Using Geographic Information System to Identify Areas Suitable for Wind Farm Construction in Kenya

Linet Makori
Department of Resource Analysis, Saint Mary's University of Minnesota, Minneapolis, MN 55904

Keywords: Geographic Information Systems (GIS), Wind Farm, Analytical Hierarchy Process (AHP), Multiple Criteria Decision Making (MCDM), Kenya

Abstract

The goal of this study was to use GIS to identify areas suitable for wind farm construction. Kenya has two commercial wind farms. With these, the country has only exploited minor wind energy resources available to it for electricity generation. While wind speed is often considered the main factor in determining the location for wind farms, there are other criteria considered when identifying sites for wind farm construction. Economic, social, technical and environmental factors collectively play a role in the selection of the sites. This project entailed establishing site selection criteria and categorizing the criteria into factor criteria that describe the degree of appropriateness for the different locations of the area of study or constraint criteria that define areas of exclusion. Using Geographic Information Systems (GIS), Analytical Hierarchy Process (AHP) and Multiple Criteria Decision Making (MCDM) method, separate factor and constraint maps were generated and the resulting data layers combined in a Geographic Information Systems (GIS) environment and suitable areas were extracted to create the suitable areas map. A total area of 18,103 square miles was found suitable for wind farm construction which is equivalent to 8% of the total study area.

Introduction

Background

With growing use of renewable energy in Africa and the gradual decrease in the cost of wind power generation, wind power generation is becoming more competitive compared to traditional fossil fuels. Consequently, wind as a renewable source of energy is being used by many countries.

In spite of 80% of Kenya's electricity emanating from renewable sources of energy, the country has not exploited all renewable energy resources available to it. Wind has been a minor portion of Kenya's renewable source of electricity (Kiplagat, Wang, and Li, 2011). Some of the main sources of commercial and private renewable energy in Kenya include hydropower, geothermal, biomass, solar, and wind; wind energy has been popular in Kenya since the 19^{th} century primarily for water pumping with very little involvement in power generation (Kiplagat *et al.*, 2011).

The country has generating most of its electricity from hydropower which over time has proven to be unreliable and unsustainable (Kazimierczuk, 2019). As stated by Pueyo (2018), between the years 2000 and 2006, the rate of electricity access in Kenya rose by 57%. Even with this increase, the country's national grid produced electricity has been of poor

Makori, L. 2020. Using Geographic Information System to Identify Areas Suitable for Wind Farm Construction in Kenya. Volume 23, Papers in Resource Analysis. 14 pp. Saint Mary's University of Minnesota University Central Services Press. Winona, MN. Retrieved (date) http://www.gis.smumn.edu

quality in addition to it not being adequate to support its populace.

One of the United Nations Sustainable Development Goals (UN SDGs) calls for universal access to energy by 2030. This has resulted in support and numerous initiatives started in the African region geared towards energy access. Still, the global commitment may not be achieved by 2030 (Chirambo, 2018). According to Pueyo (2008) there are challenges faced by the Kenyan electricity sector in its efforts to achieve the universal access to affordable energy, while ensuring economic growth, strengthening of the existing power systems, and upholding the 2016 Paris climate change mitigation agreement. This has brought about several initiatives like, Sustainable Energy for All, the African Union's Programme of Infrastructure Development in Africa (PIDA), Power Africa, and the Africa-EU Energy Partnership, together with community efforts to address some of the challenges experienced (Kazimierczuk, 2019).

Despite the limited experience in the use of wind power in Kenya, challenges experienced in using the other sources of energy have resulted in a tremendous growth in the interest for wind power generation (Montusiewicz, Gryniewicz-Jaworska, and Pijarski, 2015). The first commercial wind farm in Kenya was commissioned in 2009 at Ngong Hills- Kajiado County (Kiplagat *et al.*, 2011), and the second one, which is the largest in the continent, was commissioned in 2019 in Turkana County (Kazimierczuk, 2019). This growth is expected to rise even more in the future, especially as the resource is still greatly underutilized (Ayodele, Ogunjuyigbe, Odigie, and Munda, 2018).

This study's goal, therefore, is to use GIS to identify areas suitable for wind farm construction in the Kenya.

Study Value and Importance

Electricity is identified as one of the critical determining factors for the welfare of human beings and the economic growth of a country (Szurek, Blachowski and Nowacka, 2014). So, increasing access to energy in Kenya and the African region at large has the potential of not only improving the economic status of the country but also combating climate change among other benefits (Chirambo, 2018). Accordingly, adopting renewable energy technologies into the electricity generation sources can help alleviate some of the challenges being experienced; this is with energy being highly interconnected with social economic development, hence forming an essential factor for sustainable development and poverty eradication (Mentis, 2017).

Kenya, like most African countries, strives to attract investors in wind energy and other renewable resources by creating a conducive environment (Kazimierczuk, 2019). Montusiewicz *et al.* (2015) indicate that encouraging investors alone is not enough; identifying the most suitable locations for wind farms ensures profitability and overall success of such projects. Consequently, being able to identify these locations before the construction of wind farms contributes positively to the projects' performance.

Study Area

Kenya is a country in East Africa with an area of 224,081 mi^2 and a population of more than 51.39 million people. With a coastline on the Indian ocean, the country boarders South Sudan to the northwest, Uganda to the west, Juba land province of Somalia to the east, Tanzania to the south, and Ethiopia to the north. This is shown in Figure 1.

