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An Integrated GIS-Based ANP Analysis for Selecting Solar Farm Installation Locations: Case Study in Cumra Region, Turkey

Mevlut Uyan[1] · **Ozgul Lutfiye Dogmus**[2]

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Abstract

With the depletion of traditional energy sources, which are defined as fossil fuels, the importance of renewable energy sources has increased even more. Renewable energy is a sustainable energy source that can be reproduced with the use of existing resources and has almost no harm to the environment. Solar energy is one of the leading types of energy among sustainable energy sources and is an inexhaustible source of energy for humanity that can be used for generations. Selecting an appropriate site for the installation of solar power plants is an important decision that increases the efficiency of a solar farm. In order to minimize the negative environmental, economic and social effects in the solar farm location studies, all criteria affecting the study should be taken into consideration. This study presents the application of combining analytical network process, which is one of the multi-criteria evaluation methods, with GIS, in order to determine the most suitable locations for solar power plants in Cumra Region, Konya, Turkey. Six main criteria have been defined for the most suitable site selection in this area. Criteria maps were prepared using the GIS software and weight values determined from analytical network process and combined for the site suitability map. Suitability map was divided into three categories as low, moderate and high suitable by using an equidistant classification method.

Keywords Renewable energy · Spatial decision support systems · Solar farms · Analytical network process

1 Introduction

Energy is an important factor for sustainable development and poverty eradication. It is an essential element for life. Due to the rapid development in technology and the increasing world population, the need for energy is increasing day by day. Today, a large part of energy needs meets from fossil fuels such as oil, natural gas and coal in many countries such as Turkey. Fossil fuels are finite resources, and their depletion will threaten a sharp increase in these needs [1]. One of the most important adverse effects of fossil fuels is the pollution and environmental problems. Many literatures reveal that energy consumption and growth are the most important reasons that increasing carbon dioxide emissions [2–6].

Increasing energy consumption based on fossil fuels causes a large increase in greenhouse gas emissions, especially CO_2. In order to keep the economy sustainable without harming the environment, the share of renewable energy production should be increased. Therefore, developed countries are interested in the development and use of renewable energy sources such as solar, wind, tidal, geothermal, hydroelectric and biomass energy [7]. In recent years, the energy industry has focused on renewable energy sources to reduce the carbon footprint during energy generation [8]. To reduce greenhouse gas emissions, many countries signed the Paris Agreement in 2015 and focused on renewable energy sources [9]. Turkey aims to reduce greenhouse gas emissions by up to 21% between 2020 and 2030 [10]. Global investment on renewable energy exceeded 531 billion US$, in 2020 [11]. Annual clean energy investment worldwide would need a threefold increase by 2030 to around 4 trillion US$ to reach carbon neutrality by 2050 [12].

Energy production in Turkey is not sufficient for current energy needs. In addition, it is expected that the energy

✉ Mevlut Uyan
muyan@ktun.edu.tr

Ozgul Lutfiye Dogmus
ozgul.dogmus@gmail.com

[1] Vocational School of Technical Sciences, Konya Technical University, Konya, Turkey

[2] Graduate Education Institute, Konya Technical University, Konya, Turkey

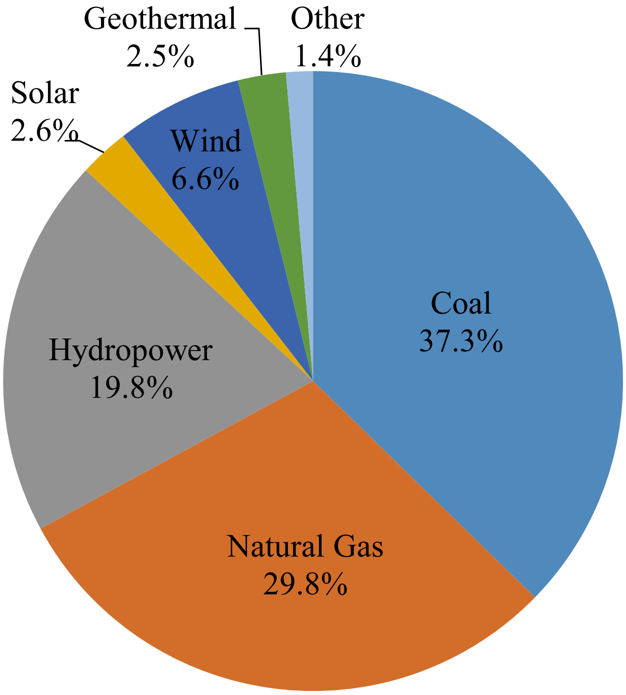

Fig. 1 Installed energy capacity shares (%) of Turkey in 2018 [14]

demand will increase between 4 and 6% annually until 2023. For this reason, the authorities in Turkey aim to increase the share of renewable energy sources in energy production to 30% by 2023. Until this date, it is estimated that energy investments will reach 110 billion US$. Due to Turkey's fastest growing energy market in the OECD countries, it has become an attractive market for energy investors [13].

