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Reaserch Article

Geospatial Evaluation of Wind Energy Potential in the SE and SS of Nigeria

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Abstract

Investment into a renewable energy project spurs the need to investigate sites with potential for a renewable energy source. Such a crucial investigation is the main motivation for this study, which uses a geospatial technology to evaluate wind energy potential within the south-east (SE) and south-south (SS) regions of Nigeria. A multi-criteria decision analysis (MCDA) model was implemented using Landsat TM images at bands 2, 3 and 4, and integrated with NASA global wind speed data, airport location map and forest reserve map of the area. The criteria for generation of wind energy potential map were wind speed ≥ 3m/s, 2000m buffer from built-up areas, 2,500m buffer from airports and outside the forest reserve. The results indicate the presence of a reasonable amount of potential for wind energy, which lies mostly in the southernmost part of the study area. The total potential area is about 104,700 hectares in land size, which is merely 1.2% of the total study area, although River state encloses most of the potential locations. When compared to global vortex wind data, by visual inspection, these potential areas show a great deal of sensitivity to wind speed, highlighting its critical importance in the present modelling. Wind farms can be located in this area, although it is a rather small-scale investment in a renewable energy resource considering that the consumable amount of energy in the study area is in a steady increase. Stakeholders and experts in energy economy will find that the need to protect this potential energy location from indiscriminate urban development and other anthropogenic activities is compelling.

Keywords: Geospatial technology, Suitability evaluation, Wind energy, Nigeria, LANDSAT, Multicriteria decision analysis

Introduction

Concerns for alternative sources of energy have grown in recent times (Shen et al., 2010; Ellabban et al., 2014; Ayodele et al., 2016; Mazzucato and Semieniuk, 2018). This implicates a number of crucial and inevitable factors. Primarily, the rate of energy consumption within the human environment is ever increasing and irreversible. The direct impacts of this scenario are consistent shortfalls in electricity supply, which is a global experience, but an immediate situation in the developing countries (DCs) such as Nigeria, where the implications of urbanization and rapid population growth in energy economy and management inspire critical discussions. Another crucial factor is the need to promote environmental friendliness, and minimize the negative effects of conventional fossil energy greenhouse gases (GHG) emission into the atmosphere (Ülker, et al., 2018). Therefore, these issues, and in consideration of the compelling sustainable development goals (SDGs), renewable energy has become a particularly attractive theme for contemporary research.

Renewable energy is environmentally friendly, which is its indisputable merit, and the underlying reasons for which it is being favored by global, regional and local political energy debates. Besides the socio-economic impacts — mostly the global economic growth, possible employment opportunities and large export earnings, renewable energy exhibits significant impacts on the local and regional electricity prices (Frondel et al., 2010; Mathiesen and Karlsson, 2011; Mulder and Scholtens, 2013). With more than 1 billion people still living without electricity globally, there is increased incentive for rural electrification projects, which highlights the need for further investigations into renewable energy resources (Zahnd and Kimber, 2009; Ahlborg and Hammar, 2014; Nasir et al., 2018). Presently, geothermal energy, biomass, solar, small hydropower and wind renewable energy resources are known and discussed extensively within the current literature. However, due to the ubiquity of wind speed as its primary source, wind energy is increasingly gaining acceptance.

Over the past two decades, wind industry has grown at around 26% per year (Twidell and Weir, 2015). Europe and China have been solid wind markets for over a decade, although the United States is currently on its way to gaining a 20% share of the world market (Hass et al., 2011; Aslani and Wong, 2014; Lin and Moubarak, 2014; Connolly et al., 2016). In the coming five years, the rapidly developing economies of Brazil, South Africa and India are likely to be among the next to reap the benefits of wind power (Sasana and Ghozali, 2017). In its biannual status report on wind energy, Greenpeace and the Global Wind Energy Council (GGWEC) revealed that wind power could be supplying up to 19% of the world's electricity and avoiding over three billion of CO2. By 2050, 25-30 % of global power could come from harnessing the wind (Moriarty and Honnery, 2012; Öztürk and Serkendiz, 2018). The main reason for this being that wind power has become the least-cost option for adding new power capacity to the grid in an increasing number of markets. Prices are continuing to fall and smart investors are seizing on the potential (Ellabban et al., 2014; Sen and Ganguly, 2017). In Nigeria, the federal government has begun to harness the abundant energy resources from wind by siting a 10MW capacity wind farm in Rimi village in Katsina state, northwest Nigeria. The 10MW wind power project can provide power for over 2,200 homes, according to industry calculations (Obiukwu, 2015; Akuru et al., 2017). This is not a one-off or localized investment, as there are speculations that the project will be extended to other parts of the country.