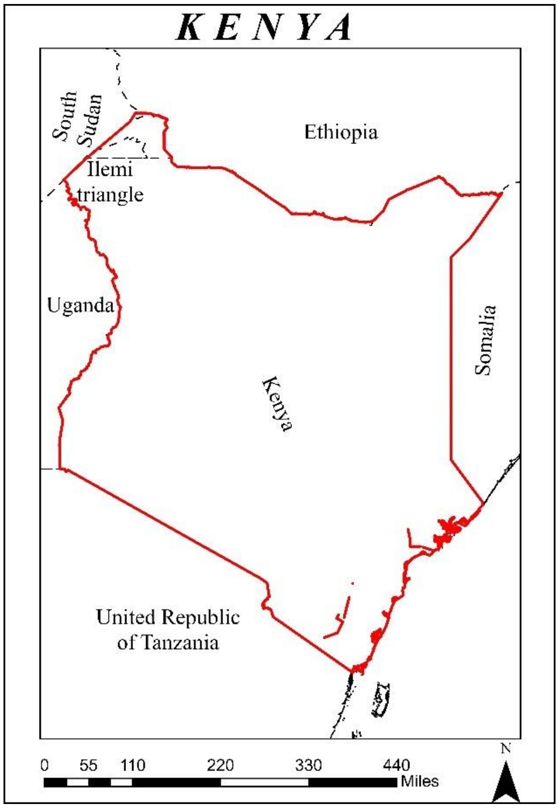

Figure 1. Kenya a country in East Africa bordering South Sudan to the northwest, Uganda to the west, Juba land province of Somalia to the east, Tanzania to the south and Ethiopia to the north. It has an area of 224,081 mi^2 and a population of more than 51.39 million people.

Study Overview

This project identifies suitable areas for the construction of wind farms, while considering multiple criteria for site selection. The methods used are MCDM and AHP. Criteria identified for this study were categorized into either constraints or factors. The constraints were converted to binary where suitable areas were coded 1 and unsuitable areas coded 0 to generate the constraint map. Using pairwise comparison based on the literature and subject matter experts (SMEs) recommendation, factors for the study were weighted and the weighted overlay operation was used to create the factor map, which together with the constraint map were overlaid to generate the suitable areas map. Several operations including buffering, filtering, clipping, overlaying and reclassification were applied on the data and results were presented in figures and tables.

Methods

This section details the methodology used for the project. This includes data acquisition and preparation, analysis methods, site selection criteria and related processes for identifying areas suitable for wind farm construction.

Data Acquisition and Sources

The project used a number of different datasets in either vector or raster format. The data was acquired from different sources. The data used and their sources is outlined in Table 1.

Data Preparation

The downloaded datasets were prepared for analysis. This involved masking and clipping datasets to have areas within the area of study boundaries and ensuring all datasets were in the correct coordinate system: Arc 1960 UTM Zone 37S.

Analysis Methods

Multiple Criteria Decision Making (MCDM)

MCDM entails making decisions while considering multiple usually conflicting criteria. MCDM is used to solve various

Table 1. A list of all the datasets used in this study and their sources.

DATA (YEAR)	SOURCE
Wind speed (2020)	Global Wind Atlas
DEM(10 meters) (2018)	Jet Propulsion Laboratory conducts for NASA
Gridline (2017)	The World Bank
Road Network (2018)	UN Office for the Coordination of Humanitarian Affairs (OCHA) website
Woodlands (2018)	Food and Agriculture Organization of the United Nations (FAO) website.
Lakes (2018)	UN Office for the Coordination of Humanitarian Affairs (OCHA) website
Protected areas (2014)	United Nations Environment World Conservation Monitoring Centre (UNEP-WCMC) website.
Rivers (2018)	UN Office for the Coordination of Humanitarian Affairs (OCHA) website
Boundary (2020)	UN Office for the Coordination of Humanitarian Affairs (OCHA) website
Airports (2019)	UN Office for the Coordination of Humanitarian Affairs (OCHA) website

site selection problems by incorporating statements of preference from experts represented by different parameters, quantities, weighting schemes, and goals (Bennui, Rattanamanee and Puetpaiboon, 2007).

Analytical Hierarchy Process (AHP)

AHP is a measurement theory that derives ratio scales from paired comparisons for both discrete and continuous data, reflecting the relative strength of preferences and feelings. The nonlinear framework allows for simultaneous consideration of variables, permitting deductive and inductive thinking as well as establishing measures in both the physical and social domains (Saaty, 1987). AHP can also be used in the aggregation of priority for the hierarchy structure by applying the principles of decomposition, comparative judgments, and synthesis of priorities (Malczewski, 2004).

Measurement for this theory is through pairwise comparisons and relies on judgements of experts to derive priority scales. According to Saaty (1987), these comparisons are made using a scale of absolute judgements that represents how much more one element dominates another with respect to a given attribute.

GIS (Geographic Information System)

GIS is a system used for manipulating, analyzing, and storing geographical data. GIS systems over the years have evolved to be useful tools for site selection based on various conditions and conflicting objectives (Bennui *et al*., 2007). For this study, ArcGIS Pro 2.4.0 was used to manipulate, edit, and overlay the different layers of datasets.

Site Selection Criteria

A wide-ranging and complex sets of factors are considered when determining suitability of an area for wind farm construction (Bennui *et al*., 2007). Eastman, Jin, Kyem, and Toledano (1995) identify two types of criteria: constraint and factor criteria that support decision-making. This project was based on these criteria.

Factor Criterion

Eastman *et al.* (1995) explains a factor criterion detracts from the suitability of a specific alternative and is measured on a continuous scale. These criteria describe a degree of appropriateness for all the areas in study. Factors considered for this project were wind speed, slope, proximity to gridlines, and proximity to roads.

