



A GIS-based multi-criteria decision-making approach (GIS-MCDM) for determination of the most appropriate site selection of onshore wind farm in Adana, Turkey

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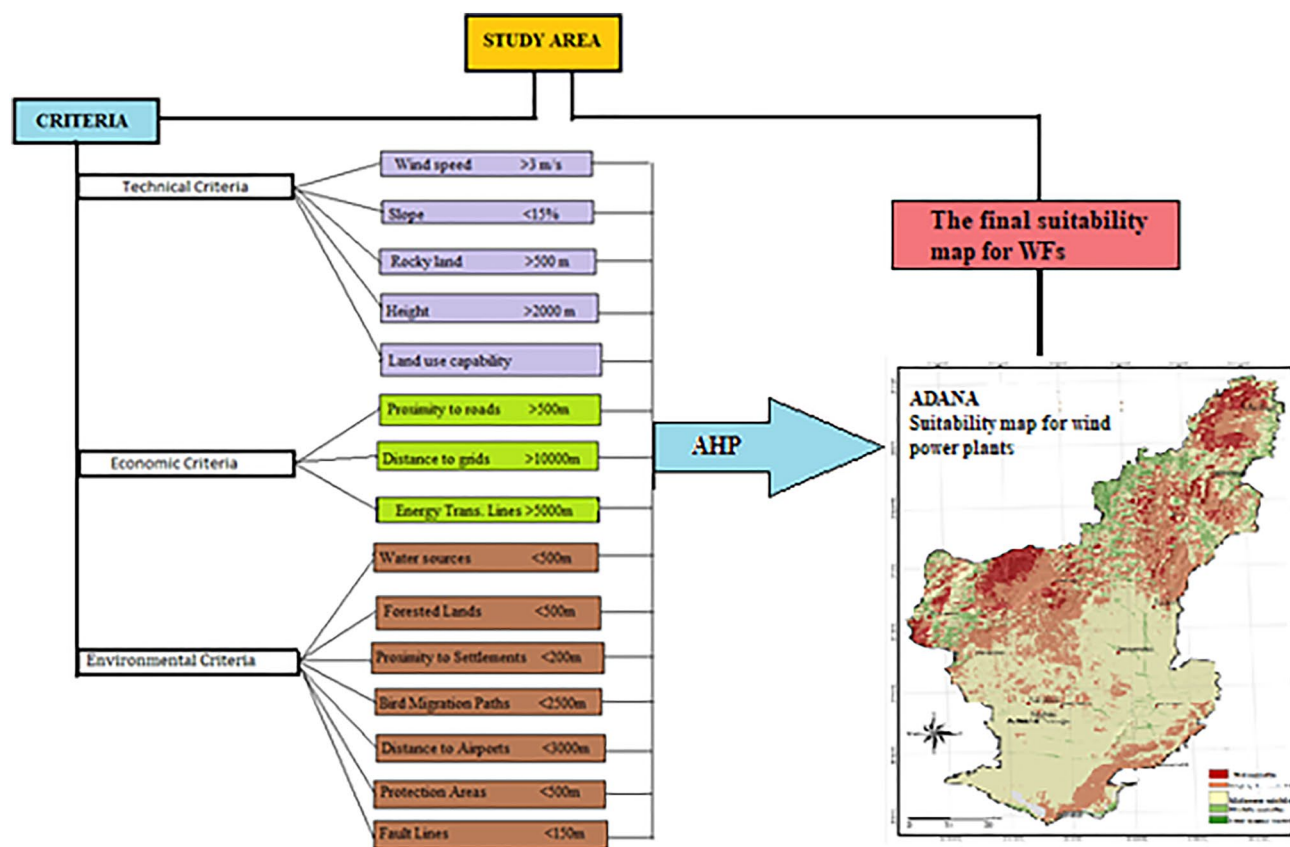
Abstract

Energy stands as an indispensable global need, yet the finite nature of rapidly depleting fossil fuel reserves poses environmental challenges. To address this, numerous nations are shifting toward sustainable energy sources to foster environmental well-being while satisfying their energy requirements. Among these alternatives, wind energy emerges as a particularly efficient option. This study focuses on identifying optimal sites for installing wind power plants in Adana province through the integration of the analytic hierarchy process (AHP) and geographic information system (GIS). Within this framework, a comprehensive set of 15 criteria was delineated along with their respective sub-criteria. It is thought that the criteria used in the study will be useful not only for Adana province but also for other provinces that are suitable for wind turbine placement and planned to be built. The outcome of this investigation delineates potential areas in Adana province deemed suitable for establishing wind power plants. As a result, analysis reveals that 9.94% of the study area is conducive to establishing a wind farm (WF), while 51.66% is deemed moderately suitable. Notably, the districts of Feke, Tufanbeyli, Saimbeyli, and Pozanti emerge as particularly well-suited for this purpose. This study aims to contribute to the existing literature by identifying precise and suitable areas by combining GIS and AHP in the WF site selection process. In the study, a new research perspective is presented by taking into account the uncertainty in the site selection process and the concept of sustainability in three different dimensions: technical, economic, and environmental, thus aiming to guide decision-makers for future WF projects. In addition, it is thought that the methods and criteria used in the study will also be guiding for future WF site selection studies.

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Graphical abstract



Keywords Energy · Geographic information systems (GIS) · Multi-criteria decision-making (MCDM) · Analytic hierarchy process (AHP) · Wind farm

Introduction

Energy stands as a crucial prerequisite for a nation's sustainable development and prosperity, constituting the foundational element for global economic and social progress (Kaplan 2015). As the International Energy Agency (IEA) indicates, fossil fuels presently serve as the predominant sources of energy production worldwide (Saraswat et al. 2021). However, these sources have become less attractive in recent years as they emit significant amounts of greenhouse gases, especially carbon dioxide, into the atmosphere (Pambudi and Nananukul 2019). Furthermore, these sources contribute to the disturbance of natural ecosystems, notably through the generation of air pollution (Giamalaki and Tsoutsos 2019; Barzehkar et al. 2021).

Today, the world economy is heavily dependent on fossil energy resources (Sliz-Szkliniarz 2013); however, natural reserves of fossil fuels are limited and are expected to be depleted in the next century if consumption continues at the current rate (Capellán-Pérez 2014; Prieto-Amparán et al.

2021; Taoufik and Fekri 2021). Rapidly depleting reserves and growing environmental concerns have led to an increasing focus on renewable energy sources, reaching significant worldwide capacity (Ali et al. 2019; Saraswat et al. 2021). Renewable energies are preferred over fossil fuels because they are free, widely available, and produce minimal pollution (Flora et al. 2021). Expanding renewable energy production is vital for reducing greenhouse gas emissions (GHG) and promoting environmental sustainability (Mekonnen and Gorsevski 2015; Ajanaku et al. 2022). In addition, switching to renewable energy sources is essential to meet energy demand and, in parallel, reduce global carbon dioxide emissions to reasonable levels (İlhan et al. 2022).

Among various renewable energy sources, wind energy is promising as a mature and rapidly growing energy source (Uyan 2013; Ali et al. 2019; Noorollahi et al. 2016; Saraswat et al. 2021; Nagababu et al. 2022). It has also been one of the most attractive sustainable energy sources due to its low operation, maintenance, and production costs and relatively low environmental impact

(Zalhaf et al. 2021). Wind energy systems reduce fossil fuel consumption at the national level and contribute to sustainable development (Siyal et al. 2015). To achieve sustainable development goals, wind energy has become a preferred renewable energy option for planners, national governments, and decision-makers (Dai et al. 2015; Doljak et al. 2021).

Many countries are now turning to sustainable energy sources that can provide alternatives to contribute to environmental sustainability and meet the energy demands of a community (Solangi et al. 2019; Barzehkar et al. 2021). One of these countries is Turkey. Turkey is energy-dependent, with 75% of its energy coming from imported energy. Thanks to its geopolitical position, it has an important place in the Eurasian energy trade. It is a country in dire need of energy because it serves as an energy corridor and because of its growing urban population and emerging industrialization. This situation naturally reveals the need for new energy resources (Urfalı and Eymen 2021). Turkey is highly dependent on natural gas imports, especially for electricity generation. However, only 15% of its annual energy is met from renewable sources (Caceoğlu et al. 2022). Therefore, searching for renewable energy sources is crucial to reducing the country's dependence on oil and natural gas imports. Among all renewable energy sources, wind energy is promising in Turkey due to its geographic location (Argin et al. 2019).

More than 98% of Turkey's wind energy potential is concentrated in the Aegean, Marmara, and Eastern Mediterranean regions. It is seen that the installed wind energy power in the country is very low compared to the technical wind energy potential (80 GW) (Yanıktepe et al. 2013). Therefore, it can be said that optimizing wind energy resources is the best option to meet the extra electricity demand in the future (Ertürk 2012).

The development of wind farm (WF) projects, which requires adequate planning and assessment, and the site selection of WFs depends on the wind resource (i.e., wind speed) of an area (Flora et al. 2021). However, regions with abundant wind speeds are not always reasonable locations for WF installation. Various parameters contribute to determining the efficiency of the installed facility. In this context, it is imperative to conduct a comprehensive analysis, considering all possible parameters that influence the success of a WF (Nagababu 2022).

Considering different criteria, site selection for farm installation is essential for greater energy, economic, and environmental efficiency. Optimal utilization of the plant's energy potential is directly related to the location chosen (Rediske et al. 2021). Choosing the right locations is of primary importance, especially regarding sustainability and reliability (Pambudi and Nananukul 2019; Abdullah et al. 2021).

Geographic information system (GIS) is an effective decision support tool for storing, analyzing, and mapping spatial planning criteria for the renewable energy sector (Gasparovic and Gasparovic 2019). GIS, which has recently developed rapidly, has increased its usage area, is used by different professional groups together, and is frequently preferred in wind energy site selection (Heimiller and Haymes 2001). GIS has been successfully used for WF projects and other renewable energy applications (Uyan 2013; Sadeghi and Karimi 2017; Urfalı and Eymen 2021).

Another widely used method is multi-criteria decision-making (MCDM), a powerful tool for identifying candidate locations in site selection for energy planning (Díaz-Cuevas 2018; Barzehkar et al. 2021).

Integrating GIS and MCDM is a good method as a decision support tool to select optimal sites for WFs by considering multiple criteria that are traditionally impossible to manage and analyze because MCDM methods aim to evaluate many criteria together and propose an optimal solution (Lee et al. 2009; Eroglu 2021).

Assigning relative weights to the criteria involved in site selection decision-making is extremely difficult. Therefore, it is necessary to adopt a technique that allows the weights to be estimated. This is possible with the analytic hierarchy process (AHP) method, one of the MCDM techniques (Saaty 1977; Saaty 2003; Chuong 2011).

