Wind Energy Assessment in Costa Rica using Multicriteria Evaluation

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Abstract

The wind energy sector has been experimenting a rapid growth in Costa Rica since the last decade and is forecasted to expand even more. In this regard, it is necessary to evaluate the wind energy resources and define the most suitable areas to install new wind farms. In this study, Geographic Information Systems (GIS) are used to identify the cantons with the highest energy potential, using a multicriteria evaluation. The criteria are the wind speed, terrain slope, land cover, distance to the transmission lines and to the roads, and population density. The terrestrial protected areas and those that are located 500m away from the roads and 1000m from the transmission lines are excluded. The results spot Tilarán, Cañas and Bagaces as the regions with higher wind energy potential and estimate that less than 25% of the country's total area is highly or moderately suitable.

Keywords: Suitability Map, Wind Speed, Multicriteria Evaluation, Costa Rica

1 INTRODUCTION

Costa Rica was the first country in Latin America to install a wind farm, and currently wind energy supply accounts for 15.88% of the national annual energy production (REN21, 2020). The government is committed to fully decarbonize by 2050, producing electricity only from renewable energy sources by 2030 (Gobierno de Costa Rica, 2018).

Although hydroelectricity is the main source of energy nowadays (Table 1), its cost of investment, which is around 4,200 US$/kW, is relatively high comparing it to the capital expenditures of the onshore and offshore wind energy generation, of approximately 3,351 US$/kW and 2,100 US$/kW, respectively (Teske, S., Morris, T., Nagrath, 2020).

Accordingly, it is not a beneficial strategy to rely uniquely on hydroelectrical energy; the electricity share must be diversified and wind energy has become an alternative for the zones where hydroelectricity is not guaranteed (Esa, 2005).

The generation of energy from wind turbines in Costa Rica will continue to increase and therefore its potential must be assessed, fact that sets the main goal for this study: identifying the most suitable areas to build wind farms considering certain factors, such as wind speed, terrain slope, population density and area availability.

Some studies have previously achieved this objective for small regions as, for instance, Triunfo in Brazil (de Araujo Lima & Bezerra Filho, 2010), Córdoba in Spain (Díaz-Cuevas, 2018), Nebraska and Iowa in United States (Grassi et al., 2012; Miller & Li, 2014).

In addition, there are other authors (e.g. Siyal et al. (2015) for Sweden and Kim et al. (2014) for South Korea) that have defined whole countries as their study area.

Table 1. Energy production by source in 2019 (Instituto Costarricense de Electricidad, 2019).

Source		%	GWh
Renewable	**Hydroelectric**	69,18	7826,66
	Wind	15,88	1796,34
	Solar	0,08	9,59
	Geothermal	13,37	1512,58
	Bagasse	0,64	72,05
Non-renewable	**Thermal**	0,85	95,64

Up until now, there is no study that has analyzed Costa Rica's wind energy potential and, given that less than 1% of the total energy production comes from non-renewable sources, which could proceed from wind farms, there is no margin for further delay.

By using ArcGIS Pro 10.7.1, one of the GIS application from Esri, a multicriteria evaluation is carried out in this analysis to determine the wind farm development potential of the country.

2 DATA

In order to model the suitability of each region, six criterions (Figure 1, Table 2) are selected:

- Wind speed: Directly related to the energy potential (Genc et al., 2005), the wind is the key factor for the turbines to generate electricity.
- Elevation and terrain slope: It is known that the slope has a negative impact on the wake effect of the wind turbines, reducing their speed (Tian et al., 2015).
- Land cover: To avoid constructing in less desirable areas, e.g. urban zones, and protect the forests (Rodman & Meentemeyer, 2006).
- Distance to the transmission lines: To save in constructing new ones to supply electricity.
- Distance to the roads: To have better access for construction and maintenance.
- Population density: To avoid visual and noise pollution (Klæboe & Sundfør, 2016).

Table 2. Criteria, data source and format.

Criteria	Data source	Data format	Resolution / Feature type
Wind speed at 50m	Global Wind Atlas (World Bank & Technical University of Denmark, 2020)	Raster	250m
Elevation and slope	CGIAR-CSI (Reuter et al., 2007)	Raster	50m
Land cover	Global Land Cover (Buchhorn et al., 2020)	Raster	100m
Transmission lines network	GeoComunes (Geocomunes, 2018)	Vector	Polylines
Roads network	Mapcruzin (Mapcruzin, 2019)	Vector	Polylines
Exclusionary protected areas	Sistema Nacional de Áreas de Conservación (Sistema Nacional de Áreas de Conservación, 2020)	Vector	Polygons
Population density	Instituto Nacional de Estadística y Censos (Instituto Nacional de Estadística y Censos, 2011)	XLS	-

All the layers are projected into the coordinate system WGS 1984 Costa Rica TM 90 and those in vector and XLS format are converted to raster.

