September, with average monthly precipitation often exceeding 200 mm (7.9 inches). The dry season, from November to March, sees significantly less rainfall, and the Harmattan winds can bring dry and dusty conditions. Humidity levels in Enugu are generally high, especially during the wet season, often reaching over 80%. During the dry season, humidity levels can drop, particularly during the Harmattan period.

Enugu is located on a plateau, which gives it a unique geological profile. The region is underlain by sedimentary rocks, primarily sandstone, shale, and coal, which are part of the Enugu Coal Field. This geological formation has made Enugu historically significant for coal mining, which was a major economic activity in the past. The soil in Enugu is predominantly lateritic, which is typical of tropical regions. This type of soil is usually red or brown, rich in iron and aluminium oxides, and well-drained but can be poor in nutrients due to leaching. The soil supports a variety of crops, including yam, cassava, maize, and vegetables, which are essential for local agriculture.

## 2.0 METHODOLOGY

This chapter presents the methods that were adopted in achieving the aim and objectives of the study. The flowchart for the methodology is shown in figure 2.1.

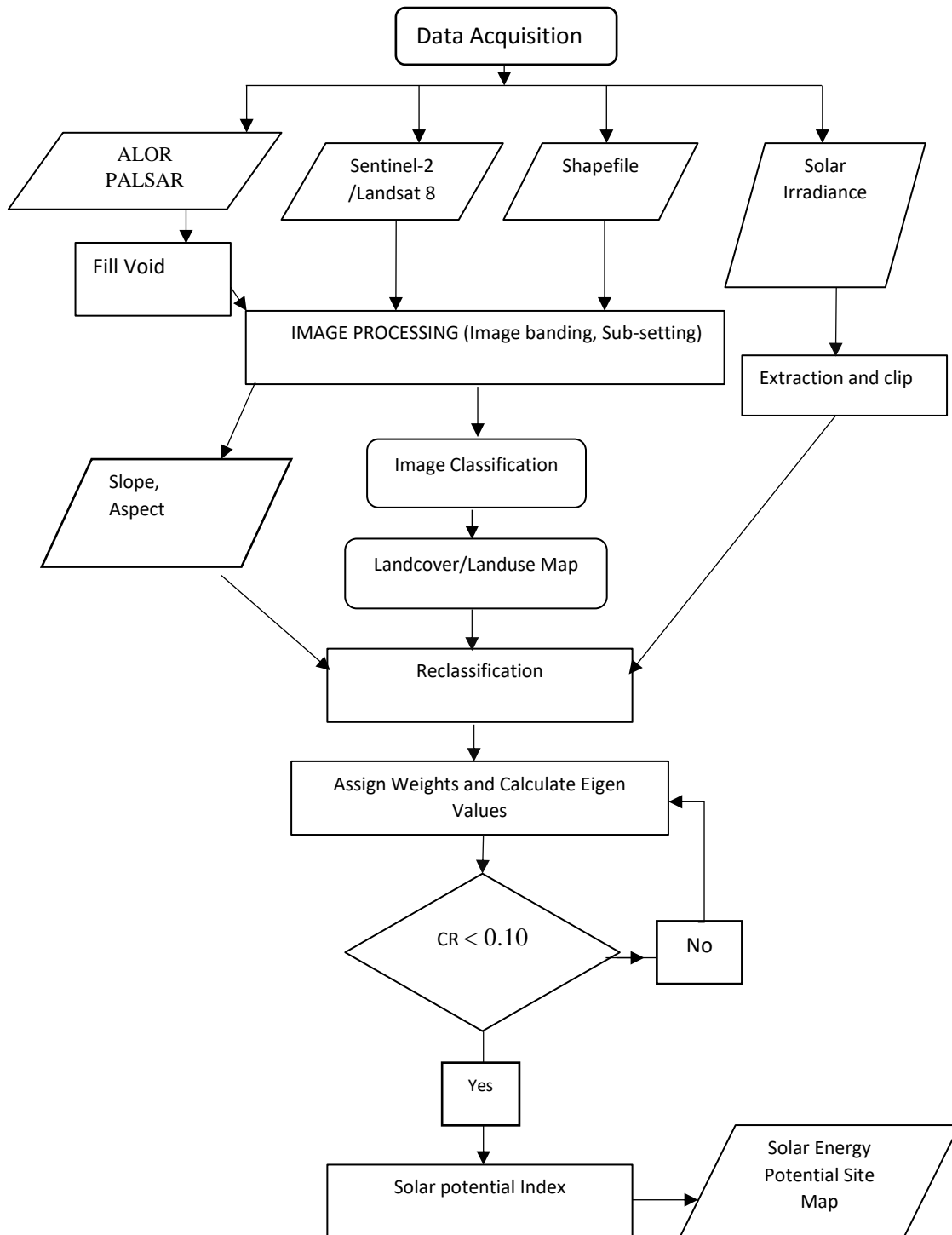


Figure 2.1: Adopted Methodology



## 2.1 Data Requirement:

Data that were required in this research included;

- i. Landsat 8 OLI Imagery Covering the Study Area
- ii. Alor Palsar DEM product (12.5m) Covering the Study Area
- iii. Solar Irradiance Data

## 2.2 Data Acquisition

### 2.2.1 Acquisition of Primary Datasets

These data were obtained through field visits peculiar to the research at hand. They included

- i. The coordinates of sample points of land cover/ landuse on ground to be used for accuracy assessment was obtained using handheld GPS.
- ii. Non-spatial (attribute) data describing the characteristics of Land cover/ land use identified on the scene was collected.

