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# Investigation of Technical and Environmental Factors in the Selection of Wind Power Plants in the Bergama Region Using the Analytic Hierarchy Process (AHP)

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## Abstract

Wind power plants represent crucial investments both globally and in Turkey, driven by escalating energy demands due to rapid population growth and technological advancements. Consequently, Turkey has substantially expanded its wind energy production in recent years. Selecting optimal locations for wind power plants requires an extensive evaluation of multiple technical and environmental factors, among which regional wind potential holds primary importance. The Aegean Region-particularly İzmir province and its Bergama district-possesses remarkable potential for wind power plants (WPP). Given the high investment costs and complex operational processes involved in wind energy projects, thorough pre-investment assessments using reliable analytical methods are essential for project viability and sustainability. This study, conducted entirely within the borders of Turkey, applies the Analytic Hierarchy Process to evaluate technical and environmental criteria for WPP site selection in the Bergama region. The results indicate that proactive safety measures (K31), wind speed (K11), and risk analysis and management strategies (K33) are the most critical criteria influencing the decision-making process. Among the five capacity alternatives assessed, the 25 MW WPP project (A5) was identified as the most suitable and effective option for implementation in the region.

**Categories:** Renewable Energy Systems, Environmental and Sustainable Engineering
**Keywords:** wind power plant, analytic hierarchy process, site selection, bergama region, renewable energy

## Introduction

Turkey possesses substantial advantages for wind energy potential due to its strategic geographic location and favorable climatic conditions. Surrounded by seas on three sides and characterized by diverse topographical features, the country offers ideal conditions for wind power generation. In recent years, significant growth in the wind energy sector has been driven by rising global interest in renewable energy and Turkey's strategic objectives for enhancing energy independence.

According to the Turkish Wind Energy Association (TUREB), Turkey's technical wind energy potential is estimated at approximately 48,000 MW [1], representing nearly one-third of the nation's total electricity production capacity. However, wind potential distribution varies significantly across the country. The highest potential is concentrated in the Aegean Region, notably within İzmir, Balıkesir, and Çanakkale provinces. Other regions, such as the Marmara Region (Istanbul, Tekirdağ, and Kırklareli), the Mediterranean Region (Hatay and Mersin vicinity), and Central Anatolia (Kayseri and Sivas provinces), also exhibit considerable wind energy capacities.
By the end of 2023, Turkey's total installed wind energy capacity reached 11,654 MW, accounting for approximately 10% of national electricity consumption [2]. The remarkable growth trajectory over the past two decades demonstrates Turkey's commitment and sectoral dynamism. In the global context, Turkey ranks 13th in terms of total installed wind power capacity. China, the USA, and Germany lead the global rankings, with Turkey closely following several European countries (Figure *1*) [3].

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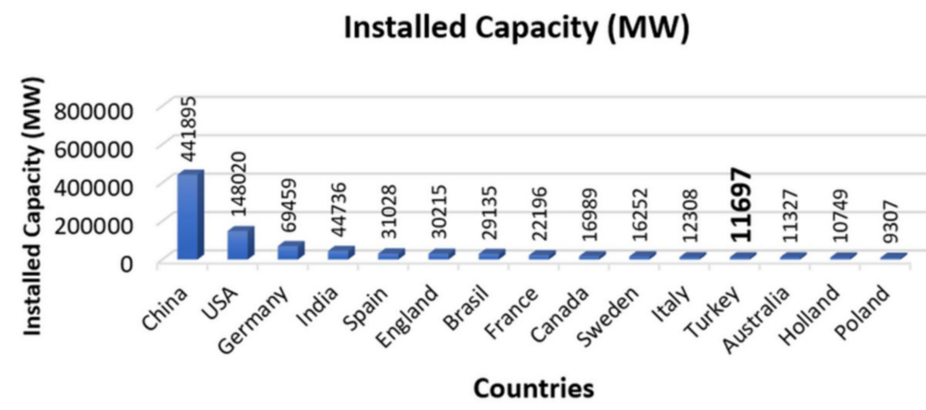


**FIGURE 1: Installed wind power capacity by country (as of 2023)**

To foster the growth of wind energy, Turkey has implemented comprehensive legislative frameworks and targeted incentive schemes. Notably, the Renewable Energy Law (Law No. 5346) established in 2005, alongside the Electricity Market Law (Law No. 6446) introduced in 2013, provides robust support mechanisms. Under the Renewable Energy Support Scheme (YEKDEM), WPP projects operational before 2020 benefit from a fixed feed-in tariff of 7.3 USD cents/kWh for 10 years. WPP projects operational between 2021 and 2025 receive a reduced tariff of 4.0 USD cents/kWh [4]. Additionally, domestic manufacturing incentives have strengthened local industry capabilities significantly.

While most wind power installations in Turkey are onshore turbines, recent advancements in technology have facilitated higher capacity, more efficient turbines. Concurrently, the Ministry of Energy and Natural Resources is developing offshore wind initiatives, including a planned 2 GW offshore WPP project in the Black Sea [5,6]. The domestic production of wind turbine components is also steadily increasing, enhancing Turkey's industrial self-sufficiency in renewable energy technologies.

Turkey's wind energy trajectory aligns closely with global renewable energy trends. According to targets set by the Ministry of Energy and Natural Resources, the installed wind energy capacity aims to reach 16,000 MW by 2027, 24,000 MW by 2030, and ultimately 29,000 MW by 2035 [7,8].