Turkey's electricity consumption reached 327 billion kWh in 2021, and it increased 12% compared to the previous year. On the other hand, electricity production increased by 12% in the same period and amounted to approximately 329 billion kWh. Electricity consumption is expected to increase by 4.8% annually, and it reaches 375.8 billion kWh in 2023 in the base scenario. By the end of 2021, the installed capacity of Turkey has reached 99,819 MW. As the end of the 2018, the distribution of Turkey's installed power by resources is shown Fig. 1. Additionally, as the end of the 2019, the number of electricity energy generation plants in Turkey was 8069 [14].

Importing a large part of the raw material need for energy production in Turkey is the most important reason for the current account deficit in terms of economy. The fact that the country is located in a region rich in renewable energy resources such as biomass, wind, solar, hydro, geothermal and wave proposes a great opportunity [13]. Turkey offers a variety of incentives to increase the share of renewable energy sources in electricity production and its all renewable energy capacity plans to increase to approximately 57,000 MW by 2023. The estimated amount of electricity production until 2023 in the strategic plan of the Ministry of Energy and National Resources (MENR) is shown Table 1 [15]. The amount of renewable energy production in Turkey for the past years is largely in line with Table 1 according to the MENR data.

Solar photovoltaic (PV) generates electrical energy from direct sunlight. It is an important power source to meet electricity demand in developing countries, especially in rural and remote areas, without emitting pollutants into the atmosphere. The increasing efficiency of PV systems and continuous cost reduction means an important role for photovoltaic generation systems in the coming years [16]. Electricity generation from solar energy has many advantages, such as amortization periods, raw material (infinite), maintenance and operating costs over others [17]. Government policies and support from various non-governmental organizations for electricity generation from solar energy have helped to establish a solid basis for the use of this renewable energy system [18].

When compared with Europe and other world countries, Turkey has a very advantageous position in benefiting from solar energy. The sun, which is a source of energy and life, shows itself with high efficiency throughout the year in many geographical regions of Turkey. Turkey has average annual global solar radiation of 1527 kWh/m^2. Europe's average annual global solar radiation map is shown in Fig. 2. According to the map, Turkey's potential is higher than other European countries. Despite this, Turkey's total PV installed power capacity in 2021 lagged behind Germany, Italy, Spain, France, Netherlands and the UK [19].

Renewable energy investments will play an important role in Turkey's fight against climate change and reducing its dependence on imported fossil fuels. Turkey has committed

Table 1 The estimated renewable energy generation resource until 2023 [15]

Renewable energy sources	2019	2020	2021	2022	2023
Solar (MW)	5750	7000	7750	8500	10,000
Wind (MW)	7633	8883	9633	10,663	11,883
Hydropower (MW)	29,748	31,148	31,688	31,688	32,037
Geothermal and biomass (MW)	2678	2717	2772	2828	2884