Investment into wind renewable energy within Nigerian context must evidently comply with standard procedures, which stipulate the need to investigate sites with potential for wind and its sustainability (Barry et al., 2011; Mentis et al., 2015). Therefore, the main aim of this research was to carry out a spatial evaluation of potential wind energy sites in the SE and part of SS Nigeria comprising of Abia, Akwa-Ibom, Anambra, Bayelsa, Cross-River, Ebonyi, Enugu, Imo and Rivers States. This is a contribution towards the science of renewable energy within the context of Nigeria. A multi criteria decision analysis (MCDA) model, proposed based on geospatial technology is being applied in this research. This is due to its versatility and extensive application in renewable energy research especially in acquiring, integrating a myriad of datasets, processing and presenting spatially referenced datasets such as the wind speed (Van Hoesen and Letendre, 2010; Latinopoulos and Kechagia, 2015; Nematollahi et al., 2016; Cevallos-Sierra and Ramos-Martin, 2018; Vaghela et al., 2018; Mohahhadi and Hosseinali, 2019). Remote sensing datasets at both ground and space platforms were acquired processed and presented as geographic Information (GIS) outputs. Cartographic representations that delineate variations in wind energy resources within these areas are being produced. Such a cartographic tool will provide a necessary guide for policy makers in their efforts to develop alternative energy sources to supplement Nigeria's current electricity situation that has continued to be inadequate.

Brief description of the science of wind energy resource

Since it is the authors' intention in this study to exploit wind energy resources and the underlying science, it will help to take a brief look at the relevant physics and mathematics of this technology. Fig. 1 that shows a wind turbine farm will be used to illustrate some key aspects of the wind energy resources. Wind is made up of moving air molecules that have some mass, and thus carries kinetic energy in an amount that is given by equation 1.

$$E = \frac{1}{2} \qquad {}^{2} \qquad (\text{Eq.1 })$$

In the equation above, E is the kinetic energy (measured in joules), m is the mass (kg), and v is the velocity (LT-1). Air has known density (~ 1.23 kg/m3 at sea level), so the mass of air hitting for example in Fig. 1, the wind turbine (which sweeps a known area) each second is given by equation 2.

$$M = v \times A \times \rho \qquad (Eq. 2)$$

where M (kgT^{-1}) is the mass per second, A (L^2) is the known areas which the turbine sweeps and ρ (kgL^{-3}) is the air density (typically 1.225Kg/m^3).

Figure 1: Wind turbines in a wind field

Therefore, the power (i.e. energy per second) in the wind hitting a wind turbine with a certain swept area is given by equation 3. According to Hansen et al. (2002) and Muller et al. (2006), the theoretical power in the wind energy, which is extracted from the airflow is given by equation 4.

$$P = \frac{1}{2} S_A \rho v^3 \qquad (\text{Eq. 3})$$

$$P_{ae} = \frac{1}{2} \rho \pi R^2 v_{eq^3} C_p(\theta_{pitch}, \quad \lambda) \quad (\text{Eq4})$$

where P is the Power in watts (i.e. joules/second), S_A is the Swept area (L2), P_{ae} (watts) is the aerodynamic power extracted from the airflow, C_p is the power coefficient which is the fraction of power in the wind captured by a wind turbine, which depends on the pitch angle θpitch (o) and on the tip speed ratio, λ (-) given by equation 5.

$$\lambda = w_{rot} * \frac{R}{V_{eq}} \qquad (\text{Eq. 5})$$

λ is the ratio between the blade tip speed w * R and the equivalent wind speed V_{eq} (LT^{-2}), R is the rotor radius; w_{rot} is the rotor speed. C_p is generally given as 0.59 which means, the 59% of wind power is the maximum power that a wind turbine can utilize. Equation (5) above shows that the power, which a particular wind turbine can extract from wind, is a cubic function of the wind speed. Equation 5 also shows that sites with greater wind speeds will generate more power because most wind turbines start generating electricity at wind speeds of around 3-4 meters per second (LT^{-1}) (Agbetuyi et al., 2013).

Although there are environmental impacts associated with wind energy, they are utilized in the development of environmental acceptable wind energy technology. Table 1 summarizes these impacts and various studies in which solutions were proposed.

Table 1: Impacts of wind energy installations and proposed solutions

Environmental Impacts	Nature of effects	Proposed solutions	Authors
Bird's collision	Rotating blades blurs birds' eyes leading to collision	300m to ≥ 500m away from wildlife conservation areas.	Aydin *et al.* (2010); Loss *et al.* (2013).
Noise generation	Impacts on habitat	400m to ≥ 500m away from the nearest habitat.	Tester *et al.* (2005); Yu and Wand (2006)
Visual impacts	Affects urban landscape	2000m from large settlements	Baban *et al.* (2001).
Safety issues	Accidents due to poor management and to safety measures.	1000m to 2000m buffer zone around city centers	Voivontas *et al.* (1998); Nguyen (2007)
Electromagnetic interference	Restriction as a result of proximity to Airport areas due to safety and visibility	wind turbines located in a 2 – 3km around the largest installation	Nguyen (2007); Aydin (2009).