### 2.2.2 Acquisition of Secondary Datasets

The secondary datasets were obtained from already existing medium. They included:

- i. Shape file of the administrative Nigeria showing Enugu State, this was obtained from the Department of Surveying & Geoinformatics, Nnamdi Azikiwe University Awka.
- ii. Landsat 8 OLI imagery, this was downloaded from [www.earthexplorer.usgs.gov](http://www.earthexplorer.usgs.gov).
- iii. Alor Palsar DEM Image, this was downloaded from [www.earthexplorer.usgs.gov](http://www.earthexplorer.usgs.gov)
- iv. Solar Irradiance was gotten from [www.ncdc.noaa.gov](http://www.ncdc.noaa.gov)

## 2.3 Hardware and Software Requirements

### 2.3.1 Hardware requirements

The hardware components include the equipment that were used for the execution of the research and they include:

- i. Handheld GPS for collection of co-ordinates of features during groundtruthing.
- ii. A computer system with sufficient memory and processing capability.
- iii. A scanner for scanning analogue maps
- iv. A printer for presentation of the result in hardcopy format.

### 2.3.2 Software requirements

The following software were used for this study:

- i. ArcGIS Software version 10.7: this was used for vectorization, image subset, spatial analysis and weighted Analysis
- ii. Erdas Imagine 2014: this was used for classification and Accuracy assessment
- iii. Microsoft suite: this was used for performing the task of editing and production of text report.

## 2.4 Processing techniques

This involves the techniques that were adopted in order to achieve the research objectives.

These techniques involve the following:

### 2.4.1 Image Sub-Mapping

This process was carried out in order to cut out the area of interest from the Landsat image and ALOR PALSAR using the shape file of Enugu State extracted from the administrative boundary of Nigeria.

### 2.4.2 Development of a classification scheme

A classification scheme was developed for the study area after [7].

This says that a landuse and landcover classification system which can effectively employ orbital and high-altitude remote sensor data should meet the following criteria [7]:

1. The minimum level of interpretation accuracy in the identification of landuse and landcover categories from remote sensor data should be at least 85 percent.
2. The accuracy of interpretation for the several categories should be about equal.
3. Repeatable or repetitive results should be obtainable from one interpreter to another and from one time of sensing to another.
4. The classification system should be applicable over extensive areas.
5. The categorization should permit vegetation and other types of landcover to be used as surrogates for activity.

6. The classification system should be suitable for use with remote sensor data obtained at different times of the year.
7. Effective use of subcategories that can be obtained from ground surveys or from the use of larger scale or enhanced remote sensor data should be possible.
8. Aggregation of categories must be possible.
9. Comparison with future landuse data should be possible.
10. Multiple uses of land should be recognized when possible.

Some of these criteria should apply to landuse and landcover classification in general, but some of the criteria apply primarily to landuse and landcover data interpreted from remote sensor data.

It is hoped that, at the more generalized first and second levels, an accuracy in interpretation can be attained that will make the landuse and landcover data comparable in quality to those obtained in other ways.

For landuse and landcover data needed for planning and management purposes, the accuracy of interpretation at the generalized first and second levels is satisfactory when the interpreter makes the correct interpretation 85 to 90 percent of the time. For regulation of landuse activities or for tax assessment purposes, for example, greater accuracy usually will be required. Greater accuracy generally will be attained only at much higher cost. The accuracy of landuse data obtained from remote sensor sources is comparable to that acquired by using enumeration techniques.

In addition to perfecting new interpretation techniques and procedures for analysis, such as the various types of image enhancement and signature identification, we can assume that the resolution Aircraft imagery. The classification level and characteristics is shown in table 2.1.

capability of the various remote sensing systems will also improve resolution, or resolving power, of an imaging system refers to its ability to separate two objects some distance apart. In most landuse applications, we are most interested in the minimum size of an area which can be recognized as having an interpretable landuse or landcover type.

Obviously, such a minimum area depends not only on the type and characteristics of the imaging system involved, but pragmatically also on the order of "generation" of the imagery, that is, how far the study image is removed in number of reproduction stages from the original record. The user should refer to the most recent information available in determining the resolution parameters of the system.

The kind and amount of landuse and landcover information that may be obtained from different sensors depend on the altitude and the resolution of each sensor. There is little likelihood that any one sensor or system will produce good data at all altitudes. It would be desirable to evaluate each source of remote sensing data and its application solely on the basis of the qualities and characteristics of the source.

However, it is common practice to transfer the data to a base map, and no matter what the guidelines are it is difficult to use a base map without extracting some additional data from such maps. Topographic maps, road maps, and detailed city maps will generally contribute detail beyond the capabilities of the remote sensor data.

The multilevel landuse and landcover classification system described has been developed because different sensors will provide data at a range of resolutions dependent upon altitude and scale. In general, the following relations pertain, assuming a 6inch focal length camera is used in obtaining

Table 2.1 Classification levels and data characteristics [7]

| Classification Level | Typical Data Characteristics  |
|----------------------|---|
| I                    | LANDSAT (formerly ERTS) type of data  |
| II                   | High-altitude data at 40,000 ft (12,400 m) or above (less than 1:80,000 scale)                            |
| III                  | Medium-altitude data taken between 10,000 and 40,000 ft (3,100 and 12,400 m) (1:20,000 to 1:80,000 scale) |
| V                    | Low-altitude data taken below 10,000 ft (3,100 m) (more than 1:20,000 scale)                              |

Based on these classifications by [7], level one classification scheme was adopted for this study.

### 2.4.3 Definition of class categories

This was done to identify and define various class features on the scene before following a familiarization visit to the site. Thus, the landcover/landuse classes in Enugu State was identified and defined according to level I classification scheme, this scheme was adopted because of the resolution of the image sets and to ensure that the features are discriminated adequately following the field visits to the study area.

### 2.4.4 Ground Truthing

Ground truth was carried out to assess the accuracy of the landcover/landuse classification and also collect sample data for accuracy assessment. For this purpose, the coordinates of 256 selected ground control points was collected and used to assess the accuracy of classification of images. Random sampling technique was used to determine the location of the points.

