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Determination of suitable areas for wind power plant installation in Şanlıurfa with GIS and AHP

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Abstract

Despite the increasing energy consumption day by day, the demand for energy is also growing. Currently, energy is obtained in two different ways: renewable and non-renewable sources. Non-renewable sources cannot meet the increasing energy demand due to their limited availability. The use of non-renewable sources results in carbon emissions, posing a risk to living beings. Therefore, people have turned to renewable energy sources in search of alternative solutions. Wind energy, as one of the renewable energy sources, stands out as a clean and sustainable energy source. To harness this source, it is necessary to establish Wind Power Plants (WPP). For the efficient operation of these plants, proper site selection is crucial. In this study, Geographic Information Systems (GIS) and the Analytic Hierarchy Process (AHP) method were utilized to determine suitable areas for WPP installation in a part of Şanlıurfa province. Seven criteria were identified to be considered in determining the suitable areas for WPP, including wind speed, land use, slope, distance to power transmission lines, distance to highways, distance to active fault lines, and distance to residential areas. These criteria were compared with each other using the AHP method to establish a priority ranking. Based on this ranking, the areas suitable for WPP installation were evaluated. The evaluation results identified a total area of 42.68 km^2 as highly suitable for WPP installation in the study area.

1. Introduction

As a result of the increasing human population and the desire of people to sustain their lives at higher standards, industry and technology are rapidly advancing. Energy consumption and the need for energy are progressively increasing due to factors such as the development of industry and technology. Non-renewable energy sources like widely used fossil fuels are inadequate to keep up with this rapid change and also contribute to carbon emissions that negatively impact living organisms. Furthermore, the depletion of these resources is inevitable.

Human intellect has always sought to find a way out. The search for alternatives to meet the increasing global energy demand continues. The most important criteria in energy sources are their lack of harm to living organisms and their renewability.

Wind energy, as one of the renewable energy sources, is considered an alternative energy source. Reasons such as the absence of threats to living organisms such as carbon emissions and greenhouse gases, as well as its unlimited availability, have increased the interest in wind energy.

The use of wind energy is continuously increasing worldwide. It stands out as an effective tool in combating climate change and reducing dependence on fossil fuels.

In recent years, the use of wind energy has also been steadily increasing in our country. According to the statistical reports published by the Turkish Wind Energy Association, the installed capacity based on wind energy is provided in Figure 1, and its proportion within the total installed capacity is shown in Figure 2. It can be observed that the installed capacity based on wind energy in our country has increased by approximately 5 times in the last 10 years. Its share within the total installed capacity has also risen from 3.96% in 2012 to 10.81% in 2022 (TUREB, 2023).

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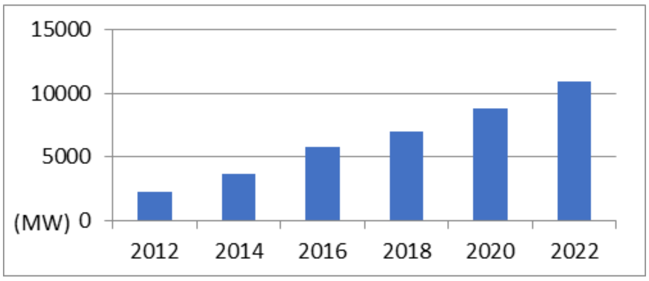

Figure 1. Installed capacity based on wind energy in Türkiye (MW)

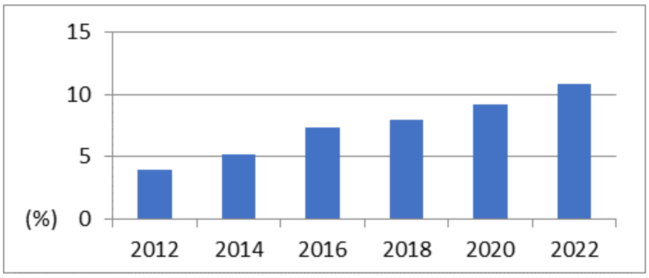

Figure 2. Proportion of wind energy in the installed capacity in Türkiye (%)

To harness wind energy, Wind Power Plants (WPP) are necessary. WPPs convert the kinetic energy of the wind into mechanical energy, which is then used to generate electricity (Hayli, 2001). These facilities consist of various wind turbines placed over large areas at different heights.

In order to obtain energy most efficiently, it is crucial to accurately determine the suitable areas for WPP installation. Environmental impacts, societal effects, geographical factors, and technical requirements should be taken into account during the site selection process. Some criteria considered in similar studies include wind speed, land use, slope, aspect, altitude, distance to residential areas, distance to power transmission lines, distance to highways, distance to airports, distance to rivers and lakes, distance to fault lines, and proximity to bird migration routes. The process of determining suitable areas involves a complex procedure that incorporates multiple disciplines.

