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Research Paper

Assessment of Factors Influencing Wind Farm Development in Nasarawa State

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ABSTRACT: *The study assessed factors that influence wind farm development in Nasarawa State, Nigeria. The study used Multi Criteria Decision Analysis (MCDA) which was integrated into Geographic Information System (GIS) environment, based on Weighted Linear Combination (WLC) and Analytical Hierarchy Process (AHP) to determine the factors that influence wind farm development in the study area. The decision criteria were identified based on literature reviews and includes: environmental, economic and social factors that influence wind farm development and were accessed through secondary sources. Analysis of data for study was performed in ArcGIS 2.2 Desktop Advanced Software developed by ESRI. The Study revealed that wind restriction exerted the highest negative impact on wind farm development sites in the study area with an exclusion of 46.25% and exclusion zone area of 12,286.41Km2 which are mostly located in the south-western part of the state such as Nasarawa, Toto, Karu, Keffi, Kokona and Doma. The study also depicts that the collective influence of constraint factors resulted in the exclusion of more than half (57.58%) of the entire study area which indicates less potential development sites for wind energy farm. The study further discovered that wind speed with mean value of 0.2008 recorded lower membership values across the study area which implies that wind speed is the major limiting factor to the development of wind energy in the study area. The study concludes that despite the several factors that influence wind farm development in the study area, substantial parts of the state still provide great suitability potentials for wind farm development. The study however recommended that during wind farm development in the state, there is need to take into account specific wind turbine sizes, heights, and other design attributes in order to ascertain the factors that influence it development.*
KEYWORDS: *Factors, influence, wind farm development, GIS, Nasarawa State.*

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I. INTRODUCTION

Energy demand has increased recently due to the development of the global economy. Fossil fuels are the primary energy sources, which accounts for 79% of the World's energy consumption. The World Energy Forum forecasted that fossil fuels are under high pressure of shortage and can deplete in the coming ten decades [1]. Such an alarming situations has led policy makers to think about alternative ways of energy generation [2]. As a result, wind energy has emerged as an important alternative to fossil fuels, which can solve the current energy disaster and diminish environmental pollution [3][4][5][6][7]. Being sustainable and a promising energy source, wind energy has progressed rapidly in recent years. During the last decade, the global installed wind capacity has grown more than 19% annually [8].

According to the World Wind Energy Association (WWEA)[9], the global wind capacity has reached 597 giga watts (GW) at the end of 2018. In 2017, the global wind capacity was 546 GW. A significant amount of wind energy, i.e., 50.1, GW was added within just one year, witnessing the massive development of this sector [9]. [10] pointed out that the success of the Indian wind industry is as much as failure. He examined that there are a lot of factors that influence the wind industry, such as technical, economic, infrastructural, and ineffective government policies.