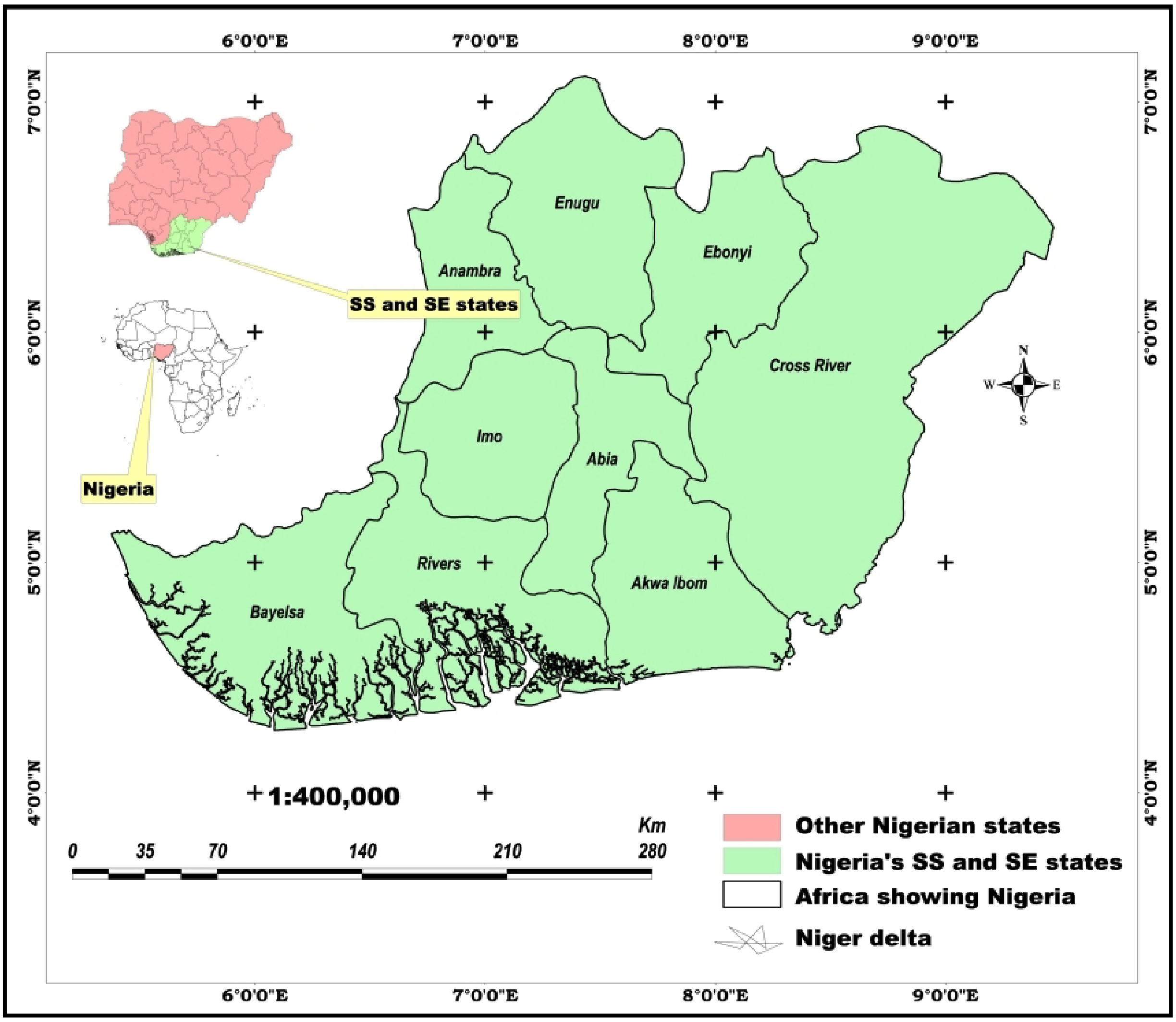

Figure 2: The SE(SE) and SS (SS) regions of Nigeria. Inset map showing Nigeria and Africa with the designated locations of the study area.

Materials and method

Study Area

The Fig. 2 above illustrates the precise location of the study area, which includes SE and part of SS Nigeria. With geographical coordinates covering latitudes 4°15'N and 7°10'N and longitudes of 5°25'E and 9°30'E, the study area measures about 88,812 km^2 and, from the 2006 national population census, encloses a population in excess of 30 million people. There are nine Nigerian states within this area, and includes Abia, Akwa-Ibom, Anambra, Bayelsa, Cross-River, Ebonyi, Enugu, Imo and Rivers states. The wealth of this region as a result of rich oil deposit, heavy and light industries including the mainstream Nigerian's petrochemical industries, is substantial to the overall GDP of Nigeria. However, electricity remains a major setback to the sustainable economic and industrial development.