In the context of Turkey, several studies have demonstrated the effective implementation of fuzzy AHP in determining optimal wind power plant (WPP) locations by integrating technical, geographical, and environmental dimensions [9]. For instance, one study conducted in the Sakarya Province employed fuzzy AHP and weighted fuzzy overlay methods to evaluate suitable regions based on site-specific constraints such as wind potential, land availability, and cost-effectiveness [10]. Another application targeted the Northeast Aegean Sea, where fuzzy AHP was combined with Geographic Information System (GIS) tools to determine offshore floating wind turbine placement, focusing on maritime spatial planning between Çanakkale and Gökçeada [11]. These studies reinforce the adaptability of fuzzy AHP-based methods in diverse Turkish geographies and support its reliability for guiding wind energy investments under various spatial and policy constraints.

In addition to national applications, fuzzy AHP has also been extensively employed in international contexts to determine wind energy site suitability under complex environmental and technical conditions. For instance, in Nigeria, a GIS-based model incorporating interval type-2 fuzzy AHP was used to identify optimal wind farm locations by evaluating factors such as wind potential, environmental suitability, and socio-economic constraints [12]. A similar methodology was adopted in Indonesia, where fuzzy AHP helped prioritize wind power locations in Tanah Laut Regency and South Kalimantan based on criteria including proximity to residential zones and terrain characteristics [13]. In Morocco, fuzzy AHP was integrated with GIS tools to assess wind farm locations in the Tarfaya region, considering slope, wind speed, land use, and infrastructure proximity [14]. These studies confirm the method's global adaptability and underscore its relevance for sustainable site planning across diverse geographic and regulatory landscapes.

In 2023, Turkey's electricity consumption increased by 1.2% from the previous year, totaling 335.2 terawatt-hours (TWh), while electricity production grew by 0.8%, reaching 331.1 TWh. Projections in the National Energy Plan anticipate a continuous rise, estimating consumption to reach 380.2 TWh by 2025, 455.3 TWh by 2030, and 510.5 TWh by 2035. In terms of electricity production sources for 2023, coal dominated at 36.2%, followed by natural gas at 21%, hydroelectricity at 19.3%, wind at 10.3%, solar at 6.7%, geothermal at 3.4%, and other resources comprising 3.2% [15]. By September 2024, Turkey's total installed power generation capacity was 114,215 MW, distributed among hydroelectric (28.2%), natural gas

(21.6%), coal (19.2%), solar (16.4%), wind (10.8%), geothermal (1.5%), and various other sources (2.4%) [16].

Recent advancements in multi-criteria decision-making (MCDM) techniques, particularly the Analytic Hierarchy Process (AHP) and its hybrid approaches, have found applications in various environmental planning contexts. Beyond their traditional use in energy infrastructure, these methods have been successfully applied to evaluate photocatalytic materials for air and water remediation due to their ability to handle complex and conflicting evaluation parameters [17,18]. For instance, studies have employed fuzzy AHP to assess nanomaterials based on their photoreactivity, stability, and environmental compatibility under different operational conditions [19,20]. These applications demonstrate the flexibility of AHP-based models in environmental assessments, supporting a broader sustainability perspective in renewable energy planning.

This study addresses critical considerations in selecting wind power plant locations using the AHP. Specifically, proactive safety measures (K31), wind speed (K11), and risk analysis and management (K33) were identified as the most crucial factors influencing site selection. Among the alternatives analyzed, the A5 WPP project with a capacity of 25 MW emerged as the optimal choice for the Bergama region. These findings underline the importance of a balanced consideration of both technical and environmental dimensions to optimize the effectiveness, safety, and sustainability of wind power investments.

# Materials And Methods

## Wind energy fundamentals and Turkey’s wind potential

Wind energy is generated as a result of the differential heating of the Earth's surface by solar radiation, creating atmospheric pressure and temperature gradients that induce air movement. It is estimated that approximately 2% of the solar energy reaching the planet is converted into wind. Wind characteristics-mainly speed and direction-vary depending on geographic and climatic factors, and wind speed notably increases with altitude. Since wind power potential is proportional to the cube of wind speed, even small increases in velocity can yield substantial energy gains, making high-altitude regions particularly advantageous.

Although wind energy systems face challenges such as high initial capital costs, variable generation (intermittency), and comparatively low capacity factors, they offer significant advantages:

A clean, renewable energy source with minimal environmental footprint.

Immunity to resource depletion and long-term market price fluctuations.

Competitiveness with traditional energy sources due to declining costs.

Low maintenance and operation requirements.

Straightforward implementation and scalability.

Rapid deployment and commissioning of WPP projects.

Wind turbines-key components of wind energy systems-convert the kinetic energy of air into mechanical power, which is then transformed into electricity. The technical feasibility and economic efficiency of WPP projects strongly depend on accurate wind resource assessments.

In Turkey, the first Wind Energy Potential Atlas (REPA-V1) was published in 2006, using a combination of medium-scale numerical weather forecasting and micro-scale wind flow models with 200-meter spatial resolution. According to this model, areas with an annual average wind speed above 7.5 m/s at 50 meters were considered suitable for wind farms, with a theoretical installation density of 5 MW/km$^2$. Based on these criteria, the country’s theoretical wind energy potential was estimated at 47,849 MW, which corresponds to approximately 1.30% of the national land area.