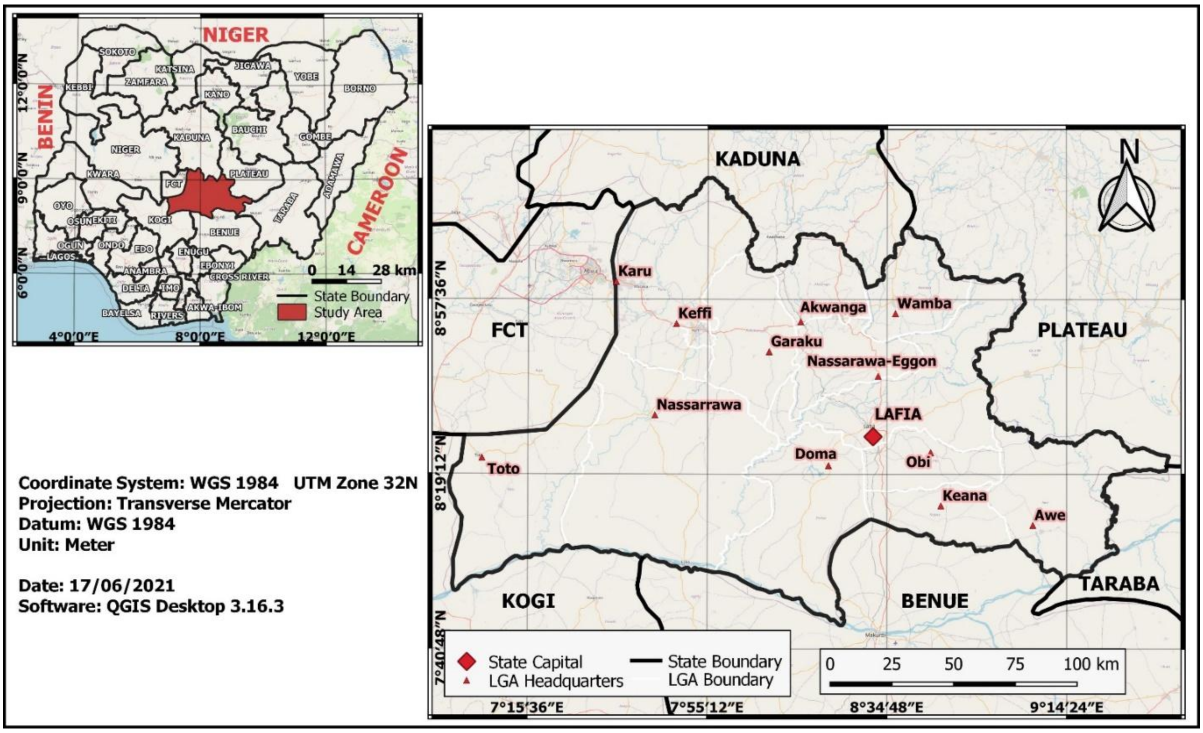
[11]analyzed the wind energy resources in India from different perspectives, i.e. financial strength and resource distribution. They found out that the lack of financial mechanism and futile policies are hindering the development of the wind industry. [12]discussed the status of wind energy in India and found that most wind turbines are old and inefficient. Besides, there is lack of capital subsidy and micro-generation technology, influencing wind energy development. [13]found that the lack of standard technology, technical inefficiency,

and human resources to manage modern wind projects are hampering wind farm development. While there is a commonly positive attitude towards wind power in general, negative attitudes, such as the not-in-my-backyard syndrome are prevalent on the local level, where residents are directly confronted with planned wind farm projects in theirneighbourhood [14][15][16]. Local negative attitudes towards wind power development most often stem from the visual and scenic intrusion of the turbines. Besides the general visibility of wind farms in the landscape, shadow flickering effects, which are caused by rotating rotor blades, and noise emitted by wind turbines, often result in annoyance and lead to rejection of wind energy on the local level. Apart from these impacts on humans, wind farms can also have negative effects on flora and fauna, particularly on birds and bats [17].

II. MATERIALS AND METHODS

Location of the Study Area

Nasarawa State is located in the basement complex of Nigeria’s central between longitude6^{o}45’03’’E and 9^{o}45’03’’E of Greenwich, and latitude 8^{o}45’00’’N and 9^{o}35’00’’N of Equator. It shares geographic boundaries with Kaduna state in the north, Federal Capital Territory (FCT) to the west, Kogi and Benue to the South, Taraba and Plateau to the east (Figure 1.1). The climate of Nasarawa State is typical of a tropical sub-humid climate having two distinctive seasons, the rainy season starts from April and last until October, while the dry season is experienced between November and March. The yearly rainfall amount range between 1100mm to roughly 2000mm and the mean monthly temperature in the state ranges between 20$^{o}_{C}$ and34$^{o}_{C,}$ with the hottest months being March/ April and the coldest months being December and January [18]. The major soil entities of Nasarawa State are of the oxisols or tropical ferruginous soils categories, the soils are primarily formed from the basement complex and old sedimentary rocks, and the landscape in the southern region of the state forms part of the low plains of the Benue origin. Other parts of the state are composed of rising and falling lowlands and a network of hills established on granites, migmatites, pegmatites and gneisses.



Methods of Data Collection

This study integrates Multi-Criteria Decision Analysis (MCDA) into a Geographic Information System (GIS) environment. The MCDA was based on Weighted Linear Combination (WLC) and Analytical Hierarchy Process (AHP) to determine weights (relative influence) of decision criteria for wind farm sitting and develop a composite suitability map from single-factor maps representing the characteristics of these criteria in the study area. The decision criteria were identified based on literature review and includes: environmental, economic and social aspects of wind farm development which addresses specific geographical constrains or advantages in the study area. The datasets used for this study were assessed from secondary sources. The environmental, social and economic features included in the set of decision criteria defined in this study was based on existing related studies [19][20][21][22]; and regarded suitable with reference to [23], who submitted that the number of criteria should be kept minimal, or as small as possible. Nevertheless, it is recognized that, the addition of numerous other features could improve the quality of the study's result. The datasets considered in this study are: wind speed; slope; Land cover/Land use; forest reserves; wetlands; inland waterbodies; transmission network; road network; railway network; town/populated places (settlement points) and the administrative area of the state. Data on forest reserves, wetlands and inland waterbodies constituted the ecologically significant areas while road and rail network formed the safety restriction. Most of the datasets were acquired in vector format except for data on wind speed, slope and land cover/use which were obtained in raster format.

