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RESEARCH ARTICLE

# Suitability Analysis for Solar Power Plant Sites Using GIS-Based Analytical Hierarchy Process: A Case Study in Manisa

Güneş Enerjisi Santrallerine Uygun Alanların CBS Tabanlı Analitik Hiyerarşi Yöntemi Kullanılarak Belirlenmesi: Manisa Örneği

**Cihan Uysal[1] ✉, Mustafa Mutlu Uysal[2]**

[1] *Sarıgöl, Manisa, Türkiye*

[2] *Balıkesir Orman Bölge Müdürlüğü, Balıkesir, Türkiye*

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**ABSTRACT**

Increasing population and industrial developments constantly raise energy needs of countries. Furthermore, there is a high correlation between the development levels of countries and their energy consumption. Many countries, such as Türkiye, meet their energy needs mainly from fossil fuels. However, the limited reserves of these fuels, their increasing costs and their negative environmental impacts have brought renewable energy sources to the fore as alternatives. One of the most common renewable energy sources is solar energy. Türkiye has a high potential in terms of solar energy because of its geographical location. Many technical, economic, environmental and social parameters are taken into account when determining the locations of the most suitable solar power plants. In the study, it is aimed to define the most suitable areas where solar power plants can be installed in Manisa Province by using geographic information system and analytical hierarchy process. In the first step of the study, 9 criteria were outlined: solar radiation, distance to energy transmission lines, slope, land use, distance to roads, distance to streams, distance to lakes, distance to settlements and aspect, and these criteria were weighted using the analytical hierarchy process. In the final step of the study, the suitability of potential solar power plants for Manisa Province was evaluated.

**MAKALE BİLGİSİ**

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**ÖZ**

Artan nüfus ve sanayi sektöründeki gelişmelere bağlı olarak ülkelerin enerji ihtiyacı da her geçen gün artış göstermektedir. Ayrıca ülkelerin gelişmişlik seviyeleri ile enerji tüketimleri arasında yüksek korelasyon bulunmaktadır. Türkiye gibi birçok ülke enerji gereksinimini ağırlıklı olarak fosil yakıtlardan karşılamaktadır. Fakat bu yakıtların sınırlı rezervde olması, artan maliyeti ve çevreye verdikleri zararlar alternatif olarak yenilenebilir enerji kaynaklarını ön plana çıkarmıştır. Güneş enerjisi en yaygın yenilenebilir enerji kaynakları arasında yer almaktadır. Türkiye bulunduğu coğrafi konum itibariyle güneş enerjisi açısından yüksek potansiyele sahiptir. En uygun güneş enerjisi santrallerinin yerleri tespit edilirken teknik, ekonomik, çevresel ve sosyal birçok parametre hesaba katılmaktadır. Bu çalışmada, Manisa İlinde güneş enerjisi santralleri kurulabilecek en uygun alanlar coğrafi bilgi sistemleri ve analitik hiyerarşi yöntemi kullanılarak belirlenmesi amaçlanmıştır. Çalışmanın ilk aşamasında solar radyasyon, enerji nakil hatlarına uzaklık, eğim, arazi kullanımı, yollara olan uzaklık, akarsulara uzaklık, göllere uzaklık, yerleşim yerlerine olan uzaklık ve bakı olmak üzere dokuz kriter belirlenmiştir ve bu kriterler analitik hiyerarşi yöntemi kullanılarak ağırlıklandırılmıştır. Çalışmanın son aşamasında ise Manisa İli için potansiyel güneş enerjisi santralleri yerlerinin uygunlukları belirlenmiştir.

✉ **Correspondence:** uysalc@yahoo.com

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## Introduction

Energy demand is increasing worldwide due to population growth, urbanization, industrialization, and technological advancements. Currently, many countries rely primarily on fossil fuels to meet their energy needs. However, the limited reserves of these fuels will further increase the need for energy in the near future. The limited nature of fossil fuels is not the only drawback, they are also considered polluting energy sources due to their negative impact on the environment (Čeřovský & Mindl, 2008). The greenhouse effect and global warming, which result from the accumulation of carbon dioxide and other gases in the atmosphere from fossil fuel consumption, are significant (Tümertekin & Özgüç, 1997). The solution to this problem lies in the use of renewable energy sources (Özgöçmen, 2007; Can, 2019). Expanding the use of these resources is crucial for increasing energy efficiency and protecting the environment. The negative effects arising from the use of these resources are negligible compared to the use of fossil fuels (Güçlüer, 2010).

Today, many developed countries use various renewable energy sources such as wind, geothermal, solar, and hydropower (Yılmaz, 2012). Solar energy is the most prominent among these sources. The total net energy reaching Earth from the sun is more than 10000 times the energy currently obtained from fossil and nuclear fuels (Şahin, 2009). As an environmentally friendly and inexhaustible energy source, solar energy has significant potential for Türkiye (Kırbaş et al., 2013). Türkiye ranks among the top in the world in terms of thermal solar energy production and consumption (Demircan & Alakavuk, 2008). In Türkiye, the Aegean, Mediterranean, and Southeastern Anatolia Regions have the greatest solar energy potential. These regions were determined by considering both their solar energy potential and sunshine duration (ETKB, 2025). Numerous technical, environmental, and economic criteria are used to determine the ideal locations for solar power plants. Multi-criteria decision-making (MCDM) methods are used to analyze these selection criteria using Geographic Information System (GIS). One of the most commonly used MCDM methods is the Analytical Hierarchy Process (AHP). Numerous studies have identified ideal solar power plant sites using the GIS-based AHP method.

