Erciyes Üniversitesi
Fen Bilimleri Enstitüsü Dergisi
Cilt 41, Sayı 3, 2025

Erciyes University
Journal of Institue Of Science and Technology
Volume 41, Issue 3, 2025

A GIS-AHP Multi Criteria Decision Based Approach for Selecting Suitable Areas for Solar PV Plants in A Large City-Scale, Turkey

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(Alınış / Received: 24.10.2025, Kabul / Accepted: 24.11.2025, Online Yayınlanma / Published Online: 31.12.2025)

Anahtar Kelimeler
Analytic Hierarchy Process (AHP),
Geographical Information System (GIS),
Multi-Criteria Decision Making (MCDM),
Optimal Location,
Solar Energy

Abstract: In this study, we use geographical information systems (GIS) and multi criteria decision-making (MCDM) guidance to identify ideal locations for solar photovoltaic (PV) plants in Konya province, Turkey. Four major criteria are considered in experiments: meteorological, topographical, infrastructure, and environmental. Thirteen additional criteria, supported by experienced weighting, are used to generate a 4 category site suitability map and identify the fraction of unsuitable locations to assess Turkey's intent to increase the production of renewable energy. The results indicate that meteorological conditions (global horizontal irradiation, slope, and land aspect) have the highest importance when selecting a suitable location, while environmental conditions (precipitation and relative humidity) have the lowest impact. However, the thematic map showed that 8.7% (3,556 km^2) of the province is highly suitable for installing solar PV plants, and 26% (10,832 km^2) of the area is classified as unsuitable. The combination of MCDM and GIS methodology applied in this study is effective for selecting optimal sites for solar PV plants and could be similarly used for renewable technologies in other developing countries, where the transition from fossil fuels to renewable energy is inevitable.

Büyük Ölçekli Bir Kentte Güneş PV Tesisleri İçin Uygun Alanların Belirlenmesine Yönelik CBS-AHP Çok Kriterli Karar Verme Yaklaşımı, Türkiye

Keywords
Analitik Hiyerarşi Süreci (AHP),
Coğrafi Bilgi Sistemi (CBS),
Çok Kriterli Karar Verme (ÇKKV),
Optimum Konum,
Güneş Enerjisi

Öz: Bu çalışmada, Konya ili için güneş fotovoltaik (PV) santralleri kurulumu açısından en uygun alanların belirlenmesinde Coğrafi Bilgi Sistemleri (CBS) ve Çok Kriterli Karar Verme (ÇKKV) yaklaşımı kullanılmıştır. Deneysel analizlerde dört ana kriter (meteorolojik, topoğrafik, altyapısal ve çevresel) dikkate alınmıştır. Deneyimli uzman görüşleriyle ağırlıklandırılmış on iki alt kriter kullanılarak dört sınıflı bir alan uygunluk haritası oluşturulmuş ve yenilenebilir enerji üretimini artırma hedefi doğrultusunda uygun olmayan alanların oranı belirlenmiştir. Sonuçlar, uygun alan seçiminde en etkili faktörlerin meteorolojik koşullar (küresel yatay ışınım, eğim ve bakı) olduğunu, en düşük etkiye ise çevresel koşulların (yağış ve bağıl nem) sahip olduğunu göstermiştir. Tematik harita analizine göre ilin %8,7'si (3.556 km^2) güneş PV santrali kurulumu için yüksek düzeyde uygun, %26'sı (10.832 km^2) ise uygun olmayan alan olarak sınıflandırılmıştır. Bu çalışmada uygulanan CBS ve ÇKKV yönteminin kombinasyonu, güneş PV santrali kurulumu için en uygun alanların belirlenmesinde etkili bir yöntemdir ve fosil yakıtlardan yenilenebilir enerjiye geçiş süreci kaçınılmaz olan gelişmekteki ülkelerde benzer şekilde uygulanabilir.

1. Introduction

Nonrenewable energy sources present two real and growing issues that are solved through the application of renewable energy sources (RESs). The first issue is an environmental concern; fossil fuels such as coal, oil, and natural gas are subject to specific geographic locations and produce significant amounts of greenhouse gases. Increases in atmospheric and oceanic temperatures, as well as other consequences of the injection of these fossil fuel pollutants has led to an extensive global response to use less damaging renewable energy sources such as solar energy [1]. The second issue highlights limited global reserves of fossil fuel that are quickly depleting. Therefore, the importation of fossil fuels leaves poorer, developing countries at a disadvantage. By constructing RESs, which include solar, hydropower, biomass, geothermal, wind, and marine energies, we can considerably reduce the amount of CO^2 production and avoid the associated environmental damage [2]. Consequently, increased use of RES can increase the energy independence of developing nations and provide a multitude of new employment opportunities [2]. Future growth in the RES sector is increasing in efficiency and decreasing in cost. Therefore, the shift to renewable energy has the potential to reduce greenhouse gas emissions, thereby limiting global climate change and ensure the delivery of safe, timely, and cost-efficient electricity [3].