In collaboration with the European Union and the European Bank for Reconstruction and Development (EBRD), Turkey revised the atlas with higher spatial resolution (100 × 100 meters). The updated Wind Energy Potential Atlas incorporates detailed measurements at altitudes of 30, 60, 100, and 150 meters, along with directional wind data at 100 meters. This enhancement enables more accurate assessments of wind power density, wind class categorizations, capacity factors, and estimated annual energy output for standard 3 MW turbines.

The new dataset is currently used to re-evaluate Turkey’s wind energy deployment capacity, incorporating updated criteria related to site exclusion, cost efficiency, and advancements in turbine technology.

Provincial and regional wind energy potential data are publicly available on the Ministry's portal repa.enerji.gov.tr.

The spatial distribution of average wind speeds across Turkey highlights regions with significant wind energy potential. In particular, western coastal zones, such as the Aegean region, are recognized as favorable locations based on national wind resource assessments [21].

## Analytic Hierarchy Process (AHP) methodology

The AHP, developed by Thomas L. Saaty in 1977, is a widely recognized and structured MCDM method. AHP is particularly effective for complex problems involving both qualitative and quantitative evaluation criteria-making it highly applicable in renewable energy planning [12].

In AHP, decision-making elements are structured hierarchically, beginning with the overall goal, followed by decision criteria and sub-criteria, and finally, alternatives. The method relies on pairwise comparisons to determine the relative importance of criteria and alternatives. These comparisons are translated into a priority scale, as shown in Table *1* [13].

| Scale | Definition | Explanation |
|---|---|---|
| **1** | **Equal importance** | **Both elements contribute equally to the objective.** |
| 3 | Slightly more important | One element is weakly preferred over another. |
| 5 | Moderately more important | One element is moderately more important than another. |
| 7 | Significantly more important | One element strongly dominates the other. |
| 9 | Extremely more important | One element is overwhelmingly more significant. |
| 2–8 | Intermediate values | Used when comparison is between two adjacent judgments. |
| 1/x | Reciprocal values | Reflects inverse of the importance when roles are reversed. |

**TABLE 1: AHP scale of importance**

See reference [22].

The main steps of the AHP method are as follows:

Structuring the problem hierarchically by identifying the objective, criteria, and alternatives.

Constructing pairwise comparison matrices for all criteria and sub-criteria.

Normalizing the matrices and computing relative weights (priority vectors).

Evaluating the consistency ratio to ensure logical coherence of judgments.

Aggregating weighted scores to determine the most suitable alternative.

AHP has been extensively applied in the energy field. For example, Fuzzy AHP was used to assess multiple renewable energy options [23], and hybrid models combining AHP with VIKOR have been proposed to optimize energy planning decisions [24-28]. These applications demonstrate the robustness of AHP in managing multidimensional and multidisciplinary decision problems in renewable energy projects.

## Field study and criteria

Bergama, located in the northwestern part of İzmir Province, is the largest district in the province by land area. It is bordered by Aliağa to the south, Kınık and the districts of Yunusemre and Soma (Manisa Province) to the east, and İvrindi, Burhaniye, and Ayvalık (Balıkesir Province) to the north; its western edge is adjacent to Dikili and the Aegean Sea. Positioned within the Bakırçay Basin, Bergama is a historically and economically significant region, renowned for its agricultural production, industrial activities, and cultural heritage. The ancient city of Pergamon, located at the district center, was a major hub of science, art, and philosophy during the Hellenistic period. Today, the dominant vegetation includes stone pine and cotton [29].

Geographically, the district is situated between the Madra Mountains to the north and the Yunt Mountains to the south. The Bakırçay Plain, stretching over 45 km in length and 15-20 km in width, defines the region's morphology. The central elevation is 68 meters, increasing to 331 meters at the Acropolis. Bergama is approximately 100 km from İzmir city and maintains close proximity to provincial centers such as Manisa and Balıkesir. Administratively, the district comprises six subregions, including Zeytindağ, Yuntdağ, Göçbeyli, Turanlı, Kozak, and the district center itself [30].

From a wind energy perspective, Bergama is distinguished by its high and stable wind speeds. The study site, located in the southwestern part of the district, was selected based on data from Turkey's updated Wind Energy Potential Atlas [3]. As shown in Figure *2*, the area demonstrates average wind speeds exceeding 8.5 m/s at a height of 100 meters-values that qualify as "very good" according to international classification systems. The topography and the proximity to the Aegean Sea contribute to the formation of strong and consistent wind corridors. These characteristics mark Bergama as a technically favorable and geographically strategic site for utility-scale wind power plant development.