Regarding studies conducted in Türkiye, Uyan (2013) determined five parameters based on economic and environmental criteria for the study area in Konya. Weighting these parameters with AHP and examining analyses using GIS, he calculated the suitable areas for solar power plant installation as approximately 40% and the unsuitable areas as 60%. Kırbaş et al. (2013) and Yalçın & Yüce (2020) also carried out studies on solar energy potential and sunshine rate and duration for Burdur Province. Kılıç and Kumaş (2016) also did research on the average monthly sunshine duration for Burdur in the future using artificial neural networks. Ayday et al. (2016) also determined suitable areas for solar power plant site selection in Eskişehir Province using criteria based on topographic parameters as well as the geological structure of the land, using open-source GIS support. Arca and Çıtıroğlu (2022) also investigated the site selection for solar power plants in Karabük Province using the Analytical Hierarchy Method, one of the GIS and MCDA methods. Their study revealed that potential areas had medium and low sensitivity levels. Arslan (2016) also conducted a district-level study of renewable energy potential in Manisa Province. It was found that solar, wind, and geothermal energy potentials were high at the provincial level. Numerous studies have been conducted worldwide using the AHP. Hang et al. (2008) also focused on the use of solar energy in China in their research based on the increasing electricity and energy demand. Their research identified areas with high solar energy potential in the western and northern regions of the country. Effat (2013) also demonstrated potential areas for solar power plant installations in the Ismailia region of Egypt using multi-criteria decision analysis. Noorollahi (2016) also outlined 11 parameters to assess suitable areas for solar power plant installations in Iran. Because the advantages of these parameters were unclear, the Fuzzy Analytical Hierarchy Method (FAHY) was used for weighting and the suitable areas for solar power plants were mapped using GIS. In the study conducted by Merrouni et al. (2018), a total of 12 criteria were established to define the most suitable solar power plant areas in Morocco. Based on these criteria, a solar power plant suitability map was produced using AHP and GIS. These maps demonstrated that approximately 20% of the area in eastern Morocco was ideal for solar power plant installation. Romero-Ramos et al. (2023) also used the GIS-AHP approach to determine the solar energy potential to meet thermal demand in southeastern Spain. The study revealed that 5% of the total area had a very high solar energy potential.

Due to its geographical location, Türkiye is among the countries with high potential for solar energy. Türkiye's total annual sunshine duration is 2740 hours, and its total annual incoming energy is 1530 kW h m-$^{2}$ (GEPA, 2025). This study has created a solar power plant suitability map for Manisa, which has an annual average solar radiation of 1600 kW h m-$^{2}$.

## Materials and Methods

In the study, ArcGIS software was used to process geographic data. First, the vector data required for the study area were obtained from the Map of Türkiye Administrative Boundaries data held by the General Directorate of Mapping (GDM, 2025). Additionally, to attain the topographic parameters used in the study, SRTM (Shuttle Radar Topography Mission) data with a spatial resolution of 30x30m were downloaded from the (USGS, 2025). Distances to streams and lakes, power lines, settlements, and road locations were determined from OpenStreetMap (OSM, 2025). After collecting the necessary data for the study, the parameters affecting the solar power plant installation were designated. These parameters were weighted using AHP. In the final step, a suitability map of the study area for solar power plants was generated.

While there is no specific legislation or regulation regarding the site selection for a solar power plant, the most significant constraint is the avoidance of locations within protected areas such as irrigated agriculture and forests. The most fundamental characteristic of criteria selection is the measurability of the criteria (Uyan, 2017). In this study, 9 criteria were identified according to the characteristics of the region, based on a literature review. These criteria were solar radiation, distance to power transmission lines, slope, land use, distance to roads, distance to streams, distance to lakes, distance to settlements, and aspect.

Solar radiation is an important criterion that directly affects the potential of solar power plants to be constructed. Charabi and Gastli (2011), Effat (2013), and Uyan (2013) have conducted detailed studies on this criterion. The solar radiation data used in the study were gathered from a portal supported by the World Bank (GSA, 2025). In addition, proximity to power lines provides a cost advantage for solar power plant installations. When identifying potential sites for solar power plants, it is preferred that the distance from transformer centers not exceed 10 km (Uyan, 2017). The power line data used in this study were acquired from OpenStreetMap.

One of the topographic criteria determined for solar power plant installation is the slope criterion. A low slope is preferred for solar power plant installation. Shading problems caused by solar panels on steep slopes are undesirable, and high slopes have increased the cost of solar power plants (Noorollahi et al., 2016). However, nowadays, with the use of platforms or devices that reduce slope-related problems, slope values can be adjusted to higher levels than in previous years. In this study, terrain with a slope of less than 16° has been classified into 5 different subcategories. Furthermore, land use data cover settlements, wetlands, and various protected areas. Solar power plants must be located within protected areas or located a certain distance away. The land use data used in this study were sourced from Corine (Copernicus, 2025). Moreover, to minimize roadside debris and potential safety issues, solar panels are expected to be located a certain distance from roads. A literature review has suggested that solar power plants should be no closer than 100 m to roads (Uzar & Koca, 2020). Road data derived from OpenStreetMap was used in this study.

Another criterion taken into account to ensure that solar power plants are not affected by potential floods and flash floods is their distance from streams. A literature review has demonstrated that solar power plants should be at least 300-400 meters away from streams (Uzar & Koca, 2020). The distance data to streams used in this study were extracted from OpenStreetMap. Because lakes, like rivers, can change size over time, solar power plants are among the crucial criteria. The goal is for solar power plants to be at least 300-400 meters away from lakes. The distance data to lakes used in this study were obtained from OpenStreetMap.

On the other hand, the distance from residential areas must also be taken into consideration for solar power plants. Because residential areas are dynamic, solar power plants are likely to be located within or in their immediate vicinity. Therefore, solar power plants are required to be located within a certain distance from residential areas (Eroğlu, 2018). Another important topographic factor in selecting a solar power plant site is aspect. This criterion involves determining the north and south sides of the study area. Identifying south-facing land is crucial because it will receive more sunlight. All in all, the most suitable areas for solar power plant installations within Manisa Province were analyzed using AHP based on criteria such as solar radiation, distance to power lines, slope, land use, distance to roads, distance to streams, distance to lakes, distance to settlements, and aspect. Developed by Thomas Saaty, AHP utilizes pairwise comparisons to prioritize criteria when multiple criteria are present (Saaty & Vargas, 2012).