Handheld GPS Garmin 76 was used to collect the field data. Digital camera was also be used to capture the landcover types and tying the pictures with the ground coordinates for easy identification of visited sites.

### 2.4.5 Image Classification

Digital image classification uses spectral information represented by the digital numbers in one or more spectral bands and attempts to classify each individual pixel based on its spectral information. In this study, the images were classified using the supervised classification method.

### 2.4.6 ALOR PALSAR Processing

ALOR PALSAR is a topographical model with elevation records of cells in certain size. However, there is still potential of existence off sunken areas because of data error or landform Karst Topography. Data error is mainly caused by the resolution limitation of DEM on both vertical and horizontal direction and system error during the generation of DEM. The process of filing sink was done to fill depressions in the DEM data; this was done using ArcGIS 10.7 software. After the DEM data was filled, drainage network, lineament density and Slope were created from the DEM data. These layers were used as constraints and factors for suitability analysis.

### 2.4.7 Solar Data Classification

The Solar data was reclassified and ranked according to suitability; the resulting layer was used as an input for suitability analysis.

### 2.4.8 Development of the Pairwise Comparison Matrix

In this study, the pairwise comparison method was adopted to assign weights to each criterion. This method provides an organized structure for group discussions and helps the decision-making group focus on areas of agreement and disagreement when setting criterion weights.

[8] proposed the pairwise comparison method in the context of the analytical hierarchy process. According to him, this method is an effective method for the determination of relative importance. The method uses a ratio matrix to compare one criterion with another. The matrix of pairwise comparisons

represents the intensities of the expert’s preference between individual pairs of criteria. They are usually chosen according to a given scale ranging from 1 to 9 for a given ‘n’ number of criteria, where 1 represents criteria of equal importance and 9 represents a criteria with extreme importance compared to the other.

**2.4.9 Estimation of the Constituency Ratio**

The value of pairwise comparison relies on subjective judgment which might lead to arbitrary result which could be bias. A numerical index, called consistency ratio (CR) was used for evaluating the consistency of pairwise comparison matrix following the proposal in AHP [8] the index indicates the ration of the consistency index (CI) to the average consistency index, which is also called Random Index (RI).

**2.4.10 Weighted Linear Combination (WLC)**

A weighted linear combination is an analytical method that can be used when dealing with multi-

attribute decision making (MADM) or when more than one attribute must be taken into consideration. Every attribute that is considered is called a criterion. Each criterion is assigned a weight based on its importance. The results are multi-attribute spatial features with final scores.

This analysis was used to create a ground water suitability index map by assigning weight of importance to the layers created.

**3.0 PRESENTATION AND DISCUSSION OF RESULTS**

**3.1 Identification and Selection of Criteria**

Selection of the criteria and factors for Solar Energy was achieved based on their theoretical relevance as documented in [9] for solar energy power plants. The following criteria (factors/constraints) (table 3.1) were used in this research.

*Table 3.1: Criteria and Requirements for solar energy power plant Suitability*

| Criteria                      | Data Source  | Requirement for suitability                         | Original Data Structure | Resolution / Feature Type |
|-------------------------------|--|---|-------------------------|---------------------------|
| Aspect                        | ALOS Palsar Dem (Earthexplorer.usgs.gov)                                 | Should be between S, SE, SW, Flat area              | Raster                  | 12.5m                     |
| Solar Radiation               | Ncdc.noaa.gov  | Should be between 1300Kw/h – 1460Kw/h               | Raster                  | 30m                       |
| Distance to Built up Areas    | Landsat 8 OLI (Earthexplorer.usgs.gov)                                   | Must be greater than at least 3km                   | Vector                  | Polygon                   |
| Distance to Transmission Line | Department of Surveying & Geoinformatics, Nnamdi Azikiwe University Awka | Must not be located further than km from Powerlines | Vector                  | Polygon                   |
| Distance to Road              | Department of Surveying & Geoinformatics, Nnamdi Azikiwe University Awka | Must not be located further than 1km from roads     | Vector                  | Polygon                   |

Based on the criteria selected (table 3.1), the data used for achieving the aim of the research were assembled. Land cover/landuse was extracted from image classification performed on the Landsat image, slope, wind speed, distance to road, distance to transmission line (medium voltage), aspect, solar radiation, distance to built up areas, and flow accumulation were extracted from the ALOS PALSAR DEM.

The data (Table 3.1) used in the study such as landcover/landuse, slope, solar radiation, road network data, stream network data, settlement data,

DEM data, power transmission data, and flow accumulation data are important for the selection of suitable sites for solar energy.

1. Landcover/Landuse data helps in determining the availability of land for energy production and assesses the impact on the environment.
2. Slope data helps in identifying the suitability of the terrain for energy production, as steep slopes may not be suitable for energy production.
3. Solar radiation data is important for solar energy production, and high solar radiation



levels are required for efficient energy production.

4. Road network data and stream network data are important for access and transportation of energy production equipment and materials.
5. Settlement data helps in avoiding conflicts with human populations, as the presence of settlements near energy production sites may result in environmental and social issues.
6. DEM data is used to determine the topography of the area, which affects the efficiency of energy production.
7. Power transmission data helps in determining the feasibility of connecting energy production sites to the grid.

These data are important for the comprehensive assessment of the suitability of sites for wind, solar and hydrothermal energy production, ensuring efficient energy production.

### 3.2 Reclassification and Standardization of Criteria

Reclassification and standardization of criteria is the first step when implementing AHP and weighted linear combination model. Each of the cells has a value for each input criteria. At this stage it will be practically impossible to combine the criteria, hence the need for reclassification of each of the individual datasets. Different number systems cannot be directly

combined effectively [10]. For instance, combining a cell value in which slope is 2° with the layer distance to built up area with value 50m is almost impossible because of disparity in units. However, standardizing them to a common measurement system that represents a relative weighting scale permits analysis to be completed freely between the datasets and show the suitability level for each of the standardized criteria.