Meteorologically, the Tropical rainforest climate (TRC) or the Equatorial monsoon dominates this area. The TRC has a very small temperature range, almost constant throughout the year. For example, Warri town within this region records a maximum temperature of 28 °C for its hottest month and a minimum of 26 °C during its coldest month. TRC is characterized by vital trade winds — the Tropical Maritime (TM) air mass, originating from the south Atlantic ocean and the Tropical Continental (CT) air mass originating from the Sahara Desert. The characteristic mass and speed of these trade winds are fundamental to energy generation, but it also gives a comparative advantage to the study area in terms of wind energy potential.

Table 2: Data and sources

	Material	**Source**	**Remarks**
1	Airport Locations	Current Topographic Maps of Nigerian	Open source GIS database
2	Landsat image band 2, 3 and 4	GLCF: Global Land Cover Facility.	Land Use/Land Cover
3	LU/LC	Generated from Landsat images	
4	Wind speed	NASA	10 yrs average
5	Nigeria shape file,	Generated from UNN Dept. GIS lab	South-Eastern part of Nigeria was extracted
6	Nigeria forest reserve	Generated from UNN Dept. GIS lab	

Wind energy potential evaluation model

In order to create a model for identifying potential wind energy sites, the present study considers primarily the wind speed. Wind energy is derived by combining wind speed and air density parameters at different degrees. Several studies (for examples, Mirhosseini et al., 2011; Davidson et al., 2016) have described the potential for wind energy in its simplest form using the parameters illustrated in equation (Eq. 6).

$$E = \frac{1}{2}\rho\vartheta^3 \qquad \text{(Eq. 6)}$$

where E is wind energy (Wm-2); ρ is air density (Kgm-3); ϑ is wind speed (ms-1)

The parameters can be obtained easily through remote sensing technology. For example, air density can be derived from Landsat imagery, wind speed (and mapped) - from the Synthetic Aperture Radar (SAR) image with spatial resolution of say 150 x150 m2. The proven usefulness of remote sensing technology in the determination of solar and wind potentials is largely demonstrated in a number of studies including Wang (2010), Keyhani et al. (2010) and Wu et al. (2013). These studies argue that remote sensing technology simplifies data acquisition for the evaluation of solar and wind energy potentials. The technology is economically feasible with a relatively small amount of manual labour compared to the traditional methods of data acquisition. The data are in a conventional format or standard that are easy, suitable and ready for use in a multi-criteria assessment.

Description of the present MCDA evaluation model

The present MCDA integrates wind speed (considered as the major criterion for wind energy in the present evaluation), data indicating forest reserves, airports zones and buts-up areas within the study area. Wind speed for the study area was extracted from NASA (National Aeronautics and Space Administration) global wind speed maps (see Fig. 3). These parameterization data as well as the criteria needed for the evaluation of the wind potential in the present study are shown in the table 3 below. Annual average wind speed that would be able to turn a wind turbine is taken from previous studies, assumed to be greater than or equal to 3m/s (Agbetuyi et al. 2013). Similarly, as demonstrated by previous studies, 200m buffer) avoided built-up areas, airport restriction area were isolated by 2500m buffer, forest reserves were protected by exclusion from the model (Nguyen, 2007; Aydin 2009). Fig. 4 shows the global wind speed maps of vortex that was used to analyses the sensitivity of the present evaluation.

Table 3: Adopted criteria for wind energy evaluation in the present study

Considered Factors	**Selection Criteria**	**Sources**
Wind Speed (Major)	3m/s	Agbetuyi *et al.* (2013)
Airport zone	2,500m buffer	Nguyen (2007); Aydın (2009)
Forest Reserve	Exclusion	Aydın (2009)
Built-up areas	Exclusion	Aydın (2009)

These criteria and factors were integrated using ArcGIS 10.5.1 spatial analysis tools, automated using the model builder algorithm (Fig. 5). In implementing the criteria, a buffer operation was first carried out with 2500m buffer region around the airports. Then, raster calculator tools were used to extract the airports data within the framework of the buffer region. Using the same raster calculator tools, the geographical locations and size built-up area were also extracted and stored in tabular format. Forest reserve shapefile was converted to raster, to enable integration with extracted airports and built-up areas raster datasets. The participating raster features were overlaid using the weighted sum model, which uses union operation to compute a geometric union of the input features.