## Results and Discussion

The criteria and sub-criteria used in the study were shown in Table 1. In this table, a value of 1 corresponded to unsuitable, while a value of 5 corresponded to high suitable. Table 1 was used as a basis when creating criteria-based suitability maps.

Solar radiation values in Manisa Province varied between 1251 and 1779 kW h m-$^2$. The solar radiation suitability map was created by classifying the land into five main categories (Figure 1). A small portion of the study area (approximately 2%) was below 1600 kW h m-$^2$ and was shown as unsuitable on the map. The majority of the study area (approximately 75%) was classified as suitable to very suitable in terms of solar radiation (Figure 1). Distance from power transmission lines was classified into five main categories, and a thematic map was prepared (Figure 2). Lands more than 10 km from power transmission lines were classified as unsuitable. The slopes of the lands within the borders of Manisa Province were classified and a slope map was created (Figure 3). A slope value of ≤ 16° was specified for GES site selection. Lands with slope values above this value were designated as unsuitable. Lands with slope values below ≤ 4° were classified as suitable to very suitable, representing 29% of the study area. In this study, the land use suitability map consisted of seven classes: built-up area, forest, wetland, irrigated agriculture, pasture, natural areas, and dry agriculture (Figure 4, Table 1). Five basic classes were created when establishing the distance criteria to roads. On the suitability map, areas closer than 50 meters are classified as unsuitable (Figure 5). Similarly, five basic classes were created when creating distance maps to streams and lakes. In both suitability maps, land below 300 m was labeled as unsuitable (Figures 6 and 7, Table 1). The distance criterion to residential areas in the study area was evaluated under five classes. Lands closer than 500 m to residential areas were graded as unsuitable, accounting for 12% of the study area (Figure 8). When creating the aspect map, north- and south-facing lands were identified and classified. South-facing lands were assigned high suitability values, while north-facing lands were assigned low or unsuitable values (Figure 9, Table 1).

**Table 1.** Criteria used in the study and assigned points

| Criteria | Sub-criteria | Points |
|---|---|---|
| Solar radiation(kWh/m2) | 1251-1599 | 1 |
| | 1599-1661 | 2 |
| | 1661-1702 | 3 |
| | 1702-1733 | 4 |
| | 1733-1779 | 5 |
| Distance from power transmission lines (m) | >10000 | 1 |
| | 4000-10000 | 2 |
| | 2000-4000 | 3 |
| | 1000-2000 | 4 |
| | 0-1000 | 5 |
| Slope (%) | 0-2 | 5 |
| | 2-4 | 4 |
| | 4-8 | 3 |
| | 8-16 | 2 |
| | >16 | 1 |
| Land use | Built-up area | 1 |

| | | |
|---|---|---|
| | Forest | 1 |
| | Wetland | 1 |
| | Irrigated agriculture | 2 |
| | Pasture | 3 |
| | Natural area | 4 |
| | Dry farming | 5 |
| Distance to roads (m) | 0-50 | 1 |
| | 50-100 | 2 |
| | 100-200 | 3 |
| | 200-500 | 4 |
| | >500 | 5 |
| Distance to streams (m) | 0-300 | 1 |
| | 300-500 | 2 |
| | 500-1000 | 3 |
| | 1000-1500 | 4 |
| | >1500 | 5 |
| Distance to lakes (m) | 0-300 | 1 |
| | 300-500 | 2 |
| | 500-1000 | 3 |
| | 1000-1500 | 4 |
| | >1500 | 5 |
| Distance to settlements (m) | 0-500 | 1 |
| | 500-750 | 2 |
| | 750-1000 | 3 |
| | 1000-1500 | 4 |
| | >1500 | 5 |
| Aspect | Northwest | 1 |
| | North | 1 |
| | Northeast | 1 |
| | West | 2 |
| | East | 3 |
| | Southeast | 4 |
| | Southwest | 4 |
| | South | 5 |
| | Flat | 3 |