To combine datasets, there is a need to standardize or transform all the individual datasets into a common measurement scale.

For this research, all the datasets were reclassified into three classes: (1) for high suitability areas (2) moderate suitability areas and (3) low suitability areas. The initially derived datasets values categorized into ranges were floating and continuous in nature and there was a need for them to be reclassified so that each range of value can be assigned one discrete integer value such as 1, 2, and 3 according to the measurement scale. This is because the inputs of the weighted overlay must contain discrete integer values. The reclassified and standardized criteria are shown in table 3.2.

Table 3.2: Criteria and Requirements for solar energy power plant Suitability

| Criteria                             | Suitability Rank Value | Ranking |
|--------------------------------------|------------------------|---------|
| <b>Aspect</b>                        | Flat area              | 3       |
|                                      | S                      | 2       |
|                                      | SE and SW              | 1       |
| <b>Solar Radiation</b>               | 1300Kw/h – 1350Kw/h    | 3       |
|                                      | 1350Kw/h – 1400Kw/h    | 2       |
|                                      | 1400Kw/h – 1460Kw/h    | 1       |
| <b>Distance to Built up Areas</b>    | < 4.5km                | 3       |
|                                      | < 4km                  | 2       |
|                                      | < 3.5km                | 1       |
| <b>Distance to Transmission Line</b> | < 2.5km                | 3       |
|                                      | < 2km                  | 2       |
|                                      | < 1km                  | 1       |
| <b>Distance to Road</b>              | < 2.5km                | 3       |
|                                      | < 2km                  | 2       |
|                                      | < 1km                  | 1       |



### 3.3 Analytical Hierarchy Process and Determination of Criteria Weight

Analytical hierarchy process is an effective tool for dealing with complex decision-making, and may aid the decision maker to set priorities and make best decisions by reducing complex decisions to a series of pairwise comparisons, and then synthesizing the results. AHP helps to capture both subjective and objective aspects of a decision. Again, both benefits and risks can be weighed, assigning a number value to each criterion (benefit or risk factor under

consideration), with more important benefits receiving a higher number on the scale to determine which projects have the highest overall value, or the most valued benefits and least risks.

AHP approach uses a ratio matrix known as the Eigenvector method to compare one criterion with another. Additionally, it uses a numerical scale with values ranging from 1 to 9, where 1 means that the two factors are equally important and 9 means that the one factor is absolutely more important than the other as shown in Table 3.3. If a factor is less important than another then this is indicated by reciprocals of the 1 to 9 values (1/1 to 1/9)

Table 3.3: Relative Importance in Pairwise Comparison

| Judgment value | Description             |
|----------------|-------------------------|
| 1              | Equal importance        |
| 3              | Moderately importance   |
| 5              | Strongly Importance     |
| 7              | Very strongly important |
| 9              | Extremely important     |

Source: [8]

#### 3.3.1 Pairwise Comparison Matrix Formation

Pairwise comparison matrix was formed by inputting the judgment value between factors as the matrix

elements by following the basic rules as established by [8]. Using the table 3.3, table 3.4 was formulated using pairwise comparison matrix.

Table 3.4. Pair-wise comparison matrix for solar energy power plant Suitability

|                               | Aspect | Solar Radiation | Distance to Built up areas | Distance to Transmission Line | Distance to Road |
|-------------------------------|--------|-----------------|----------------------------|-------------------------------|------------------|
| Aspect                        | 1      | 2               | 3                          | 3                             | 4                |
| Solar Radiation               | 0.5    | 1               | 2                          | 3                             | 4                |
| Distance to Built up Areas    | 0.33   | 0.33            | 1                          | 2                             | 3                |
| Distance to Transmission Line | 0.33   | 0.33            | 0.5                        | 1                             | 2                |
| Distance to Road              | 0.25   | 0.25            | 0.33                       | 0.5                           | 1                |
| Total                         | 3.57   | 5.07            | 6.78                       | 8.53                          | 11.03            |

### 3.3.2 Computation of the Criterion Weights

After the formation of pair-wise comparison matrix, computation of the criteria weights was done. The computation involved the following operations:

- i. Finding the sum of the values in each column of the pair-wise comparison matrix.
- ii. Division of each element in the matrix by its column total (the resulting matrix is referred to as normalized pair-wise comparison matrix).

- iii. Computation of average of elements in each row of the normalized matrix, i.e. dividing the sum of normalized scores of each row by the number of criteria. These averages provide an estimate of the relative weights of the criteria being compared. It should be noted that for preventing bias through criteria weighting, the consistency ratio (CR) was used [11].

### 3.3.3 Normalized Pairwise Comparison Matrix

Table 3.5 shows the normalized pairwise comparison matrices that were formed, as shown in the table 3.5.

Table 3.5: Normalized Pairwise Comparison Matrix for solar energy power plant Suitability

|                               | Aspect | Solar Radiation | Distance to Built up areas | Distance to Transmission Line | Distance to Road | Mean |
|-------------------------------|--------|-----------------|----------------------------|-------------------------------|------------------|------|
| Aspect                        | 0.41   | 0.51            | 0.44                       | 0.32                          | 0.29             | 0.39 |
| Solar Radiation               | 0.21   | 0.26            | 0.29                       | 0.32                          | 0.29             | 0.27 |
| Distance to Built up Areas    | 0.14   | 0.08            | 0.15                       | 0.21                          | 0.21             | 0.16 |
| Distance to Transmission Line | 0.14   | 0.08            | 0.07                       | 0.11                          | 0.14             | 0.11 |
| Distance to Road              | 0.10   | 0.06            | 0.05                       | 0.05                          | 0.07             | 0.07 |

### 3.3.4 Prioritization weight matrix

In computing the element of this matrix, the normalized sum of each row is divided by the total

number of its criteria. The obtained averages provide an estimate of the relative weights of the criteria being compared. See 3.6 more details.