Techniques for Data Analysis and Model Specification

Analysis of data for this study was performed in ArcGIS 2.2 Desktop Advanced software developed by Esri.

❖ Datasets Pre-Processing

Pre-processing of datasets that was carried out in this study include: data projections from Geographic Coordinate System (GCS) to a common Projected Coordinate System (PCS) to enable linear measurements such as distance and area calculations and collective geo-processing such as querying, buffering and overlay. Pre-processing also included conversion of vector data to raster (gridcell) data and resampling all data layers to a common cell size using bilinear resampling techniques. Before conversion to raster format, the geometry of vector data was checked and all identified geometry problems were repaired using the ArcGIS Data Management toolbox.

❖ Decision Constraint Analysis

Individual constraint layers were created for each decision constraint using the 'Reclassify' or 'Raster Calculator' tool in the ArcGIS Spatial Analyst toolbox. Unfeasible areas were assigned zero value (0) and all other areas a value of one (1). Furthermore, a composite constraint layer was generated using 'Raster Calculator', where all individual constraint layers were multiplied so as to identify areas classified as feasible considering all constraint criteria. Hence, the resulting composite constraint layer details exclusion zones (unfeasible areas) assigned a value of zero (0), as well as potential development sites (feasible areas) assigned a value of one (1).

❖ Standardization of Decision Factors

The decision factors were mainly standardized through the application of fuzzy sets theory using the 'Fuzzy Membership' overlay tool in the ArcGIS Spatial Analyst toolbox. A standardized map layer was generated for each respective decision factor, specifying the membership grade in the range of zero (0: not gratified) and one (1: fully gratified). Therefore, a membership grade or value of zero (0) stands for not suitable location (grid cell) and a value of one (1) an optimal location. Euclidean distance map layers were generated for some decision factors before there standardization and this was performed using the 'Euclidean Distance' tool in the ArcGIS Spatial Analyst toolbox. Furthermore, decision factors F6 (Land cover/use) was standardized by assigning membership values to the individual classes/categories in the attribute table and a layer with new cell values was generated using the lookup tool in Spatial Analyst toolbox.

❖ Multi-Criteria Decision Analysis and Composing of Suitability Index

Several multi-criteria decision analysis (MCDA) methods have been worked out for both commercial and free open-source GIS and applied in recent years. According to a brief review of these methods by Malczewski (2004; 2006), they include: deterministic, probabilistic and fuzzy based multi-attribute and multi-objective techniques. Among the multi-attribute methods such as the: Boolean operator overlay, Weighted Linear Combination (WLC), Ordered Weighted Averaging (OWA), concordance analysis and ideal point method, the first two are most commonly applied for site selection studies or suitability analysis [24][25]. These methods have developed from the original map overlay concept by [26]. However, overlay procedures that use Boolean operators can do little more than identify areas, which simultaneously satisfy the specified criteria. Therefore, additional procedures based on the MCDA methods such as the ones listed above are required to evaluate the suitability of sites and produce rankings of locations in terms of their attractiveness [27]. In addition to the Boolean based decision constraint, this study adopted the WLC techniques to generate/compile an overall suitability index (SI) in which every individual grid-cell depicts composite degree of wind energy farm site suitability. Furthermore, in order to make statistical analysis possible, the suitability index for each of the three-policy scenario was reclassified in conformity with the suitability classes described in Table 1, using the 'Reclassify' tool in the ArcGIS Spatial Analyst toolbox. After the reclassification, total area of all the suitability classes of land within each policy scenario in study area was calculated using the 'Tabulate Area' tool in the ArcGIS Spatial Analyst toolbox. Furthermore, the areas deemed 'satisfactory' for wind farm development was defined with reference to the lower SI score of the 'moderate suitability' class and hence described with the following suitability index score interval: $0.50 < SI \leq 1$.