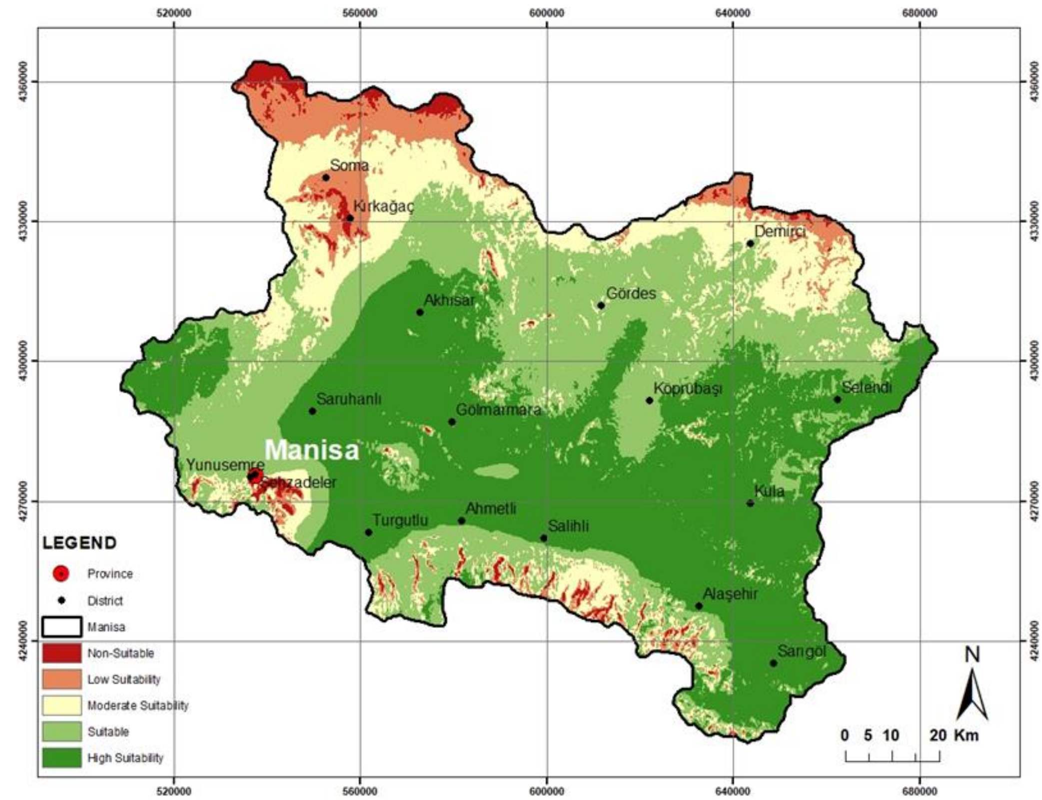


**Figure 1.** Suitability map according to solar radiation criteria

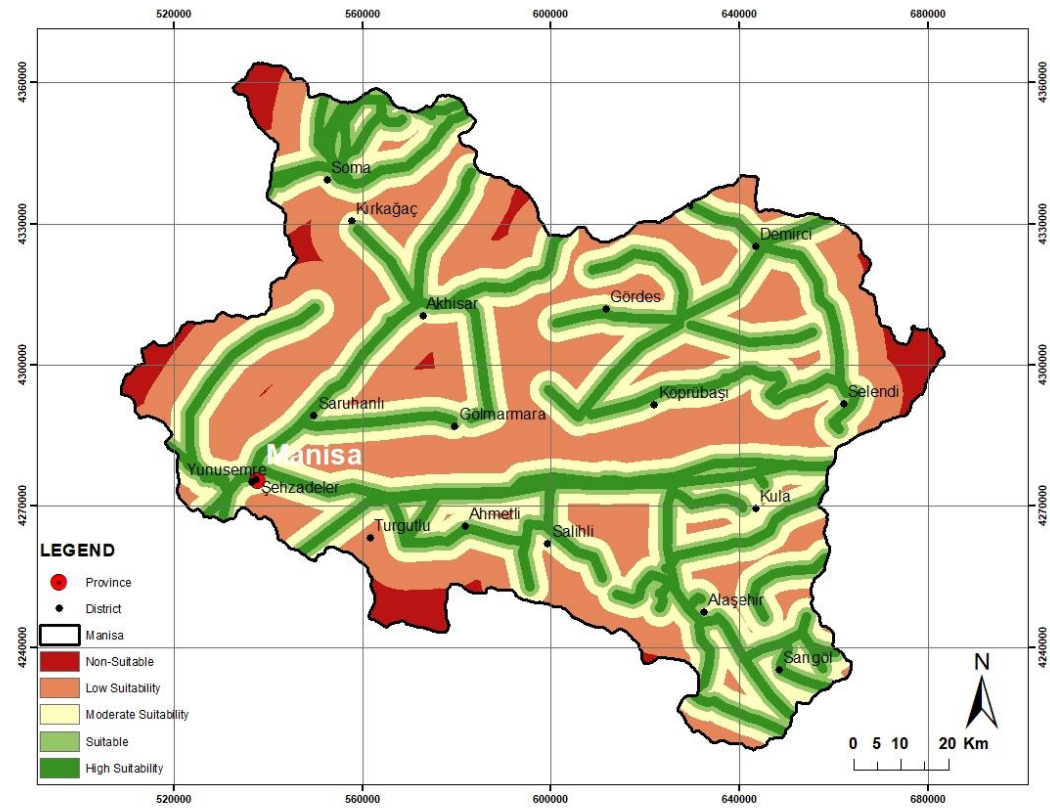


**Figure 2.** Suitability map according to distance criteria from power transmission lines

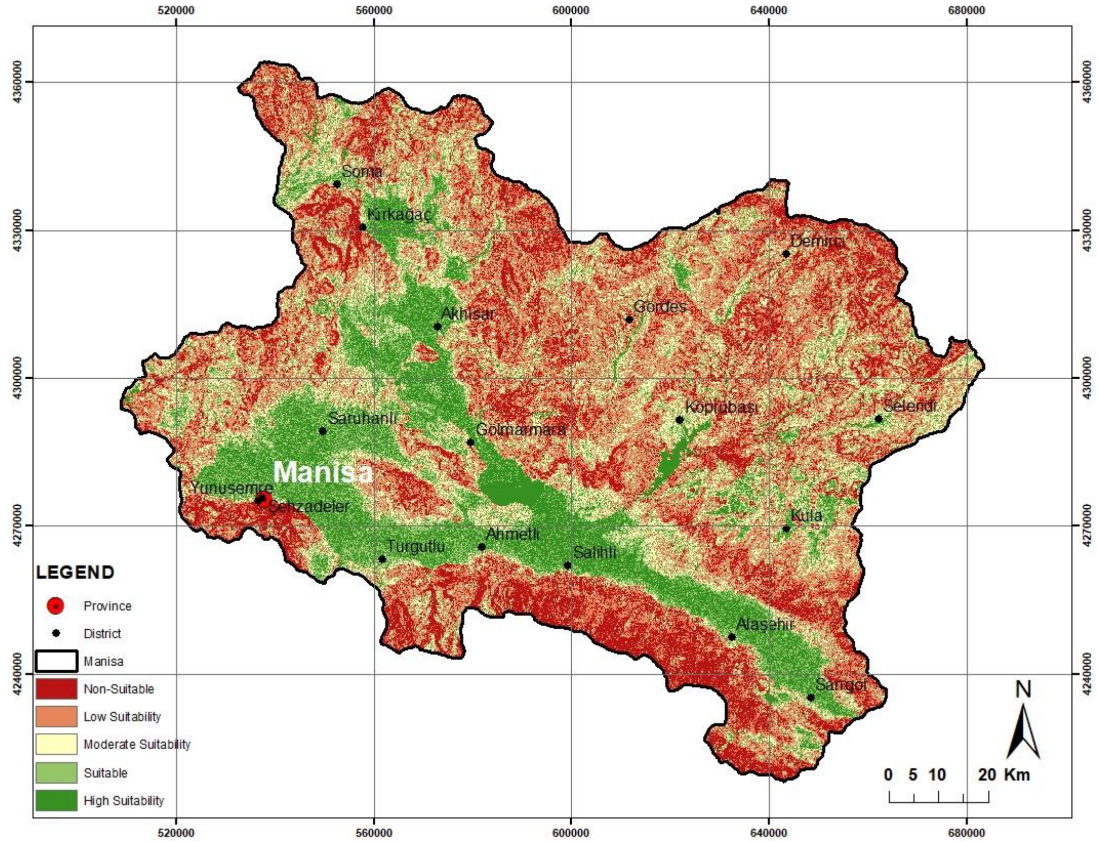


**Figure 3.** Suitability map according to slope criteria

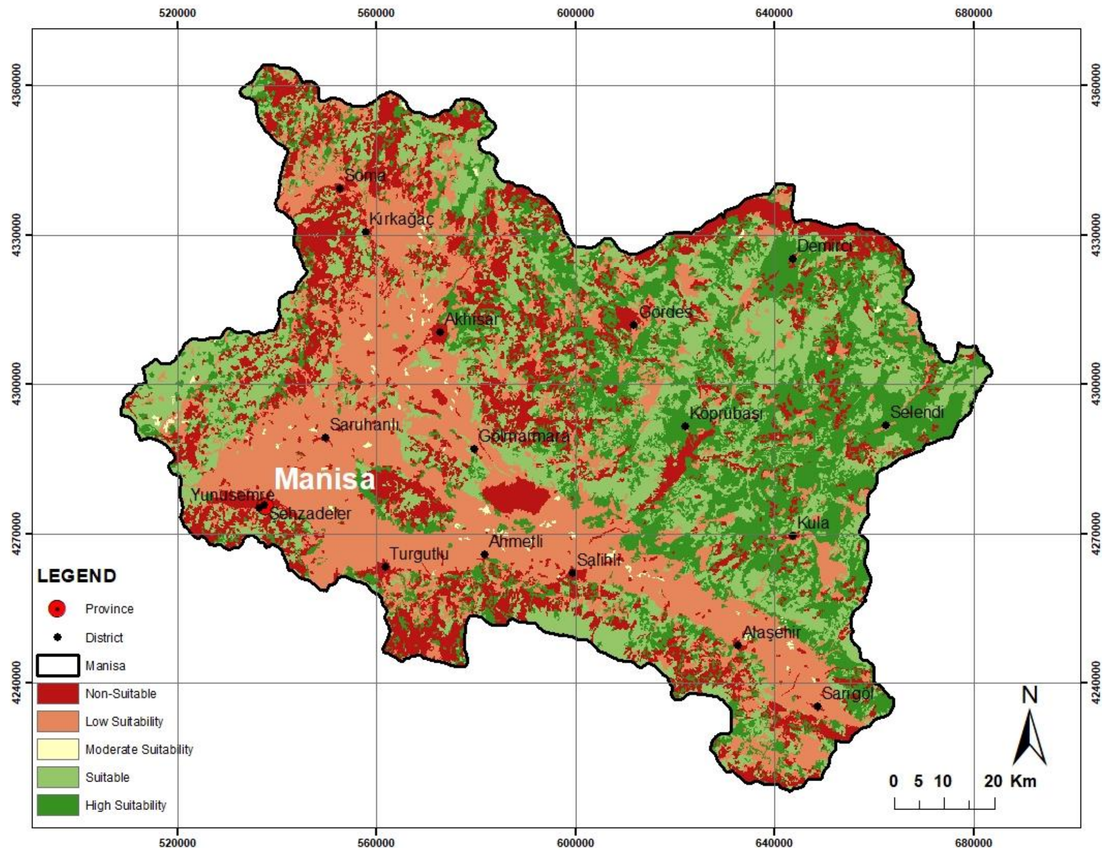


**Figure 4.** Suitability map according to land use criteria

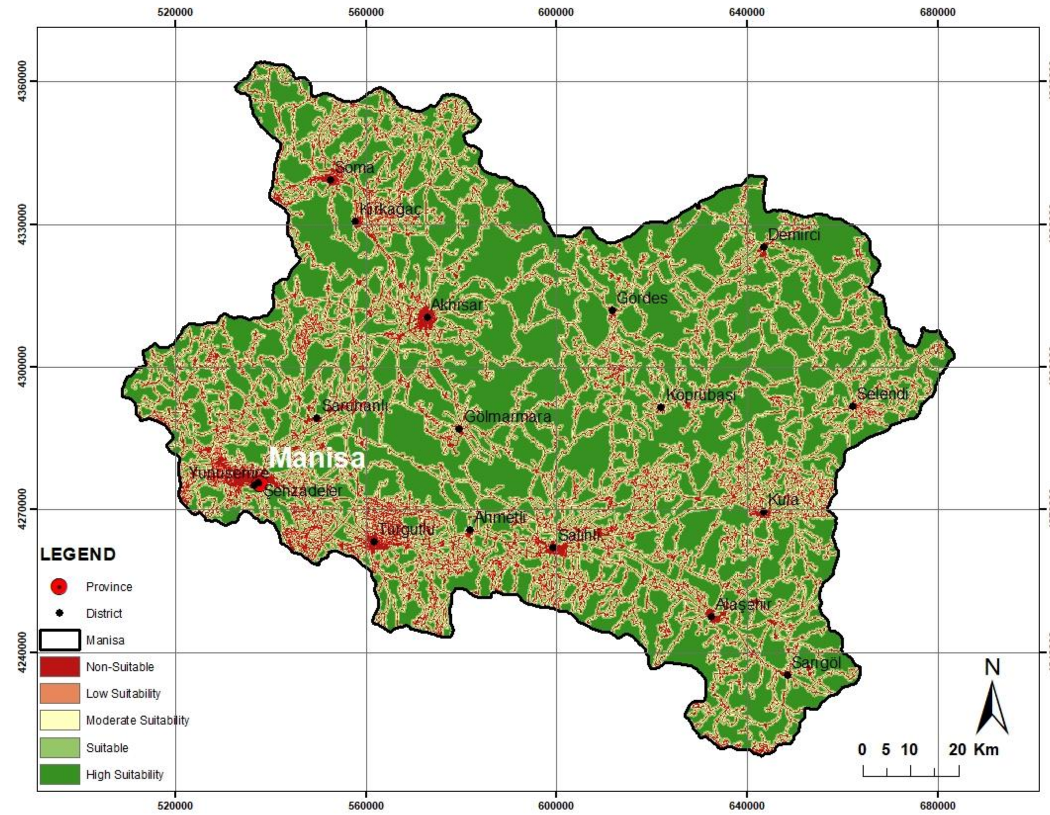


**Figure 5.** Suitability map according to distance criteria from roads

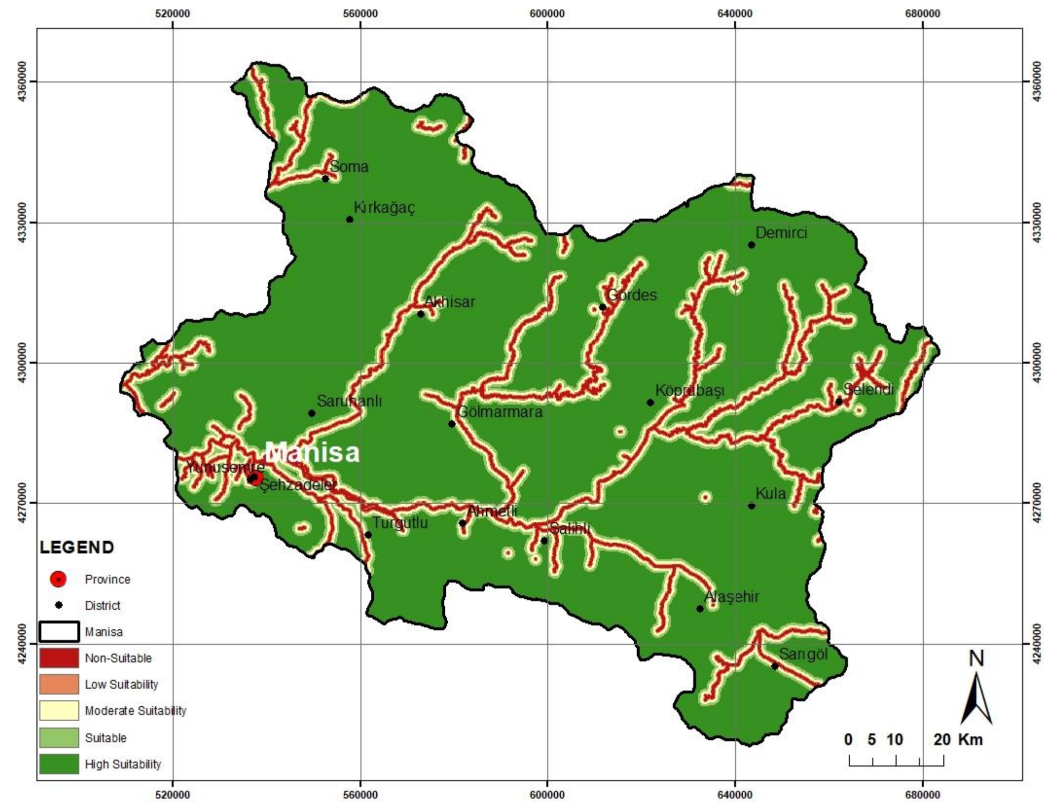