Many studies in the literature evaluate land suitability for WF siting by applying the MCDM method. For example, Nagababu et al. (2022) conducted a case study in India using a two-stage GIS-MCDM-based algorithm to identify reasonable sites for WFs at the micro level. Doljak et al. (2021) a GIS-MCDA-based study was conducted in Serbia for site selection of WFs and estimation of technical generation potential for wind energy. Ajanaku et al. (2022) conducted a site selection study for the wind power plant in the state of West Virginia using the GIS-AHP method. Van Haaren et al. (2011) used the GIS-AHP method to identify existing WFs in New York in the USA and determined that the installed WFs are not located in suitable areas. Tegou et al. (2010) conducted a site selection study using the GIS-AHP method in Lesvos, Greece. Their results showed that only 1.4% of the region has good wind potential. Georgiou et al. (2012) conducted a WF site selection study in Larnaca province of Cyprus using the GIS-AHP method and determined that only 0.1% of the region has a high potential for WF construction. Urfalı and Eymen (2021) conducted a site selection study for WFs in Kayseri province using GIS and AHP methods and determined the potential suitable sites for WF. Karipoğlu et al. (2021) conducted a WF site selection study in Develi region with the same method.

In addition to these studies, there are also studies on WF site selection with other MCDM methods in the literature. For example, Daneshvar Rouyendegh et al. (2018) used the

Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) method combined with intuitionistic fuzzy set (IFS) in their study. Villacreses et al. (2017) used AHP method that was implemented for calculating the weights, the ordered weight average method (OWA), occupational repetitive actions (OCRA), VlseKriterijuska Optimizacija I Komoromisno Resenje (VIKOR), and TOPSIS as MCDM method for WF site selection in Ecuador. Aydin et al. (2010) applied GIS-based on the OWA method for wind farm locations in the west of Turkey. Eroğlu (2021) aimed to find the most suitable places for wind power plants by using GIS and the fuzzy analytic hierarchy process (FAHP).

Compared to other MCDM methods, the AHP method has some disadvantages such as the fact that it allows the evaluation of a limited number of criteria, since the participants make continuous pairwise comparisons in individual evaluation it takes a long time, the need to provide Expert Choice software, the ranking of other criteria may change with the addition of a new criterion, the difficulty of creating pairwise comparison matrices when the number of criteria is high, the need for clear definition of criteria, and the instability in personal judgements (Özkan 2007; Hartwich 1999). Nevertheless, the AHP method was preferred in this study due to its advantages such as being a more familiar and applicable method and obtaining fast results in a short time.

Within the scope of this study, it aims to determine the most suitable locations for wind power plants in Adana province with AHP-GIS integration. In this regard, experts in the region and studies in the literature were considered, and 15 criteria and sub-criteria were defined under three main headings. Suitable areas for WF siting were determined by calculating the weight values of these criteria.

Although Adana province is a suitable region for the installation of WF, there is no previous study in the literature on WF site selection in Adana province. In addition, although there is no wind power plant currently installed in Adana (TUREB 2023), a pre-license has been obtained for Feke and Pozantı districts (Energy Atlas 2023). With this study, it has been seen that the districts that were previously pre-licensed are suitable for WF installation. In addition, the suitability of the pre-licensed districts as well as other districts for the projects to be planned throughout Adana province in the future has been evaluated. This study will be very useful for site selection for wind power plants to be established in the future in Adana province.

Study area

Adana is located in southern Turkey, between 36°30–38°25 north latitude and 34°48–36°41 east longitude, in the Mediterranean Region. It has a surface area of 13,844 km² and

is Turkey's seventh most populous province. Adana is surrounded by Kayseri to the north, Osmaniye to the east, Kahramanmaraş to the northeast, Hatay to the southeast, Niğde to the northwest, Mersin to the west, and the Mediterranean Sea to the south. There are 15 districts in the province, which is bordered on the south by the 160 km long Mediterranean coast (Fig. 1). The area of the province is 49% mountainous, 23% highlands, and 27% plains and flat areas. Adana has a Mediterranean climate. Summers are hot and dry, and winters are mild and rainy. While Adana province was chosen as the study area, the region, and the high wind energy potential played an important role.

Material and method

The demand for renewable energy is increasing worldwide. Although wind energy is a good sustainable energy source, proper siting is important for efficiency. Identifying potential sites for WFs is an important step in the renewable energy resources planning phase. The suitability of the WF site depends primarily on the wind speed of the location, along with different criteria (Ajanaku et al. 2022).

This study presents a modeling approach for identifying potential locations for WFs in Adana province, including expert opinions on siting criteria and a comprehensive literature review. Based on this approach, the criteria are first identified. Decision criteria are the criteria that are effective in ranking alternatives, while exclusion criteria include unsuitable and prohibited areas for installing WFs.

In the study, 15 criteria determined under three main headings were addressed, and the high number of criteria contributed to the study with a comprehensive approach. As a result of extensive literature research and expert opinions, it was seen that the criteria selected in the study were particularly prominent and important criteria for WF site selection and these 15 criteria were evaluated within the scope of the study (Table 1).

The methodology used in the study is shown in Fig. 2. First, after defining the relevant criteria, the necessary data were collected based on the criteria. Within the scope of the hierarchy created, 15 criteria and their sub-criteria under three main headings were evaluated. The first is the technical criteria of wind speed, slope, rocky terrain, elevation, and land capability. In the second main criterion, economic criteria, distance to roads, networks, and power transmission lines were evaluated. Thirdly, environmental criteria included distance to wetlands, distance to forested areas, distance to settlements, bird migration routes, distance to airports, protected areas, and distance to fault lines. Then, reclassification maps were produced with GIS, and in the MCDM process, the weights of the criteria were calculated using the AHP method. In the last part of the study, the

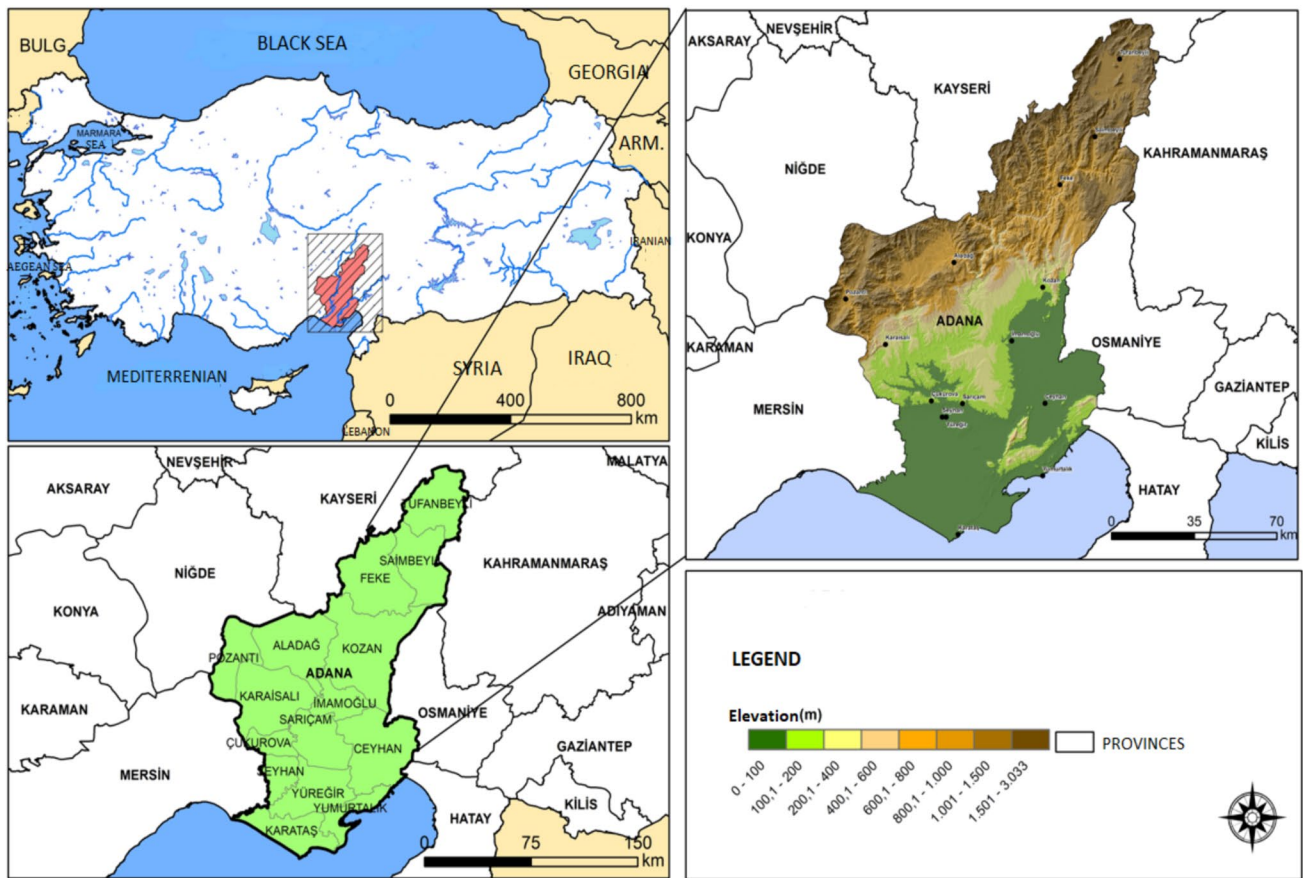


Fig. 1 Study area

criteria maps obtained from spatial GIS analysis for Adana province were processed according to their weights, and a suitability map was obtained.

Exclusion criteria

According to legal regulations and literature review, the exclusion zone is unsuitable for WF installation. In some cases, buffer zones are also considered to determine the minimum distance around these areas (Degirmenci et al. 2018).

WF sites generally need to be far from protected areas and settlement centers. They should also be close to substations and transmission lines (Baban and Parry 2001). In addition, it is important to be close to the highway network because areas close to the highway network should be preferred for convenience during the construction of WFs. The slope should be a maximum of 15% (Urfalı and Eymen 2021). The study excluded regions with a slope greater than 15% (Nagababu et al. 2022; Villacreses et al. 2017; Ayodele et al. 2018). In addition, since the WF start-up speed is usually 3 m/s, regions with wind speeds below 3 m/s were excluded from the study (Karipoglu et al. 2021).

In the study, 15 different criteria were determined, and in addition to these criteria, buffer zones were determined for 11 constraints by taking extensive literature reviews and expert opinions into account. Buffer zone distances are presented in Table 2.

Evaluation criteria

In this study, 15 criteria and their sub-criteria were evaluated under the headings of technical, economic, and environmental criteria to determine suitable areas for wind power plant selection in Adana province (Fig. 2).

When the studies in the literature were examined, criteria such as rocky terrain, distance to fault lines, distance to forested areas, and distance to bird migration routes were seen as the most striking missing criteria and were addressed in this study.

Technical criteria

Wind speed, slope, rocky terrain, height, and land use criteria were considered among the technical criteria for WF site selection.