The boundaries of the 82 cantons of Costa Rica are spatially joined with the population density data and the slope is derived from the Digital Elevation Model of Consortium for Spatial Information (CGIAR-CSI).

It is assumed that the amount of people per area did not change much throughout the years as the census available data is from 2011.

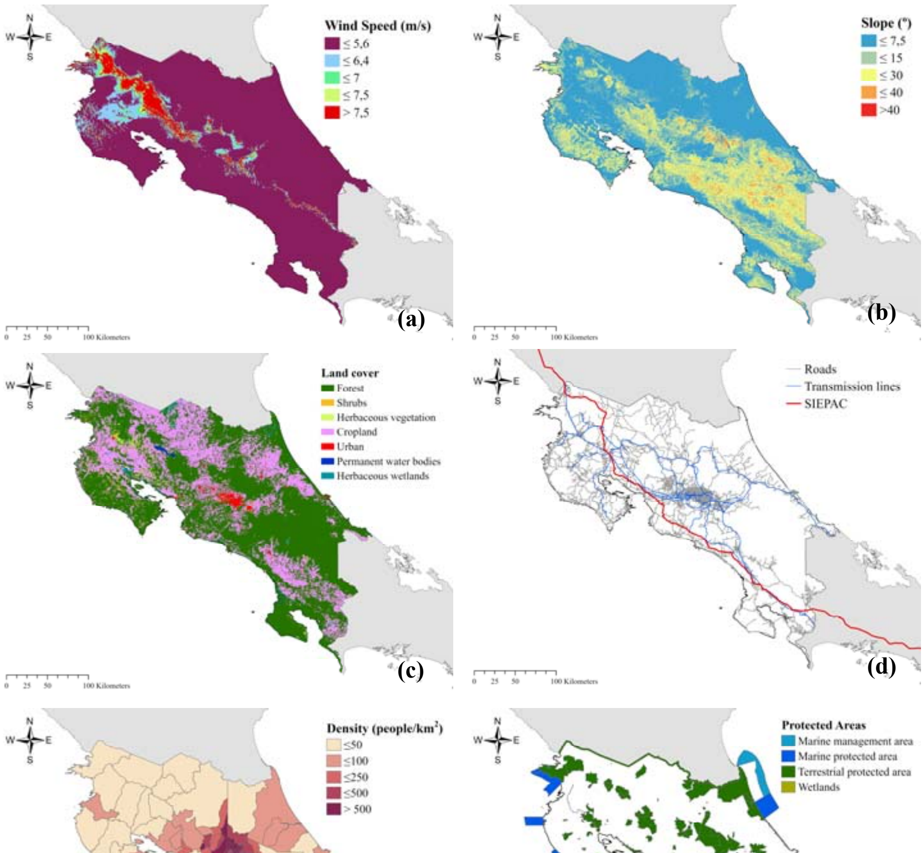

Figure 1. Average wind speed at 50m (a), terrain slope (b), land cover (c), transmission lines and roads network (d), population density (e) and protected areas (f) of Costa Rica.

3 METHODOLOGY

In accordance with the state-of-art research from Miller & Li (2014), the decision criteria must be weighted and scored (Table 3), taking into account their importance and suitability.

In this case, weights from 1 to 3, being 1 the least important and 3 the most relevant, are assigned to each factor. The wind speed is considered the main factor influencing the locations suitability, while the population density is set as the least important criteria.

On the other hand, the criteria need to be reclassified according to suitability scores, that range from 0, if they are totally unsuitable, to 4, for the best performance of the wind farms.

Table 3. Weights (horizontally) and suitability scores (vertically) for each criterion. The vegetation and wetland are herbaceous and the water bodies are permanent.