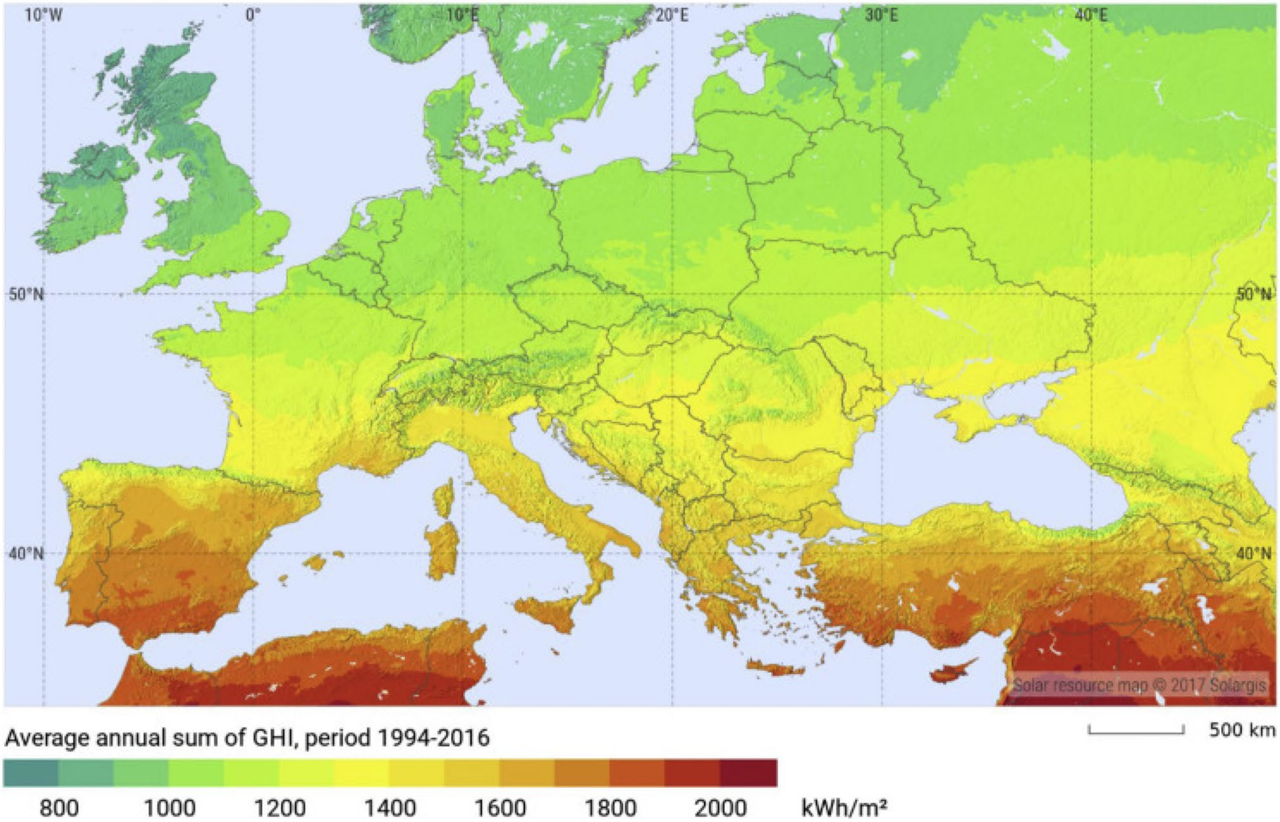

Fig. 2 Average annual global solar radiation in Europe [20]

to create 26 gigawatts of wind and solar power generation capacity by 2030 under the Paris Agreement [21].

Any installation that converts a renewable source to energy requires a large initial capital investment, so setting up generation facilities for renewable energy sources is quite expensive for both government and private investors. Therefore, it is very important to make the right decision for investment [13]. For example, according to the prices of 2022 in Turkey, the cost of 1 MW solar power plant varies between 580,000 and 650,000 US$. These costs include solar panels, mounting systems, inverters, remote monitoring systems (computer, network, etc.), cable, connection connectors, construction and labor. Solar farms should be installed in a suitable area in terms of legislation and energy efficiency. Land selection should be well researched before investing. In order to minimize the negative environmental, economic and social effects in the solar farm location studies, all criteria should be taken into consideration [21]. Selecting the suitable areas for a solar farm is a multi-criteria evaluation (MCE) problem. Figure 3 shows the percentages of using MCE methods in energy-related decision making problems in the literature.

This paper was proposed on a GIS-based, MCE model that uses analytic network process (ANP) to identify the most appropriate sites for solar farms in Cumra Region, Turkey.

2 Materials and Method

2.1 Study Area

The Cumra Region, which was chosen as the study area, is administratively connected to the province of Konya, which

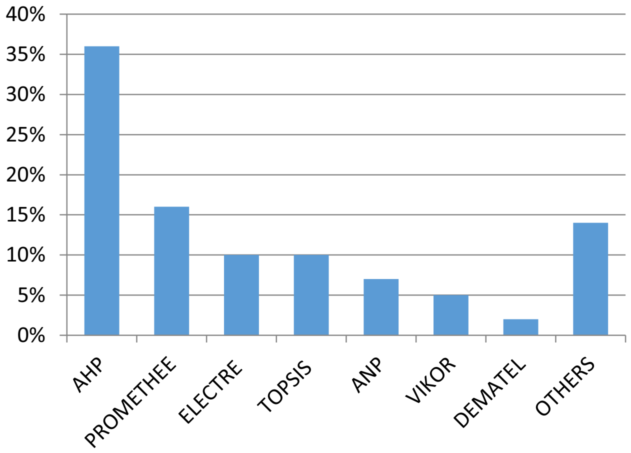

Fig. 3 Percentage of using MCE methods in energy-related decision-making problems in the literature [13]