TABLE 1: Matrix of Pairwise Comparison and Weights of Factors

	F1	F2	F3	F4	F5	F6	Weights
F1	*	4	4	6	9	6	0.48636
F2	¼	*	1	3	6	3	0.17465
F3	¼	1	*	3	6	3	0.17468
F4	1/6	1/3	1/3	*	2	1	0.06485
F5	1/9	1/6	1/6	½	*	1/2	0.03462
F6	1/6	1/3	1/3	1	2	*	0.06484

Source: AHP Pairwise Comparison of Decision Factors

III. RESULTS AND DISCUSSION

TABLE 2: Influence of Decision Factors on Wind Farm Development in the Study Area.

Decision factors	Exclusion Zone Area (Km2)	Percent of Total study area (%)
Wind Restriction	12286.41	46.25
Environmental Restriction	5634.74	21.21
Safety Restriction	1198.81	4.51
Settlement Restriction	689.30	2.60
Composite Restriction	15347.13	57.58

Source: Data Analysis (2021)

Decision factor C1 (wind restriction) exerted the highest negative impact on finding potential development sites in the study area as it resulted to the exclusion of 46.25% of the entire study area with an exclusion zone area of 12,286.41km2. The excluded land areas are mostly located in the south-western part of the State covering the whole or part of the following Local Government Areas: Nasarawa, Toto, Karu, Keffi, Kokona and Doma. Furthermore, decision factor C3 (Environmental protection) also resulted in the exclusion of significant parcels of land accounting for 21.21% of the study area. On the contrary, safety restrictions and settlement restriction indicated great potential development sites with very small exclusion zones accounting for 4.51% and 2.6% of the entire study area. Overall, the collective influence of the decision constraint factors resulted in the exclusion of more than half (57.58%) of the entire study area. Although this indicates less potential development sites for wind energy farm when compared to the findings of [28][29] who reported composite constrained area of 27.6% for New South Wales, Australia and 56.8% for Lesvos island, Greece, respectively, there is still a considerable parcel of land (42.42%) with wind farm development potential in the study area.

TABLE 3: Mean Membership Value of the Decision Factors

Decision Factor	Mean Membership Value
Wind Speed	0.2008
Slope	0.5202
Proximity to Transmission Network	0.6156
Proximity to Road	0.5466
Distance from Ecologically Significant Area	0.7518
Land cover/use	0.6278

Source: Data Analysis (2021)

Table 3 presents the mean fuzzy membership values of the decision factors which depict the influence of individual factors on the general suitability of the study area for wind farm development. Majority of the decision factors accounted for moderate to high suitability land areas across Nasarawa State with membership values higher than the "moderate ($SI > 0.50$) and high ($SI > 0.75$) suitability threshold". On the contrary, decision factor F1 (wind speed) with mean value of 0.2008 recorded lower membership values across the study area. This implies that wind speed is the major limiting factor to the development of wind energy farm in Nasarawa State and corroborates the findings of [28][21] who reported wind speed as the predominant limiting factor of land suitability in their studies.

Although decision factors F2 (slope), F3 (proximity to road), F4 (proximity to transmission network) and F6 (land cover/use) recorded relatively higher mean values than F1 (wind speed) and contributed positively to finding 'satisfactory' ($0.50 < SI \leq 1$) wind farm locations, they accounted for limitations to the availability of ideal locations (priority area) for wind farm development in the study area, with mean values of 0.5202, 0.5466, 0.6156 and 0.6278 in decreasing order of limitations respectively. On the contrary, decision factor F5 (distance from ecologically significant areas) had a mean value of 0.7518 which is above the high suitability threshold and thus posed relatively no limitations across an extensive area of Nasarawa State.