Today, RES constitutes over 20% of the total global electricity generation, with solar energy ranking fourth after hydro, bio-energy, and wind [4]. Recently, solar energy has become increasingly desirable as an RES because it is the most enduring and cleanest source of energy available. By 2050, solar energy could account for 8%–15% of global electricity, depending on multiple factors. Most solar energy technologies currently in the market are based on the “photovoltaic effect,” which involves the generation of voltage and electric current in a material upon exposure to light [5-7].

The Turkish National Energy Plan prioritizes the use of solar energy. In this study, we assessed the potential of the Konya region in Turkey to generate solar energy to serve as part of this program. The plan aims to increase the nation’s solar energy installed capacity to 52.9 GW by 2035. Turkey’s advantageous geographical position, which lies in the sunny belt between 36 ° N and 42° N latitude, is highly suitable for the generation of solar energy. The yearly average solar radiation is 3.6 kWh/(m^2-day), and the total annual insolation period is almost 2460 h, making the region an ideal location for solar PV applications [8-10]. Konya Province, where the study was conducted, is geographically the largest province in Turkey, and therefore has a substantial potential for solar energy development, as stated by the Electricity Generation Authority of Turkey in 2019 (Fig 1). Therefore, government institutions, local administrations, and other renewable-energy investors are investigating suitable areas for construction of solar plants. Until now, financial perspectives and feasibility assessments of RES have been explored in various provinces in Turkey, but only limited studies have focused on Konya, especially from a regional perspective [11-14]. To assess the suitability of a potential location for a solar PV plant, several essential criteria must be investigated. These include the reduction of the project cost by utilizing existing superstructures and infrastructures, and determining the effects of local meteorological, topographical, and environmental conditions, as well as existing land use on a solar PV plant while maximizing energy production. The most critical of decision factors for selecting the optimal site for a solar plant and restrictions were identified and evaluated by [15], who investigated and reported on the environmental, geographical, economical, climatic, and topographical criteria with all connected subcriteria. Techniques using geographical information systems (GIS) can be used to analyze multiple variables, combine the information, and specify potential locations based on these evaluation criteria [16]. Multiple criteria decision-making (MCDM) methods can then be applied to determine the optimal alternative by sorting them according to how they fulfill a set of criteria [17]. Furthermore, the analytic hierarchy process (AHP) in MCDM solves complex problems by determining criteria weights or priorities and sorting alternatives according to the evaluation criteria [18, 19]. GIS-based AHP methods have become popular tools for many energy-planning projects and have been studied extensively [20-23]. Similarly, there are also some remarkable studies about the practices of MCDM approaches for RES planning alternatives [24-26]

The primary scientific contribution of this study is the development of a robust and comprehensive GIS-MCDM methodology to precisely determine the optimal location for solar PV plants in the Konya region of Turkey. This is achieved by utilizing thirteen crucial, expert-weighted criteria to generate a highly detailed suitability map. This combined application of MCDM methods, specifically the Analytical Hierarchy Process (AHP), within GIS systems, significantly strengthens the novelty of this study by offering a rigorous, systematic, and data-driven approach. Ultimately, this research provides a crucial decision-support tool for policymakers and stakeholders to optimize solar PV plant siting in Turkey, thereby enriching the existing literature on renewable energy spatial planning.

2. Material and Method

2.1. Case study

This section first provides a description of the study area, followed by the summarization of the methodology in two main sections. In the first section, relevant criteria were identified, and reclassification maps produced according to the constraint criteria. Next, AHP methods were used to calculate the weights of the subcriteria, and suitability maps were produced to identify possible locations using layer maps of all criteria layers.

2.2. Study area

This study was performed in Konya City (Figure 1) with an area of 40,838 km^2, located between latitudes of 36° 41′ N and 39° 16′ N and longitudes of 31° 14′ E and 34° 26′ E in Central Anatolia, covering 7% of the entire area of Turkey. Konya has a population of 2.3 million people, equally divided between rural and urban areas [27].

2.3. Production of reclassification maps according to the constraint criteria

Before the reclassification maps were completed, buffer zone constraints criteria were adapted using the ArcGIS software on all vector data sets (distance from the protected area, distance from the transport network, distance from lakes, and rivers etc.). Previous studies have proposed appropriate distance safety and used Euclidean distance methods [5, 28]. Subsequently, GIS-analysis was applied to eliminate areas unsuitable for the installation of solar PV plants. Four major [Meteorological (C1), Topographical (C2), Infrastructural (C3), and Environmental (C4)] and 13 minor criteria were considered, as shown in Figure 2. These criteria were chosen after an extensive literature review and are essential for ensuring rational decision-making for the siting of solar PV plants [15, 20, 21]. According to the suitability score [e.g., very highly suitable (5), highly suitable (4), moderately suitable (3) low suitability (2), very low suitability (1)), all data were converted into raster format, and reclassified maps were prepared, as shown in Figure 3. The following subsections provide information about each of the conditions (C1–C4) and data sources for GIS analysis, as shown in Table 1.