	Wind speed (m/s)	**Slope (º)**	**Land cover**	**Distance to transmission lines (km)**	**Distance to roads (km)**	**Density (people/km²)**
Weights / **Score**	**3**	**2**	**2**	**2**	**2**	**1**
4	> 7.5	[0, 7.5]	Cropland	(0, 5]	(0, 1]	(0, 50]
3	(7, 7.5]	(7.5, 15]	Vegetation	(5, 10]	(1, 2.5]	(50, 100]
2	(6.4, 7]	(15, 30]	Shrubs	(10, 15]	(2.5, 5]	(100, 250]
1	(5.6, 6.4]	(30, 40]	Forests	(15, 20]	(5, 10]	(250, 500]
0	[0, 5.6]	> 40	Urban / Water bodies / Wetlands	> 20	> 10	> 500

The wind speed suitability is determined as in the classes of wind power density from specified by the National Renewable Energy Laboratory (2007), that estimate that mean wind speeds superior to 7.5m/s at 50m above sea level provide around 500W/m^2 power densities and those inferior to 5.6m/s are not enough.

Terrain slopes that are less than 7.5º are ideal for the construction and maintenance of wind parks, whereas building on slopes higher than 40º is almost impossible. Slopes between 30 and 40º are not recommended because of the resulting wind speed reduction.

With regard to the land cover, the highest scores are assigned to the cultivated and managed vegetation and agriculture fields and to the herbaceous vegetation. Shrubs and forests are poor locations for offshore wind farm development, which is impossible in urban areas, permanent water bodies and herbaceous wetlands.

The investment on power sector infrastructure, the transmission and distribution systems, will increase in the next decade and it is essential to account for the minimum construction costs (Kishore & Singal, 2014). The new wind turbines have to be installed near the already existent transmission lines, at a distance of less than 1km in the best scenario, and close to the roads.

The areas with the higher population density are located in Costa Rica's capital, San José, and its surroundings, and are unsuitable. By contrast, there are many cantons with less than 50 people per km^2 that would be really appropriate places to install new wind farms if the other criterion were not deemed.

The workflow to define the most suitable areas is shown in Figure 2. Firstly, the wind speed, slope, land cover and population density are reclassified considering the suitability scores (Table 3) and the Euclidian distances are calculated from the roads and from the transmission lines to each point in the geographical space. The resulting layers are reclassified.

Once the six criterions are reclassified, it is possible to combine them using the *Raster Calculator* tool and extract the unsuitable areas, i.e. the ones that are protected. The roads, and transmission lines are dismissed after applying a buffer of 500m and 1000m, respectively.

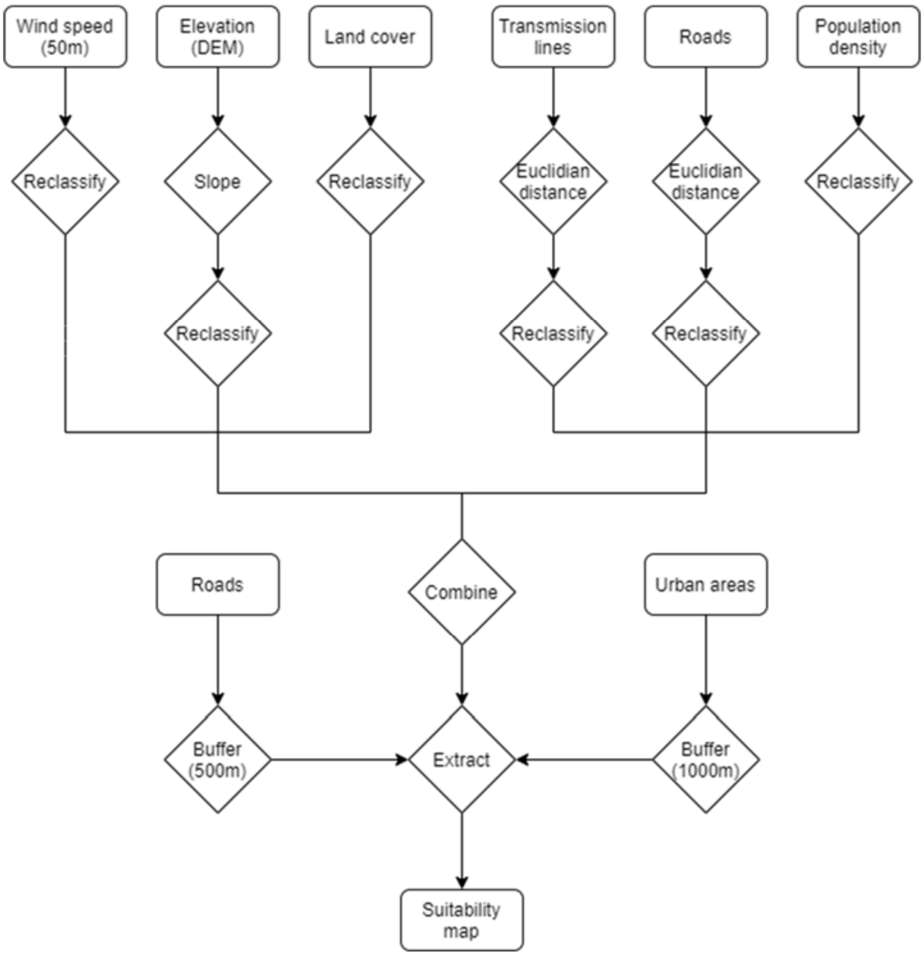

Figure 2. Flowchart to create the suitability map for wind farm development.