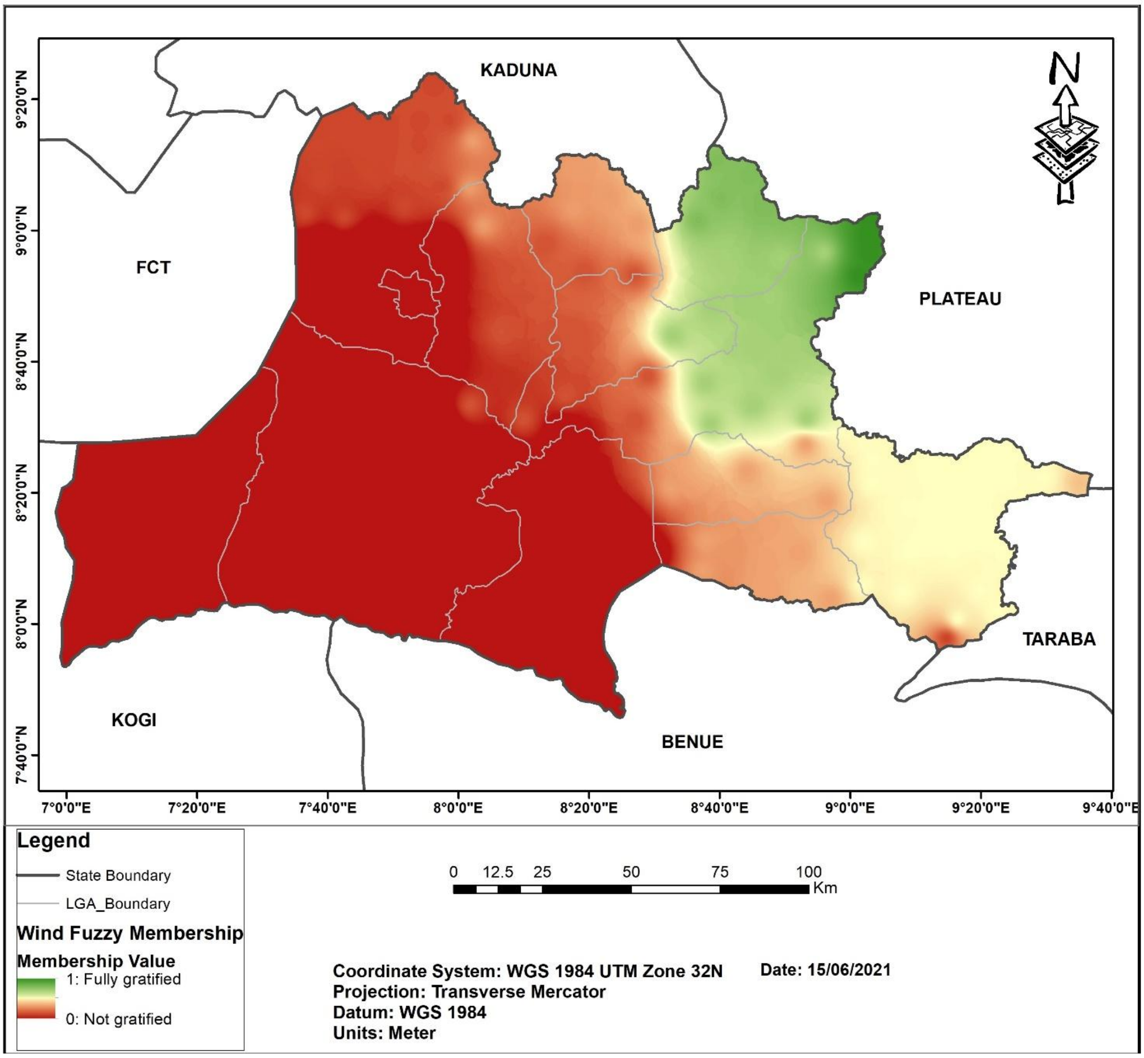


Figure 1: Standardised Decision Factor F1 (Wind Speed)