Wind speed is considered the most important factor when determining the location of a wind farm (Konstantinos, Georgios, and Garyfalos, 2019). A viable wind power project requires regular and sufficient wind speed. As referenced in Ayodele *et al.* (2018), Ayodele, Jimoh, Munda and Agee (2012) state that, according to the National Renewable Energy laboratory (NREL) classification, areas with wind speed above 4.4 meters/second at 10 m anemometer height are appropriate for wind farm sites while those below are not appropriate.

For ease of transportation of equipment, selected sites should be accessible by road. Konstantinos *et al.* (2019) state locations already accessible or near to the existing road network are considered for wind farm locations. A safe distance of 500 meters to the road network should be observed, while areas more than 10,000 meters from roads are classified as unsuitable (Ayodele *et al.*, 2018).

Generally, cost of a project is a major aspect when setting up wind farms, hence, having wind farms close to existing gridlines helps reduce the initial construction cost of a wind farm. However, a distance of 250 meters is observed between the gridline and the wind farm (Ayodele *et al.*, 2018). This also minimizes the challenges associated with long electricity transmission distances.

Accessibility of the location is a factor to consider when choosing a location for wind farm construction. As seen in Konstantinos *et al.* (2019), quoting the Ministry of Environment Planning and Public works (2001), vehicles can access areas with inclinations of up to 20%. Wind farms are therefore best suited for low slope areas because of their low turbulence and ease of accessibility (Ayodele *et al.*, 2018).

Constraint Criteria

Constraints limit the alternatives being considered; they are based on a Boolean criterion where items for consideration are coded with 1 with those not for consideration coded with 0 (Eastman *et al.*, 1995). They represent the areas of exclusion, and the constraints for this study include forests and woodlands, lakes and areas within 500 meters of lakes, rivers and streams and areas within a 200 meters buffer of streams and rivers, airports and areas within 5,000 meters of airports and protected areas such as tourist attractions, historical sites, and wildlife sanctuaries.

Woodlands and forest areas, because of their obstructive nature, are considered not suitable for wind farms; neither are wet areas suitable for electric connections, hence they should not be considered for wind farm installation (Ayodele *et al.*, 2018). In addition, according to Konstantinos *et al.* (2019), remote barren lands with low land use are of preference for wind farm locations. To preserve lakes' shoreline, a buffer distance of 500 meters from the wind farm is maintained (Effat, 2017) and according to Bennui *et al.* (2007), a safety zone within 200 meters from rivers is maintained.

Ayodele *et al.* (2018) notes wind farms could impede water ways hence river areas are not suitable for wind farm locations. In addition, areas such as archeological sites, historic sites, tourist areas, wildlife, and areas of cultural heritage are not included in wind farm suitability studies (Ayodele *et al.*, 2018).

According to Sarpong and Baffoe (2015), airports are not suitable for wind

Table 2. Reclassification of factor criteria classes assigned values 0 to 4; 4 representing extremely suitable areas and 0 representing unsuitable areas. The measurement units for proximity to roads and gridlines was in meters, Slope in % and wind speed in meters per second. Wind speed's classification was based on NREL (National Renewable Energy Laboratory) classification while the other factors' was based on wind energy experts' advice.

Roads (meters)	Gridlines (meters)	Slope (%)	Wind Speed(meters/second)	Value	Class
<500	<250	>20	<4.4	0	Unsuitable
>15001	>20000	10.1-20.0	4.4-5.0	1	Less Suitable
10001-15000	10001-20000	6.1-10.0	5.1-6.0	2	Suitable
5001-10000	5001-10000	3.1-6.0	6.1-7.0	3	Very Suitable
501-5000	251-5000	<3.0	>7.0	4	Extremely suitable

farms because radio transmission and radar signals may be interfered by wind turbines; a minimum distance of 5,000 m from the airports is considered as well.

Factor Map

The factor map was created based on the factor criteria aforementioned. Factors describe a degree of suitability of an area for a given purpose. A factor map is the result of combined factors achieved by the steps outlined below.

Euclidian Distance

Using the Euclidian distance tool, Euclidean distance was established for road networks and electricity transmission gridline datasets. This established proximity of different locations in the study area to the amenities.

Slope

Slope indicates the incline of an area. Using the DEM (Digital Elevation Model) dataset and the slope tool in ArcGIS Pro, the slope of the study area was calculated in percentage to establish the incline of the study area.

Reclassification

The four factor datasets were then classified and reclassified using the Reclassify tool into the classes and values shown in Table 2 and symbology was updated for consistency and presentation.

Criteria Weights

Using the input and judgment of three wind energy experts from the Rural Electrification and Renewable Energy Corporation – Kenya, the criteria weights for the factors were calculated. With this, pairwise comparison was used to establish the weights for the different criteria. Each criterion was compared to each of the other three criteria and was assigned a value between 1 and 9 where 1 represents equal importance and 9 extreme importance. The assigned values were then normalized before establishing the criteria weights.

Weighted Overlay

The criteria weights calculated were used with the ArcGIS Pro weighted overlay tool which overlays several rasters and weights, each according to its importance or weight to generate the weighted factor map.

Factor Binary Map

The factor binary map for this project was reclassified into binary form (0 for unsuitable areas and 1 for suitable areas). From the factor map classifications, areas with values 0 and 1 (unsuitable and less suitable classes) were coded 0 for unsuitable whereas areas with values 2, 3, and 4 (suitable, very suitable and extremely suitable classes) were coded 1 for suitable.

Constraint Map

Constraints are areas excluded from the study. Using the constraint criteria, the constraint map was created by creating a 500 meters buffer on the lakes, a 200 meters buffer on rivers and streams, and a 5,000 meters buffer on airports. Areas in the regions described above, together with woodlands and protected areas were coded 0 for unsuitable while the other areas were coded 1 for suitable. The different constraint criteria datasets were combined into a constraint map using the ArcGIS Pro cell statistic tool which calculates statistics from multiple rasters on a pixel-by-pixel basis.