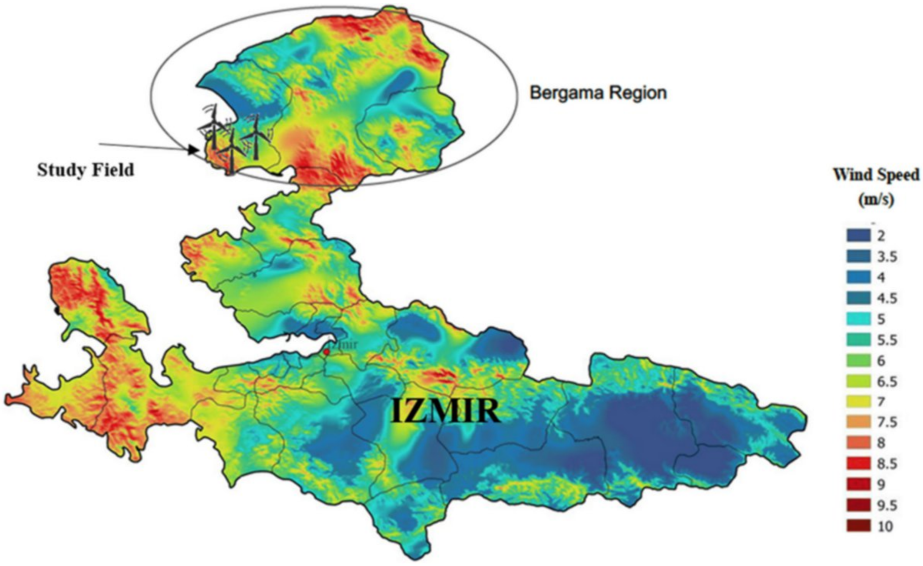


**FIGURE 2: Wind potential at 100 meters in the Bergama region**

The site selection process for the planned WWP in the southwestern part of Bergama was conducted using the AHP, a MCDM method that facilitates the evaluation of alternatives across structured criteria. In this study, five alternative capacity options were defined: A1 (5 MW), A2 (10 MW), A3 (15 MW), A4 (20 MW), and A5 (25 MW). These alternatives were analyzed based on a comprehensive criteria framework consisting of technical, environmental, and occupational safety categories.

As presented in Table *2*, the AHP model incorporates 15 sub-criteria grouped under three primary headings:

Technical criteria (K1): wind speed (K11), energy production capacity (K12), connection to the national electricity grid (K13), topography and accessibility (K14), and operational system characteristics (K15);

Environmental criteria (K2): land acquisition for the WPP project (K21), availability of water resources (K22), wildlife and protected areas (K23), national aviation status and communication lines (K24), and contribution to environmental cleanliness (K25);

Occupational safety criteria (K3): proactive measures (K31), planned and systematic operations (K32), risk analysis and management (K33), safe transportation and installation (K34), and expert staff and qualified personnel (K35).

| K1: Technical criteria | K2: Environmental criteria | K3: Occupational safety criteria | Wind power plant capacity alternatives |
|---|---|---|---|
| **K11: Wind speed** | **K21: Land acquisition for the project** | **K31: Proactive measures** | **Alternative A1: 5 megawatts (MW)** |
| K12: Energy production capacity | K22: Availability of water resources | K32: Planned and systematic operations | Alternative A2: 10 megawatts (MW) |
| K13: Connection to the national electricity grid | K23: Wildlife, protected areas, and historical sites | K33: Risk analysis and management | Alternative A3: 15 megawatts (MW) |
| K14: Topography and accessibility | K24: National aviation status and communication lines | K34: Safe transportation and installation | Alternative A4: 20 megawatts (MW) |
| K15: Operational system | K25: Contribution to environmental cleanliness | K35: Expert staff and qualified workers | Alternative A5: 25 megawatts (MW) |

**TABLE 2: Criteria for selecting different power capacities and alternative wind power plants**

The relative significance of the three primary evaluation categories-technical (K1), environmental (K2), and occupational safety (K3)-was assessed using pairwise comparisons within the AHP framework. As illustrated in Table *3*, the expert-based assessments revealed that technical criteria were considered moderately more important than environmental concerns and substantially more important than occupational safety issues. This prioritization reflects a practical emphasis on performance and energy output in early-stage project decision-making, particularly for high-capacity installations.

| | K1 | K2 | K3 |
|---|---|---|---|
| **K1** | **1** | **3** | **0.50** |
| K2 | | 1 | 0.25 |
| K3 | | | 1 |

**TABLE 3: Pairwise comparison matrix of main criteria (K1–K3)**

Following this, the sub-criteria under the technical group (K1) were evaluated to derive more granular weightings. These include wind speed (K11), energy production capacity (K12), connection to the national electricity grid (K13), topography and accessibility (K14), and operational system characteristics (K15). The pairwise comparison results for these sub-criteria are presented in Table *4*.

Among these, wind speed (K11) emerged as the most influential factor. In the Bergama region, wind speed values vary between 10 and 12 m/s on average, with particularly strong and stable flows in elevated and coastal zones. Such wind conditions are highly favorable for energy generation due to the cubic relationship between wind speed and power output.

The theoretical potential of wind energy was calculated using the classical power (Equation 1):

$$P = 0.59 \times \eta \times \rho \times A \times V^3$$

Where:

P : Net power output (W)

η : Turbine efficiency (typically between 0.25 and 0.45)

ρ : Air density ($kg/m^3$), standard value at 20°C = 1.225 $kg/m^3$

A : Swept area of the rotor ($m^2$), calculated as $A = \pi R^2$

V : Wind speed (m/s)

0.59: Betz limit - theoretical maximum power coefficient (59.3%)

As seen in Table 4, wind speed (K11) was consistently prioritized over other technical considerations, further underscoring the necessity of accurate wind assessment in site selection processes for utility-scale WPP projects.

| | K11 | K12 | K13 | K14 | K15 |
|---|---|---|---|---|---|
| **K11** | **1** | **3** | **3** | **5** | **6** |
| K12 | | 1 | 2 | 3 | 4 |
| K13 | | | 1 | 2 | 3 |
| K14 | | | | 1 | 2 |
| K15 | | | | | 1 |

**TABLE 4: Pairwise comparison matrix of technical sub-criteria (K11–K15)**

The relative weights of the environmental criteria (K2) were determined through pairwise comparisons, as detailed in Table 5. The five sub-criteria considered in this group were as follows: land acquisition for the project (K21), availability of water resources (K22), presence of wildlife, protected areas, and historical sites (K23), national aviation status and communication lines (K24), and contribution to environmental cleanliness (K25). These factors reflect the spatial, ecological, and regulatory dimensions that directly influence the feasibility of WPP projects.