Table 3.6: Prioritization weight matrix for solar energy power plant Suitability

|                                 | Aspect | Solar Radiation | Distance to Built up areas | Distance to Transmission Line | Distance to Road | Mean | W%     | row total of normalized matrix |
|---------------------------------|--------|-----------------|----------------------------|-------------------------------|------------------|------|--------|--------------------------------|
| Aspect                          | 0.41   | 0.51            | 0.44                       | 0.32                          | 0.29             | 0.39 | 39.34  | 1.97                           |
| Solar Radiation                 | 0.21   | 0.26            | 0.29                       | 0.32                          | 0.29             | 0.27 | 27.15  | 1.36                           |
| Distance to Built up Areas      | 0.14   | 0.08            | 0.15                       | 0.21                          | 0.21             | 0.16 | 15.85  | 0.79                           |
| Distance to - Transmission Line | 0.14   | 0.08            | 0.07                       | 0.11                          | 0.14             | 0.11 | 10.85  | 0.54                           |
| Distance to Road                | 0.10   | 0.06            | 0.05                       | 0.05                          | 0.07             | 0.07 | 6.80   | 0.34                           |
| Total                           | 1.00   | 1.00            | 1.00                       | 1.00                          | 1.00             | 1.00 | 100.00 | 5.00                           |

### 3.3.5 Estimation of the Consistency Ratio

This stage involved calculating a consistency ratio (CR) to check reliability of the judgments values which are relative to large samples of purely random judgments. The AHP deals with consistency explicitly because in making paired comparisons, just

as in thinking, people do not have the intrinsic logical ability to always be consistent.

To determine consistency ratio, the analytical hierarchy process compares it by random index (R.I). Mathematically, Consistency Ratio (C.R.), can be defined using equation (3.1) presented on page 81

$$CR = CI/RI$$

In calculating the consistency value, the mathematical formula  $CR = CI/RI$  was used.

Random index (RI) is the consistency index of a randomly generated pair-wise comparison matrix of order 1 to 10 obtained by approximating random indices.

Table 3.7: Random Index by [8]

| Size of matrix (n) | 1 | 2 | 3    | 4   | 5    | 6    | 7    | 8    | 9    | 10   |
|--------------------|---|---|------|-----|------|------|------|------|------|------|
| Random index (RI)  | 0 | 0 | 0.58 | 0.9 | 1.12 | 1.24 | 1.32 | 1.41 | 1.46 | 1.49 |

Source: [8]

**Note:** If the value of the obtained Consistency Ratio is less than 0.1, it means that there is a reasonable level of consistency in the pairwise comparisons, and that the computed weights are within the acceptable limit. If the reverse is the case ( $CR > 0.1$ ) it means that the weights obtained are inconsistent and needs to be checked.

The consistency ratio (CR) is design in such a way that if  $CR < 0.10$ , the ratio indicates a reasonable level of consistency in the pairwise comparisons; if, however,  $CR \geq 0.10$ , the values of the ratio are indicative of inconsistent judgments. From the judgment a Consistency Ratio (CR) of 0.09 was achieved for solar energy power plant Suitability, which was less than the maximum allowable ratio of 0.10., hence the judgement is accepted.

1. The value of Consistency index, CI for solar energy power plant Suitability was calculated as such:

$$\lambda_{max} = (2.41*0.39) + (3.91*0.27) + (6.83*0.16) + (9.5*0.11) + (14*0.07)$$

$$= 0.93 + 1.05 + 1.09 + 1.04 + 0.98$$

$$\lambda_{max} = 5.09$$

$$CI = (5.09 - 5) / (5-1) = 0.0225$$

$$CR = 0.0225 / 1.12 = 0.02$$

$$CR = 0.02 < 0.10 \text{ (Acceptable)}$$

From the judgment, a Consistency Ratio (CR) of 0.02 was achieved for solar energy power plant suitability,

which was less than the maximum allowable ratio of 0.10., hence the judgement is accepted.

### 3.4 Suitability Calculation

The weighted linear combination (WLC) model has become popular in recent year and for the study, WLC methods was used over the Boolean method. Site suitability was calculated by using raster calculator in ArcGIS 10.7. The criteria were standardized to a continuous scale of suitability from the least to the most suitable, thus giving flexibility in the site selection.

The suitability index method permits the assignment of weights, this was implemented in ArcGIS 10.7. In order to make the map easily understandable, a reclassification was performed to define the three suitability index levels/categories—low, moderate and high. The natural breaks reclassification method in ESRI’s ArcGIS 10.7 was used for this purpose. The natural breaks (jenks) classification algorithm finds data break points between classes depending on the natural patterns in which the data are clustered. Class break points are set where there are relatively huge jumps in the data values. Hence using the formula to calculate for the following renewable energy Suitability:

For solar energy power plant Suitability, SI is =  $(S1*39) + (S2*27) + (S3*16) + (S4*11) + (S5*7)$ . See figure 3.2 and 3.3.