Suitable Areas Map

Suitable areas map contains areas identified to be suitable for wind farm construction.

Combined Map

The combined map was created by combining the binary factor map and the constraint map. This was achieved by using the ArcGIS Pro Boolean And function that performs a Boolean And operation on the cell values of two input rasters. With this, if both input values are true (one), the output value is 1. If one or both inputs are false (zero), the output is 0.

Extraction and Conversion

From the resulting dataset, the Select By Attributes tool was used to extract areas coded 1 for suitable. This dataset (Suitable areas) was further converted to polygons by the Raster to Polygon conversion tool. The converted dataset was additionally manipulated using the Aggregate Polygons Cartography tool that combines polygons within a specified distance of each other into new polygons. Areas separated by a distance of 150 m were aggregated. The output formed the final map of suitable areas for wind farm construction.

Results

This section details the findings of the project based on the methodology. This includes calculated criteria weights, factor criteria, constraint map, combined map, and the suitable areas map.

Criteria Weights

Of the four factors, wind speed has the highest impact on identifying locations suitable for wind farm construction with a weight of 57%, followed by proximity to gridlines with a weight of 27% and slope having the least influence with 6%. A consistency ratio of 0.068665 was attained.

Factor Criteria

The reclassified factor criteria maps are shown in Figures 2 – 5. These maps show the suitability of the different locations of the area of study with each of the four factor criteria (wind speed, slope, proximity to road network, and proximity to grid line) classified into 5 suitability

Table 3. Factors' criteria weights on the judgements of three wind experts from the Rural Electrification and Renewable Energy Corporation – Kenya. Weights were calculated using pairwise comparison of the AHP (Analytical Hierarchy Process) where the assigned weights for the different pairs, 1 represents equal importance comparison, 3 moderate importance, 4 moderate plus importance, 5 strong importance, 7 very strong importance, 1/3 reciprocal of moderate importance, ¼ reciprocal of moderate plus importance, 1/5 reciprocal of strong importance and 1/7 reciprocal of very strong importance. Wind speed had the highest criteria weight with 57% and Slope had the lowest criteria weight of 6%.

	Wind speed	Slope	Road	Gridlines	Criteria weight %
Wind speed	1	7	7	3	57%
Slope	1/7	1	1/3	1/5	6%
Road	1/7	3	1	1/4	10%
Gridlines	1/3	5	4	1	27%

classes (unsuitable, less suitable, suitable, very suitable, and extremely suitable) with values of 0, 1, 2, 3, and 4 respectively.

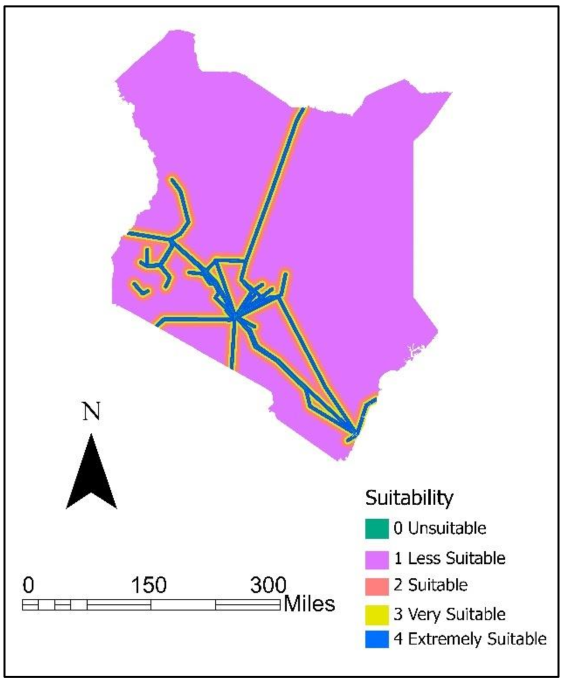

Figure 2. Reclassified map of proximity to gridline criterion classified into five classes 0 to 4 where 0 for unsuitable areas that are less than 250 meters from the gridline, 1 for less suitable representing areas more than 20,000 meters from the gridlines, 2 for suitable areas that are within a distance between 10,001 meters and 20,000 meters from the gridlines, 3 for very suitable areas that are a distance of between 5,001 meters and 10,000 meters from gridlines and 4 representing extremely suitable areas within a distance of between 251 meters and 5,000 meters.

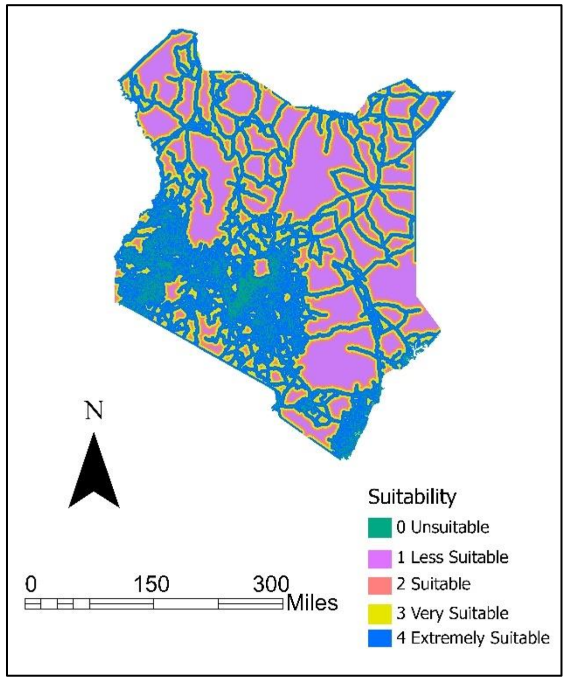

Figure 3. Reclassified map of proximity to the road network criterion of the different locations in the study area classified into 5 classes 0 to 4; where 0 for unsuitable areas that are less than 500 meters from roads, 1 for less suitable representing areas more than 15,000 meters from the road network, 2 for suitable areas that are within a distance between 1,0001 meters and 15,000 meters from roads, 3 for very suitable areas that are a distance of between 5,001 meters and 10,000 meters from roads and 4 representing extremely suitable areas within a distance of between 501 meters and 5,000 meters from roads.

