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Conference paper

AHP Optimization Method for Windy Site in Costal Annaba Region

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ABSTRACT

The majority of countries worldwide rely on fossil fuels as a source of energy. Nevertheless, the utilization of this source of energy is associated with significant environmental problems. To reduce their impact, innovative clean energy solutions are needed. Wind power is currently the most cost-effective and competitive renewable energy source. The identification of an optimal location for a wind farm is a crucial aspect of the decision-making process. This involves considering numerous factors, including wind speed, terrain quality, distance to the power grid, road network, housing, agricultural land, and environmental concerns. The use of Multi-Criteria Decision Method (MCDM) and Geographic Information System (GIS), along with other techniques, facilitates the selection of sites that meet the desired criteria. This study employed GIS and MCDM-AHP methods in order to identify suitable sites for wind farm installation in an eastern Algerian coastal area. In the context of MCDM analysis, it is important to note that not all criteria are of equal importance. Consequently, each criterion is assigned a specific weight to reflect its importance. The weights assigned in this study were calculated using the Analytic Hierarchy Process (AHP). The result was a wind speed suitability map that combined all criteria into two site categories in fact, 20% of the land area is highly suitable and 10% is found to be most suitable.

1. INTRODUCTION

In recent years, the demand for energy has increased due to technological progress and population growth. According to the Global Energy Scenario, approximately 80% of the energy demand is met by the combustion of fossil fuels. This process is leading to an increase in greenhouse gases emissions, which is resulting in a serious environmental problem (Gil-García et al., 2023; Shah et al., 2023; Uusitalo et al., 2017). Due to the seriousness of the situation, governments all over the world have started to

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implement plans for the transition to the use of renewable energy sources (Loring, 2007). Algeria is the largest country in Africa and possesses considerable potential for the development of renewable energy sources, such as solar, wind, hydrogen, geothermal, and bio-power energy (Zahraoui et al., 2021). The state has planned to install approximately 22 GW of renewable energy capacity by 2030, including 1 GW of bio-power energy, 13.5 GW from solar PV, 2 GW from CSP, 15 MW from geothermal, 400 MW cogeneration, and 5 GW from wind energy (Himri et al., 2022). Among all renewable energy sources, wind energy has been identified as a promising solution for generating electricity. It is both environmentally sustainable and economically profitable in the long term (Muhammad et al., 2021). In Algeria, several studies have been carried out to assess wind resources and a number of atlases have been produced (Boudia et al., 2016; Boudia & Santos, 2019; Chellali et al., 2011; Daaou Nedjari et al., 2018; Hammouche, 1991; Kasbadji Merzouk, 2000). These studies show that wind energy is present at different sites across Algeria, with varying levels of strength. The objective of this work is to contribute to the study of wind energy characteristics in Algeria, with a specific focus in Annaba Province, situated in the north-eastern part of the country. The study is carried out in two stages: firstly, the Wind Analysis and Application Program (WAsP) software is used to determine the wind resources of Annaba region and locate the windiest areas. In the second stage, a Geographical Information System (GIS) and Multi-Criteria Decision Making (MCDM-AHP) methodology were used to select the optimal location for the wind farm.

2. MATERIAL AND METHODS

2.1 Description of the Study Area

The Province of Annaba is located 600 km east of the capital, Algiers and extends 80 km along the Mediterranean coast. It covers an area of 1439 km^2, which represents 0.06% of the national territory. Annaba is the fourth largest city in Algeria in terms of population. Its terrain is diverse, consisting of forested mountains, hills, foothills, and plains. The Province also boasts a lake, Fetzara, covering 6600 ha, and the Seybouse River, which is 255 km long. Annaba has a Mediterranean climate, characterized by long, hot and dry summers with an average temperature of 18°C. The winters are mild and humid, with abundant rainfall ranging from 650 to 1000 mm/year (Ministry of Tourism and Handicrafts, 2024).