Table 1 Criteria used in the study and related literature sources

Wind speed (m/s)	Abdullah et al. (2021); Doljak et al. (2021); Ayodele et al. (2018); Ajanaku et al. (2022); Flora et al. (2021); Nasery et al. (2021); Zalhaf et al. (2021); Rediske et al. (2021); Sánchez-Lozano et al. (2016); Tercan (2021); Urfali and Eymen (2021); Karipoğlu et al. (2021); Ari and Gencer (2020); Eroğlu (2021)
Slope (%)	Abdullah et al. (2021); Doljak et al. (2021); Ajanaku et al. (2022); Flora et al. (2021); Nasery et al. (2021); Zalhaf et al. (2021); Rediske et al. (2021); Sánchez-Lozano et al. (2016); Tercan (2021); Urfali and Eymen (2021); Ari and Gencer (2020); Eroğlu (2021)
Rocky terrain (km)	Eroğlu (2021)
Height (m)	Doljak et al. (2021); Ajanaku et al. (2022); Zalhaf et al. (2021); Rediske et al. (2021); Urfali and Eymen (2021); Ari and Gencer (2020)
Land capability (km)	Abdullah et al. (2021); Doljak et al. (2021); Nasery et al. (2021); Rediske et al. (2021); Tercan (2021); Urfali and Eymen (2021)
Proximity to roads (km)	Abdullah et al. (2021); Doljak et al. (2021); Ajanaku et al. (2022); Flora et al. (2021); Nasery et al. (2021); Zalhaf et al. (2021); Rediske et al. (2021); Sánchez-Lozano et al. (2016); Tercan (2021); Urfali and Eymen (2021); Karipoğlu et al. (2021); Ari and Gencer (2020); Eroğlu (2021)
Proximity to grids (km)	Flora et al. (2021); Zalhaf et al. (2021); Rediske et al. (2021); Sánchez-Lozano et al. (2016); Urfali and Eymen (2021); Eroğlu (2021)
Proximity to energy transmission lines (km)	Doljak et al. (2021); Ajanaku et al. (2022); Nasery et al. (2021); Zalhaf et al. (2021); Sánchez-Lozano et al. (2016); Tercan (2021); Urfali and Eymen (2021); Karipoğlu et al. (2021); Ari and Gencer (2020)
Proximity to water bodies (km)	Ajanaku et al. (2022); Tercan (2021); Urfali and Eymen (2021); Karipoğlu et al. (2021); Eroğlu (2021)
Proximity to forested areas (km)	Karipoğlu et al. (2021); Eroğlu (2021)
Proximity to settlements (km)	Abdullah et al. (2022); Doljak et al. (2021); Ajanaku et al. (2022); Flora et al. (2021); Nasery et al. (2021); Zalhaf et al. (2021); Rediske et al. (2021); Sánchez-Lozano et al. (2016); Tercan (2021); Urfali and Eymen (2021); Karipoğlu et al. (2021); Eroğlu (2021)
Proximity to bird migration routes (km)	Tercan (2021); Karipoğlu et al. (2021); Eroğlu (2021)
Proximity to airport (km)	Ajanaku et al. (2022); Flora et al. (2021); Zalhaf et al. (2021); Rediske et al. (2021); Sánchez-Lozano et al. (2016); Tercan (2021); Urfali and Eymen (2021)
Proximity to protected areas (km)	Ajanaku et al. (2022); Flora et al. (2021); Tercan (2021); Urfali and Eymen (2021); Karipoğlu et al. (2021); Ari and Gencer (2020)
Proximity to fault lines (km)	Tercan (2021); Karipoğlu et al. (2021)

Wind speed Average wind speed is an important determining factor for the economic viability of a WF project at a given site (Flora et al. 2021). In many studies on the site selection of WFs in the literature, average wind speed is considered the most basic and prominent evaluation criterion (Baseer et al. 2017; Azizi et al. 2014; Tercan 2021). Therefore, wind speed is also considered as an evaluation criterion in this study. The annual average wind speeds for the study region were obtained from the General Directorate of Meteorology, and areas with wind speeds below 3 m/s were excluded because the WF start-up speed is usually 3 m/s (Karipoglu et al. 2021; Saraswat et al. 2021; Gipe 2010; Li and Zhi 2016; Nasery et al. 2021). Accordingly, areas with wind speeds below 3 m/s are classified as 'unsuitable,' 3–5 m/s as 'moderately suitable,' 5–6 m/s as 'suitable,' and >6 m/s as 'very suitable.' Figure 3a shows the wind speed map.

Slope Slope affects both wind speed and transportation, construction, and maintenance costs (Ali et al. 2019; Moradi et al. 2020; Guignard et al. 2019; Tercan 2021). For these

reasons, this study considers the slope criterion as an evaluation criterion. Areas with low slopes are the best for building WFs because a high slope means high turbulence, which makes the wind unusable for energy production and makes it difficult to access that area (Ari and Gencer 2020). So, the lower the slope of the land, the more suitable it is (Rediske et al. 2021). Since there is no clear consensus on the optimal value of the land slope, various authors in the literature have suggested that different slope values ranging from 3 to 30% are acceptable (Atici et al. 2015; Ayodele et al. 2018; Gass et al. 2013; Noorollahi et al. 2016; Ari and Gencer 2020). Previous studies have considered areas with a slope of less than 15% (Villacreses et al. 2017; Ayodele et al. 2018) and a maximum elevation of 2000 m (Ayodele et al. 2018; Noorollahi et al. 2016) as suitable for WF installation as they are easily accessible by vehicles (Nagababu 2022). This study accepted the maximum slope value as 15% (Ayodele et al. 2018; Ali et al. 2019; Saraswat et al. 2021). Areas with a slope above 15% were taken as exclusion areas. The slope data were generated from SRTM elevation data, and Fig. 3b shows the slope map.

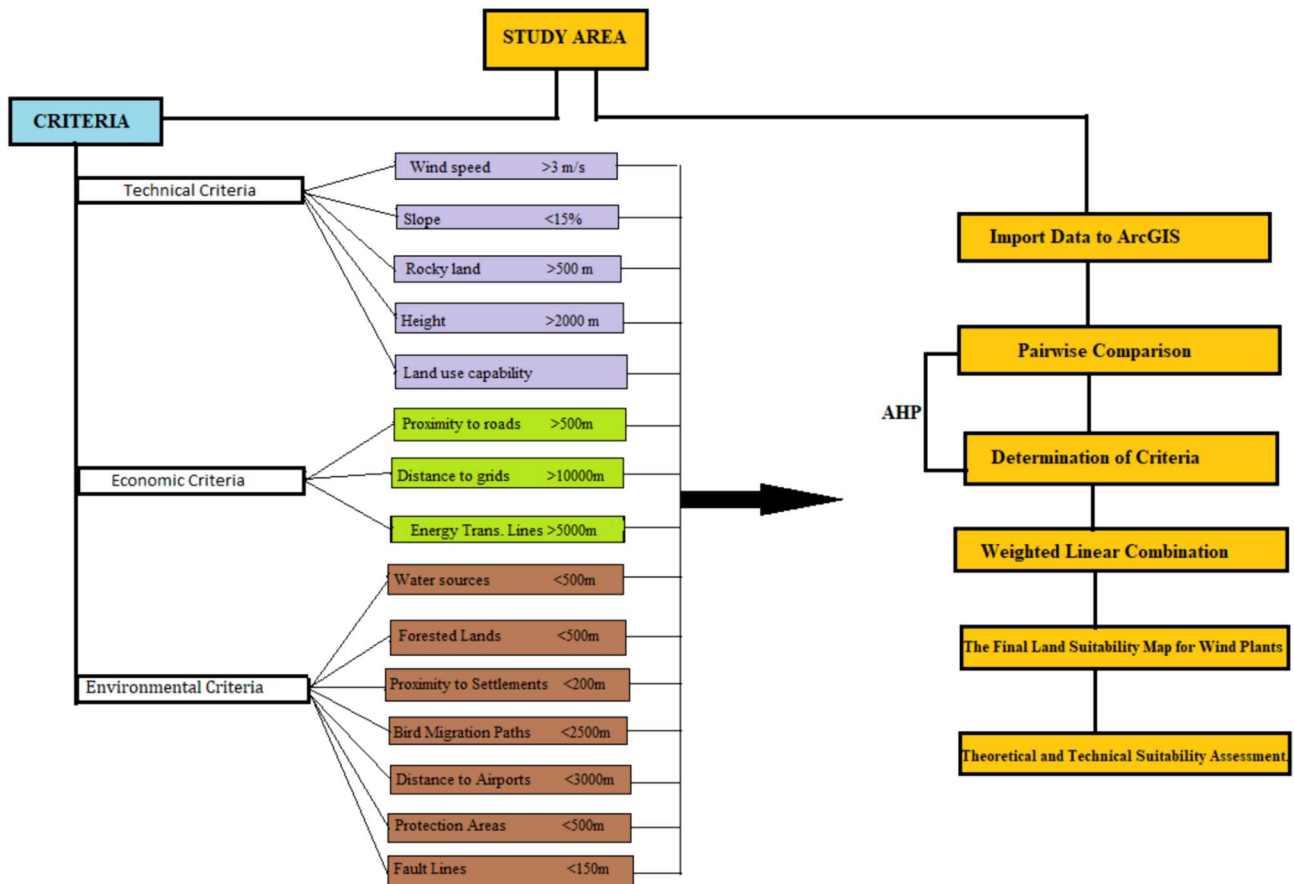


Fig. 2 General methodology and framework of the wind power plant site selection process

Table 2 Buffer zones and their distances

Water sources	< 500 m	Senani et al. (2021); Urfalı and Eymen (2021)
Bird migration paths	< 2500 m	Eroğlu (2021)
Energy transmission lines	> 5000 m	Urfalı and Eymen (2021)
Fault lines	< 150 m	Karipoglu et al. (2021)
Distance to airports	< 3000 m	Zalhaf et al. (2021); Urfalı and Eymen (2021)
Rocky lands	< 500 m	Eroğlu (2021)
Forested lands	< 500 m	Eroğlu (2021)
Protection areas	< 500 m	Urfalı and Eymen (2021)
Distance to grids	> 10000 m	Flora et al. (2021)
Proximity to settlements	< 2000 m	Eroğlu (2021); Rediske et al. (2021)
Proximity to main roads	< 500 m	Zalhaf et al. (2021); Rediske et al. (2021); Eroğlu (2021)

Rocky terrain In rocky terrain, explosives are often used to break rocks, a process that affects both the environment and the cost of the project. This increases the construction costs of WFs. This criterion should be considered in WF site selection studies (Eroglu 2021). However, it was not considered in most studies in the literature and was included in the technical criteria in this study. The rocky terrain map of the study area is divided into four classes (Fig. 3c).

Height Since the decrease in air density will reduce the efficiency of farms at high altitudes, it is not preferred to have too much altitude (Gass et al. 2013; Arı and Gencer 2020) and Saraswat et al. (2021) determined the maximum altitude as 2000 m in their studies, and in this study, the maximum altitude was accepted as 2000 m. The altitude map was divided into five classes (Fig. 3d).