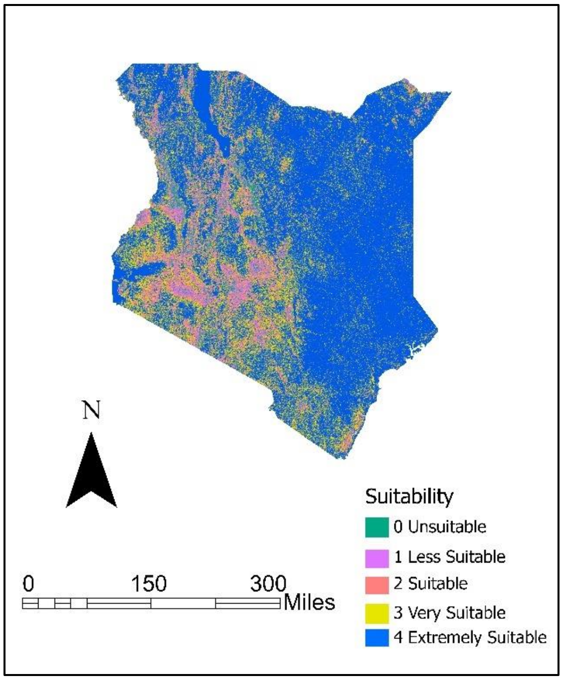

Figure 4. Reclassified map of the slope of the study area classified into 5 classes 0 to 4, with 0 for unsuitable areas with a slope greater than 20%, 1 for less suitable representing areas with a slope between 10.1% and 20%, 2 for suitable areas with a slope between 6.1 and 10, 3 for very suitable areas with a slope between 3.1% and 6%, and 4 representing extremely suitable areas with a slope less than 3%.

Factor Map

This was a combination of the individual reclassified factor maps using weighted overlay and assigned criteria weights as shown in Figure 6 Based on the factor criteria, the less suitable areas account for approximately 76% of the country while the extremely suitable areas add up to approximately 0.1% which is 224 square miles.

Factor Binary Map

The binary factor binary map for this study is shown in Figure 7. With the reclassification, the majority of the study area is classified as unsuitable; this makes up approximately 171,136 square miles of the study area.

Constraint Map

The constraint criteria for the study were analyzed and combined to create the constraint map shown in Figure 8. The map depicts that the unsuitable areas excluded from this study were fairly distributed across the country.

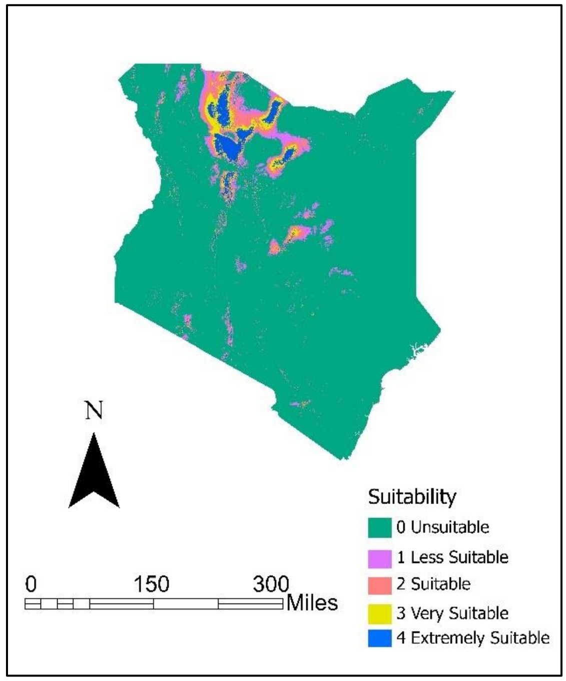

Figure 5. Reclassified wind speed of the study area classified into 5 classes 0 to 4, with 0 for unsuitable areas with a wind speed of less the 4.4 meters per second, 1 for less suitable representing areas with wind speed between 4.5 meters per second and 5 meters per second, 2 for suitable areas with wind speed between 5.1 meters per second and meters per second, 3 for very suitable areas wind speed between 6.1 meters per second and 7 meters per second, and 4 representing extremely suitable areas with wind speed greater than 7 meters per second.

Combined Map

The factor binary map and the constraint map were combined to form the combined map; a binary map shown in Figure 9.

Suitable Areas Map

The final map of the identified areas suitable for construction of wind farms is shown in Figure 10 and a map representing total suitable area by county is shown in Figure 11. The suitable areas are spread across the country with the greater eastern part of the country having minimal areas.