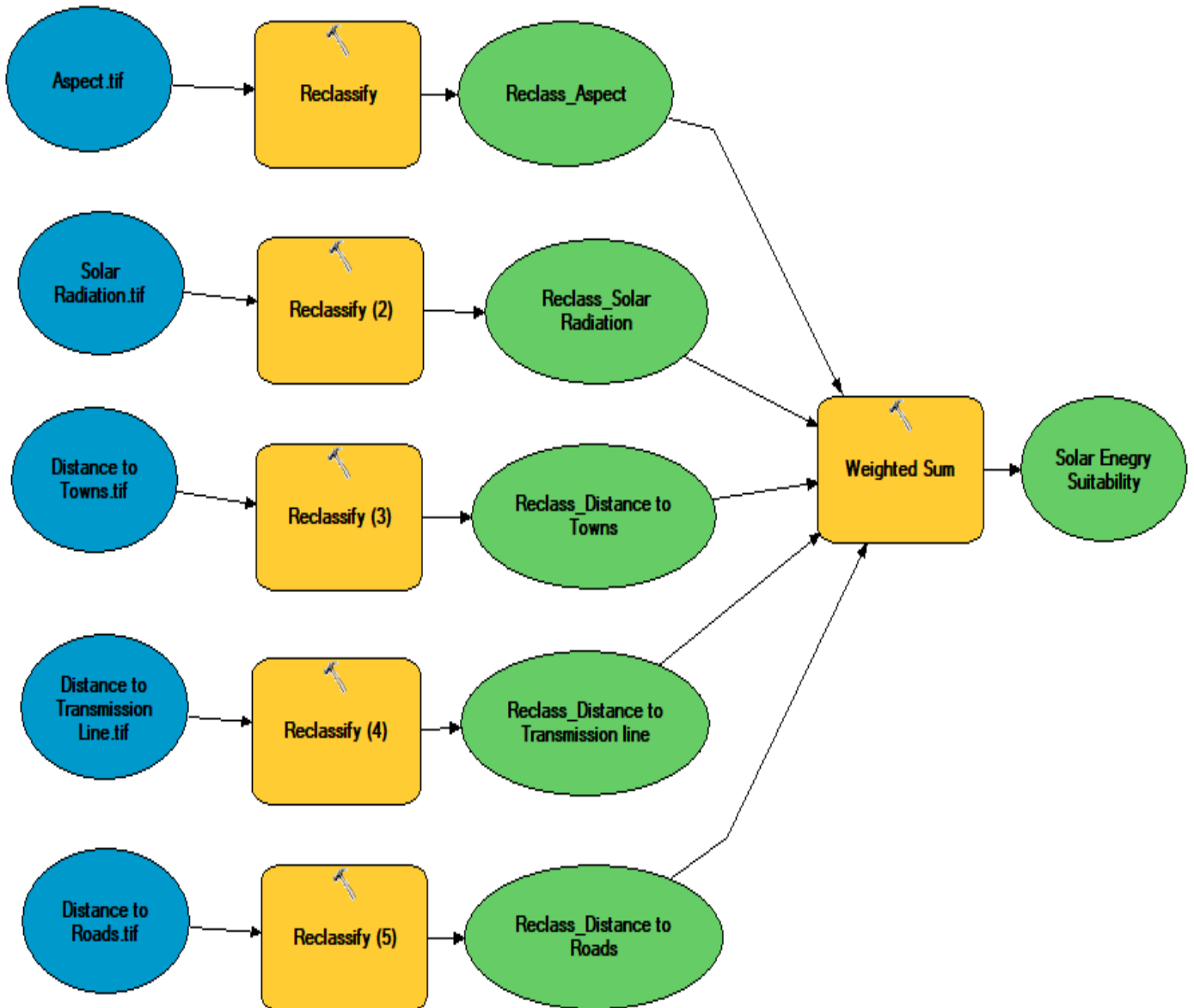


Figure 3.2: Solar energy Suitability Graphic Model

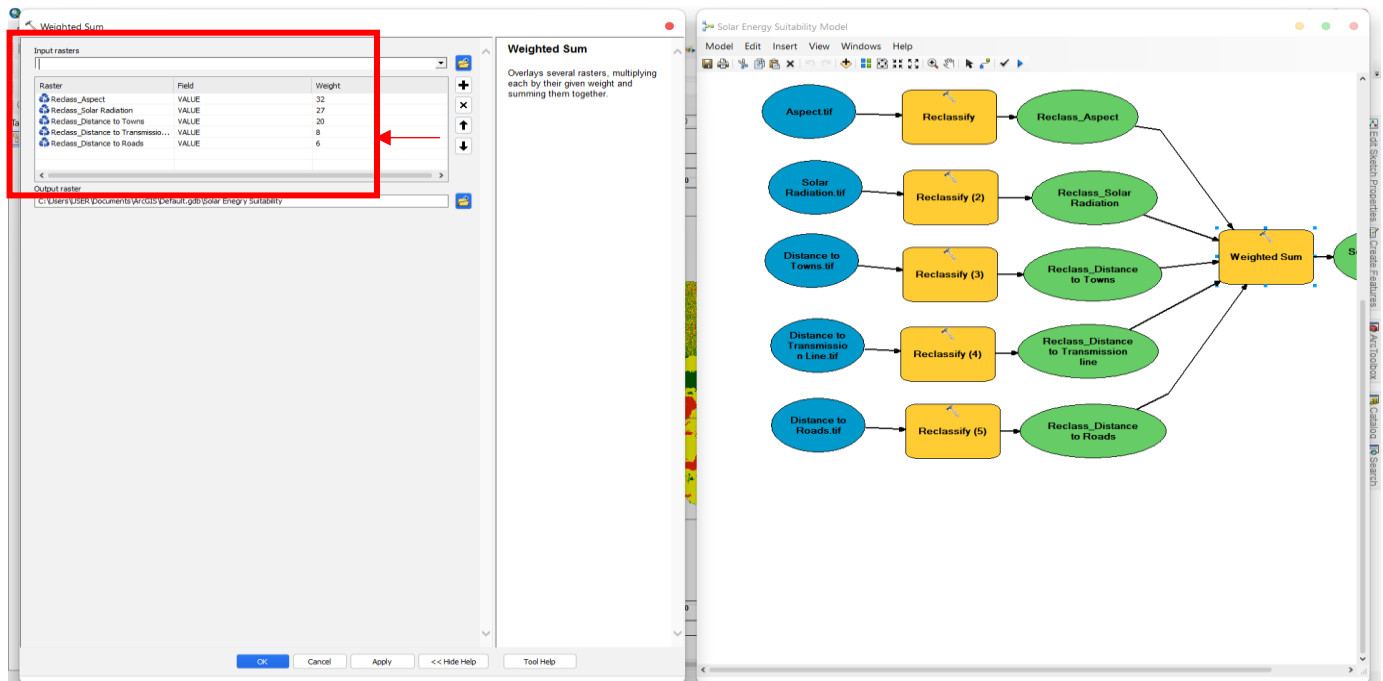


Figure 3.3: Solar energy weighted sum calculation in the Graphic Model

Note: S1... are thematic layers representing the factors for solar energy Suitability, see table 3.8. The output presented potential sites with the highest suitability renewable energy in Enugu State Nigeria.