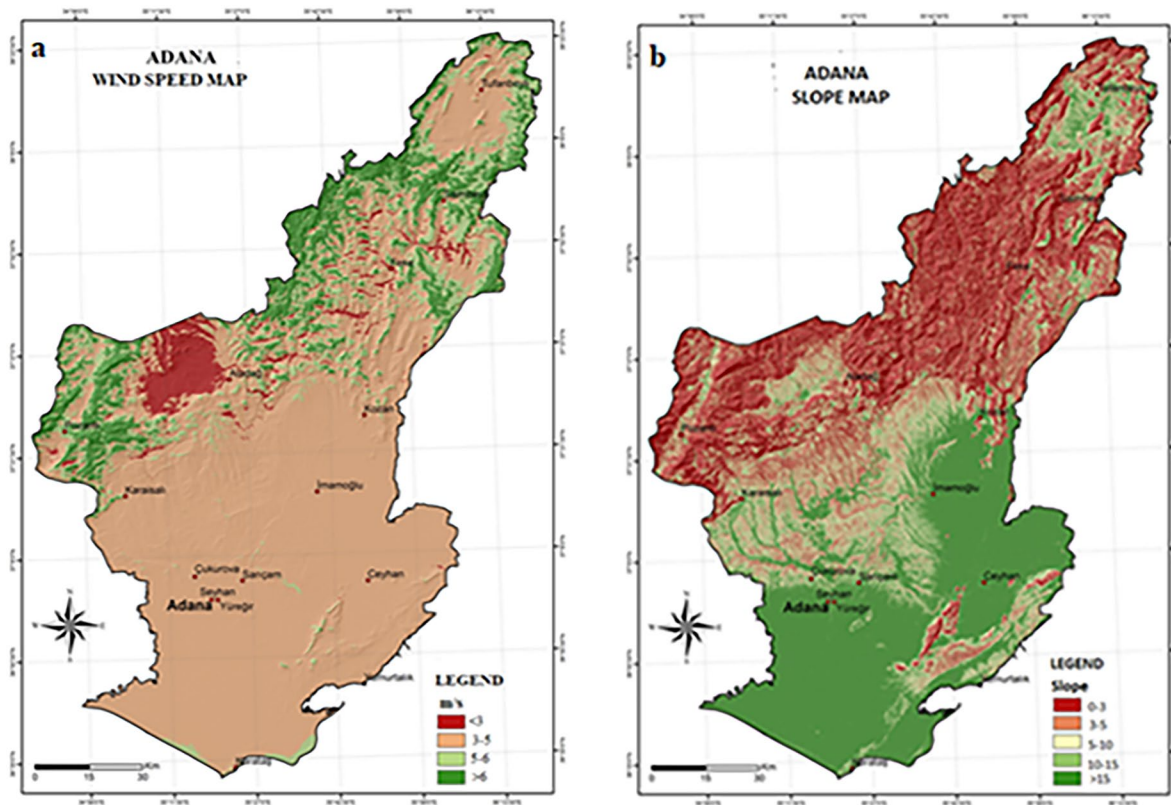


Fig. 3 Technical criteria **a.** wind speed map **b.** slope map **c.** rocky land distance map **d.** height map **e.** land use capability map

Land capability One of the most important factors affecting the location of WFs is the land cover/use status of the area where the WF will be built (Gorsevski et al. 2013; Pamučar et al. 2017; Konstantinos et al. 2019). As far as possible, WFs should not be planned in land cover classes such as protected areas, wetlands, residential areas, tourism areas, and beaches (Tercan 2021). Areas such as wasteland, desert, prairie, meadow, and shrubland are quite suitable for WF installation (Nagababu et al. 2022). In this study, the CORINE (Coordination of Information on the Environment) dataset was used to create the land cover layer. In this study, the land capability map assigns different classes to different types of land use. Class I is designated for agriculture, class II for vineyard, class III for heathland, class IV for garden, class V for pasture, class VI for forest, class VII for meadows, and class VIII for bare rocky areas. The classified land cover/use map is given in Fig. 3e.

Economic criteria

In this study, the economic criteria are distance to roads, distance to substations, and distance to power transmission lines. Distance to power transmission lines and distance to substations are considered key factors, as the development of

new infrastructures increases investment and operating costs and damages the environment (Senani et al. 2021).

Proximity to roads Distance to roads is considered a key economic factor, and the candidate WF location should be as close as possible to the existing road network so that the site is accessible without the need to build a new road to reach the WF site (Kahraman et al. 2009; Pamučar et al. 2017). Furthermore, construction and maintenance costs will be significantly lower as vehicles can easily access the site (Pamučar et al. 2017; Nasery et al. 2021). New roads will bring new costs in areas without existing transportation systems (Karipoglu et al. 2021).

However, no generally valid definition of a maximum distance between WFs and the road network exists. It is preferable to keep the distance to the road as small as possible to reduce transportation costs (Flora et al. 2021).

On the other hand, reducing the distance between the WF and roads negatively impacts road transportation due to high noise. Also, roads will be shaded due to the rotation of the blades of WTs and some changes in the visual landscape (Höfer et al. 2016). Therefore, the minimum distance of this work from main roads and railways is 0.5 km (Ullah et al. 2021; Zalhaf et al. 2021; Rediske et al. 2021).

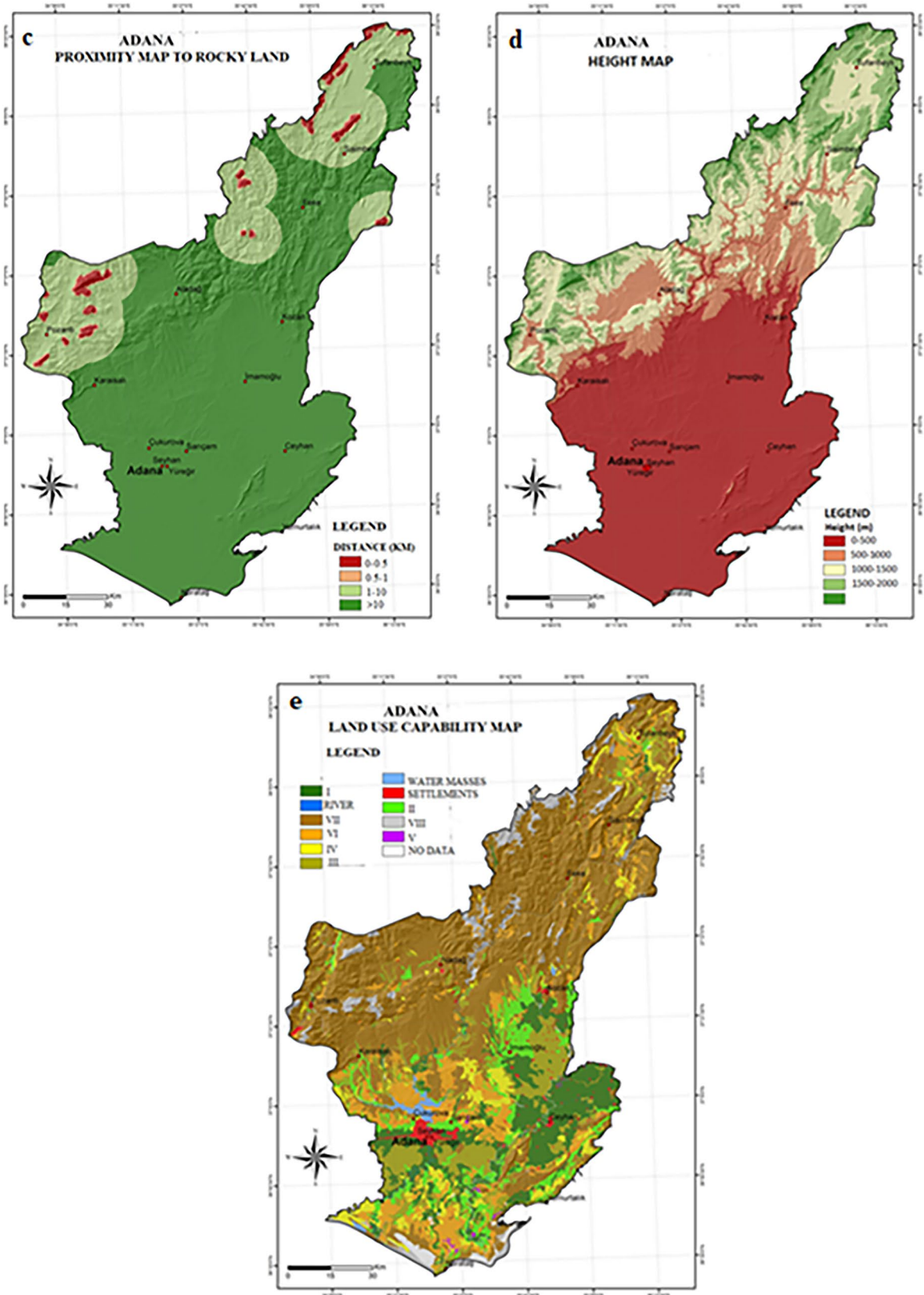


Fig. 3 (continued)

In this study, the map of proximity to roads is divided into six classes with a minimum distance of 0.5 km, as shown in Fig. 4a.

Proximity to grids In order to minimize the cost of electricity delivered to consumption centers, proximity to grid lines is of utmost importance when choosing the location of WFs. WFs far away from electricity transmission lines will require additional connections, and costs will increase accordingly (Gorsevski et al. 2013; Villacreses et al. 2017; Ayodele et al. 2018; Tercan 2021). Considering the losses during energy transmission, the proximity of WFs to substations is of great importance regarding energy efficiency (Heimiller and Haymes 2001; Urfalı and Eymen 2021). Therefore, when choosing a location, it is necessary to consider the availability and accessibility of the existing electricity grid (Flora et al. 2021).

In this study, a distance of 10 km around the electricity grid is taken as the suitable area for installing WFs. Distances greater than this are considered exclusion zones. However, a safety distance of 500 m is included between the WF and electricity lines (Flora et al. 2021) (Fig. 4b).

Proximity to energy transmission lines The distance to power transmission lines is an important criterion in the location selection of WFs. Considering the distance to power transmission lines (TL) while choosing the location will provide an advantage in reducing energy loss (Karipoglu et al. 2021). Ease of access to energy transmission lines is an important issue. As the distance between the production area and transmission lines decreases, both production cost decreases and efficiency increases (Atıcı et al. 2015; Ayodele et al. 2018; Gass et al. 2013; Georgiou and Skarlatos 2016; Noorollahi et al. 2016). Also, lower distance reduces the workload (Ari and Gencer 2020). In the study, the map was divided into five classes (Fig. 4c).