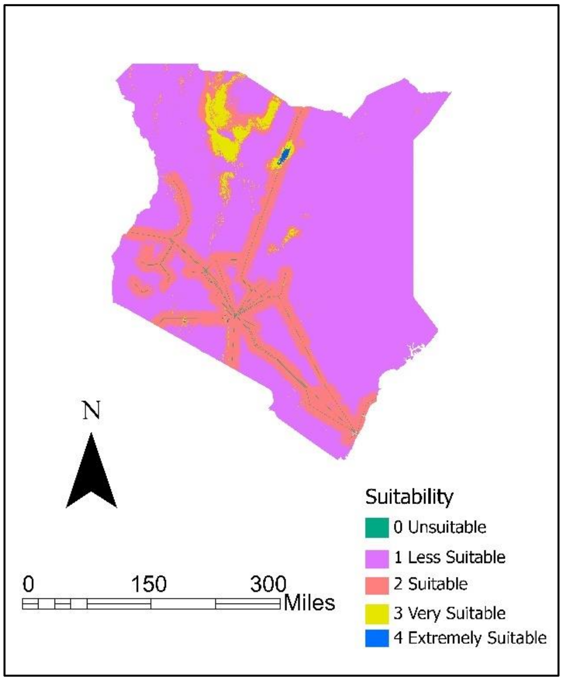

Figure 6. Weighted Factor map classified into 5 classes 0-4; 0 representing unsuitable areas, 1 for the less suitable areas, 2 for the suitable areas, 3 for the very suitable areas and 4 for the extremely suitable areas.

Discussion

This section offers a detailed discussion of the results of the study, the limitations, and recommendations.

Criteria Weights

The study's consistency ratio of 0.06866 is acceptable because it falls below the highest acceptable ratio of 0.1. This is an indication that the pairwise comparison matrix passed the consistency test.

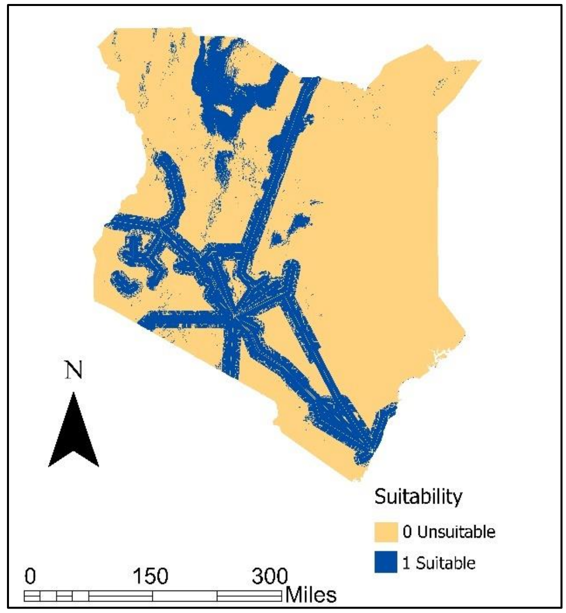

Figure 7. Weighted factor map converted to binary with 0 showing the unsuitable areas and 1 showing the suitable areas.

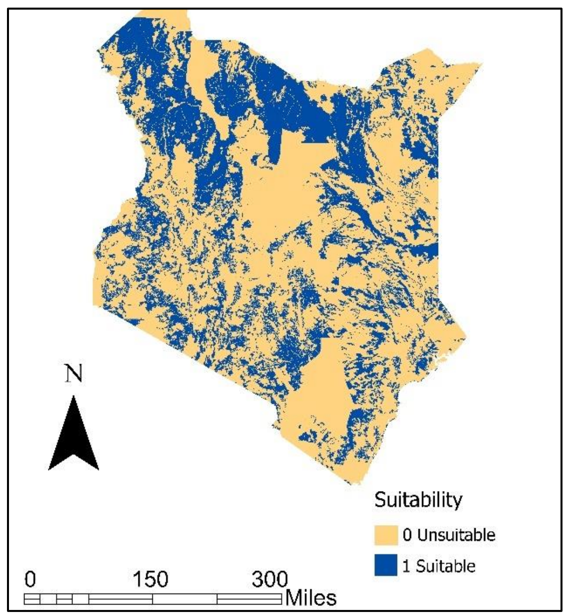

Figure 8. Constraint map with all constraint criteria datasets incorporated. Unsuitable areas in cream represented by value 0 and suitable areas in dark blue represented by value 1.

With the criteria weights shown in Table 3, it can be observed that from the wind energy experts' judgements, wind speed accounts for close to 60% of the criteria weights and the remaining 40% is assigned to other criteria (proximity to road networks, proximity to electric gridlines, and slope).

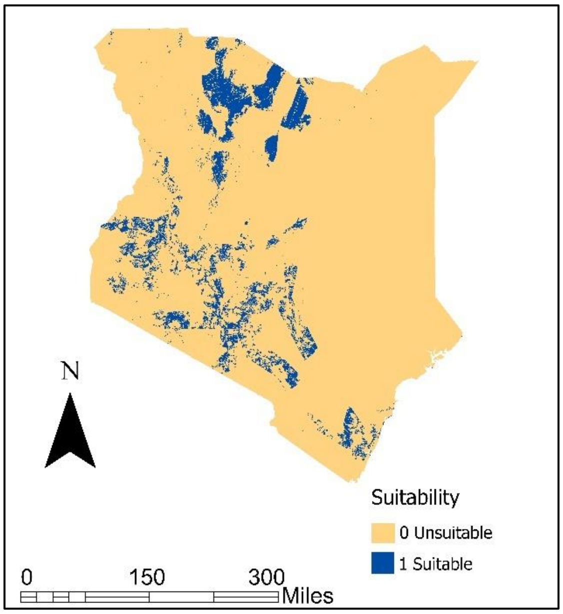

Figure 9. A combined map of the factor binary map and the constraint map incorporating all the factors and constraints for the study. Unsuitable areas in yellow represented by value 0 and suitable areas in dark blue represented by value 1.