As shown in Table 5, land acquisition (K21) was assigned the highest relative weight among the environmental criteria. This outcome aligns with practical challenges in securing legally viable project areas, particularly in semi-rural regions with agricultural or touristic value. The second highest weight was given to wildlife and protected zones (K23), underscoring the need to balance energy investments with biodiversity conservation and heritage protection.

In accordance with Turkish environmental legislation, wind energy developments must comply with land use planning rules, including the conservation of energy resource zones, watershed integrity, and water supply areas. Furthermore, local regulations set by the İzmir Metropolitan Municipality stipulate that wind turbines must be located at least 250 meters away from residential areas. The construction of renewable energy facilities is strictly prohibited in absolute and short-range protection zones of drinking water reservoirs. These legal constraints reinforce the significance of environmental criteria such as K21 and K23 within the AHP model, as they represent potential veto points in the project approval process.

| | K21 | K22 | K23 | K24 | K25 |
|---|---|---|---|---|---|
| **K21** | **1** | **3** | **4** | **5** | **3** |
| K22 | | 1 | 2 | 3 | 1 |
| K23 | | | 1 | 2 | 0.5 |
| K24 | | | | 1 | 0.25 |
| K25 | | | | | 1 |

**TABLE 5: Comparison matrix of environmental criteria (K2)**

The occupational safety criteria group (K3) was evaluated through pairwise comparisons to determine the relative importance of five sub-criteria: proactive measures (K31), planned and systematic operations (K32), risk analysis and management (K33), safe transportation and installation (K34), and expert staff and qualified workers (K35). The results of these comparisons are presented in Table 6. Among them, K31 received the highest weight, highlighting the increasing emphasis on preventive safety practices in large-scale infrastructure projects such as wind farm installations. This finding aligns with the regulatory transformation initiated by Turkey's Occupational Health and Safety Law No. 6331, enacted on June 20, 2012, which mandates systematic risk prevention, emergency planning, and workplace health auditing.

Wind turbine components, due to their massive dimensions and height-related assembly procedures, present inherent safety risks. As such, proactive measures (K31) are critical for minimizing fall hazards, electrical accidents, and equipment-related injuries during construction and maintenance phases. Additionally, planned and systematic operations (K32) and risk analysis and management (K33) were also assigned substantial weights, reflecting their operational necessity in structured project execution. The relatively lower weights of K34 and K35 suggest that while transportation logistics and personnel qualifications are important, they are perceived as secondary to broader systemic safety strategies.

The weighted distribution of all criteria groups-technical, environmental, and occupational safety-is visualized in Figures *3*, *4*, and 5, which collectively synthesize the results presented in Tables *4*, *5*, and 6. As shown in these figures, wind speed (K11), project area determination (K21), and proactive safety measures (K31) emerge as the most influential sub-criteria within their respective categories, underscoring their central role in the multi-criteria evaluation of wind power plant site selection.

| | K31 | K32 | K33 | K34 | K35 |
|---|---|---|---|---|---|
| **K31** | **1** | **3** | **2** | **4** | **3** |
| K32 | | 1 | 1 | 3 | 2 |
| K33 | | | 1 | 2 | 3 |
| K34 | | | | 1 | 2 |
| K35 | | | | | 1 |

**TABLE 6: Pairwise comparison matrix of occupational safety criteria (K31–K35)**

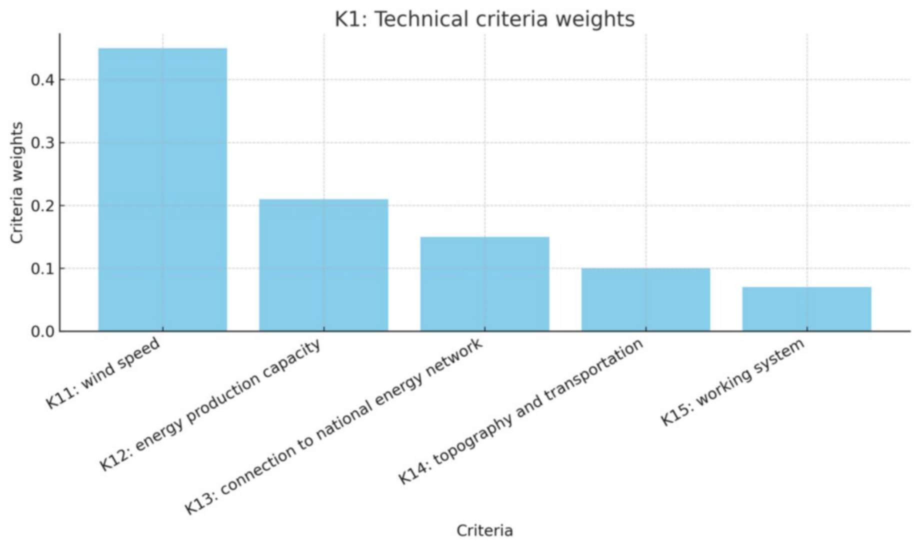


**FIGURE 3: Weights of technical criteria: wind speed (K11), energy production capacity (K12), connection to national energy network (K13), topography and transportation (K14), and working system (K15)**