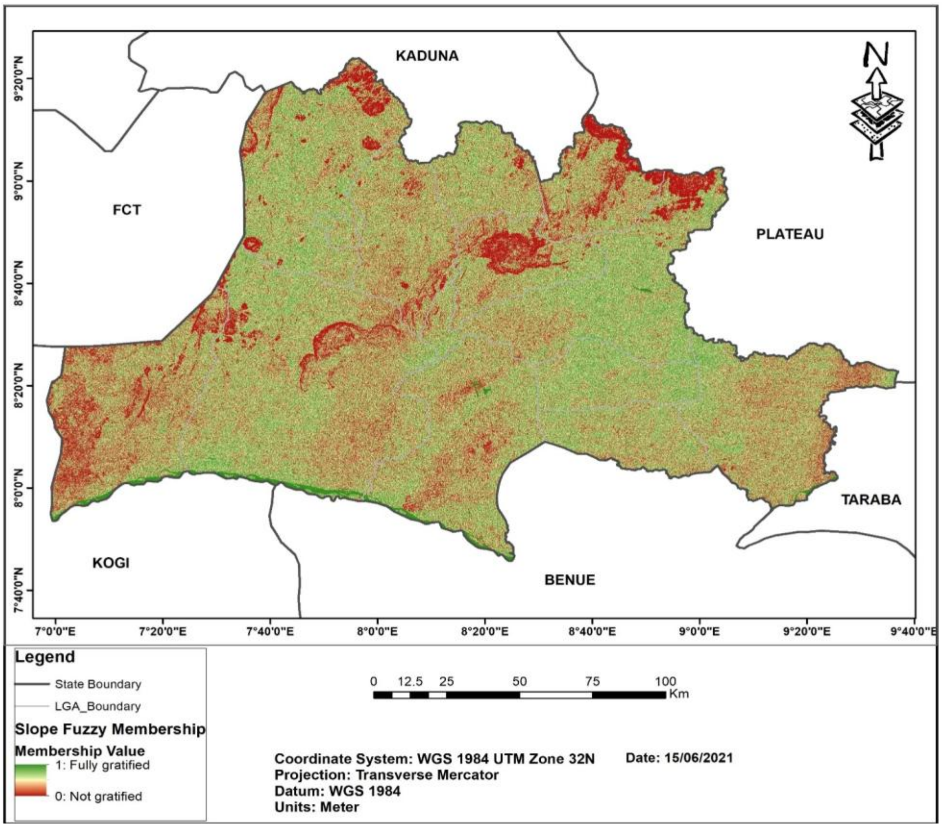


Figure 2: Standardised Decision Factor F2 (Slope)

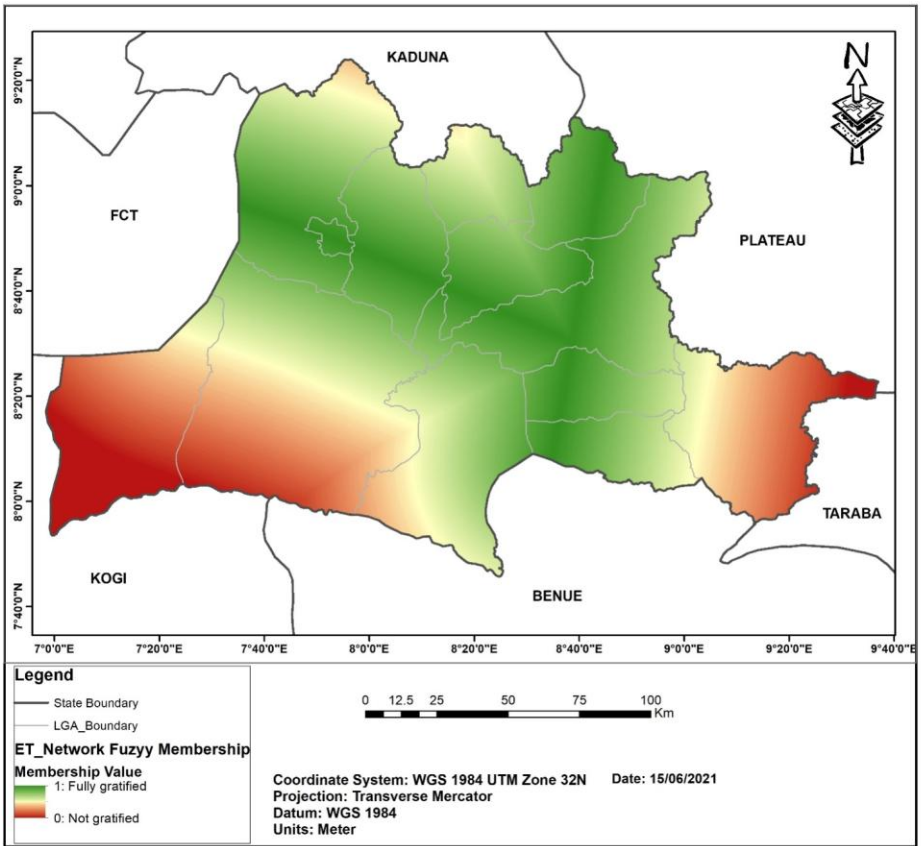


Figure 3: Standardised Decision Factor F3 (Electricity Transmission Network)