2.3.1. Meteorological conditions

In this study, three different meteorological parameters and global horizontal irradiance (GHI) levels were categorized as sub-criteria based on the literature review (Table 1). GHI data was preferred in the study because of its easy access (http://globalsolaratlas.info/download) and it is accuracy has been proven by different scientific studies [29-31]. In addition, other selected meteorological criteria (humidity and precipitation) reduce the efficiency of a PV plant in practice compared to standard testing conditions [26, 27]. Figure 3 shows the generated reclassified maps using the inverse distance weighted interpolation method, and Table 1 describes the sub-criteria and relevant literature in detail. The reclassified map for GHI is illustrated in Figure 1.

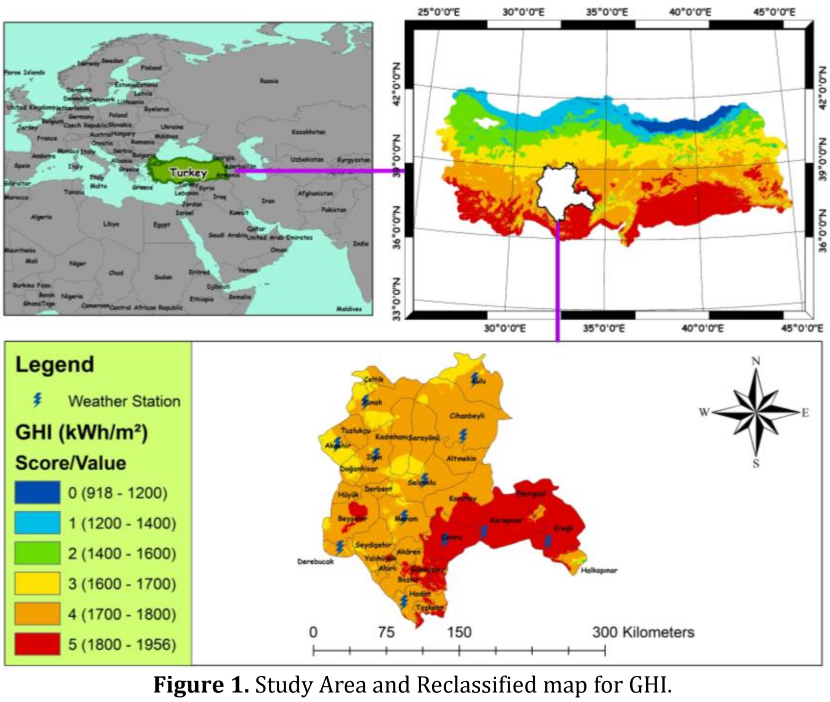

Figure 1. Study Area and Reclassified map for GHI.

2.3.2. Topographical and land use conditions

In addition to GHI, other topographical and land-use characteristics, such as land aspect, slope, and land-use properties, should be considered for selecting suitable areas for installing a solar project. According to relevant literature, flat terrain and similar land characteristics reduce the high investment cost of solar energy required in hilly or mountainous regions [15, 32]. Therefore, reclassified maps for all topographical sub-criteria were generated by a Corine Land Cover (CLC) map (spatial resolution: 100 m; year: 2018; scale: 1:100.000), which was designed with the intent of producing a land-use map for all EU countries, by using the land cover layer (CLMS, 2019) in the ArcGIS software. For detailed information on each land class, please refer to table A.1 in the Appendix. The limitation buffer zone, including the threshold values and all data sources, is illustrated in Table 1.

2.3.3. Infrastructural conditions

To minimize potential investment costs and avoid negative environmental impact, the following three crucial sub-criteria were selected through literature recommendations [21, 28, 33, 34]: distance from the existing power network, distance from residential areas, and distances from transportation. Separately, all buffer masks that were applied to the sub-criteria, as detailed in were given in Table 1. Figure 3 shows the reclassified map layers for each criterion based on the study area and data sources.