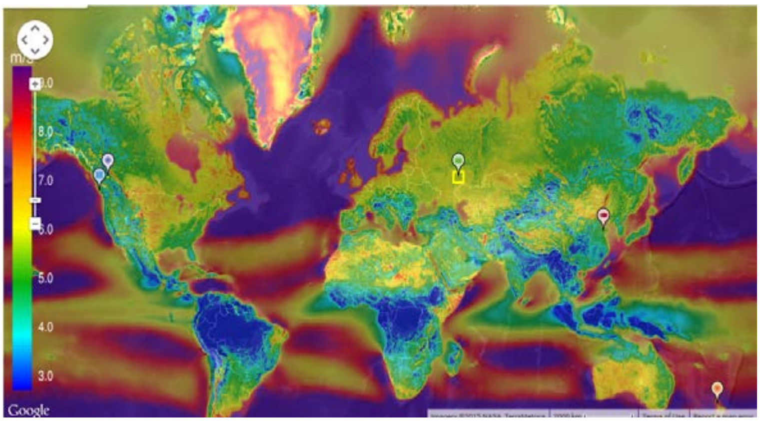

Figure 3: Global Wind Speed Map by Vortex, (Source: URL 1)

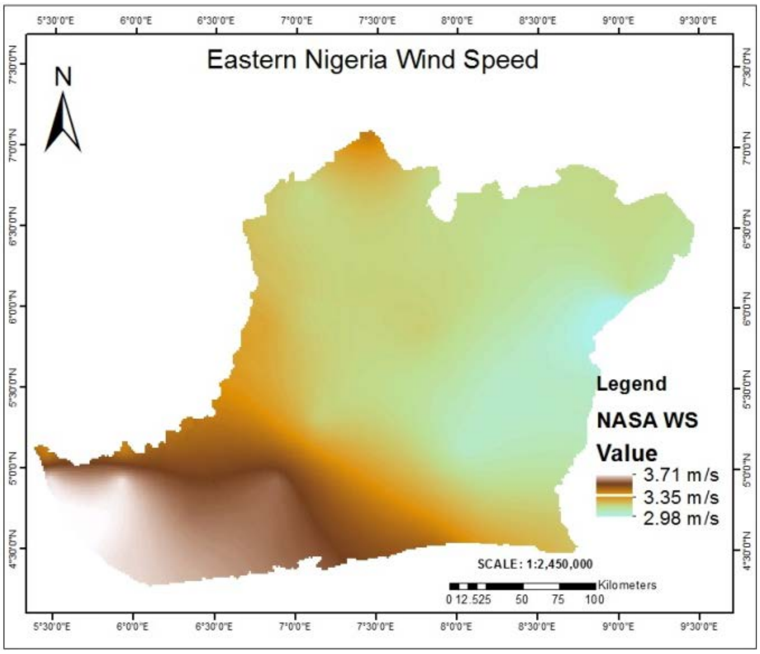

Figure 4: Map from NASA Global Wind Speed for S.E and Part of S.S Nigeria Source: NASA global wind map

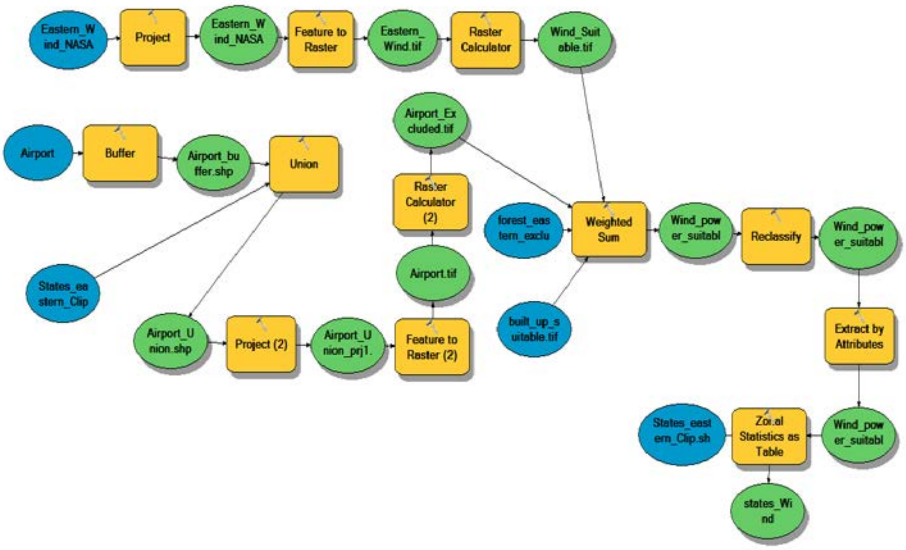

Figure 5: GIS Model Builder for the present MCDA for geospatial evaluation of wind energy potential in the SE and SS regions of Nigeria.