Table 3.8: Coding of Factors

| Code | Factors                       |
|------|-------------------------------|
| S1   | Aspect                        |
| S2   | Solar Radiation               |
| S3   | Distance to Built up Areas    |
| S4   | Distance to Transmission Line |
| S5   | Distance to Road              |

The outcome of the assessment delineated distinct zones within Enugu State based on their suitability for solar development, each carrying significant implications for the region's energy landscape. Through a classification process, areas of high,

moderate, and low suitability were identified, shedding light on the solar potential across the state. In the findings, high suitable areas emerged as promising sites for solar development, covering an extensive expanse of 1000.4 square kilometres, accounting for approximately 13.39% of Enugu State's total land area. These regions boast optimal conditions for solar infrastructure deployment, characterized by ample sunlight exposure and favourable terrain, making them prime candidates for harnessing solar energy to meet local power demands. The identification of such areas not only highlights opportunities for sustainable energy generation but also paves the way for strategic planning and investment in solar projects to bolster the state's energy resilience and mitigate reliance on conventional fossil fuels, see figure 3.4.



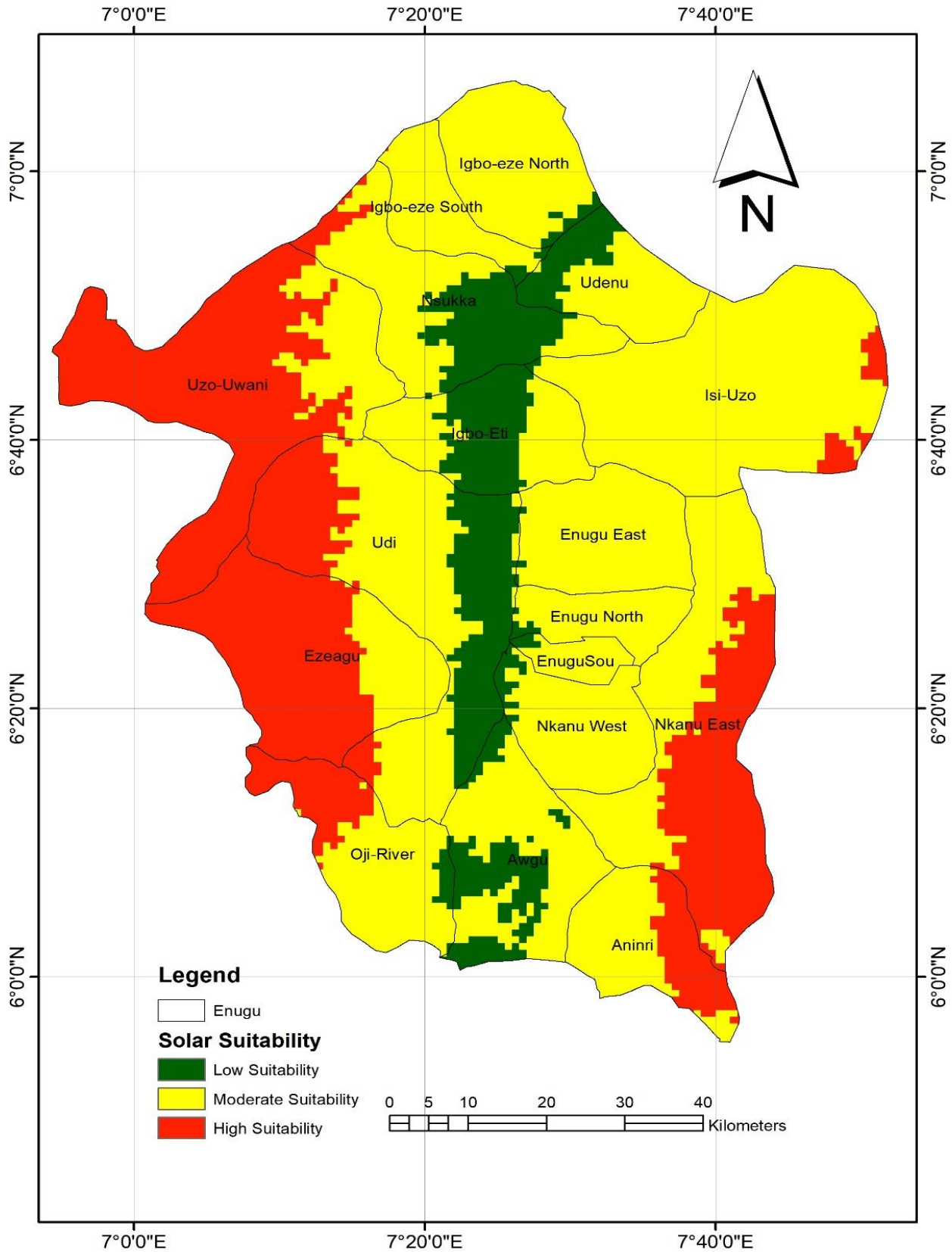


Figure 3.4: Solar Suitability Map

Moreover, the analysis revealed moderate suitability zones encompassing 2605.50 square kilometres, constituting approximately 33.82% of the state's territory. While these areas may not exhibit the same level of solar resource abundance as their high suitable counterparts, they still present viable opportunities for solar development with the implementation of appropriate technologies and infrastructure. Recognizing and leveraging these moderately suitable regions can diversify the energy portfolio, contribute to grid stability, and promote decentralization in energy generation, thereby enhancing energy security and fostering sustainable development in Enugu State.