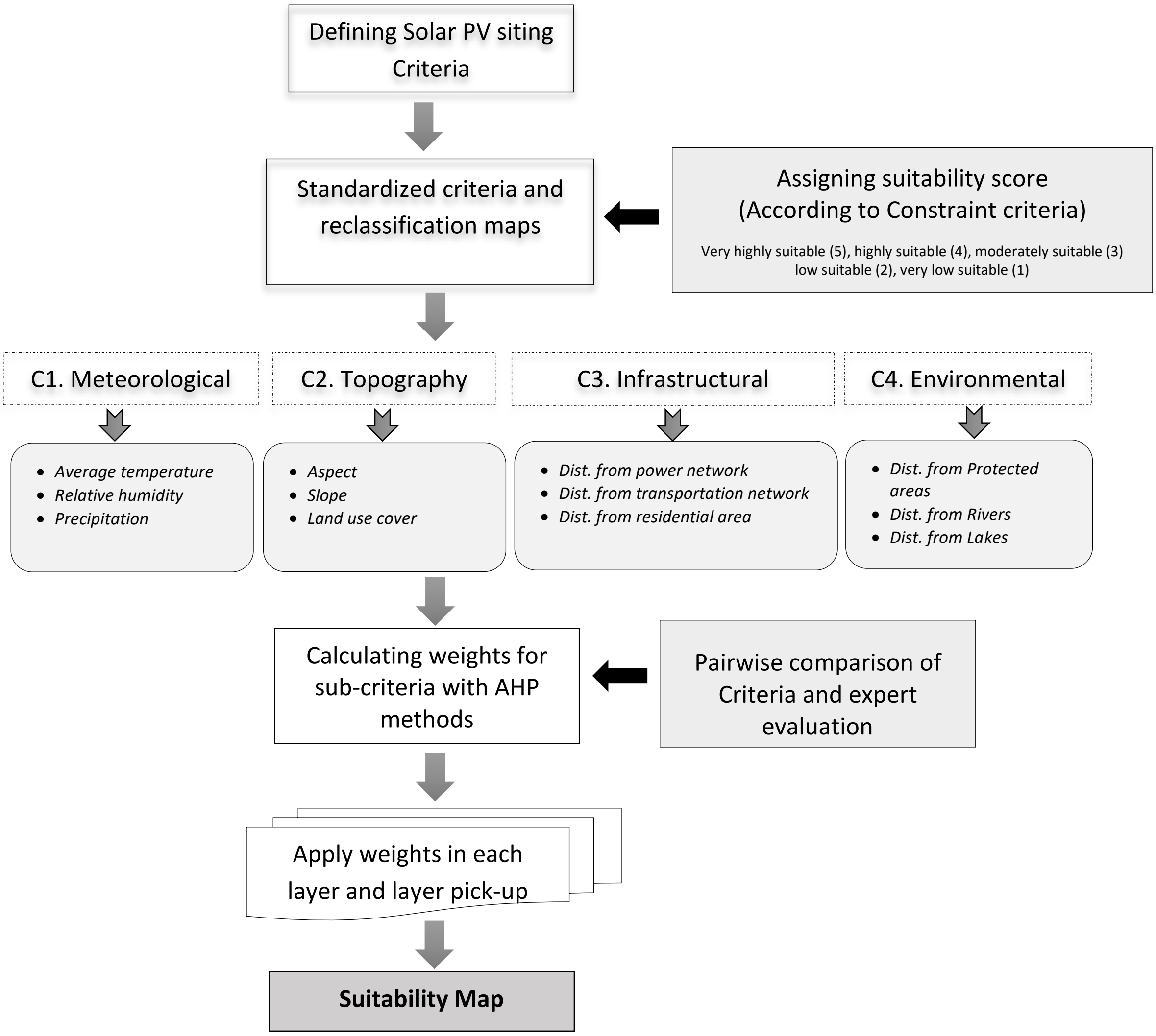

Figure 2. Steps to conducted method.

2.3.4. Environmental conditions

The following subcriteria were selected for buffers: distance from protected areas, distance from rivers, and distance from lakes. The protected areas and essential water bodies are conserved nationally, and therefore considered unsuitable for the construction of a large-scale solar PV plant[15]. Reclassified maps for land suitability were prepared and presented in Figure 3.

2.4. AHP

The AHP developed by Saaty in the 1970s is a practical MCDM technique that has been used to solve complex decision problems and identify suitable sites within specific criteria. [42]. We used the AHP method to further assess the sites identified through the spatial analysis. Table 1. List of used criteria and ranking score.