4 RESULTS AND DISCUSSION

The map for wind farm development in Costa Rica is shown in Figure 3 and the suitability is described in five categories: high, medium, low, very low and unsuitable.

The terrestrial protected areas and wetlands account for more than 25% of the area and consequently there are many unsuitable locations, up to 50.81% (Table 3). It is also observed that most existent wind farms are found in the medium and high suitability areas, which are in total approximately 13,106 km^2.

Table 4. Estimated areas for each suitability category.

Category	Unsuitable	Very low	Low	Medium	High
Area (km^2)	25,979	1,436	10,613	12,047	1,058
Area (%)	50.81	2.81	20.75	23.56	2.07

The cantons with the highest suitability for wind farm development are Tilarán, Cañas and Bagaces in the north-west and, on the contrary, the areas adjacent to Chirripó National Park and La Amistad International Park are the least suitable.

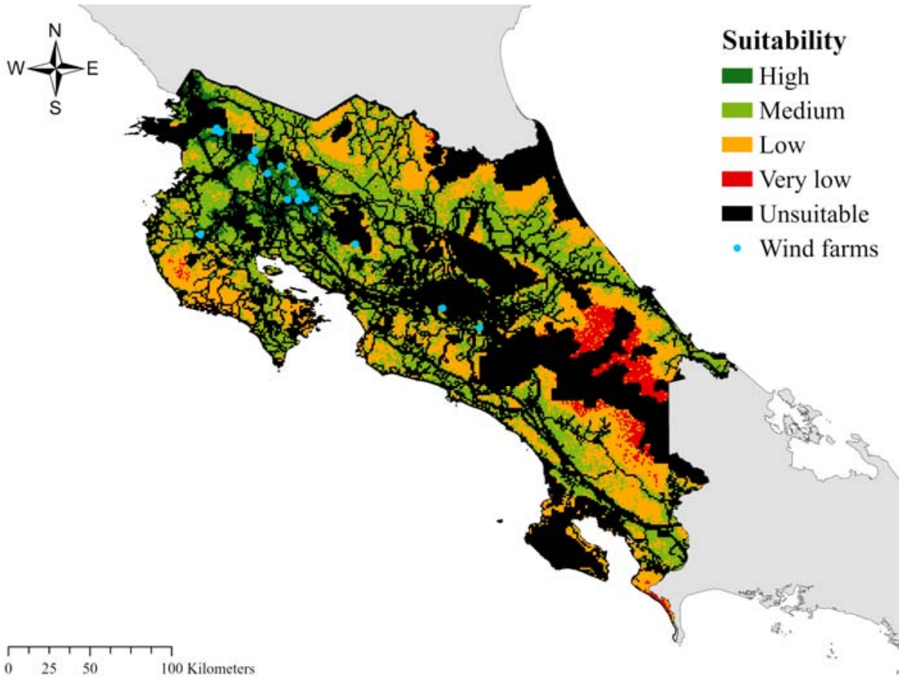

Figure 3. Wind farm development suitability map and existent wind farms in Costa Rica.

Due to the map resolution and alterable criteria in the evaluation, this map can be useful as a guide for prospect projects to develop wind farms in Costa Rica, but should not be considered as a unique resource to decide the location of the park installation.

5 CONCLUSIONS AND FUTURE WORK

This research estimated the offshore wind energy potential for wind farm selection using a GIS-based methodology in Costa Rica. Six criteria are selected to conduct a multicriteria evaluation: wind speed, terrain slope, land cover, distance to the transmission lines and to the roads, and population density. The terrestrial protected areas are excluded from the analysis.

As a result, the country has areas of at least 12,047 and 1,058km^2 that are moderately and highly suitable, respectively. Tilarán, Cañas and Bagaces are the best cantons to produce wind energy, mainly due to the wind energy potential and low population density.

Using diverse weights and types of multicriteria evaluation would be a natural continuation of this study, which could be also improved by varying the buffers and euclidian distance parameters. Other data sources with higher resolution would also be necessary to assess the suitability with better precision.

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