has the largest surface area of Turkey. It is geographically located between 37.25° and 37.80° north latitudes and 32.42° and 33.21° east longitudes (Fig. 4). Cumra Region is located in the south of Konya Plain, which is the largest closed basin of Turkey and its area 2051 km^2 its distance from Konya city centre is 45 km. The urban population is approximately 68,000. Cumra is one of the most important agricultural production regions in Central Anatolia. Topographically, Cumra generally has a flat structure.

Annual means of solar radiation values are between 1724 and 1766 kWh/m^2/year (Fig. 5), in this area and it has a great potential for solar energy investment. Figure 6 is shown solar radiation values and sunshine duration for Cumra Region.

2.2 Methodology

Geographic information systems (GIS) have emerged as an important tool for spatial planning and management. One of the main reasons for this is that GIS can be used in the planning process by including multiple factors in the decision-making process regarding land use. Therefore, its applications can be particularly valuable not only for visualization and data management, but also for evaluating selection alternatives based on spatially relevant factors [22]. With the integration of MCE and GIS, the analysis can be provided fast and efficiently, so costs can be managed, errors can be reduced and an advantageous method can be created by increasing decision accuracy. This integration can be used for different spatial tasks and provide solutions to problems [23–25]. The combined use of GIS and MCE in site selection studies is very common in the literature. Ahmadi et al. [26] proposed a model combining analytical network process (ANP), fuzzy VIKOR and GIS to solve the problem of finding suitable locations to build a wind powered pump storage plant. Barzehkar et al. [27] discussed a hybrid decision support system using MCE based on GIS, fuzzy logic and a weighted linear combination approach to determine the most suitable locations for renewable energy generation infrastructure. Finn and McKenzie [28] used AHP, MCE and GIS together to determine solar energy potential on a large scale, using high resolution spatial data. Mokarram et al. [29] used a fuzzy-based method to homogenize the criteria to find suitable areas required to establish solar farms, followed by the AHP and Dempster-Shafer methods used independently. Ali et al. [30] identified suitable areas for locating small scale wind and solar farms with GIS and AHP in southern Thailand. Figure 3 shows the percentage of using MCE methods in energy-related decision-making problems in the literature [13]. The core of Analytic Hierarchy Process (AHP) method is to state a complex problem in a hierarchical structure. AHP deals with attribute weighting problem by making pairwise comparisons among competing attributes. AHP does not consider the mutual dependencies among attributes while obtaining importance degrees of them. Therefore, analytic network process (ANP) is developed to cope with this difficulty.