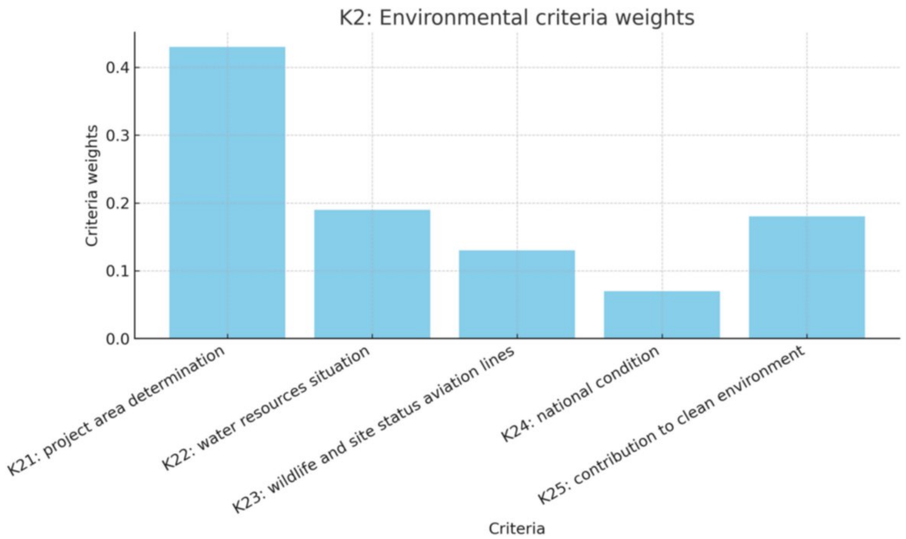


**FIGURE 4: Weights of environmental criteria: project area determination (K21), water resources situation (K22), wildlife and site status aviation lines (K23), national condition (K24), and contribution to clean environment (K25)**

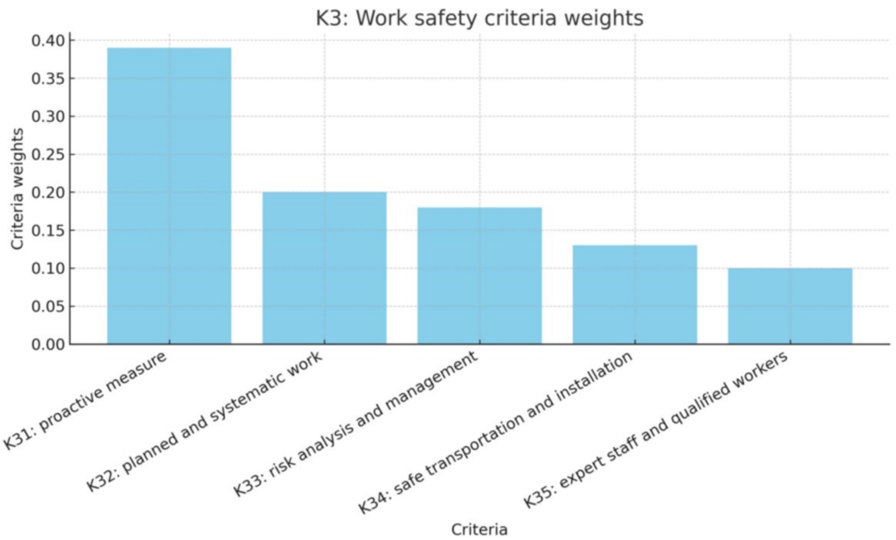


**FIGURE 5: Weights of occupational safety criteria: proactive measure (K31), planned and systematic work (K32), risk analysis and management (K33), safe transportation and installation (K34), and expert staff and qualified workers (K35)**

To identify the most suitable WPP project for the selected site in Bergama, each of the five capacity alternatives-A1 (5 MW) through A5 (25 MW)-was evaluated against all 15 sub-criteria using the AHP prioritization scale. The complete pairwise comparison values for these alternatives are provided in Table 7, which integrates the results of the preceding technical (K1), environmental (K2), and occupational safety (K3) assessments.

As seen in the matrix, alternatives A4 and A5 consistently receive higher scores for key technical and safety-oriented criteria such as wind speed (K11), energy production capacity (K12), and proactive measures (K31), indicating their superior alignment with the high-priority attributes established earlier. In contrast, alternatives A1 and A2 show stronger performance only in criteria with relatively lower weights, such as transportation accessibility (K14) or grid connection simplicity (K13), which may offer implementation convenience but do not carry substantial influence in the decision model.

The structure of Table 7 ensures that each alternative's score under a given criterion reflects expert judgment of its relative favorability using Saaty's 1-9 AHP scale. These scores are subsequently used in the next step to calculate the weighted performance of each alternative by combining them with the normalized criterion weights obtained from the AHP process (as presented in the following section). This integrative scoring method allows for a comprehensive and hierarchical evaluation across all criteria categories.

| Criteria | A1 | A2 | A3 | A4 | A5 |
|---|---|---|---|---|---|
| **K11** | **2** | **3** | **5** | **7** | **9** |
| K12 | 2 | 3 | 5 | 7 | 9 |
| K13 | 6 | 5 | 4 | 3 | 2 |
| K14 | 5 | 4 | 3 | 2 | 1 |
| K15 | 5 | 4 | 3 | 2 | 1 |
| K21 | 6 | 5 | 4 | 3 | 2 |
| K22 | 5 | 4 | 3 | 2 | 1 |
| K23 | 5 | 4 | 3 | 2 | 1 |
| K24 | 5 | 4 | 3 | 2 | 1 |
| K25 | 2 | 3 | 3 | 4 | 4 |
| K31 | 3 | 4 | 5 | 6 | 7 |
| K32 | 3 | 4 | 5 | 6 | 7 |
| K33 | 2 | 3 | 3 | 4 | 4 |
| K34 | 4 | 3 | 2 | 2 | 2 |
| K35 | 3 | 4 | 4 | 5 | 5 |