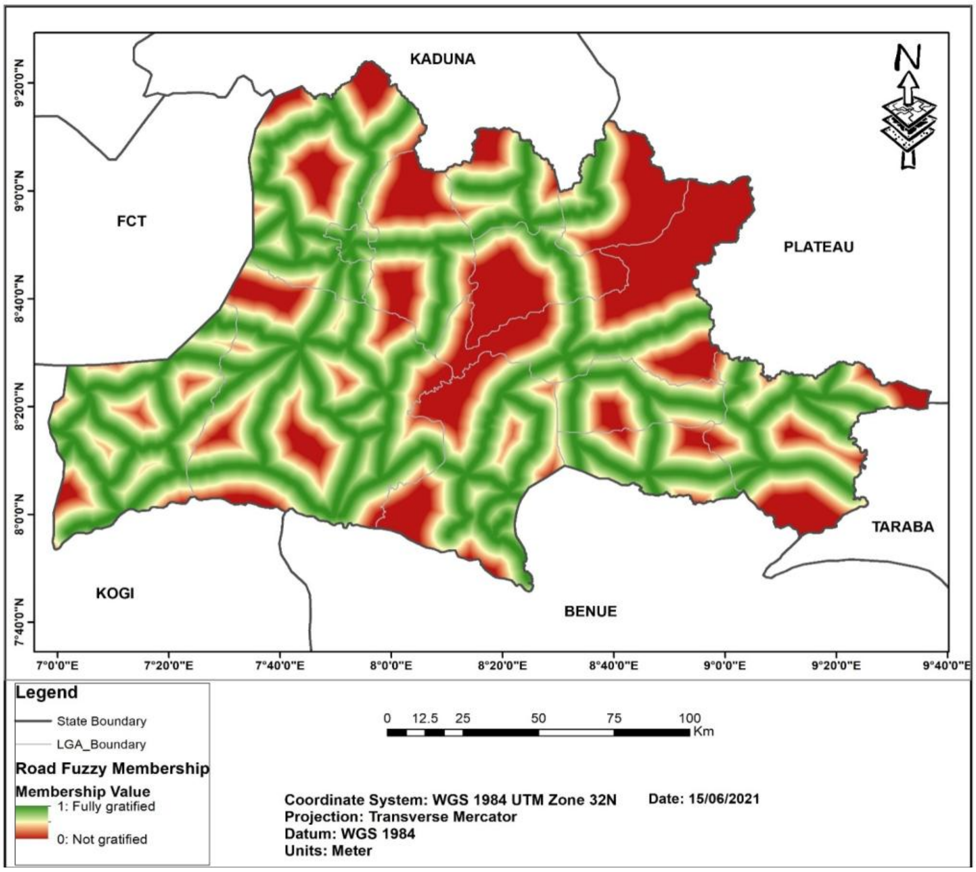


Figure 4: Standardised Decision Factor F4 (Road Network)