Environmental criteria

This section briefly discusses various environmental factors affecting decision-making regarding WF siting. These criteria are listed in seven titles: water bodies, forested areas, proximity to settlements, bird migration routes, airports, protected areas, and fault lines.

Proximity to water bodies Water is the basic element of life. Therefore, it is very important to use water resources correctly and carefully (Karipoglu et al. 2021). Wetlands should be considered as they affect a project's installation costs. A more important aspect of the Wetland criterion is the degradation of animal habitats due to WFs (Sliz-Szkliniarz and Vogt 2011; Van Haaren and Fthenakis 2011; Eroglu 2021).

Therefore, water bodies are unsuitable for wind power plants (Karipoglu et al. 2021). Adana is a province rich in water resources. In this context, a map of proximity to water bodies was prepared for Adana province and divided into five classes (Fig. 5a).

Proximity to forested areas Building WFs close to forests is not recommended, as the density of trees can impede the passage of wind (Rediske et al. 2021). In addition, the environmental impact assessment reports required for the installation of power plants also require that forested areas should not be destroyed as much as possible. The forested areas where the WF is installed should not be damaged both during and after the installation. Therefore, these criteria should be considered in wind power plant site selection studies (Eroglu 2021). The total surface area of Turkey is 78 million hectares, and 21.7 million hectares of this area are forested (Karipoglu et al. 2021). Since Adana province is located in the Mediterranean region, there is a large forested area. In the study, a map of proximity to forested areas was created and divided into five classes (Fig. 5b).

Proximity to settlements WFs can generate mechanical and aerodynamic noise and create turbulence (Wang 2015). To minimize these drawbacks, it would be beneficial to choose the most suitable location for WFs without compromising energy production (Wu et al. 2020). WFs also have the potential to deteriorate urban and landscape aesthetics (Sibille 2009) and cause a loss of real estate value. They also have visual impacts on the surrounding landscape. During sunrise and sunset, the blades of WFs can cause shadow flicker (Nazir et al. 2020; Saidur et al. 2011; Freiber et al. 2019). For all these reasons, WFs should be planned as far away from urban settlements as possible (Tercan 2021; Flora et al. 2021). On the other hand, being too far away from residential areas will increase transmission line costs. For this reason, WFs should be established at an optimum distance from residential areas by defining a certain buffer distance (Eroglu 2021). The safety distance in settlements is 2000 m (Flora et al. 2021). In this study, the distance up to 2 km from urban areas was considered a buffer zone, and the settlement proximity map was created and divided into five classes (Fig. 5c).

Proximity to bird migration routes WFs in unsuitable geographic locations can negatively impact birds through habitat destruction and increased mortality rates. Determining a location that will affect birds' migration routes in WF site selection can cause serious damage to the ecosystem. Because wind power plants are responsible for bird deaths due to collisions (Eroglu 2021). The literature estimates that 0.003 percent of all bird deaths are caused by WFs and airplanes (Değirmenci et al. 2018; Genc et al. 2021).

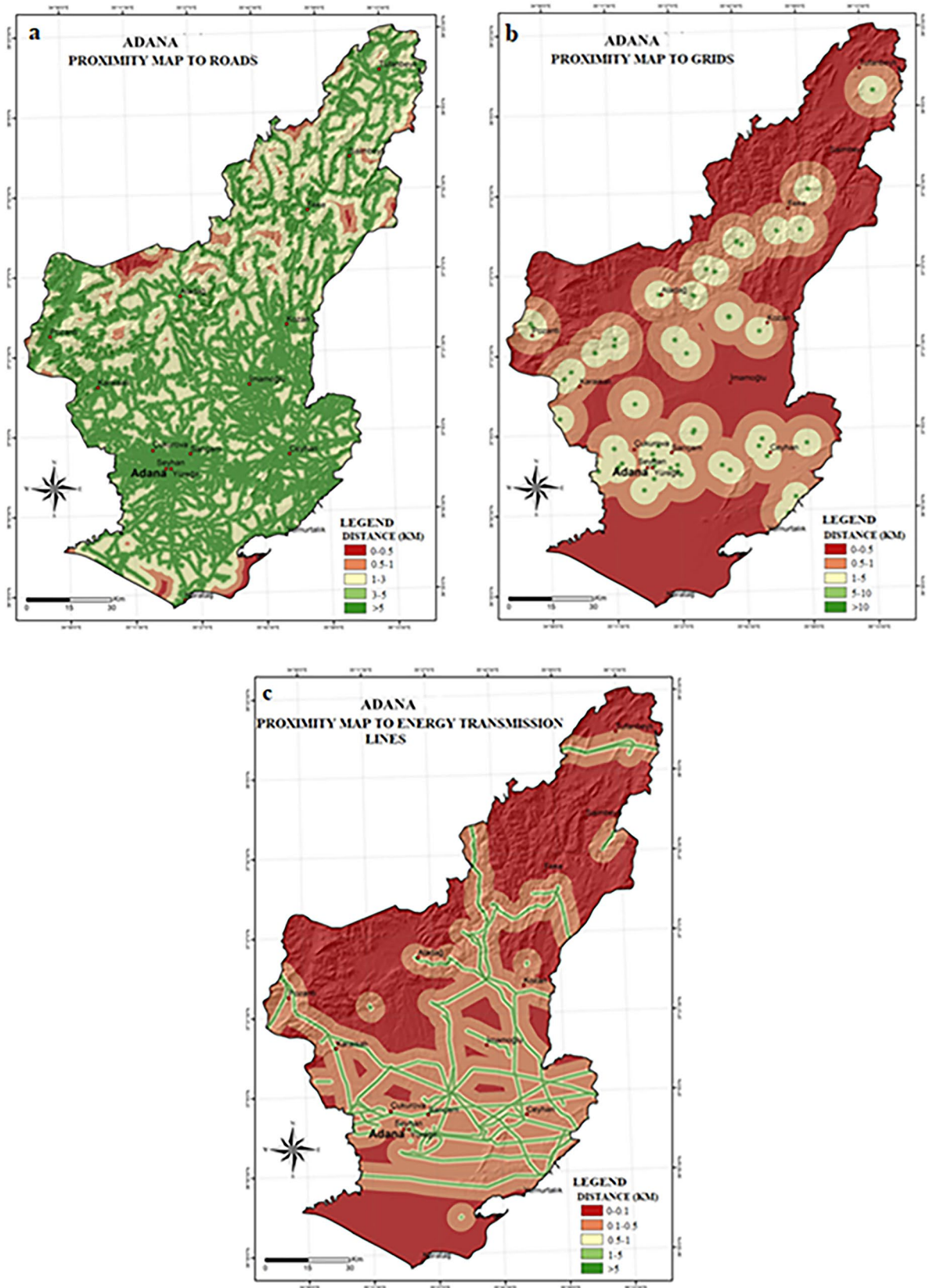


Fig. 4 Economic criteria a. proximity map to roads b. Proximity map to grids c. proximity map to energy transmission lines

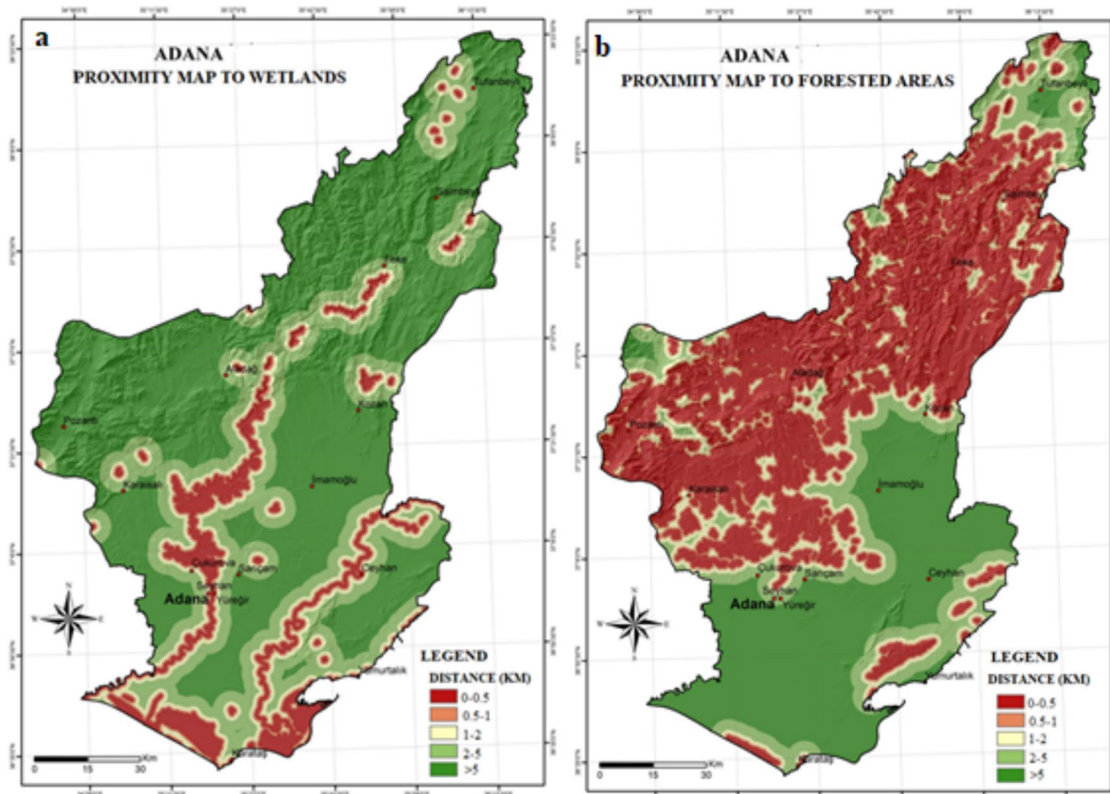


Fig. 5 Environmental criteria. **a.** proximity map to wetlands **b.** proximity map to forested areas. **c.** proximity map to settlements **d.** proximity map to bird migration paths. **e.** Map of the bird migration paths

Bird fatalities occur due to many factors, such as topography, bird species and bird activities, local wind direction and strength, and design features of farms. Therefore, WFs should be planned away from important bird areas or migration routes (Tercan 2021). Although there have been numerous studies on WF siting and multiple criteria have been defined and used for suitability modeling of WFs, few studies have included site assessment based on wildlife habitat destruction (Aydin et al. 2010; Ayodele et al. 2018; Peri and Tal 2020; Xu et al. 2020; Ajanaku et al. 2022). In this study, a distance of 2.5 km around the routes of migratory birds was considered as a buffer zone, and the map was divided into four classes (Fig. 5d).

Figure 5e illustrates a map of bird migration routes in Turkey (Karipoglu et al. 2021). The map shows that bird migration routes are located south of Adana province.