**TABLE 7: Comparative AHP scores of capacity alternatives (A1–A5) against all criteria (K11–K35)**

AHP, Analytic Hierarchy Process

The overall weight coefficients of all sub-criteria were derived by combining the hierarchical comparisons from previous stages. These final values are presented in Table 8 and visualized in Figure 6. Among all 15 sub-criteria, proactive safety measures (K31) received the highest weight (0.222), followed by wind speed (K11) with 0.149, and risk analysis and management (K33) with 0.117. This distribution reflects the strong emphasis on safety planning and wind potential as primary decision drivers in the context of wind energy site selection.

| Criteria | Weight coefficient |
|---|---|
| **K11** | **0.149** |
| K12 | 0.075 |
| K13 | 0.049 |
| K14 | 0.029 |
| K15 | 0.018 |
| K21 | 0.055 |
| K22 | 0.022 |
| K23 | 0.013 |
| K24 | 0.008 |
| K25 | 0.024 |
| K31 | 0.222 |
| K32 | 0.110 |
| K33 | 0.117 |
| K34 | 0.060 |
| K35 | 0.048 |

**TABLE 8: Final weight matrix of evaluation criteria**

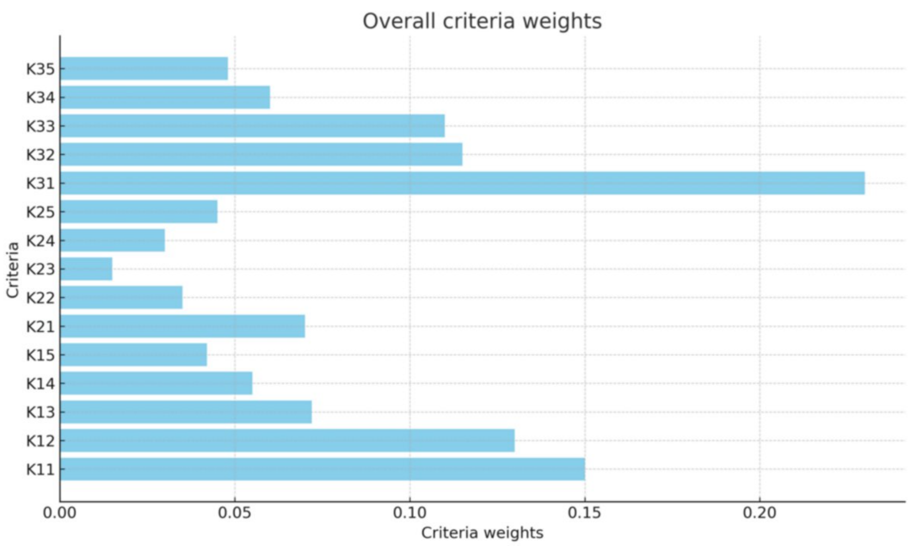


**FIGURE 6: Distribution of overall criteria weights: technical (K11–K15), environmental (K21–K25), and occupational safety criteria (K31–K35)**

These weights were subsequently applied to the performance scores of each WPP alternative, as outlined in Table 7, to compute the overall scores of each WPP project. The calculation follows the linear weighted sum model used in AHP, expressed as:

Equation 2:

$$\text{Overall Score}_{A_1} = P_{A_1} \times W$$

Where:

$w_j$: refers to the weight of criterion j (from Table 8)

$P_{i,j}$: refers to the AHP score of alternative Ai under criterion j (from Table 7).

For example, the overall score for alternative A1 is calculated as follows:

$$\text{Overall Score}_{A_1} = \begin{bmatrix} 2 & 2 & 6 & 5 & 5 & 6 & 5 & 5 & 2 & 3 & 3 & 2 & 4 & 3 \end{bmatrix} \times \begin{bmatrix} 0.149 \\ 0.075 \\ 0.049 \\ 0.029 \\ 0.018 \\ 0.055 \\ 0.022 \\ 0.013 \\ 0.008 \\ 0.024 \\ 0.222 \\ 0.110 \\ 0.117 \\ 0.060 \\ 0.048 \end{bmatrix}$$

Following this approach, the model determined that Alternative A5 (25 MW) achieved the highest performance score across all evaluation criteria. It demonstrated dominant or near-dominant scores in the most influential criteria (K11, K31, and K33), which collectively account for over 48% of the total weight. Alternative A4 (20 MW) ranked second, offering competitive performance with slightly lower values in high-weight criteria.