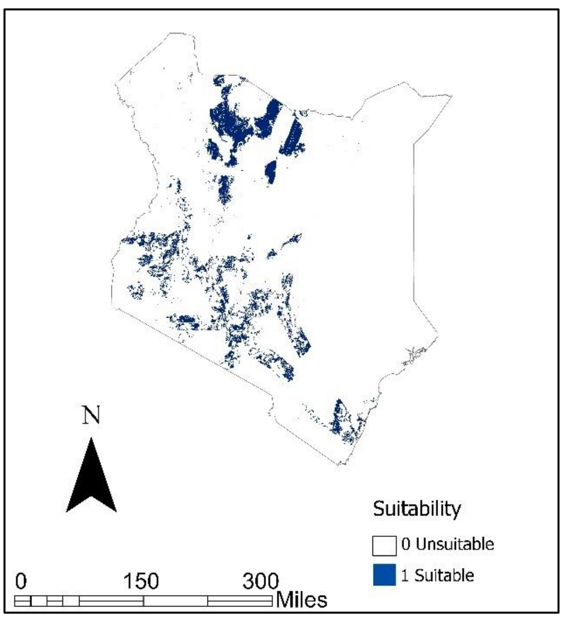

Figure 10. Extracted areas suitable for the construction of wind farms shown in dark blue and the unsuitable areas, with value 0 in white totaling to 18,103 square miles.

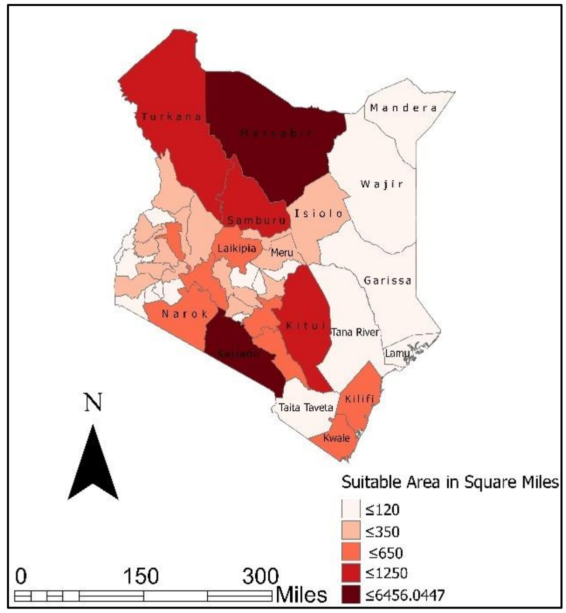

Figure 11. Graduated scale presentation of suitable areas in square miles per county. With Marsabit County having the largest area of 6,456.0447 square miles, Garissa and Trans-Nzoia Counties having the lowest areas of 0 square miles.

This is an indication that while wind speed or the wind resource is important, other aspects should also be considered when identifying sites suitable for wind farm construction in Kenya.

Factor Criteria

The proximity to gridlines map shown in Figure 2 shows the unavailability of electric gridline in the eastern part and part of the north western region of the study area. Figure 2, showing proximity to road networks, shows a fair distribution of road networks across the study area. As shown in Figure 4, the majority of the study area has a slope of < 3% hence categorized as extremely suitable. The wind speed map (Figure 5) indicates that the majority of the study area's wind speed is less than 4.4 meters/second hence classified as unsuitable for wind farm construction. The factor binary map shown in Figure 7 shows that the majority of the study area is classified as unsuitable.

Constraint Criteria

Due to legal, environmental, and social factors, areas excluded from the study were defined in the constraint criteria. As shown in the constraint map in Figure 8, the restricted areas are spread across the study area and accounted for about 66% of the total area. This therefore means that an area of approximately 150,347 square miles of the study area was excluded due to its unsuitability for wind farms.

Suitable Areas

Identified areas suitable for construction of wind farms in Kenya are shown in Figure 10 and total to approximately 18,103 square miles which translates to 8% of the total country area. Marsabit County in the northern part of the country had the largest share of the suitable areas for the construction of wind farms with an area of 6,456 square miles as shown in (Table 4). Table 4 shows five counties in Kenya with the largest areas suitable for construction of wind farms.

Table 4. The five counties in Kenya with the largest area identified as suitable for construction of wind farms.

County	Area in Square Miles
Marsabit	6456.044693
Kajiado	1283.27959
Kitui	983.807777
Turkana	847.914318
Samburu	646.7607326

From the suitable areas map shown in Figure 10, a better part of the eastern side of the country has minimal or no areas identified in the study as suitable for wind farm construction. This is due to the amount of wind resource available as well as the unavailability of an electricity transmission network in the region. While there is a proposed electricity grid set to pass through the region, this study used data on the existing electricity grid. The 5 counties with the least area of suitable areas are shown in Table 5 below.

Table 5. The five counties in Kenya with the least area identified as suitable for construction of wind farms.

County	Area in Square Miles
Mandera	1.239797
Lamu	0.800742
Tana River	0.0562
Trans-Nzoia	0
Garissa	0

Based on the judgements of wind experts, wind speed had the highest weight. The suitable areas map shown in Figure 10 reveals that areas with higher wind speed had more suitable areas for wind farm construction. This shows a correlation between the location of a wind farm and wind speed.

Limitations

This project is subject to several limitations, one being that land ownership of the study area was not established. Also, due to a vast study area and unavailability of data, cost of land was not considered and the results have not been compared with those of other known approaches for the same study area.

Recommendations

Recommendations would include establishing land ownership and cost of land in the area before embarking on wind farm construction and conducting similar research with a different methodology and comparing results to those of this project as well as perhaps comparing newer data over time in the same study area.