Proximity to airport WFs can cause irreparable problems in the functioning of communication, navigation, and surveillance systems used in air traffic control and ensuring air transportation safety, including interference with aviation radar signals and distractions to the pilot's view. Therefore, proximity to the airport is an important factor in the siting

in Turkey (Karipoglu et al. 2021). **f.** proximity map to airports **g.** proximity map to protection area **h.** proximity map to fault lines

of WFs (Gigovi'c et al. 2017; Azizi et al. 2014; Tercan 2021; Saraswat et al. 2021). WFs must be located a significant distance from airports and require a large buffer zone around airports. This study created an airport proximity map considering a buffer zone of 3 km and divided it into five classes (Fig. 5f).

Proximity to protected areas Cultural assets, natural assets, wildlife protection, development areas, and national parks are protected areas. These areas are unsuitable for WF construction (Urfalı and Eymen 2021). In order to protect the ecosystem and biodiversity, it is recommended that WFs be built at a significant distance from these areas. In Adana province, Aladağlar National Park and Yumurталık Nature Reserve are among the main protected areas. In this study, a distance of 500 m was taken as the safety zone for protected areas, and a map of proximity to protected areas was created and divided into five classes (Fig. 5g).

Proximity to fault lines Turkey has many active and passive fault lines due to its geographic location. Areas with low earthquake risk should be selected for wind power plant installation (Colak et al. 2020). Spatial data for the

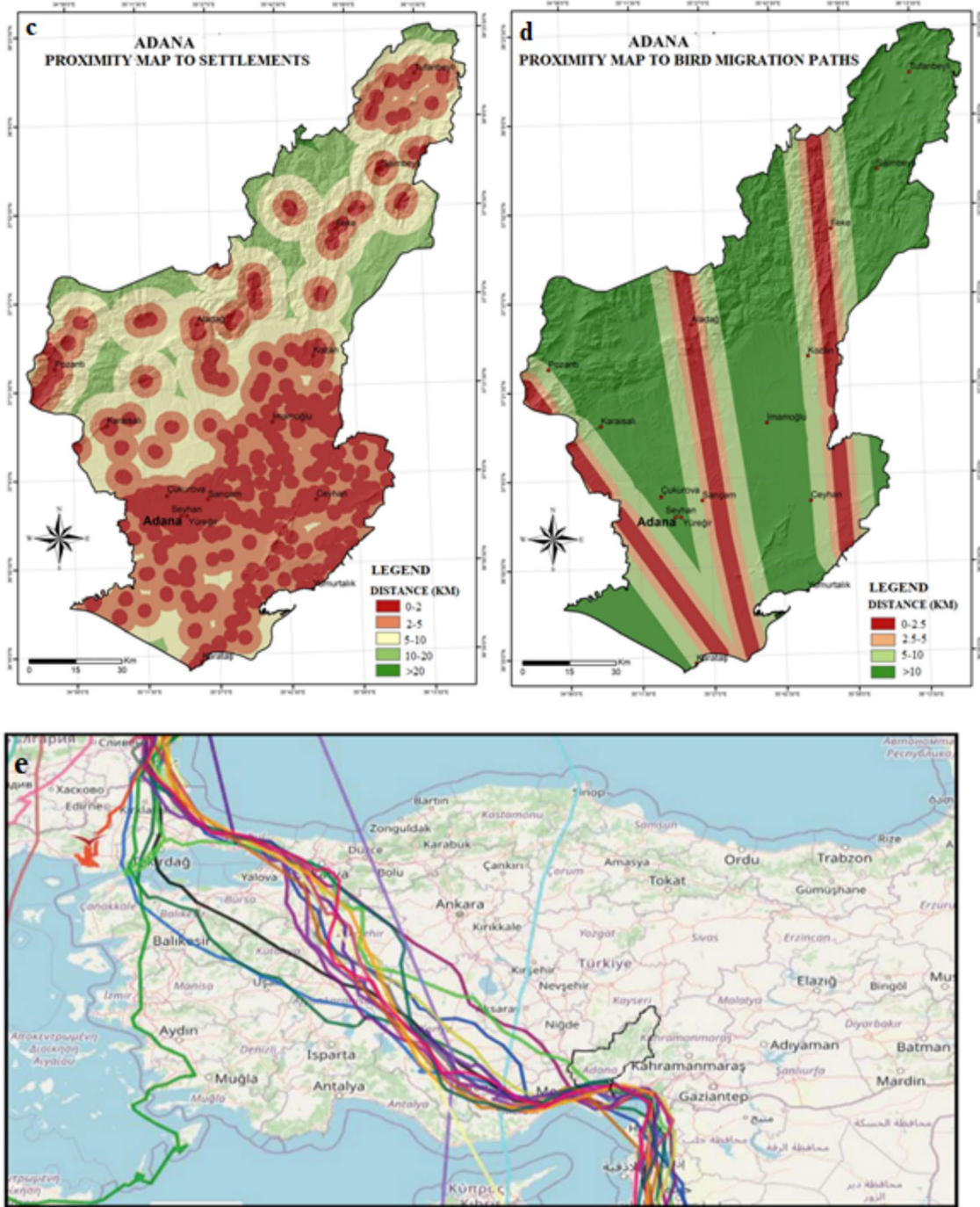


Fig. 5 (continued)

fault line were obtained from Kandilli Observatory and Earthquake Research Institute. Fault lines should be 150 m away to determine suitable wind power plant locations (Malczewski 2010; Karipoglu et al. 2021). Since the risk of earthquake and destruction is high near the fault lines, a buffer distance of 150 m was considered for installing the

power plant and the fault lines proximity map was divided into four classes (Fig. 5h).

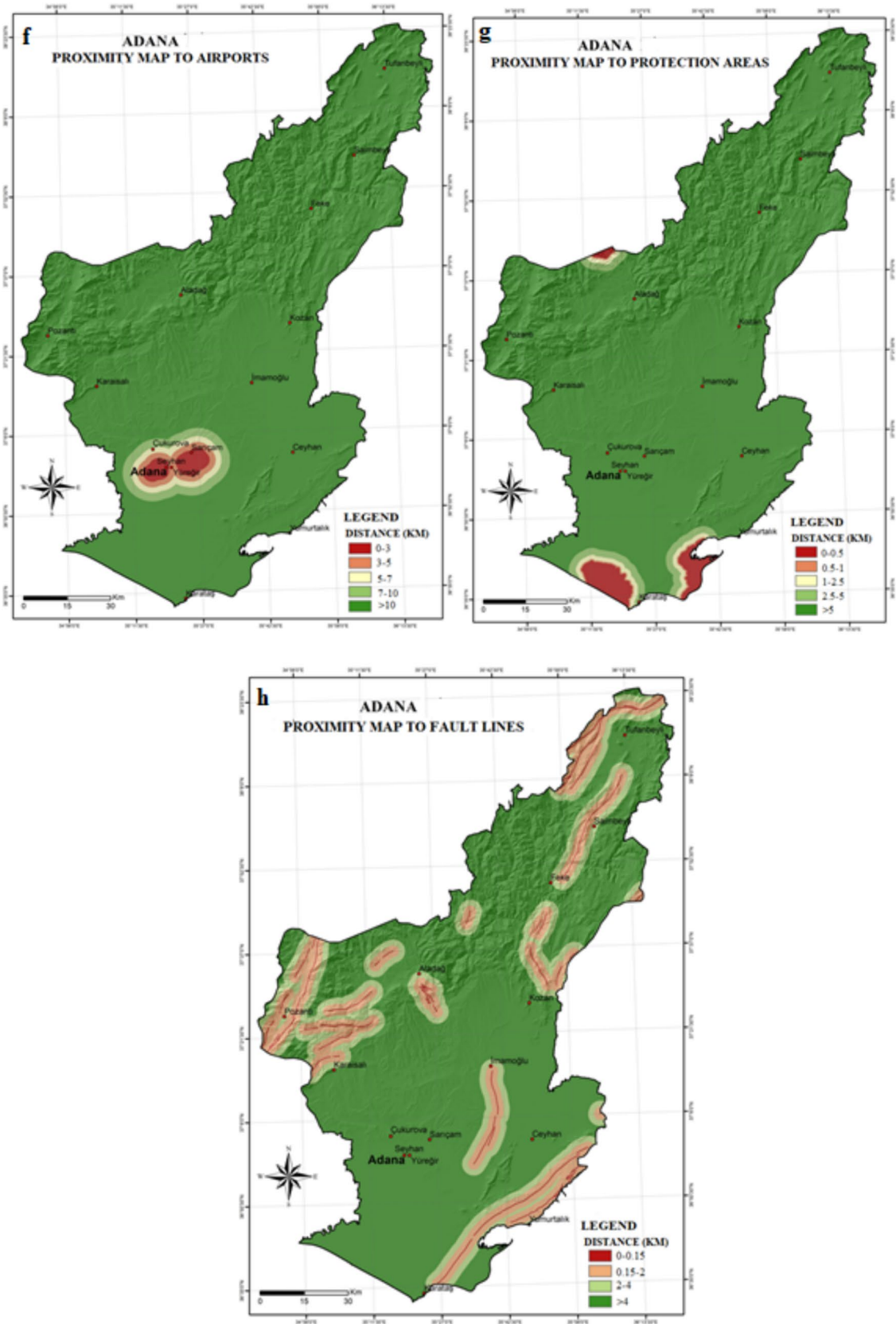


Fig. 5 (continued)

Analytic hierarchy process

MCDM are important for studies on appropriate site selection for power plants. MCDM techniques enable renewable energy management (Akdag and Guler 2010). This method is a tool that allows the best choice to be made among multiple and simultaneous criteria. As energy management problems become more complex, multi-criteria decision-making has emerged to deal with conflicting decision problems (Degirmenci et al. 2018; Karipoglu et al. 2021). This study developed a GIS-based MCDM model to determine land suitability for wind power plants to be established in Adana province using the AHP method, one of the MCDM techniques.

Evaluating suitable sites for WFs involves conflicting issues and complexities that require an advanced decision-making approach. Among the available alternatives, the AHP decision-making approach has a strong ability to deal with complex and conflicting problems with different criteria. The AHP approach was developed by Prof. Saaty in 1979 (Merrouni et al. 2018; Saaty 1990; Saraswat et al. 2021).

In the AHP method, the problem is first defined, and then the first step starts with creating a hierarchical structure. Pairwise comparison matrices constitute the next stage. (Detailed pairwise comparison matrices were created by taking the geometric mean of the scores given by the decision-makers.) The importance of the items in the matrix relative to each other is rated using Saaty's 9-point scale. After the pairwise comparison matrices are created, normalized matrices are created and the average of each row is taken, and the priority values are calculated. The relative importance weights are calculated in the last step, and the consistency ratio (CR) of the pairwise comparisons matrix is calculated. If the calculated $CR \leq 0.10$ for the matrices, the comparisons made by researchers are acceptable for the algorithm (Wind and Saaty 1980; Saaty 1990; Saaty et al. 2003; Kursunoglu and Onder 2015).