Fig 1. The localization of the studied area over the Algerian map.

2.2 WAsP Software

WAsP is an industry standard computational tool used in this study to evaluate wind energy and select windy sites within the study region. The program uses a linear model that combines a comprehensive set of models to calculate the effects of obstacles, surface roughness and topography on wind flow (Kamdar et al., 2021; Sheehan et al., 2022). Additionally, it uses a statistical model, namely Weibull distribution, to analyze wind speed and direction data. In this work, 10 years of measurements recorded by the ONM between 2011 and 2020 were used. A two-dimensional grid of wind resources with a resolution of 200 m at 50 m height is obtained for the Annaba region (Figure 2). We notice that the wind speed varies between 3 m/s and 10 m/s. The highest speeds are observed at high altitudes, particularly on mountains. Approximately 50% of wind speed records are around 5 m/s. However, not all of these regions can be systematically eligible for farm establishment. In order for a site to be considered suitable, it is necessary to take into account a number of factors, including its geographical location, climatic conditions, economic context and environmental impact. Seven criteria layers are employed in this study (Table 1).

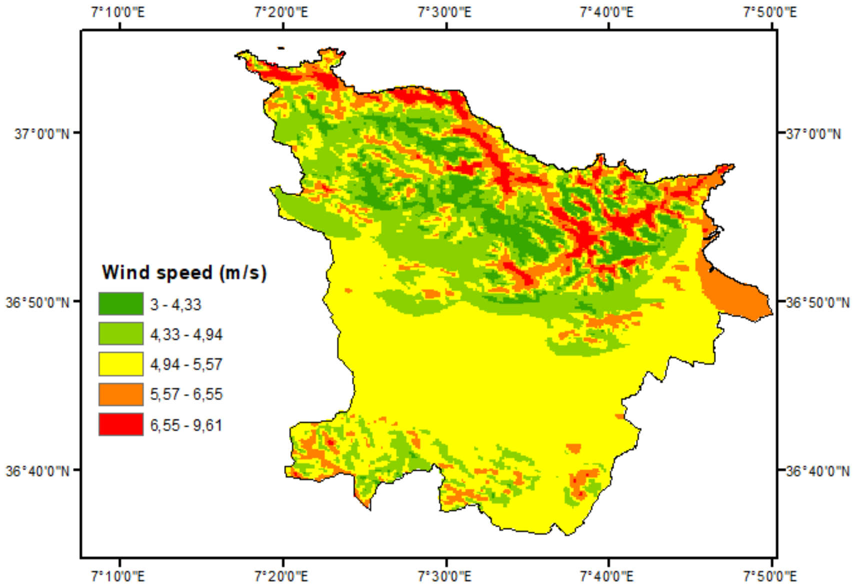

Fig 2. Wind speed map of Annaba at 50 m height

Table 1. Data Layers Criteria.

Criteria	Layers
C1	Annual mean wind speed at 50 m height AGL
C2	Slope
C3	Electric power lines
C4	Urban area
C5	Airport
C6	Elevation
C7	Road network

2.3 MCDM-AHP Method

The criteria layers were combined using the GIS-MCDM approach. The AHP method is used to calculate the weight of the criteria and employs a pairwise comparison measurement mode to quantify the importance of each criterion. We used Table 2, introduced by Thomas Saaty (Saaty & Vargas, 2006) for pairwise comparisons. The comparison matrix in this study is taken from (Islam et al., 2022).

Table 2. Saaty's Pairwise Comparison Scale (Saaty & Vargas, 2006).