In this study, Geographic Information Systems (GIS) were utilized, and the identified criteria were evaluated using the Analytic Hierarchy Process (AHP) method to determine suitable areas for WPP installation.

2. Method

Utilizing information systems is a fast way to process complex data and obtain final results. In this study, Geographical Information Systems (GIS) were employed to perform Multi-Criteria Decision Analysis (MCDA) using the Analytic Hierarchy Process (AHP) methodology.

The AHP method was initially developed by Thomas L. Saaty (Ekiz, Şirin, & Erener, 2022). The AHP method enables the determination of weight criteria based on priority ranking by comparing the determining criteria with each other (Saaty, 1994). AHP evaluates all criteria together and employs pairwise comparisons (Arca & Çıtıroğlu, 2020) to identify the most prioritized criteria, offering a rational and efficient approach to generate solutions (Saaty, 1994).

There are several criteria that are effective in the selection of areas for WPP installation. Since WPPs will interact with the surrounding areas, criteria that may have an impact on the environment, such as proximity to residential areas and land use, should be considered (Memduhoğlu, Özmen, Göyçek, & Kılıç, 2014). In this study, seven influential criteria have been identified. These criteria include wind speed, land use, slope, distance to power transmission lines, distance to highways, distance to active fault lines, and distance to residential areas. Due to minimal variation in altitude within the study area, it was not included in the evaluation. Furthermore, criteria such as proximity to bird migration routes, distance to airports, and distance to lakes and rivers can be considered in larger study areas but were not deemed significant criteria for this particular study area.

Once the criteria have been selected and weighted, they can be analyzed together within the GIS software to identify suitable areas for WPP installation.

2.1. Study Area and Data

The study area has been determined as a region within the boundaries of Şanlıurfa province, as depicted in Figure 3.

Figure 3. Study area

The study area consists of Şanlıurfa city settlement, partially Harran Plain, partially Tektek Mountains, forested areas, pasturelands, meadows, and mixed agricultural lands. It has an approximate area of 2,250.74 km².

The summers are dry and hot, while the winters are rainy. The average wind speed varies between 3.85 m/s and 6.97 m/s at a height of 100 meters (GWA, 2023).

The data corresponding to the identified criteria in this study were obtained from various sources and adapted by cutting them according to the study area boundary. Table 1 presents the collected data.

Some of the data were used directly, while others were transformed before being utilized.

Table 1. Data types and sources of the criteria

Criteria	Data Type	Data Source
Wind Speed	Raster	Global Wind Atlas (GWA, 2023)
Land Cover	Raster	CORINE 2018 (Copernicus, 2023)
Slope	Raster	Alos Palsar DEM (ASF, 2023)
Electrical Transmission Lines	Vector	OpenStreetMap (OSM, 2023)
Highways Network	Vector	OpenStreetMap (OSM, 2023)
Live Fault Lines	Vector	Republic of Turkey, Mineral İnvestigation and Exploration General Directorate (MTA, 2023)
Residential Areas	Raster	CORINE 2018 (Copernicus, 2023)

3. Results

After determining the criteria, a comparison matrix, Table 2, was created to compare these criteria in terms of their relative importance. The comparison matrix contains values that represent the relative importance between criteria (Ömürbek & Şimşek, 2014). For example, the wind speed criterion is three times more important than the slope criterion, indicating that the weight of the wind speed criterion should be higher than the weight of the slope criterion.

All criteria were compared in this manner and assigned specific values. Based on the values obtained from the comparison matrix, the weight criteria for all criteria were determined and presented in Table 2. To assess the accuracy of the weight determination process, the Consistency Ratio (CR) was calculated, resulting in a CR value of 2%. According to Saaty's recommendation, the maximum acceptable consistency ratio is 10%. If the value exceeds this threshold, the comparison matrix needs to be reviewed and revised (Saaty, 1990).

Through the ArcGIS software, criteria were transformed, distance analysis was conducted, and reclassification processes were performed to create thematic maps for each criterion. The reclassified thematic map for the land use criterion is provided in Figure 4.

Within the study area, potential areas for wind energy installation were analyzed, and a result map, Figure 5, was created. In this map, the results were categorized into five hierarchical classes: "not suitable," "slightly suitable," "moderately suitable," "suitable," and "highly suitable."