**Figure 6.** Suitability map according to distance criteria from streams

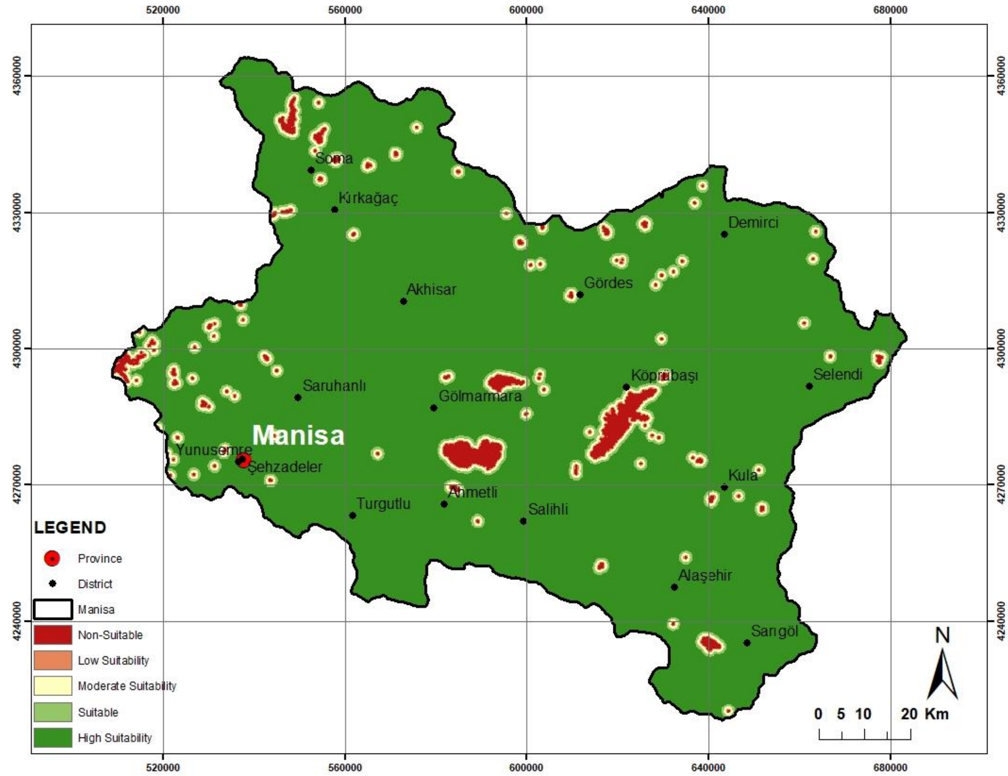


**Figure 7.** Suitability map according to distance criteria from lakes

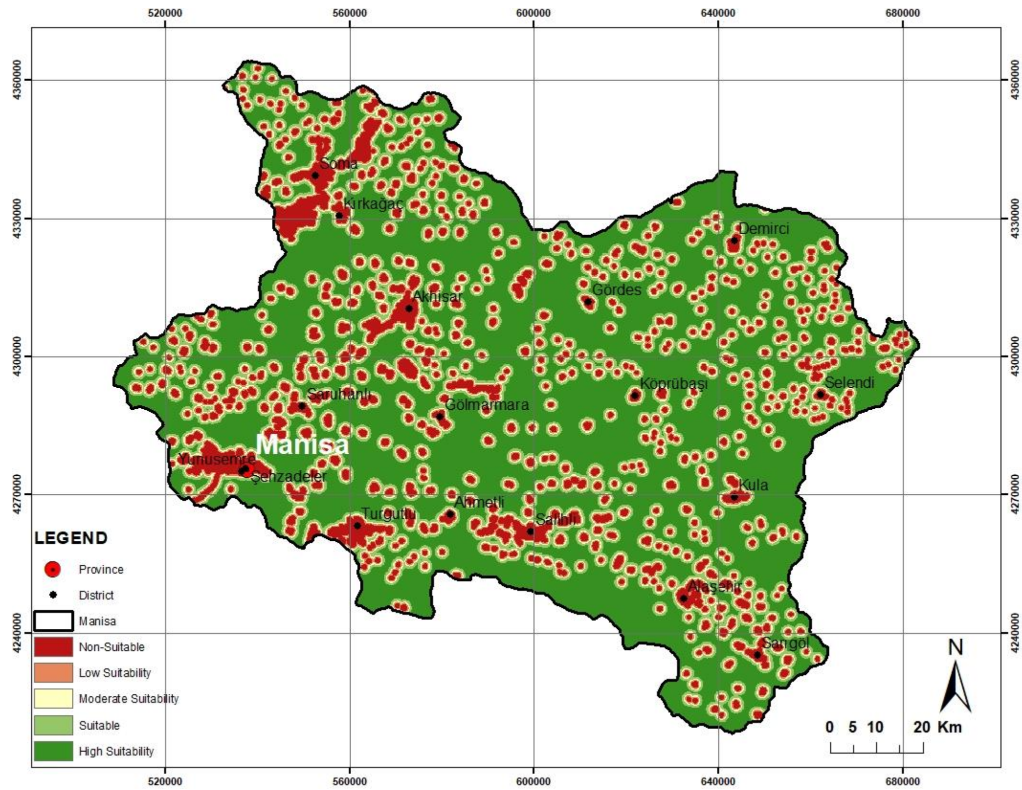


**Figure 8.** Suitability map according to distance criteria from settlements

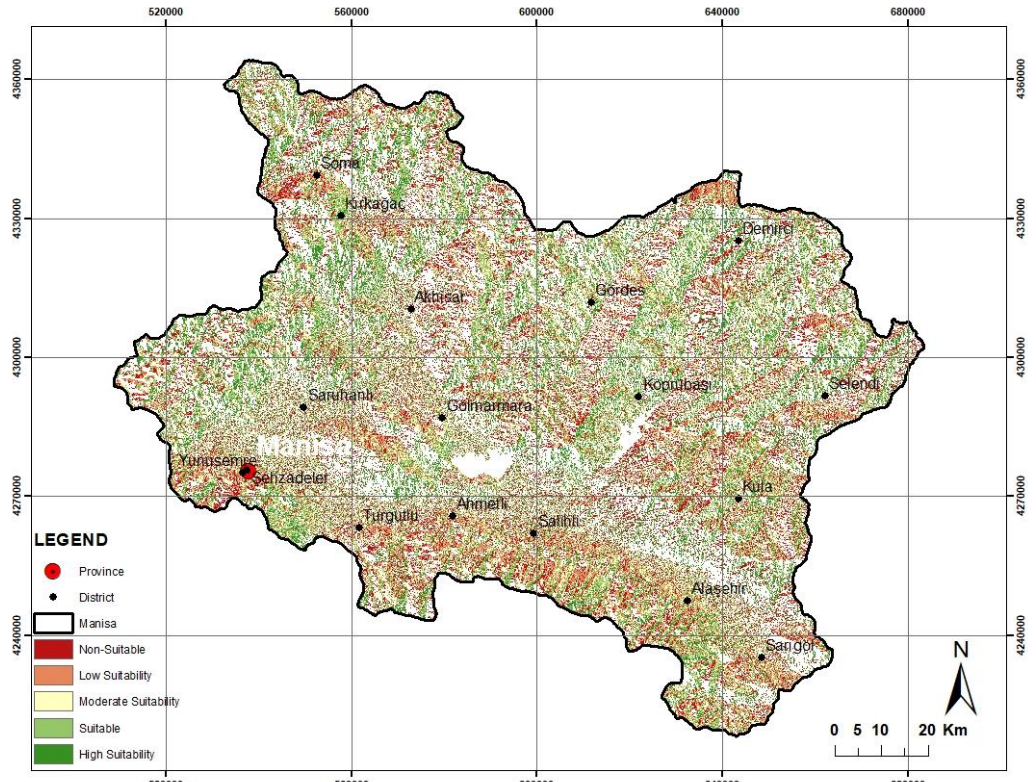


**Figure 9.** Suitability map according to aspect criteria

One of the most frequently used decision-making methods in spatial planning and analysis studies is the AHP. The fundamental problem encountered in multi-criteria decision-making is determining weights, importance, or superiority in order to make a selection from among various alternatives by considering multiple criteria. AHP is an iterative MCDM method effectively used to solve this problem. One of the most important features of the AHP method is that it allows the decision maker to incorporate both objective and subjective thoughts into the decision-making process. This method, effectively used in multi-criteria decision-making, creates a ranking process by assigning weights between 1 and 9 to the criteria (Yalçın & Sabah, 2017). In this study, the nine criteria identified for the AHP were analyzed using software developed by Goepel (2018) for the AHP (BPMSG, 2025). First, pairwise comparisons were made in terms of AHP priorities. When creating these comparison matrices, the importance of a pair of criteria was determined, and the significance of the superior criterion relative to the other criterion was calculated. Automatic calculations were performed by assigning scores between 1 and 9 to the criteria's superiority. After the comparison process, the weights of the criteria were demonstrated in Table 2. The weights assigned to the selection criteria are sorted in descending order as slope, aspect, solar radiation, land use, distance to power transmission lines, distance to settlements, distance to roads, distance to rivers, and distance to lakes, respectively. Consistency ratio is calculated as;