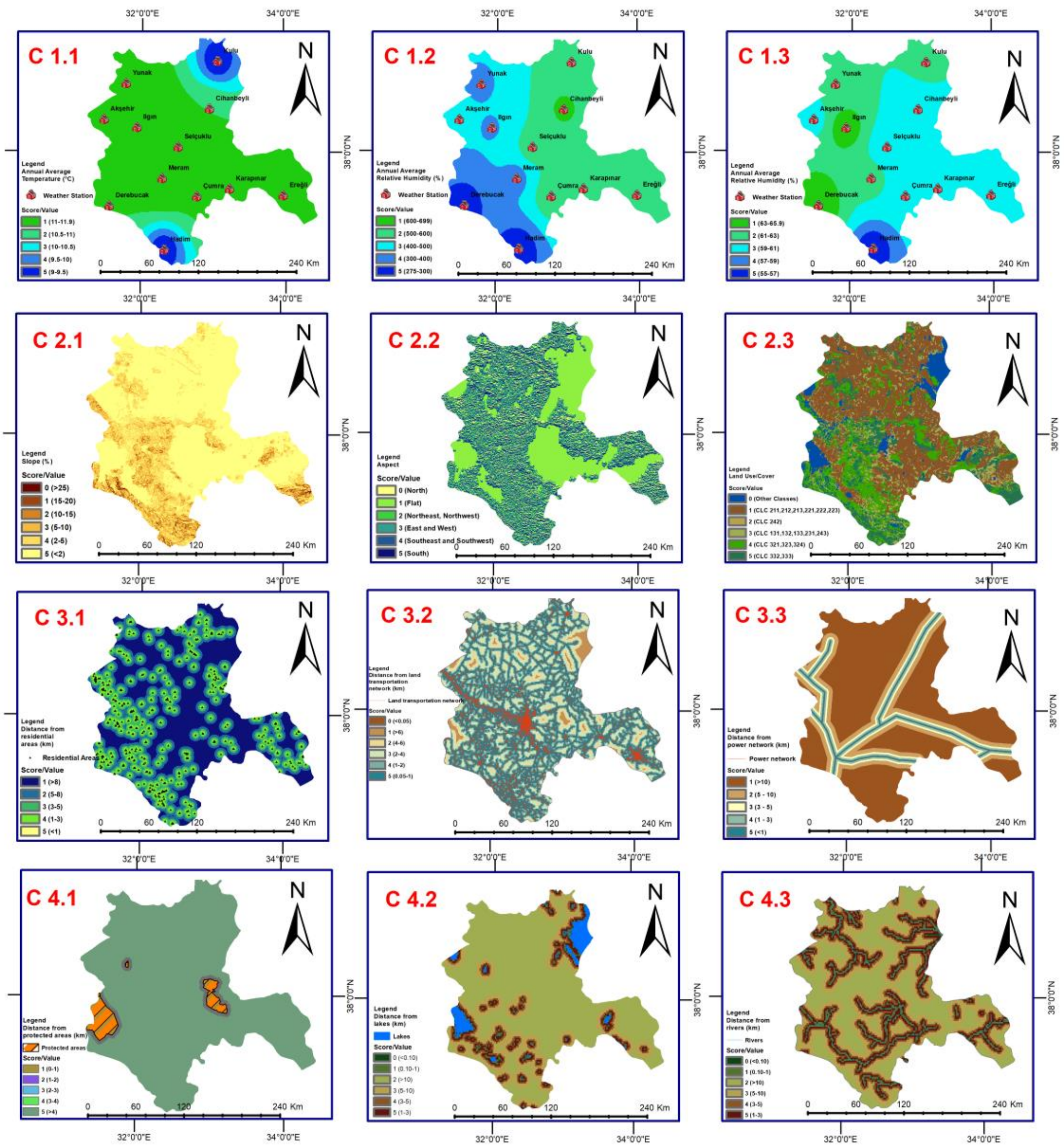

Figure 3. Reclassification maps used for twelve sub-criteria*. * C 1.1 Annual average temperature, C 1.2 Annual average precipitation, C1.3 Annual average relative humidity, C 2.1 Slope, C 2.2 Land aspect, C 2.3 Land use, C 3.1 Distance from residential area, C 3.2 Distance from transportation network, C 3.3 Distance from power network, C 4.1 Distance from 'protected areas', 4.2 Distance from lakes, C 4.3 Distance from rivers.

Table 1. List of used criteria and ranking score.

Criteria/ Data sources	Sub-Criteria	Buffer Zone	Unit	Suitability Score/ Ranking [a]	References
Global horizontal irradiance [c] *Global Solar Atlas*	GHI	918-1200	kWh/m2	(1) 1200-1400 (2) 1400-1600 (3) 1600-1700 (4) 1700-1800 (5) 1800-1956	[35] [36]
C1. Meteorological - *Global Solar Atlas* - *General Directorate of State Meteorological Affairs of Turkey*	Air Temp.	-	°C	(1) 11-11.7 (2) 10.5-11 (3) 9.5-10.5 (4) 8.5-9.5 (5) 7.4-8.5	[15]
	Precipitation	-	mm	(1) 450-472 (2) 400-450 (3) 350-400 (4) 300-350 (5) 274-300	[37]
	Humidity	-	%	(1) 62-62.4 (2) 61.5-62 (3) 61-61.5 (4) 60-61 (5) 59.4-60	[35]
C2. Topographical - *Copernicus Land Monitoring Service* - *Earth Data*	Land aspect	North		(1) Flat (2) Northeast, Northwest (3) East and west (4) Southeast and Southwest (5) South	[38]
	Slope	>25°	%	(1) 15-25 (2) 10-15 (3) 5-10 (4) 2-5 (5) <2	[37]
	Land use [b]	111, 112, 121, 122, 123, 124, 141, 142, 311, 312, 313, 313, 331, 411, 412, 421, 422, 423, 511, 512, 521, 522 ,523	CLC	(1) 211, 212, 213, 221, 222, 223 (2) 24-242 (3) 131, 132, 133, 231, 243, 244 (4) 321, 322, 323, 324 (5) 332-333	[15] [5]
C3. Infrastructural - *Konya Province Environmental Plan*	Dist. from power network	-		(1) >10 (2) 5-10 (3) 3-5 (4) 1-3 (5) <1	[15] [39]
	Dist. from land transportation network	<0.05	Km	(1) >6 (2) 4-6 (3) 2-4 (4) 1-2 (5) 0.05-1	[38]
	Dist. from residential areas	-	Km	(1) >8 (2) 5-8 (3) 3-5 (4) 1-3 (5) <1	[6]
C4. Environmental - *(MTA, 2019).* - *Konya Province Environmental Plan*	Dist. from lakes	<0.10	Km	(1) 0.10-1 (2) >10 (3) 5-10 (4) 3-5 (5) 1-3	[40]
	Dist. from protected areas	National parks, ecological or cultural values, important bird areas.	Km	(1) 0.10-1 (2) 1-2 (3) 2-3 (4) 3-4 (5) >4	[15]
	Dist. from rivers	<100	Km	(1) 0.10-1/(2) >10/(3) 5-10/(4) 3-5/(5) 1-3	[40]