In this study, the weights of all criteria in the hierarchy were calculated using Microsoft Excel, and a land suitability map was produced. At this stage, the weighted linear combination (WLC) method is generally used (Bilgilioglu et al. 2021, 2022). The evaluation is made with the values calculated using the following formula (Eq. (1)) (Malczewski 1999).

$$WCSI_i = \sum_{j=1}^n W_j \times x_{ij} \quad (1)$$

$WCSI_i$ is the land suitability index for WF siting, n is the number of criteria, W_j j is the weight of criterion j , and x_{ij} is the sub-criteria weight corresponding to cell i of criterion j (Saaty 2005; Mutlu and Sari 2017, 2022).

Thus, the AHP method, which is one of the MCDM techniques, was used with ArcGIS 10.0 software to select the most suitable potential location for WFs to be established in Adana province.

Results and discussion

In the study, 15 criteria were determined under three main headings, and 15 weighted raster maps were produced with GIS-based MCDM hierarchy under their sub-criteria. These maps were combined with the WLC technique to produce the final land suitability map for WFs to be installed in the future. In addition, pairwise comparison matrices were created, and the weights of the criteria and sub-criteria were calculated using the AHP method. When the CR values calculated for the pairwise comparison matrices of the criteria in the hierarchy created within the scope of the study are examined, it is seen that all of these values are lower than 0.10, and the comparisons made are consistent. The pairwise comparison matrix and calculated weight values for the main criteria are given in Table 3. Similarly, the CR values and criteria weights calculated for the pairwise comparison matrices created for the sub-criteria are given in detail in Table 4.

Examining the main criteria, it is seen that the most effective criterion for onshore WF site selection is the wind speed criterion, but technical criteria come to the forefront. Considering the calculated weights of all criteria in the hierarchy, they were combined using weighted linear combination overlay analysis in ArcGIS 10.0 software, and the final land suitability map for onshore WF site selection was produced. Within the scope of the study, the obtained land suitability map was divided into five classes: very high suitable, high suitable, medium suitable, very low suitable, and not suitable (Fig. 6).

Based on the land suitability map, 0.19% (2.593 ha) of the study area was determined as very highly suitable, 9.94% (135.461 ha) of the study area was determined as highly suitable, 51.66% (704.019 ha) as moderate suitable, 29.54% (402.608 ha) as highly low suitable, and 8.67% (118.221 ha) of the study area was determined as unsuitable areas for wind power plants (Table 5). Similarly, based on the suitability map, Feke, Tufanbeyli, Saimbeyli, and Pozantı districts are highly suitable, Aladağ, Kozan, and Karaisalı districts are medium suitable, and İmamoğlu, Çukurova, Sarıçam, Seyhan, Yüreğir, Ceyhan, Karataş, and Yumurtalık districts are very low suitable for WFs in Adana province.

Various MCDM methods, separately or in combination, and various criteria were used for site selection of wind farm in literature. For example, Nagababu et al. (2022) used the FAHP and TOPSIS method and evaluated 9 criteria. Abdullah et al. (2021) used the FAHP method and 10 criteria.

Table 3 Pairwise comparisons matrix and calculated weights for each main criteria

Pairwise comparison	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	Weights
Wind speed (A)	1	7	5	7	9	7	7	5	9	7	5	8	8	7	7	0.272
Slope (B)	1/7	1	1/3	3	5	3	1	1/2	5	3	3	5	3	3	3	0.078
Height (C)	1/5	3	1	5	7	5	3	1	7	5	5	7	5	5	5	0.139
Land use capability (D)	1/7	1/3	1/5	1	5	3	1/3	1/3	5	3	1/2	5	3	2	3	0.056
Rocky land (E)	1/9	1/5	1/7	1/5	1	1/3	1/5	1/5	2	1/3	1/3	3	1/3	1/2	1/3	0.018
Proximity to roads (F)	1/7	1/3	1/5	1/3	3	1	1/3	1/5	3	3	1/2	3	1	1/2	1/3	0.031
Proximity to grids (G)	1/7	1	1/3	3	5	3	1	1/3	3	3	1	5	3	3	3	0.007
Proximity to energy trans. lines (H)	1/5	2	1	3	5	5	3	1	5	5	3	7	5	5	5	0.119
Proximity to wetlands (I)	1/9	1/5	1/7	1/5	1/2	1/3	1/3	1/5	1	1	1/5	2	1/2	1/2	1/3	0.016
Proximity to forested areas (J)	1/7	1/3	1/5	1/3	3	1/3	1/3	1/5	1	1	1/3	3	1/3	1/2	1/2	0.023
Proximity to settlement (K)	1/5	1/3	1/5	2	3	2	1	1/3	5	3	1	5	5	3	3	0.065
Proximity to bird migration paths (L)	1/8	1/5	1/7	1/5	1/3	1/3	1/5	1/7	1/2	1/3	1/5	1	1/3	1/2	1/5	0.012
Proximity to airports (M)	1/8	1/3	1/5	1/3	3	1	1/3	1/5	2	3	1/5	3	1	2	1/3	0.031
Proximity to protection areas (N)	1/7	1/3	1/5	1/2	2	2	1/3	1/5	2	2	1/3	2	1/2	1	1/2	0.028
Proximity to fault lines (O)	1/7	1/3	1/5	1/3	3	3	1/3	1/5	3	2	1/3	5	3	2	1	0.042

$$\lambda_{\max} = 17.1586$$

$$CI = 0.15418$$

$$CR = 0.0969 \leq 0.1$$

Doljak et al. (2021) used the AHP method and 22 criteria. Ajanaku et al. (2022) used the AHP method and 10 criteria. Flora et al. (2021) used the Boolean decision-making approach and 9 criteria. Nasery et al. (2021) used the FAHP method and 6 criteria. Zalhaf et al. (2021) used the FAHP method and 8 criteria. Sánchez-Lozano et al. (2016) used the FAHP method and 10 criteria. Tercan (2021) used the Best Worst Method (BWM) and 19 criteria. Eroğlu (2021) used the FAHP method and 17 criteria.

In this study, 15 criteria were evaluated to determine the most suitable locations for WFs. Data analysis was visualized with maps, thus facilitating the interpretation of the findings and helping decision-makers understand the complex relationship between criteria, location preferences, and decision-making factors. It was also seen that high accuracy can be achieved with AHP-GIS integration. The AHP method is a useful method due to its usability, and its applicability in different geographic regions can be further investigated. In addition, combining this method with any MCDM method applied in related studies can improve the results of the proposed model. The approach proposed in the study will be useful in making strategic decisions for planning the wind energy potential of Adana, and the methodology used has the potential to be applied to other study regions for planning onshore WFs.

In addition, the study was limited by the fact that only the annual average wind speed was evaluated in meteorological terms while selecting the criteria. However, it would be useful to examine more comprehensive and detailed wind characteristics, such as wind stability, in-depth. Furthermore, the criteria can be improved by using factors such as land cost, lightning speed, turbine type, and shape, and the study can be further expanded with integrated renewable energy sources. Another

limitation of the study is the uncertainty in the criteria weights. The importance of the criteria may vary depending on location, time, and from expert to expert. Therefore, it may be useful to compare the results by producing different maps for different scenarios with different weights (Canco et al. 2021; Can et al. 2024).

The results of the study show that this province has a significant potential for wind energy utilization by utilizing very high, high, and moderately suitable areas of the study region. However, since this is the first time this study has been used for wind farm siting in Adana, further research focusing on additional methods to compare the results would be beneficial.

In this study, a detailed site suitability analysis was carried out by determining 15 criteria and their sub-criteria within the scope of Adana province. When the studies in the literature were examined, it was seen that the criteria of rocky terrain, proximity to forested areas, proximity to bird migration routes, and proximity to fault lines were used in very few studies. These criteria were evaluated and contributed to the study. The suitability map obtained aims to increase energy efficiency by minimizing the negative effects of WFs. As mentioned before, there are currently no WFs installed in Adana province, but preliminary licenses have been obtained for Feke and Pozantı districts. Therefore, the framework adopted in this study not only provides a basis for making new spatial planning decisions/strategies correctly but also supports existing planning decisions.

Table 4 AHP model weights of the sub-criteria and the computed CR values for pairwise comparison matrix

Criteria	Sub-criteria	AHP weights	CR values
Wind speed (m/s)	<3	0.071	0.0337 < 0.10
	3–5	0.107	
	5–6	0.311	
	>6	0.511	
Slope (%)	0–3	0.393	0.0788 < 0.10
	3–5	0.296	
	5–10	0.166	
	10–15	0.093	
	> 15	0.051	
Height (m)	0–500	0.432	0.0766 < 0.10
	500–1000	0.283	
	1000–1500	0.152	
	1500–2000	0.086	
	> 2000	0.048	
Land use capability	I (agriculture)	0.024	0.0428 < 0.10
	II (vineyard)	0.034	
	III (heathland)	0.050	
	IV (garden)	0.073	
	V (pasture)	0.108	
	VI (forest)	0.157	
	VII (meadow)	0.227	
	VIII (bare rocky)	0.327	
Rocky land (km)	0–0.5	0.077	0.0634 < 0.10
	0.5–1	0.124	
	1–10	0.273	
	> 10	0.526	
Proximity to roads (km)	0–0.5	0.421	0.0487 < 0.10
	0.5–1	0.269	
	1–3	0.173	
	3–5	0.088	
	> 5	0.048	
Proximity to grids (km)	0–0.5	0.400	0.0599 < 0.10
	0.5–1	0.276	
	1–5	0.178	
	5–10	0.094	
	> 10	0.052	
Proximity to energy transmission lines (km)	0–0.1	0.399	0.0824 < 0.10
	0.1–0.5	0.248	
	0.5–1	0.205	
	1–5	0.096	
	> 5	0.052	
Proximity to wetlands (km)	0–0.5	0.060	0.0604 < 0.10
	0.5–1	0.089	
	1–2	0.136	
	2–5	0.248	
	> 5	0.467	
Proximity to forested areas (km)	0–0.5	0.052	0.0735 < 0.10
	0.5–1	0.077	
	1–2	0.142	
	2–5	0.263	
	> 5	0.465	

Table 4 (continued)

Criteria	Sub-criteria	AHP weights	CR values
Proximity to settlement (km)	0–2	0.059	0.0847 < 0.10
	2–5	0.080	
	5–10	0.147	
	10–20	0.257	
	> 20	0.458	
Proximity to bird migration paths (km)	0–2.5	0.092	0.0743 < 0.10
	2.5–5	0.131	
	5–10	0.262	
	> 10	0.515	
Proximity to airports (km)	0–3	0.053	0.0568 < 0.10
	3–5	0.082	
	5–7	0.130	
	7–10	0.267	
	> 10	0.469	
Proximity to protection areas (km)	0–0.5	0.052	0.0885 < 0.10
	0.5–1	0.081	
	1–2.5	0.128	
	2.5–5	0.252	
	> 5	0.487	
Proximity to fault lines (km)	0–0.15	0.083	0.0569 < 0.10
	0.15–2	0.137	
	2–4	0.214	
	> 4	0.565	

Conclusion

The need for renewable energy has greatly increased due to the rapidly increasing population growth worldwide and the corresponding increase in energy demand. WFs are among the most suitable energy generation methods for sustainable energy projects (Urfali and Eymen 2021). Most of the wind energy potential in Turkey is concentrated in the Aegean, Marmara, and Eastern Mediterranean regions. Adana province also has a suitable potential for new wind power plants to be established in the Eastern Mediterranean region. However, despite potential areas in this province, no power plants have been installed yet. Therefore, Adana province was selected as the study area.