It is observed that there is a total area of 42.68 km² classified as "highly suitable" for wind energy installation. The "suitable" class covers an area of 486.56 km², the "moderately suitable" class covers 950.42 km², the "slightly suitable" class covers 646.96 km², and the "not suitable" class covers 124.12 km².

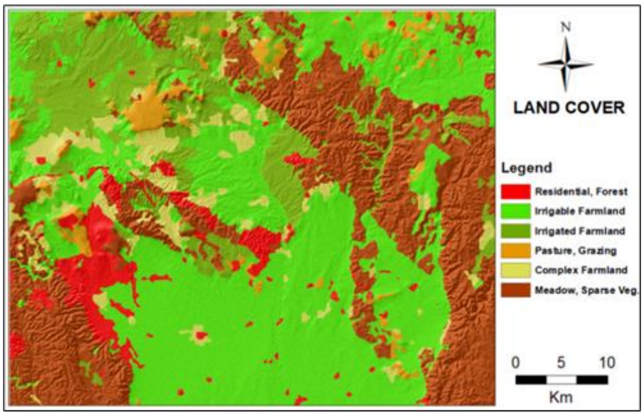

Figure 4. Reclassified land use map

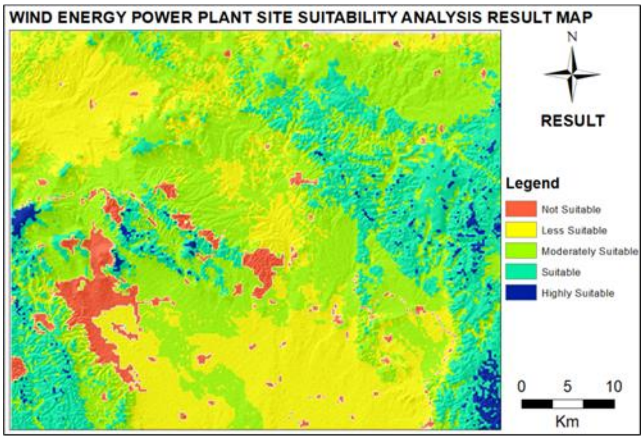

Figure 5. Suitability result map of areas for wind energy installation

4. Discussion

Upon examining the results, it is observed that the unsuitable areas for wind energy installation are mainly residential areas and forested areas, as shown in Figure 4. The most suitable areas, on the other hand, are found to be mountainous regions that are unsuitable for agriculture and classified as grasslands and pastures. Therefore, these results contribute to increasing the reliability of the analysis.

In order to install WPP in the study area, site-specific measurements need to be conducted, and information should be obtained from meteorological sources. More detailed results can be obtained by considering parameters such as wind power density, wind capacity, prevailing wind direction, and topographical factors. It is also necessary to seek support from experts in the field of WPP and individuals from various sectors (such as energy, infrastructure, etc.). Furthermore, a thorough analysis of the terrain should be conducted, taking into account biological indicators such as trees and shrubs, as well as valuable clues provided by geological features shaped by wind erosion and deposition (Memduhoğlu, Özmen, Göyçek, & Kılıç, 2014).

Table 2. Comparison matrix and criterion weight values

	Wind Speed	Land Use	Slope	Distance to Power Transmission Lines	Distance to Highways	Distance to Fault Lines	Distance to Residental Areas	Weight (%)
Wind Speed	1	2	3	4	4	5	6	34
Land Use	0,5	1	2	3	3	4	5	23
Slope	0,33	0,5	1	2	2	3	4	15
Distance to Power Transmission Lines	0,25	0,33	0,5	1	1	2	3	9
Distance to Highways	0,25	0,33	0,5	1	1	2	3	9
Distance to Fault Lines	0,2	0,25	0,33	0,5	0,5	1	2	6
Distance to Residental Areas	0,17	0,2	0,25	0,33	0,33	0,5	1	4

5. Conclusion

Based on the seven criteria determined for the study area and their calculated weight (importance) values, an analysis of suitable areas for WPP has been conducted using GIS. The analysis resulted in five different suitability classes.

In contrast to existing studies in the literature, the analysis focused specifically on identifying areas suitable for WPP within the boundaries of Şanlıurfa province.

Future studies will involve analyzing the entire Şanlıurfa province for potential WPP locations. Due to the size of the study area and the need for detailed analysis, the findings will be supported by field measurements and meteorological data. Factors such as distance to rivers and lakes, airports, bird migration routes, elevation, prevailing wind direction, aspect, wind power density, and wind capacity will be considered to enhance the analysis. Furthermore, the study will not only identify suitable areas for WPP installation but also pinpoint suitable immovable properties owned by the state. The aim is to prevent bureaucratic, legal, and social issues that may affect the WPP implementation process.

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