[a]: *(1) Very low suitable/(2) Low suitable/(3) Moderately suitable/(4) Highly suitable/ (5) Very highly suitable*
[b]: *Corine Land Cover (CLC) land groups was given as an appendix table A.1.*
[c]: *Global horizontal irradiance condition was given separately except the thirteen conditions.*

The collected results were then compared with the most common methods for aggregating individual pairwise comparison matrices for group decision-making, which can be classified under two main categories: the weighted geometric mean method and the weighted arithmetic mean method [41]. Subsequently, the weights of all assessment criteria were selected by normalizing the separate eigenvectors associated with the reciprocal ratio matrix [22]. Because of the critical difference levels of the influencing criteria for the potential solar PV site selection, a group of seven experts was organized to provide their input on the study. At this stage, the group of experts (The group consisted of two academics (authors of this paper), three industry experts/solar PV owners, and two city planners) answered a direct questionnaire form to construct an analytical matrix based on Saaty's discrete 9-value scale [42]. For instance, a C3 value of one indicates minimal impact while a value of nine suggests extreme impact, according to that expert on that issue. To avoid possible inconsistencies caused by human error, a consistency ratio (CR) was adapted from similar studies [15, 20]. A consistency index (CI) was required to calculate the CR values.

$$CR = \frac{CI}{RI} \tag{1}$$

where RI is the random consistency index that varies depending on the matrix size, as shown in Table 2. CI is calculated as

$$CI = \frac{(\lambda max - n)}{(n-1)} \tag{2}$$

where (λmax) is the maximum eigenvalue of the pairwise comparison matrix, and n is the size of the matrix. For CR ≤ 0.10, or less than 10%, the degree of consistency is considered satisfactory, indicating that the weights assigned are appropriate. However, CR > 0.10 indicates major inconsistencies in the expert comparison [42]. The present study considered seven elements associated with the decision criteria or n = 4. Accordingly, RI = 0.90, and CR = 0.011, which is within the acceptable range. Details of the AHP methods are not provided in this study. A comprehensive description of the methodology can be found in previous studies [23, 42] papers.

Finally, the weighted linear combination approach was used for the MCDM in the GIS platform. The combination of all assessment layers was completed to generate the PV plant convenience index (PVPCi) based on equation (3). The ArcGIS 10.4.1 tool was utilized to produce maps, all of which were multiplied by the assigned normalized weight according to the suitability scale: 0 for unsuitable, 2 for low suitability, 3 for moderately suitable, and 4 for highly suitable.

$$PVPCI_i = \sum_{j=1}^{n} w_j \, x_{ij} \tag{3}$$

where PVPCIi is the PV plant's convenience coefficient for cell i, wj is the relative significant weight of criterion j, xij is the standardized score of cells i for criterion j, and n is the total number of criteria.

Table 2. Random consistency index values [24].

N	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.54	1.56	1.57	1.59

3. Results and Discussion

In this study, the weights of all criteria (4 main criteria and 13 sub-criteria) were examined using the GIS-MCDM method. A questionnaire study was conducted with seven experts to obtain evaluation weights 956iterat criteria. The decision cluster weights of all sub criteria are ranked using the AHP according to the expert input, as indicated in Table 3. Among the 4 main criteria, 'meteorological conditions' (0.4183) and 'topographical and land use conditions' (0.3914) have the highest importance for site selection. Other influential conditions were: 'infrastructural and superstructural conditions' (0.1212) and 'environmental conditions' (0.0692). In terms of sub-criteria, the most important factors are global horizontal irradiation (0.2727), slope (0.1492), land aspect (0.1377), and air temperature (0.1267). The lowest sub-criteria factors with final weight score were precipitation (0.0079), relative humidity (0.0109), and distance from lakes (0.0209). However, these study results have emphasized the importance of several parameters such as 'land aspect', 'slope' or 'global horizontal irradiance' for suitable locations due to the conceptual differences based on the location of the study area. The high importance assigned to meteorological and topographical factors (GHI, slope, aspect) is consistent with findings in other semi-arid regions, where maximizing solar capture and minimizing ground preparation costs are paramount. These parameters, including the evaluation criteria, can vary in the literature [43, 44]. Similar results were discussed by [25, 28, 45], in which the authors claimed that land use, global horizontal irradiance, air temperature, and land aspect were ranked as the most important parameters with in the study area.