Results and Discussion

Fig. s 6, 7 and 8 show the result of the present geospatial evaluation of wind energy potential in the SS and south eastern part of Nigeria. Fig. 6 (labeled as wind speed suitability) identified the potential and non-potential zones based on wind data. It seemed that buffering the airports located within these areas at 2500m has a significant effect in deflecting and polarizing the wing source to the area marked as high potential. Fig. 7 provides five ranks (based on the weighting scheme applied on the raster pixel values) of wind energy, potential based on the integration of the parameterization datasets. Excluded forest areas and built-up area may have some impacts on the direction and magnitude of wind energy within the high potential areas. In this figure the areas depicted in green are the areas within the acceptable range of wind speed. While the other areas are not within the acceptable wind speed range. The figure shows that all the areas within the south of the study area have great potentials. This is crucial in that it provides information on the localized wind source within the study area. Fig. 8 provides a dot map of all the areas within the study area that has demonstrated great potentials for wind renewable energy and these are within the southernmost section comprising of the states of Bayelsa, Rivers, Akwa-Ibom and southern part of Abia state. The rest of the study area show very low potential, which are not significant considering the adopted thresholds, except for the northernmost section of Enugu state.

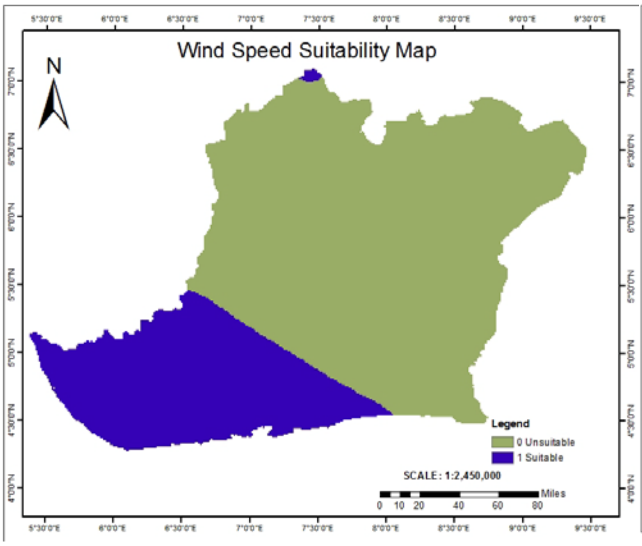

Figure 6: Wind suitability map of SEand SS.

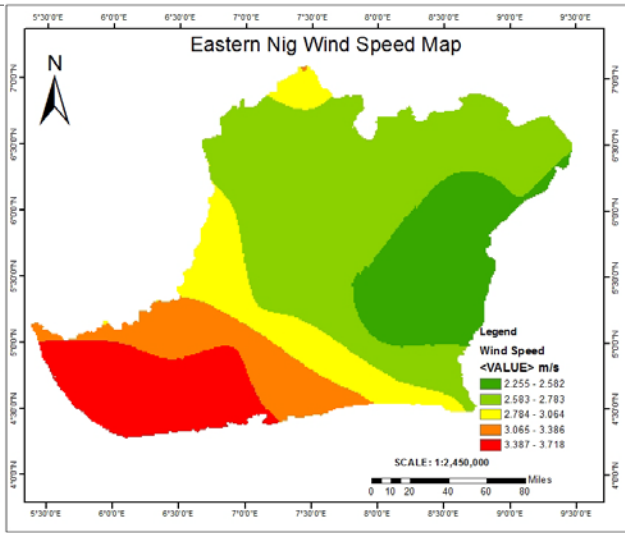

Figure 7: Wind Speed Suitable Factor Map

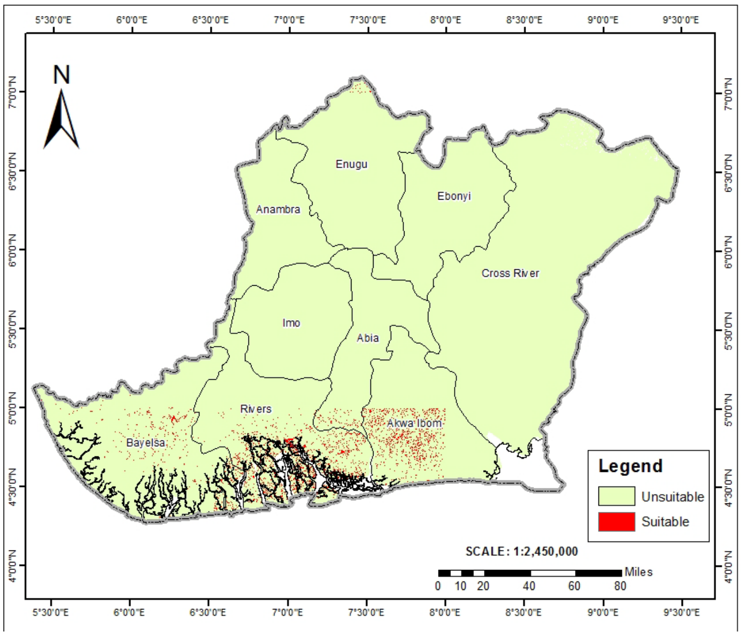

Figure 8: Wind Energy Potential Map of SEand SS.