Conversely, low suitable areas, spanning 4066.6 square kilometres and comprising 52.79% of the state's landscape, pose challenges for solar deployment due to various constraints such as shading, topographical limitations, or land use conflicts. Despite their diminished suitability, these regions are not devoid of potential; rather, they require innovative approaches and targeted interventions to overcome barriers and unlock latent solar resources. Addressing the constraints in low suitable areas demands holistic planning strategies, incorporating land-use planning, technological advancements, and policy frameworks to optimize solar utilization while mitigating environmental impacts and ensuring equitable access to clean energy solutions.

By delineating Enugu State's solar suitability landscape, this study provides policymakers, investors, and stakeholders with invaluable insights to inform decision-making processes, guide resource allocation, and foster collaboration towards realizing the state's renewable energy aspirations. Embracing the opportunities presented by high and moderate suitable areas while addressing the challenges posed by low suitable zones can propel Enugu State towards a sustainable energy future, characterized by resilience, affordability, and environmental stewardship.

## 4.0 CONCLUSION AND RECOMMENDATIONS

### 4.1 Conclusion

The study's comprehensive assessment of Enugu State's solar suitability landscape underscores the significant potential for renewable energy development in the region. Through meticulous analysis, we identified distinct zones classified as high, moderate, and low suitability for solar development, each offering unique opportunities and challenges.

The delineation of high suitability areas presents promising prospects for sustainable energy generation, with optimal conditions for solar infrastructure deployment. Strategic investments and planning initiatives within these zones could bolster the state's energy resilience, reduce dependence on conventional fuels, and drive economic growth.

Moderate suitability zones, although not as abundant in solar resources as high suitability areas, still offer viable opportunities for solar development. Leveraging appropriate technologies and infrastructure in these regions could diversify the energy portfolio, enhance grid stability, and contribute to sustainable development objectives.

While low suitability areas pose challenges for solar deployment, innovative approaches and targeted interventions hold potential to unlock latent solar resources within these regions. Holistic planning strategies, incorporating land-use planning, technological advancements, and policy frameworks, are imperative to optimize solar utilization and mitigate environmental impacts.

Overall, our findings provide policymakers, investors, and stakeholders with valuable insights to inform decision-making processes and guide resource allocation towards realizing Enugu State's renewable energy aspirations. Embracing the opportunities presented by high and moderate suitability areas while addressing the challenges posed by low suitability zones is essential for propelling the state towards a sustainable energy future characterized by resilience,

affordability, and environmental stewardship. This study serves as a crucial step towards navigating the transition towards a solar-powered paradigm in Enugu State, contributing to the broader goals of energy security and sustainability.

#### 4.2 Recommendation

The goal throughout this research was to provide a reliable and complete analysis of the data available. Based on the experience and the results obtained, it is recommended that

1. The study's approach is recommended to serve as a basis for making location suitability decisions for siting similar renewable energy sources in other regions of Nigeria.
2. The results obtained provide spatial location data that can enhance decision-making and improve efficiency in the siting of wind, solar, and hydro energy power plants. It is recommended that this data be utilized as a decision support system during the implementation process.
3. Further research should be conducted to identify additional criteria for siting renewable energy sources, with a particular focus on solar and hydro energy power plants. Incorporating more factors into the multi-criteria analysis will enhance the accuracy of the results in identifying suitable locations on the ground.
4. The study's workflow model is recommended for seamless and rapid suitability analysis. The model can be exported to a Python script and used with compatible software to facilitate easy implementation and updates.

#### REFERENCES

[1]. Fagbenle, R. L. (1991). Prospects and problems of solarizing transport technology, Nigerian

- [2]. Hermann, S. (2001). A Solar Manifesto. James and James, Ltd. London, 2001, pp. 1-22. Google Scholar.
- [3]. El Bassam, N., & Maegaard, P. (2004). Integrated Renewable Energy for Rural Communities: Planning Guidelines, Technological Application. Amsterdam, Elsevier.
- [4]. Bergey, M. L. S. (1999). Small wind Turbines for rural energy supply in Developing Countries. *Journal of Renewable Energy for Agriculture and Health*. 8, 1-6
- [5]. Stiebler, M. (2008). Wind Energy systems for Electric Power Generation, Springer Publishers, Berlin, pp. 1 - 9, 11 – 23.
- [6]. Kwon, S. D. (2010). Uncertainty analysis of wind energy potential assessment. *Applied Energy*. 87, 856-865.
- [7]. Anderson J.R., Ernest E.H, John T.R, And Richard E.W. (1967). *A Land Use And Land Cover Classification System For Use With Remote Sensor Data*. [https://www.pbcgis.com/data\\_basics/anderson.pdf](https://www.pbcgis.com/data_basics/anderson.pdf).
- [8]. Saaty, T.L. (1980). The Analytic Hierarchy Process. New York: McGraw-Hill.
- [9]. Michal M, And Beata C (2017) Multi-Criteria Analysis for Solar Farm Location Suitability. *Reports On Geodesy and Geoinformatics* Vol. 104/2017; Pp. 20-32
- [10]. ArcGIS Desktop Help. (2014). Classifying Your Data. ESRI. Retrieved from: <https://desktop.arcgis.com/en/arcmap/latest/map/working-with-layers/classifying-your-data.htm>
- [11]. Cay, R. N., & Uyan, M. (2013). Analyzing Criteria Weights in Decision Making. *Journal of Decision Sciences*, 5(2), 123-135.

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