Table 3. Relative, General and final weights of sub-criteria.

General weight	Main Criteria	Sub-criteria	Relative weight (Lack of relation)	Final Weight	Rank
0.4183	Meteorological conditions	Global Horizontal Irradiation	0.652	0.2727	1
		Annual average temperature	0.303	0.1267	4
		Annual average relative humidity	0.026	0.0109	12
		Annual average precipitation	0.019	0.0079	13
0.3914	Topographical and land use conditions	Land aspect	0.3519	0,1377	3
		Slope	0.3813	0,1492	2
		Land use/cover	0.2668	0,1044	5
0.1212	Infrastructural and Superstructural conditions	Distance from power network	0.3954	0,0479	6
		Distance from land transportation network	0.3123	0,0378	7
		Distance from residential area	0.2923	0,0354	8
0.0692	Environmental conditions	Distance from protected areas	0.3513	0,0243	9
		Distance from rivers	0.3356	0,0232	10
		Distance from lakes	0.3131	0,0217	11

However, in another study [45], is the authors highlighted that when determining the most suitable location, topographical parameters as well as environmental and infrastructural parameters such as distance from protected areas, distance from power network, and distance from residential areas are equally important [46]. The results show that the selection criteria profoundly influence the determination procedure. To avoid uncertainty in the methodological approach, the expert knowledge should be supported by literature review as well as further research and dialogue involving academics, stakeholders, solar power sector professionals, and policymakers.

Figure 4 indicates the most suitable area for potential solar PV plants. The final suitability map (Figure 4) was grouped into four categories as '0 unsuitable,' '1 very minimally suitable,' '2 minimally suitable,' '3 moderately suitable,' and '4 highly suitable,' as shown in the map legend. It was clearly observed from this map that 8.7% of the land was classified as highly suitable, and 64% of the land was classified as moderately suitable for solar PV plants. However, technically classified as suitable land may differ depending on the construction conditions and the agricultural status of the location.

Ruiz et al. (2020) examined this situation comprehensively. Hence, the areas suggested as potential locations for the solar PV plant in this study may be reduced by including different criteria and factors. As shown in Figure 4, the unsuitable area covers 26% of the study area, and high-suitability areas are mainly spread around the south and southeast of the Konya region. The suitability map indicated that the Taskent, Hadim, Bozkir, Guneysinir, Karapınar, Ereğli, and Emirgazi regions are the most suitable areas compared to the other areas of Konya. Therefore, 3,556 and 26,368 km^2 areas were designated as highly and moderately suitable land in the Konya district, respectively.