## Results And Discussion

The final performance evaluation of the alternative WPP projects is summarized in Table 9. Among the five alternatives, A5 (25 MW) achieved the highest overall performance score based on the AHP evaluation, receiving a total index of 5.56. These results are also illustrated in Figure 7 where a clear linear trend is observed between installed capacity and overall performance. The high score of A5 is primarily attributed to its favorable evaluations in the most heavily weighted criteria: proactive safety measures (K31), wind speed (K11), and risk management (K33), which together account for more than 48% of the total decision weight.

| Alternatives | A1 | A2 | A3 | A4 | A5 |
|---|---|---|---|---|---|
| Total performance | 3.19 | 3.68 | 4.20 | 4.98 | 5.56 |

**TABLE 9: Total performance scores of alternative WPP projects**

WPP, wind power plant

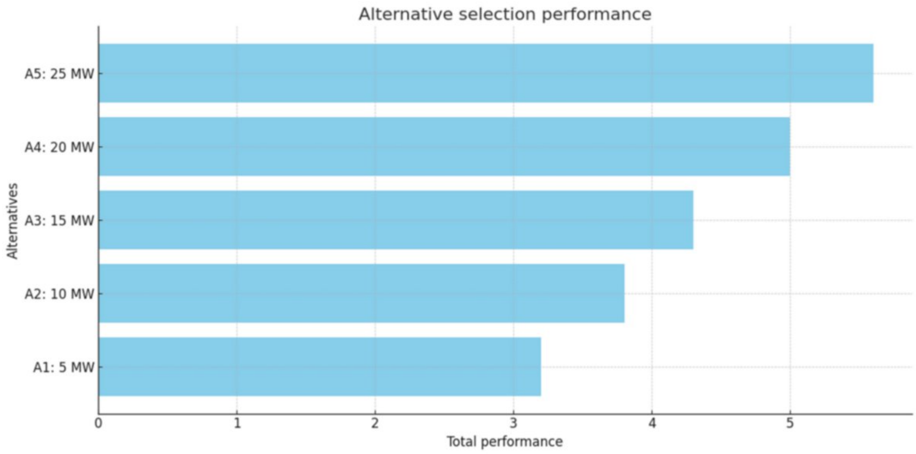


**FIGURE 7: Total performance scores of wind power plant (WPP) capacity alternatives (A1: 5 MW, A2: 10 MW, A3: 15 MW, A4: 20 MW, A5: 25 MW) derived from AHP evaluation**

The implementation of the 25 MW WPP project can be technically achieved using 5 MW turbines. In real-world applications, the actual electricity output of a wind turbine depends not only on nominal capacity but also on site-specific wind profiles, turbine efficiency, and hub height. For instance, a 2 MW turbine operating under optimal conditions (average wind speed ⩾ 8.5 m/s) can produce over 5 million kWh/year, which corresponds to the annual electricity consumption of approximately 1,500 households. Therefore, the cumulative production capacity of the A5 alternative could reach 12-15 GWh annually, assuming regional wind conditions similar to those identified in the Bergama wind potential atlas. The average wind speed in this region is reported to vary between 10 and 12 m/s based on a 12-month measurement campaign conducted by the Turkish Ministry of Energy and Natural Resources (2023) [31] and corroborated by the Global Wind Atlas database [32].

As a renewable, emission-free energy source, WPP projects like the one proposed in this study contribute directly to Turkey's sustainable energy targets and decarbonization strategy. The Bergama region, with its high wind potential and available open land, is strategically aligned with national energy policies and investment incentives. The WPP project area, shown in Figure *8*, demonstrates the regional landscape and operational viability for wind farm development, further validating the practical feasibility of the A5 alternative.

In alignment with these results, the high decision weights assigned to proactive safety measures (K31) and risk management (K33) resonate with findings from similar studies in infrastructure and energy-related sectors. For example, a fuzzy AHP-based safety assessment conducted on a large construction site in Iran emphasized the importance of risk probability and consequence as primary decision-making criteria [33]. Similarly, prioritization study on occupational safety indicators using fuzzy AHP identified safety management systems as the most critical evaluation dimension [34]. Moreover, an AHP-based method selection study for occupational risk assessment in Turkish SMEs revealed that the sufficiency of proactive safety policies ranked among the top criteria in decision-making [35]. These examples confirm that the emphasis placed on occupational safety within this study not only reflects sectoral best practices but also supports the broader transition toward safety-integrated planning in renewable energy projects.

**FIGURE 8: Field view of the proposed WPP project location in Bergama**

WPP, wind power plant

## Conclusions

In recent years, wind energy has emerged as a vital component of national energy strategies worldwide, including in Turkey, where installed capacity has seen rapid growth. The Bergama region, located in western Turkey, offers strong and stable wind profiles, making it an attractive candidate for further wind power investments. Identifying the optimal capacity configuration for such WPP projects is a critical engineering and planning challenge that requires the integration of technical, environmental, and safety considerations.

This study applied the AHP to systematically evaluate five capacity alternatives (ranging from 5 MW to 25 MW) based on 15 sub-criteria grouped under three main dimensions: technical performance, environmental compatibility, and occupational safety. The results of the AHP model revealed that the A5 alternative (25 MW) attained the highest aggregate performance score, primarily due to its strong alignment with the most heavily weighted criteria: proactive safety planning, wind speed, and risk analysis and management.

The findings support the conclusion that larger-capacity wind power configurations can offer more sustainable and efficient solutions when sited in high-potential regions such as Bergama. Beyond technical feasibility, the integration of safety and environmental factors into the decision model provides a holistic framework that can be adapted to similar site selection problems across Turkey. Future research may consider extending this approach using fuzzy logic or hybrid MCDM models to incorporate greater uncertainty in expert judgments. Additionally, the presented model can serve as a decision-support tool for investors, planners, and policymakers working to expand Turkey’s renewable energy infrastructure.

## Additional Information

### Author Contributions

All authors have reviewed the final version to be published and agreed to be accountable for all aspects of the work.

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