Conclusions

The goal of this project was to use GIS to identify areas suitable for wind farm construction in Kenya. To achieve that, multiple criteria were used to include factor and constraint criteria. The factors (slope, wind speed, proximity to gridlines, and proximity to road network) and constraints (waterbodies (rivers and lakes), forests and woodlands, airports and protected areas) were separately analyzed first.

Using AHP, criteria weights for the factors of the study were calculated and applied in the weighted overlay tool to create the factor map. The constraints were combined as well to create the constraint map and further a combined map in binary, 1 for suitable areas and 0 for the unsuitable areas, from combining the factor and constraint maps.

The suitable areas, coded with the value 1 were then extracted to form the suitable areas map. A total area of 18,103 square miles was found suitable for wind farm construction which is equivalent to 8% of the total study area.

.

Acknowledgements

I would like to thank Dr. John Ebert and Greta Poser for continually supporting and mentoring me throughout this program. A special thanks Tom Sego, Paul Nyariki and Douglas Tong'i, all of the Rural Electrification and Renewable Energy Corporation – Kenya for the valuable information they provided in regards to evaluating the study's factors and general expert guidance. Lastly, I would like to thank my family and friends for their support throughout the pursuit of my graduate degree.

References

Ayodele, T. R., Ogunjuyigbe, A. S. O., Odigie, O., and Munda, J. L. 2018. A multi-criteria GIS based model for wind farm site selection using interval type-2 fuzzy analytic hierarchy process: The case study of Nigeria. Applied Energy, 228, 1853–1869. https://doi-org.xxproxy.smumn.edu/10.1016/j.apenergy.2018.07.051.

Ayodele, T. R., Jimoh, A. A., Munda, J. L., and Agee, J. T. 2012. Wind distribution and capacity factor estimation for wind turbines in the coastal region of South Africa. Energy Conversion & Management, 64, 614–625. https://doi-org.xxproxy.smumn.edu/10.1016/j.enconman.2012.06.007.

Bennui, A., Rattanamanee, P., and Puetpaiboon, U. 2007, "Site Selection for Large Wind Turbine Using GIS", International Conference on Engineering and Environment, Songkhla, Thailand, pp. 1-2.

Eastman, J. R., Jin, W., Kyem, P. A. K., and Toledano, J. 1995. "Raster Procedures for Multi-Criteria/Multi-Objective Decisions", Photogrammetric Engineering and Remote Sensing, Vol. 61, No. 5, pp. 539-547.

Chirambo, D. 2018. Towards the achievement of SDG 7 in sub-Saharan Africa: Creating synergies between Power Africa, Sustainable Energy for All and climate finance in-order to achieve universal energy access before 2030. Renewable & Sustainable Energy Reviews, 94, 600–608. https://doi-org.xxproxy.smumn.edu/10.1016/j.rser.2018.06.025.

Kazimierczuk, A. H. 2019. Wind energy in Kenya: A status and policy framework review. Renewable & Sustainable Energy Reviews, 107, 434–445.

https://doi-org.xxproxy.smumn.edu/10.1016/j.rser.2018.12.061.
Kiplagat, J. K., Wang, R. Z., and Li, T. X. 2011. Renewable energy in Kenya: Resource potential and status of exploitation. Renewable and Sustainable Energy Reviews, 15(6), 2960–2973. https://doi-org.xxproxy.smumn.edu/10.1016/j.rser.2011.03.023.
Konstantinos, I., Georgios, T., and Garyfalos, A. 2019. A Decision Support System methodology for selecting wind farm installation locations using AHP and TOPSIS: Case study in Eastern Macedonia and Thrace region, Greece. Energy Policy, 132, 232–246. https://doi-org.xxproxy.smumn.edu/. 10.1016/j.enpol.2019.05.020.
Malczewski, J. 2004. GIS-based land-use suitability analysis: a critical overview. Progress in Planning, 62(1), 3–65. https://doi-org.xxproxy.smumn.edu/10.1016/j.progress.2003.09.002.
Mentis, D. 2017. Spatially explicit electrification modelling insights: Applications, benefits, limitations and an open tool for geospatial electrification modelling. Retrieved May 26, 2020 from https://search-ebscohost-com.xxproxy.smumn.edu/login.aspx?direct=true&db=edsndl&AN=edsndl.oai.union.ndltd.org.UPSALLA1.oai.DiVA.org.kth-207801&site=eds-live.
Montusiewicz, J, Gryniewicz-Jaworska, M., and Pijarski, P. 2015. Looking for the Optimal Location for Wind Farms. Advances in Science and Technology Research Journal, (27), 135. https://doi-org.xxproxy.smumn.edu/10.12913/22998624/59095.
Saaty, R. W. 1987. The analytic hierarchy process—what it is and how it is used. Mathematical Modelling, 9(3), 161–176. https://doi-org.xxproxy.smumn.edu/10.1016/0270-0255(87)90473-8.
Sarpong D., and Abalone, P. E. 2015. Selecting suitable sites for wind energy development in Ghana. *Ghana Min J 2015*; 16:8–20.
Sego, T., Nyariki, P., and Tong'I, D. 2020 Personal communication. Rural Electrification and Renewable Energy Corporation – Kenya. 2020. June 2020 – August 2020.
Szurek, M., Blachowski, J., and Nowacka, A. 2014. GIS-based method for wind farm location multi-criteria analysis. Mining Science, 65. https://doi-org.xxproxy.smumn.edu/10.5277/ms142106.
Pueyo, A. 2018. What constrains renewable energy investment in Sub-Saharan Africa? A comparison of Kenya and Ghana. World Development, 109, 85–100. https://doi-org.xxproxy.smumn.edu/10.1016/j.worlddev.2018.04.008.