$CR$ = CI / RI ………………………………………….. (1)

based on the random index value (RI) and consistency separation criterion provided by the consistency index value (CI). The CI value is obtained as;

$CI$ = (λ−n) / ($n$−1) ……………………………………..(2)

depending on the consistency vector mean λ and the number of criteria n. After the criteria weight calculations were completed, the Consistency Ratio (CR) in the matrix rating was measured. A consistency ratio below 10% is considered appropriate (Saaty, 2000). If a value above this value is observed, the pairwise comparison matrix must be rearranged (Drobne & Lisec, 2009). In this study, the consistency ratio was calculated as 8.01%. Following these processes, a suitability map for Manisa's solar power plant location selection was created (Figure 10).

**Table 2.** Criteria weight values

| Criteria | Weight |
|---|---|
| Slope | 29 |
| Aspect | 24 |
| Solar Radiation | 13 |
| Land use | 13 |
| Distance from power transmission lines | 10 |
| Distance to settlements | 4 |
| Distance to roads | 3 |
| Distance to streams | 2 |
| Distance to lakes | 2 |

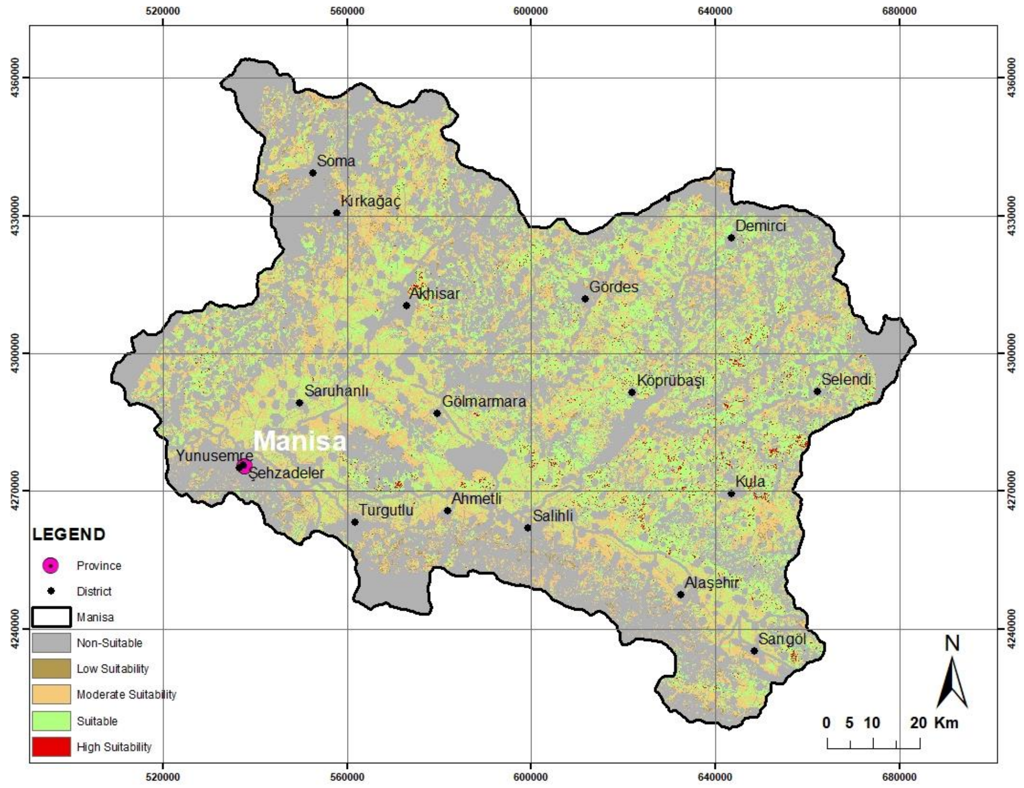


**Figure 10.** Solar power plant suitability map for Manisa

Observing the suitability map for solar power plants, approximately 54% of Manisa Province was found unsuitable for solar power plant installations. Ideal areas, encompassing the high suitable and suitable classes, accounted for approximately 27% of the study area. These areas corresponded to potential solar power plant locations and were distributed throughout the province, with a predominantly eastern and southern distribution. High suitability areas for solar power plants were located in the Sarıgöl, Alaşehir, Salihli, Selendi, and Kula districts. In addition to these districts, high suitability areas for solar power plants could also be observed in limited areas in the Turgutlu, Ahmetli, Köprübaşı, and Akhisar districts (Figure 10).

## Conclusion

In this study, a suitability map for solar power plant locations was generated by determining and weighting criteria for Manisa Province using GIS-based AHP, and then summing all weighted criteria. The significant overlap between existing solar power plant locations and the suitable locations identified in this study indicated that the identified criteria and method were sufficient for the overall assessment. Therefore, the generated solar power plant suitability map has the potential to be used in preliminary assessments and analyses for investors. Despite Manisa's high solar energy potential, it has not reached sufficient energy production levels in practice. Given the ever-increasing demand for energy today, it would be beneficial to implement policy changes and provide incentives across the province, region and country to effectively utilize solar energy and other renewable energy sources.

## Additional Information and Declarations

**Authors' Contributions:** The authors declare that they have contributed equally to the article.
**Conflict of Interests:** There are no conflicts of interest regarding the publication of this paper.


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