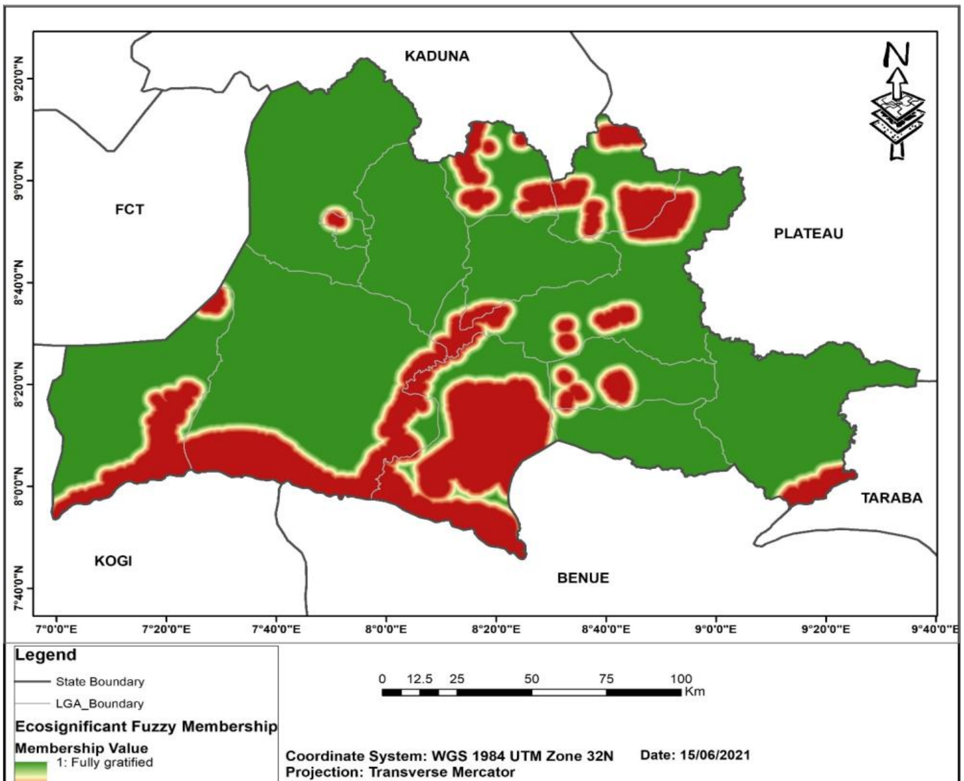


Figure 5: Standardised Decision Factor F5 (Ecologically Significant Area)

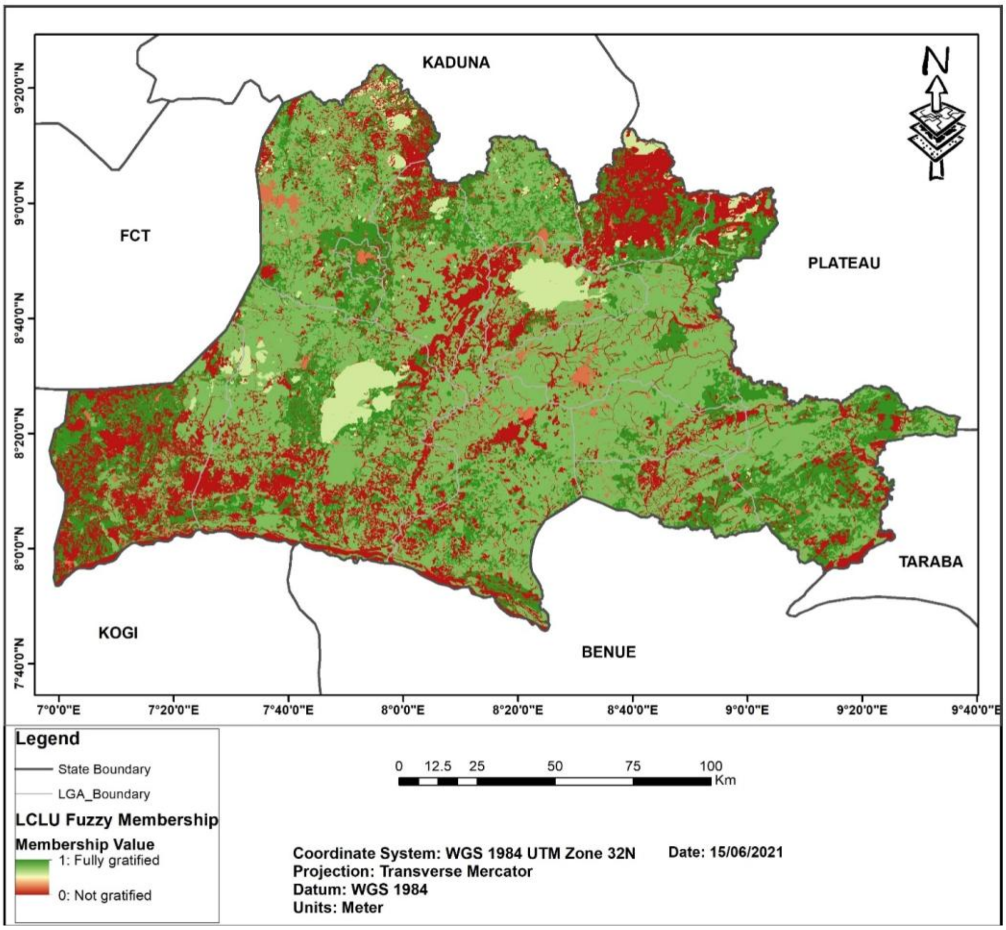


Figure 6: Standardised Decision Factor F6 (Land cover/use)

IV. CONCLUSION

In line with the findings of this study, the study concludes that despite the several factors that influence wind farm development in the study area, substantial parts of the state still provide great suitability potentials for wind farm development. The study recommends that during wind farm development in the state, there is need to take into account specific wind turbine nature in terms of sizes, heights and other design attributes in order to ascertain the constraint factors influencing it development.

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