The land sizes of the wind energy potential areas are calculated based on the size of the pixel and the total sum or pixel count for each zone under consideration. For the participating Nigerian states within the study area, the values of the spatial extent of the wind energy potentials are as follows: Rivers State: 505,000,000sq.m or 50,500Ha, Akwa-Ibom State: 346,500,000sq.m or 34,650Ha, Bayelsa State: 160,000,000sq.m or 16,000Ha, Abia State: 27,000,000sq.m or 2,700Ha and Enugu State: 8,500,000sq.m or 850Ha. The total land area for wind energy suitable sites to 1,047,000,000sq.m or 104,700Ha. Table 4 summarizes these data, while Fig. 9 presents this data statically with a simple pie chart.

Table 4: Land sizes of the wind energy potentials computed for the Nigerian states within the study area

STATES	COUNT	AREA (Sq.m)
Abia	108	27000000
Akwa-Ibom	1386	346500000
Bayelsa	640	160000000
Enugu	34	8500000
Rivers	2020	505000000
		1047000000

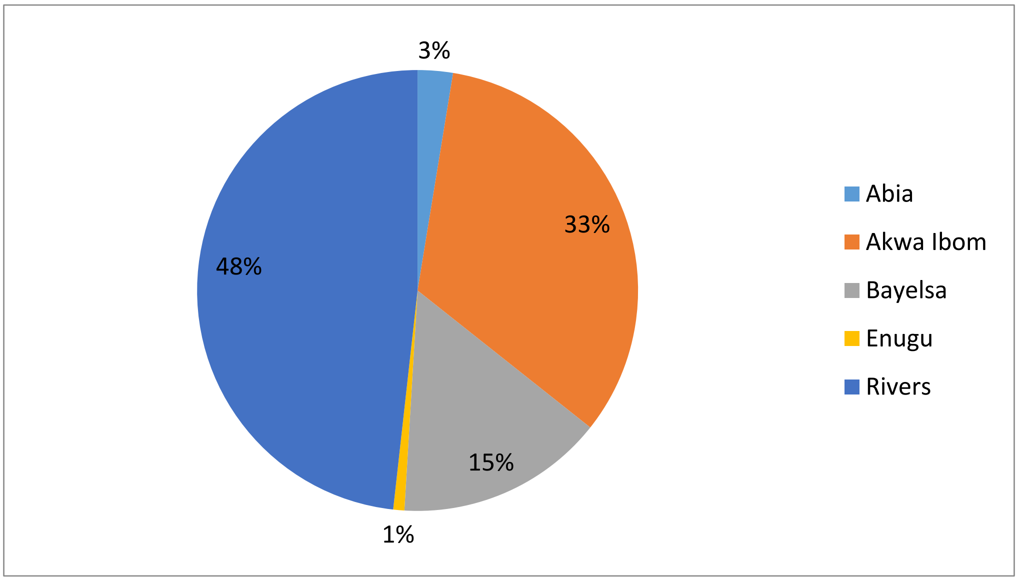

Figure 9 Percentage of Wind Potential sites in States

Due to the number of parameterization factors that were applied to this model, it was crucial to determine the sensitivity of each of the factors to the overall wind energy potential of the study area. In the present research, the vortex global wind map was easily accessible, so it was used to assess the sensitivity of wind speed. From the base map, the vortex map representing the study area was extracted with technical details as follows: (i) resolution ranges from 3-1km, (ii) heights are at 60, 80, 100, and 120m; (iii) data period – long-term mean wind, temperature and density data of 10 years' period. Although these details constrain one-to-one matching of details, it was possible to undertake a visual inspection of the derived wind energy potential map, foregrounded by the global vortex map (See Fig. 10). From this perspective, there are some agreement with the wind energy potential map depicting similar areas within the global vortex wind map. Thus, wind speed shows a major sensitivity to the final output of this research. This highlights the critical importance of wind speed to the present evaluation within the present study area.

Conclusion

The federal government of Nigeria recently embarked on a developmental project which is harnessing the wind energy with the aim to enhance electricity supply across the country. Rimi village in Katsina state of Nigeria's north-west geopolitical region is the pilot area, but there are ample speculations that the project will be extended to other parts of the country.

Investment into wind renewable energy potential within the context of Nigeria must follow a standard procedure, and therefore investigations into the possibilities and scopes of sites with potentials for wind energy are inevitably fundamental. This is the main rationale of the present research, which is in fact a novel contribution to research towards renewable energy and efficient national electrification within the context of the Nigeria.

The present research employs a multi criteria decision analysis (MCDA) ideology within a geospatial technology platform to integrate a plethora of datasets and from them develop a model of wind energy potential sites within the SEand part of SS regions of Nigeria. Wind energy was evaluated based on wind speed, extracted from NASA's global wind speed data, and integrated with data on airports at 2500m buffer, forest reserve and built-up areas.