In this study, 15 criteria and their sub-criteria were determined under three main headings within the scope of site selection for wind power plants, weight calculations were made, and a land suitability map was created for Adana province with the WLC technique. The created land suitability map is divided into five classes as very high suitable, high suitable, medium suitable, very low suitable, and unsuitable areas for wind power plant installation. Looking at the classes, 0.19% of the study area was very highly suitable, 9.94% of the study area was highly suitable, and 51.66% was moderately suitable for WF installation.

Since the criteria addressed in the study are derived from global research, they may not always be met as they depend on different regions, climates, and legislation. However, it is up to decision-makers to determine which criteria should be applied in studies (Rediske et al. 2021). On the other hand, the methodology used in the study, although it deals with wind energy, has general characteristics and can, therefore, also be used to assist in site selection decisions related to various other renewable energy sources. In addition, using the proposed methodology in WF siting studies in other countries and conducting comparative studies between countries can further validate the methodology.

In the study, unsuitable areas for WF installation were found to be 8.67% (118,221 ha). This indicates that there is a significant amount of wind potential in Adana province. In addition, the results will contribute to the decision-making process for wind energy investments in Adana and provide a basis for renewable energy planning and implementation for Turkey and other countries. With the method used, any region in the world can be easily analyzed, and WF location selection can be made.

This is the first study on wind power plant site selection for Adana province. In this regard, it is thought that it will be beneficial to utilize the existing wind energy potential for Adana province and evaluate it in the most efficient way.

Fig. 6 Final land suitability map for wind power plants

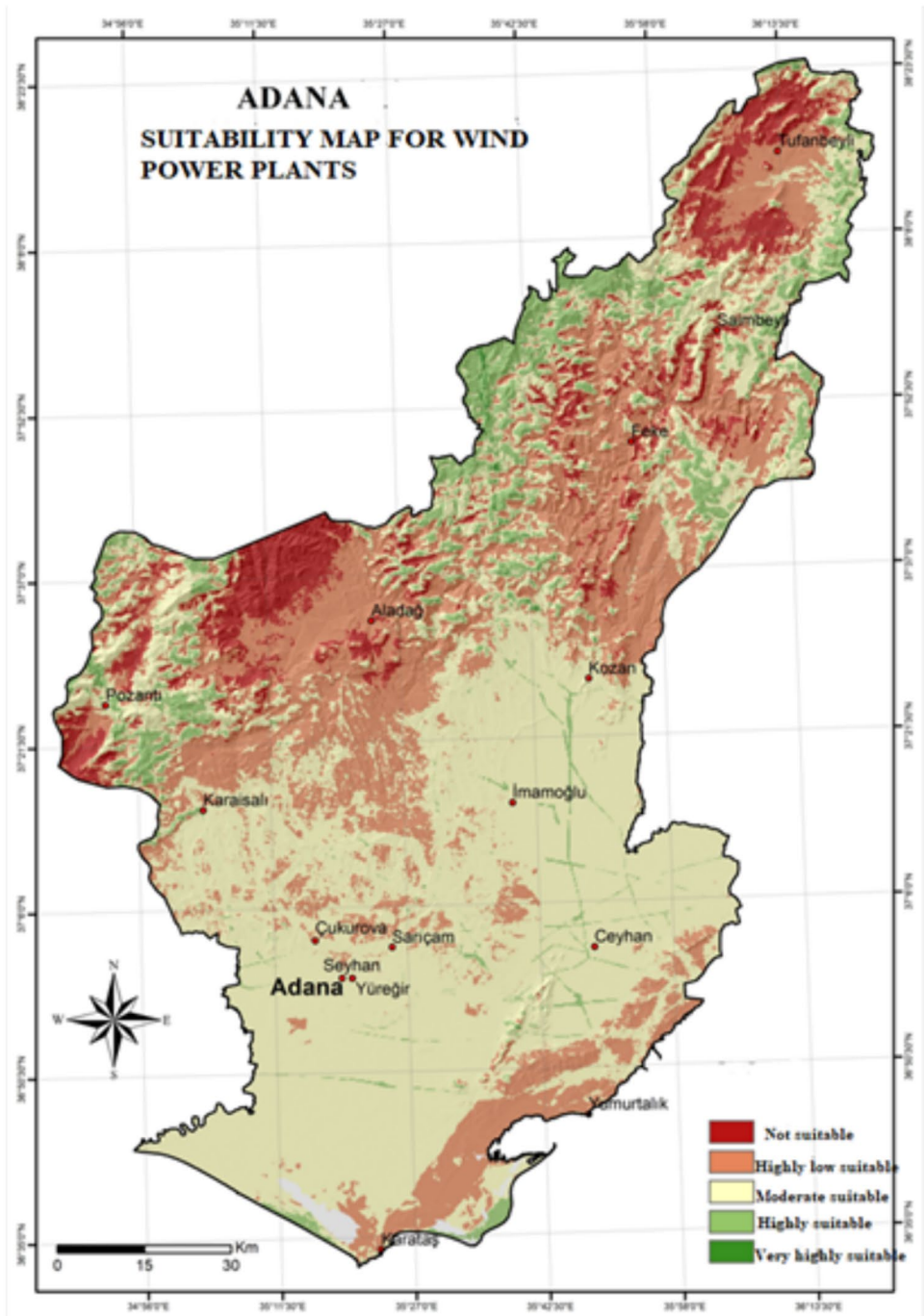


Table 5 Suitability classification for wind power plants

Land suitability for wind power plants	Area (ha)	Ratio of area%
Very highly suitable	2.593	0.19
Highly suitable	135.461	9.94
Moderate suitable	704.019	51.66
Highly low suitable	402.608	29.54
Not suitable area	118.221	8.67
Total area	1.362.902	100.00

This study has contributed to the literature by determining the areas that can be accurate and efficient with AHP-GIS integration within the scope of the WF site selection process, and it is thought that the study will benefit wind energy investors and decision-makers by serving as a pre-investment evaluation tool.

For future studies, more detailed local surveys on site selection are recommended. Such investigations can be enriched with hourly and daily data, wind directions, wind stability, land cost, land ownership, etc., as such data are

not considered in the present paper. It would also be more beneficial to consider the preferences and technical opinions of planners and policymakers in the decision-making process for WF site selection. Future studies could also investigate integrating wind energy with other renewable sources, such as solar or hydroelectric power, to create more comprehensive and resilient energy systems. On the other hand, as climate change affects wind patterns, it would be useful for future research to consider how these changes may affect the long-term viability of wind energy projects (Amsharuk and Laska 2023). Furthermore, since Adana is a coastal province, it would be useful to include offshore WF siting studies in future studies.

Appendix: Pairwise comparison Tables

Wind speed (m/s)	<3	3–5	5–6	>6
<3	1	1/2	1/4	1/6
3–5		1	1/4	1/5
5–6			1	1/2
>6				1

Slope (%)	0–3	3–5	5–10	10–15	>15
0–3	1	2	3	4	5
3–5		1	3	4	5
5–10			1	3	4
10–15				1	3
>15					1

Height (m)	0–500	500–1000	1000–1500	1500–2000	>2000
0–500	1	2	4	5	6
500–1000		1	3	4	5
1000–1500			1	3	4
1500–2000				1	3
>2000					1

Rocky land (km)	0–0.5	0.5–1	1–10	>10
0–0.5	1	1/2	1/4	1/5
0.5–1		1	1/3	1/4
1–10			1	1/3
>10				1

Proximity to roads (km)	0–0.5	0.5–1	1–3	3–5	>5
0–0.5	1	2	3	5	6
0.5–1		1	2	4	5
1–3			1	3	4
3–5				1	3
>5					1

Proximity to grids (km)	0–0.5	0.5–1	1–5	5–10	>10
0–0.5	1	2	3	4	5
0.5–1		1	2	4	5
1–5			1	3	4
5–10				1	3
>10					1

Proximity to energy transmission lines (km)	0–0.1	0.1–0.5	0.5–1	1–5	>5
0–0.1	1	2	3	4	5
0.1–0.5		1	2	3	4
0.5–1			1	4	5
1–5				1	3
>5					1

Proximity to wetlands (km)	0–0.5	0.5–1	1–2	2–5	>5
0–0.5	1	1/2	1/3	1/4	1/5
0.5–1		1	1/2	1/3	1/5
1–2			1	1/3	1/4
2–5				1	1/3
>5					1

Proximity to forested areas (km)	0–0.5	0.5–1	1–2	2–5	>5
0–0.5	1	1/2	1/3	1/5	1/6
0.5–1		1	1/3	1/4	1/5
1–2			1	1/3	1/4
2–5				1	1/3
>5					1

Proximity to settlement (km)	0–2	2–5	5–10	10–20	>20
0–2	1	1/2	1/3	1/4	1/5
2–5		1	1/3	1/4	1/5
5–10			1	1/3	1/4
10–20				1	1/3
>20					1

Proximity to bird migration paths (km)	0–2.5	2.5–5	5–10	>10
0–2.5	1	1/2	1/3	1/4
2.5–5		1	1/3	1/4
5–10			1	1/3
>10				1

Proximity to airports (km)	0–3	3–5	5–7	7–10	>10
0–3	1	1/2	1/3	1/5	1/6
3–5		1	1/2	1/4	1/5
5–7			1	1/3	1/4
7–10				1	1/3
>10					1

Proximity to protection areas (km)	0–0.5	0.5–1	1–2.5	2.5–5	>5
0–0.5	1	1/2	1/3	1/5	1/6
0.5–1		1	1/2	1/4	1/5

Proximity to protection areas (km)	0–0.5	0.5–1	1–2.5	2.5–5	>5				
1–2.5			1	1/3	1/4				
2.5–5				1	1/4				
>5					1				
Proximity to fault lines (km)	0–0.15	0.15–2	2–4	>4					
0–0.15	1	1/2	1/3	1/5					
0.15–2		1	1/2	1/4					
2–4			1	1/4					
>4				1					
Land use capability	I	II	III	IV	V	VI	VII	VIII	
I	1	1/2	1/3	1/4	1/5	1/6	1/7	1/8	
II		1	1/2	1/3	1/4	1/5	1/6	1/7	
III			1	1/2	1/3	1/4	1/5	1/6	
IV				1	1/2	1/3	1/4	1/5	
V					1	1/2	1/3	1/4	
VI						1	1/2	1/3	
VII							1	1/2	
VIII								1	

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