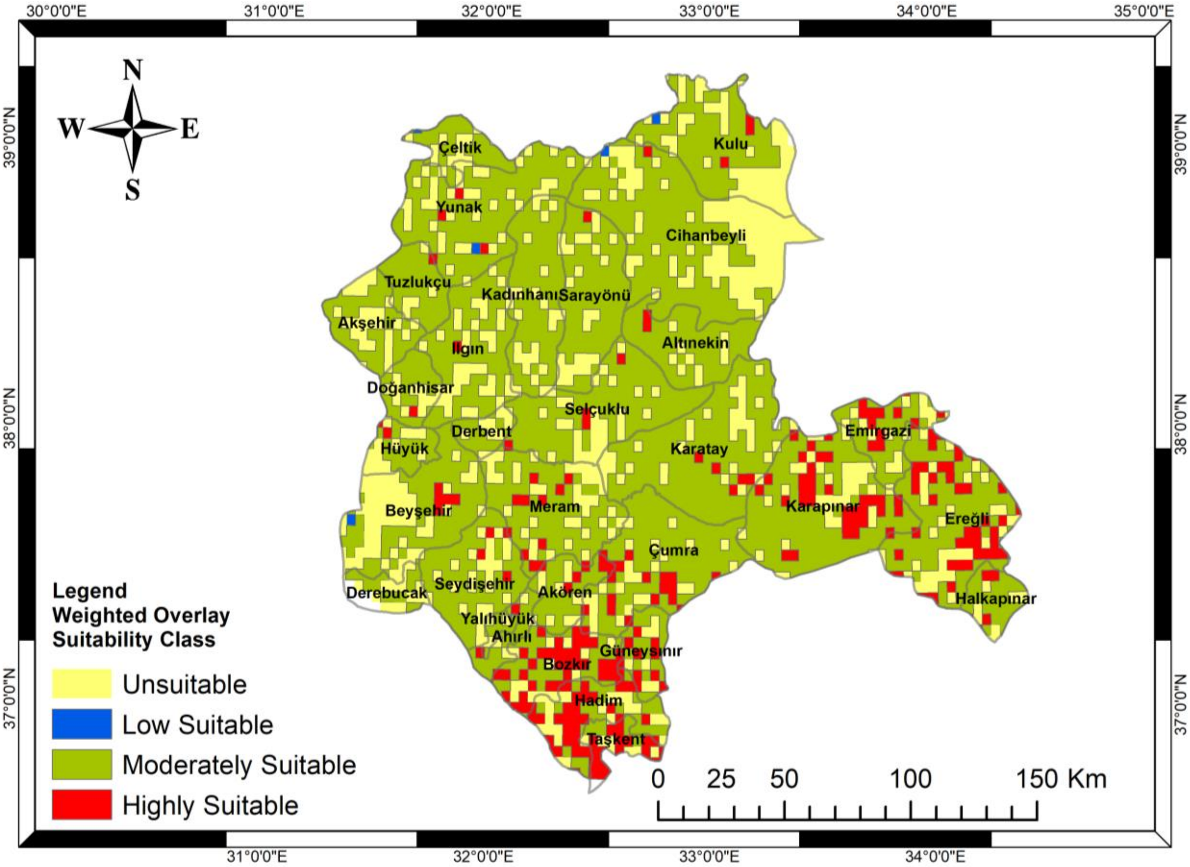

Figure 4. Suitability map for solar PV plant.

4. Conclusion

This paper addresses the following critical research question: "Where are the most suitable locations in Konya Province the largest district in Turkey to build solar PV plant installations?". To answer this, a combination of GIS analysis and MCDC techniques was applied to define the possible locations for solar PV plants in Konya. By using a GIS-based approach, four main criteria (meteorological, topographical, infrastructural, and environmental) were defined from the literature review, and the effectiveness of 13 subcriteria was weighted through interviews with academic experts. This allowed us to produce a thematic map using the ArcMap software by combining each criterion to assess the potential site. Based on the results of the current study, global horizontal irradiance and land slope were determined as the most effective criteria for the selection of suitable areas in Konya, followed by land aspect, air temperature, and land use. Therefore, the study results of the GIS-based MDCM method provide a good ability to determine the optimal area for the solar PV plant and alternative RES; however, the evaluation parameters should be carefully defined to obtain the optimal area, and possible changes in the selected criteria can be acceptable depending on regions and purposes. To enhance the accuracy of the proposed methods, other economic indicators must be considered. The most important limitation of this study is the availability of data for GIS mapping. The availability of these data is very effective for site selection and reveals the current situation. Additionally, social impacts, such as the reactions of affected citizens, are very important factors. For this reason, other criteria, such as economic conditions, agricultural status, and government priorities should be considered in the site selection process. In future studies, MCDC approach can be integrated with hybrid fuzzy analytical hierarchy process to addresses and also determined the most appropriate location. Turkey has vast potential RESs, which are not being optimally utilized, resulting in the nation's dependence on foreign energy. Therefore, this study could prove beneficial for stakeholders and energy decision-makers, such as academics, government officials, and private companies, of developing countries similar to Turkey.

Acknowledgment

The Authors would like to thank the Erciyes University for providing all research possibilities.

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Appendices

Appendix A. Corine land cover classes

ARTIFICIAL SURFACES

URBAN FABRIC
- 111 Continuous urban fabric
- 112 Discontinuous urban fabric

INDUSTRIAL, COMMERCIAL AND TRANSPORT UNITS
- 121 Industrial, commercial and public units
- 122 Road and rail networks and associated land
- 123 Port areas
- 124 Airport

MINES, DUMPS AND CONSTRUCTION SITES
- 131 Mineral extraction sites
- 132 Dump sites
- 133 Construction sites

ARTIFICIAL NON-AGRICULTURAL VEGETATED AREAS
- 141 Green urban areas
- 142 Sport and leisure facilities

AGRICULTURAL AREAS

ARABLE LAND
- 211 Non-irrigated arable land

PERMANENT CROPS
- 221 Vineyards
- 222 Fruit trees and berries plantations

PASTURES
- 231 Pastures

HETEROGENEOUS AGRICULTURAL AREAS
- 242 Complex cultivation patterns
- 243 Land principally occupied by agriculture, with significant areas of natural vegetation

FOREST AND SEMINATURAL AREA

FORESTS
- 311 Broad-leaved forest
- 312 Coniferous forest
- 313 Mixed forest

SCRUBS AND/OR HERBACEOUS VEGETATION
- 321 Natural grassland
- 322 Moors and heathland
- 324 Transitional woodland-scrub

OPEN SPACES WITH LITTLE OR NO VEGETATION
- 331 Beaches, dunes, sand
- 332 Bare rock
- 333 Sparsely vegetated areas
- 334 Burnt areas
- 335 Glaciers and perpetual snow

WETLANDS

INLAND WETLANDS
- 411 Inland marshes
- 412 Peat bogs

COASTAL WETLANDS
- 421 Salt marshes
- 423 Intertidal flats

WATER BODIES

INLAND WATERS
- 511 Water courses
- 512 Water bodies

MARINE WATERS
- 521 Coastal lagoons
- 522 Estuaries
- 523 Sea and ocean