From the result of this research, there is a considerable amount of potential for wind energy found mostly in the southernmost part of the study area, although there are specs of such potentiality in location within the northern part of Enugu state. Rivers state encloses most of the potential locations. Altogether, the study reveals a potential area amounting to 104,700 Ha land area, merely 1.2% of the total case study. Upon a sensitivity analysis by visual inspection of the new model, foregrounded by vortex global wind speed map, the result shows a great deal of sensitivity to wind speed which highlights the critical importance of wind speed to the present evaluation within the present study area.

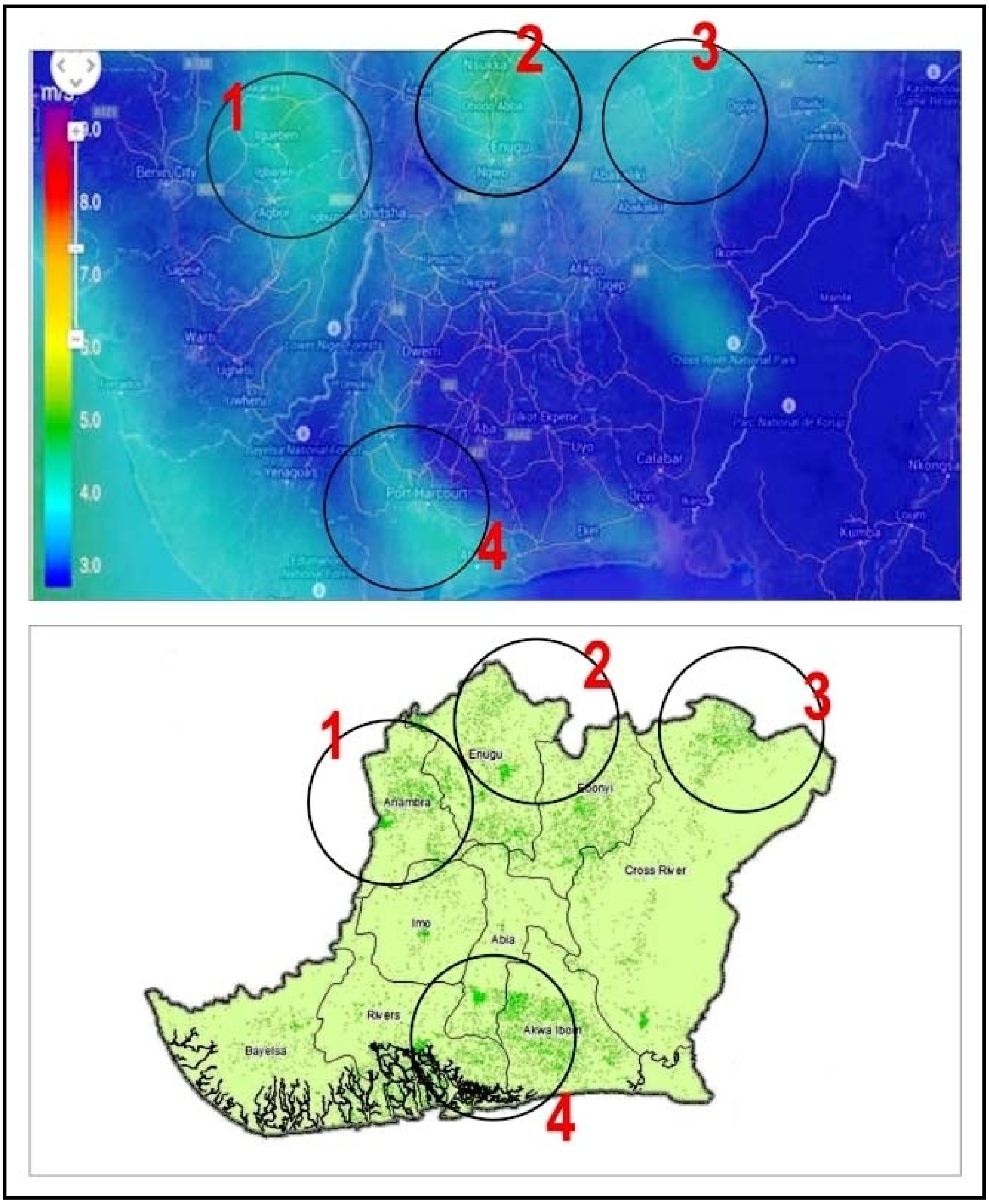

Figure 10: Sensitivity analysis of wind speed to the overall wind energy potential

Wind farms can be located in this area, although it is a rather small-scale investment in a renewable energy resource considering that the consumable amount of energy in the study area is in a steady increase. Stakeholders and experts in energy economy will find that the need to protect this potential energy location from indiscriminate urban development and other anthropogenic activities is overwhelming. This research and its output are recommended as a base for further research towards the development of renewable energy power sector, most especially now that the sole dependent on the fossil energy, despite being a source of hazard to our environment, has evidently proved to be incapable of driving a sustainable energy within Nigeria's geopolitical and economic development.

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