Verbal judgment	Numerical value
Absolutely important	9
Strong important	7
Fairly important	5
Weakly important	3
Equally important	1
Intermediate value between above scale values	2, 4, 6, 8

Deriving criteria weights in AHP only makes sense if the comparison matrix is consistent or near consistent. To assess this, (Saaty & Vargas, 2006) has suggested a consistency ratio (CR) as follows:

$$CI = \frac{(\lambda_{max} - n)}{(n-1)} \tag{1}$$

where: λ_{max} is the matrix maximal eigenvalue, n number of criteria, CI is the consistency index. This is used to calculate the consistency ratio, defined as:

$$CR = \frac{CI}{RI} \tag{2}$$

The Random consistency index (RI) values are taken from Table 3.

Table 3. Random index value versus number of criteria (Yavaşoğlu et al., 2019).

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

3. RESULTATS AND DISCUSSIONS

According to the wind speed map layer (figure 2) values, approximately 50% of the land area is suitable for wind farm development, 20% of the land area is highly suitable and 10% is most suitable. In this paper, to avoid damage to the environment, decrease the investment cost and increase the accuracy of site locating, seven criteria have been selected and listed in Table 1. In the second part of this work, The AHP method was utilized to calculate the weights of the criteria (Goepel, 2018). The values of the calculated weights are presented in Table 4 and then allocated to the factor layers, which were subsequently reclassified using the weighted function. The calculated consistency ratio is 0.057 (<0.1) this indicates that MCDM-AHP method produce consistent weights values. Finally, the suitability map (Figure 3) for power plant locations has been obtained. It should be noted that the windiest sites depicted in Figure 2 are not always the same in the MCDM map, as shown in Figure 3. It is evident that certain sites, such as mountains, display a wind speed of 9 m/s in the wind map but eliminated by the application of the MCDM-AHP model due to the strong slope. As illustrated in Figure 3, the optimal locations for the establishment of a wind farm are found in the northwestern region of the area, specifically in Chetaïbi, Treat, and Oued El Aneb. Additionally, the southern region (Eulma) and the northern region (Seraidi) also present promising prospects.

Table 4. Weight values for the considered criteria.

Criteria	C1	C2	C3	C4	C5	C6	C7
Weights (%)	34	30	12	10	7	4	3

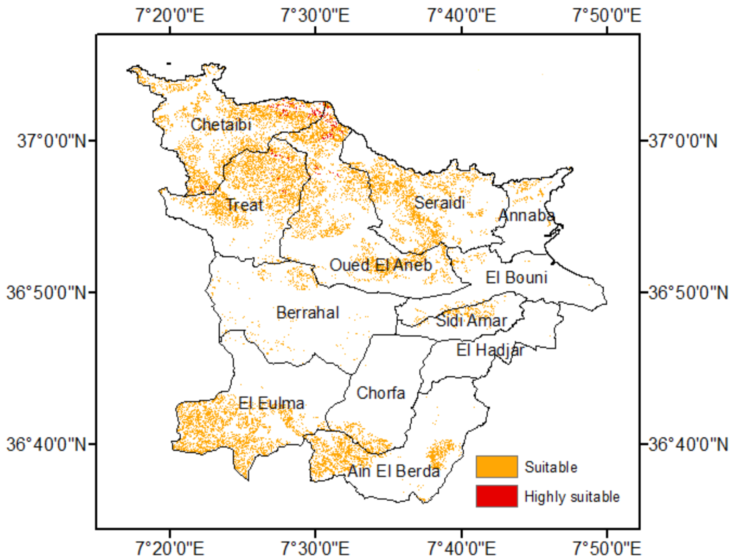

Fig 3. Wind speed suitability map of Annaba Province

4. CONCLUSION

The most crucial criteria for the site selection process have been identified and integrated using the weight function within a geographic information system (GIS) software. The weights are calculated using the analytic hierarchy process (AHP) and then assigned to the criteria layers through pairwise comparisons. The criteria employed in this study may be applied to any wind farm site selection project. The results indicate that the most suitable sites are located in the north, northeast, and south of Annaba. This study can be considered a guide for investors and the government of Annaba Province in the implementation of wind farms. A similar study could be conducted for the selection of sites in other regions of Algeria using different methodologies and criteria.

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