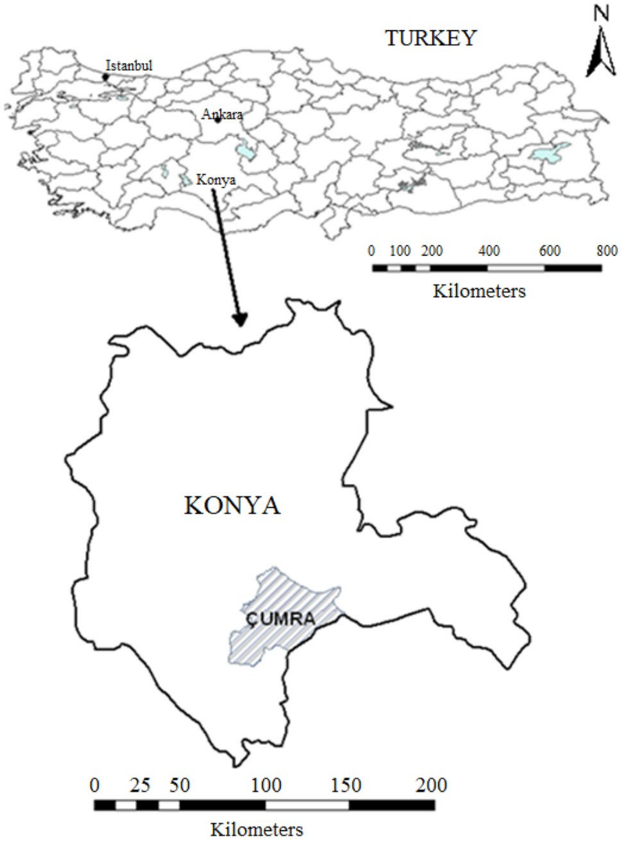

Fig. 4 Study area for solar farm site selection

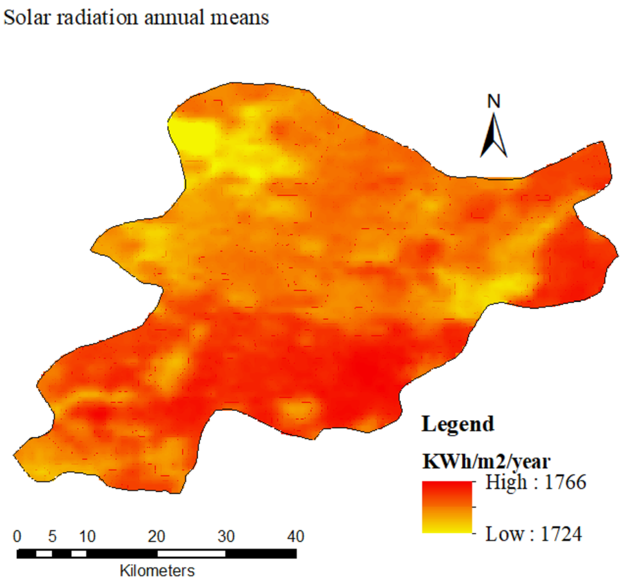

Fig. 5 Solar radiation annual means in study area

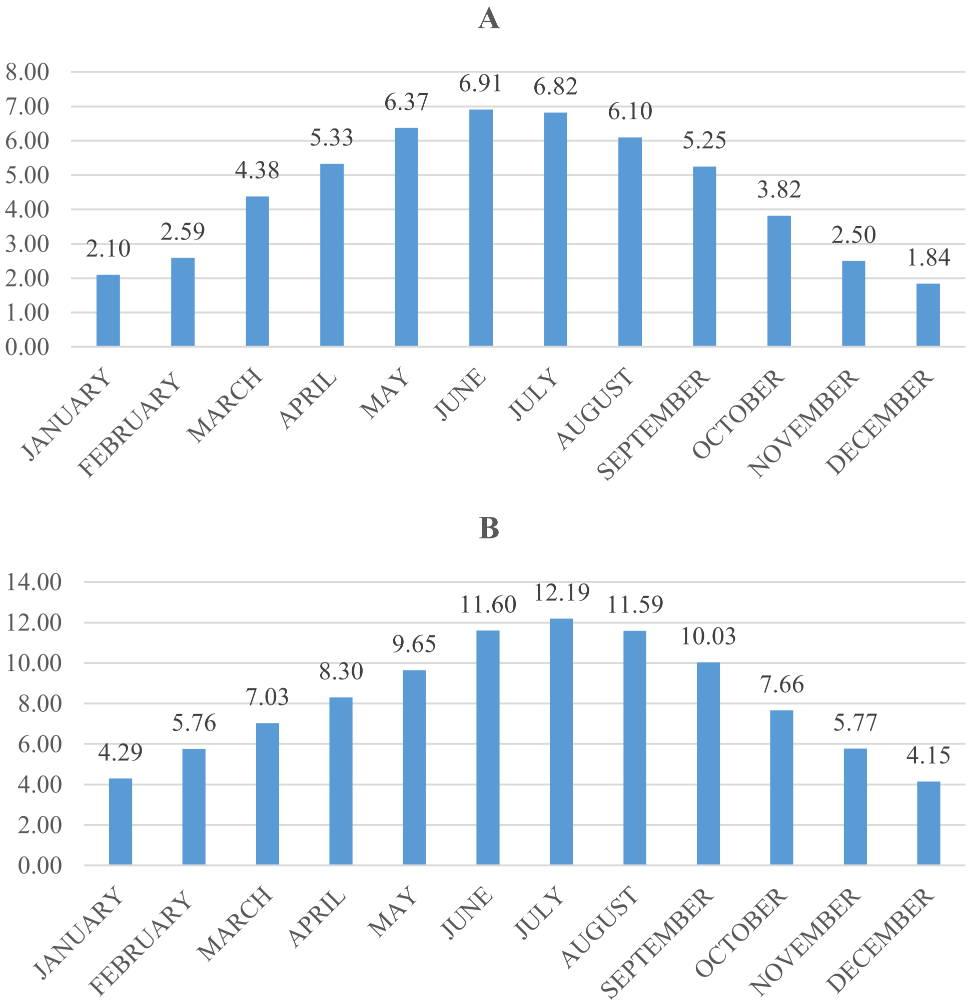

Fig. 6 **A** Solar radiation values (kWh/m^2 day) and **B** sunshine duration (hours) for Cumra Region

Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) method enables decision makers to identify the best alternative which is close to the positive ideal solution and far from the negative ideal solution as much as possible. Preferences are modelled by using binary outranking relations in ELimination Et Choix Traduisant la REalité (ELECTRE) method. It involves pairwise comparison of alternatives based on the degree to which assessment of the alternatives and preference weights confirm or contradict the pairwise dominance relationships between the alternatives [31]. Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE) is an outranking method to determine the priority relationship among criteria, and obtain partial and complete ranking through different preference functions. Decision-Making Trial and Evaluation Laboratory (DEMATEL) is a comprehensive method for constructing and analysing structural models involving causal relationships between complex criteria [32]. VIsekriterijumska Optimizacija I Kompromisno Resenje (VIKOR) method provides a maximum group utility for the majority and a minimum individual regret, which can provide a compromised solution that is the closest to the ideal solution [33]. These methods are often used together.

In order to determine a solar farm location, it is necessary to evaluate, combine and analysis many important criteria according to their different characteristics. These operations require a very complex process. Firstly, specific factors for the study area must be determined. As a multi criteria decision, solar farm location selection cannot be made based on a single factor; several factors must be taken into account in order to achieve the main goal. In general, defined criteria are divided into two groups as factors and constraints. A factor increases or decreases the suitability of an alternative considered, while a constraint limits the alternatives in question. In other words, restrictions are applied to determine which areas are not allowed for a particular activity [34, 35]. Current literature and legal regulations are very important for determining factors and constraints.

Evaluation criteria including the factors and constraints were determined (Tables 2 and 3). A factor is a criterion that increases or decreases from the suitability of a particular alternative for the activity under consideration [36].

Six factors were determined for the study area based on various reasons such as literature review and expert opinions [17, 28, 37–40]. Solar irradiation is the most fundamental factor influencing the electricity generation potential and the economic benefits of solar power systems. Higher solar radiation implies more electricity generation potential and greater economic feasibility. Land morphology influencing the construction and maintenance cost, is also an important factor for selecting a suitable site for solar power systems. The slope of the area determines the acceptability of the site. Compared with the high inclination area, a flat area is more favourable for large-scale solar power plants [41]. Although solar radiation value and slope is the most important criteria for solar farms site selection, it was not used in this study. Because solar radiation value for all study area between 1724 and 1766 kWh/m^2/year (Fig. 5), so it will not affect the result of the study. Topography is almost flat in study area (Fig. 7). The highest slope value in the study area is 20% and since most of these areas are in forest class, they are restricted areas.

Table 3 The constraints of solar farm site selection

Constraints	Buffer of roads and railways distance = 100 m Buffer of surface waters distance = 500 m Buffer of protection areas (archaeological sites, forest land and environmental protection area) distance = 1000 m Agricultural land classification = Grades I–II

The considered factors were listed below for this study and shown with buffer scores at Fig. 8:

(F1) Aspect

Aspect can be explained as the direction of sun exposure. It is the position of a place against the sun, which in turn affects the time of sunbathing [42]. A south-facing slope is an ideal orientation for solar farm sites [43]. The aspect information was obtained from the Digital Elevation Model (DEM) of the NASA Shuttle Rader Topographic Mission (SRTM) with 30 m resolution. The aspect factor

Table 2 Factors and sub-factors of solar farm site selection

Goal	Factors	Sub-factors
Land suitability	**(F1)** Aspect	N, NE, NW
		W
		E
		S, SE, SW
	(F2) Distance from transmission lines (m)	2000 >
		2000–5000
		5000–8000
		8000–10,000
		10,000 <
	(F3) Distance from surface waters (m)	500–2000
		2000–5000
		5000–7000
		7000 <
	(F4) Distance from transformer centre (m)	3000 >
		3000–6000
		6000–9000
		9000–12,000
		12,000 <
	(F5) Distance from residential areas(m)	1000–2000
		2000–3000
		3000–5000
		5000 <
	(F6) Distance from roads and railways (m)	100–1000
		1000–2000
		2000–5000
		5000–8000
		8000 <

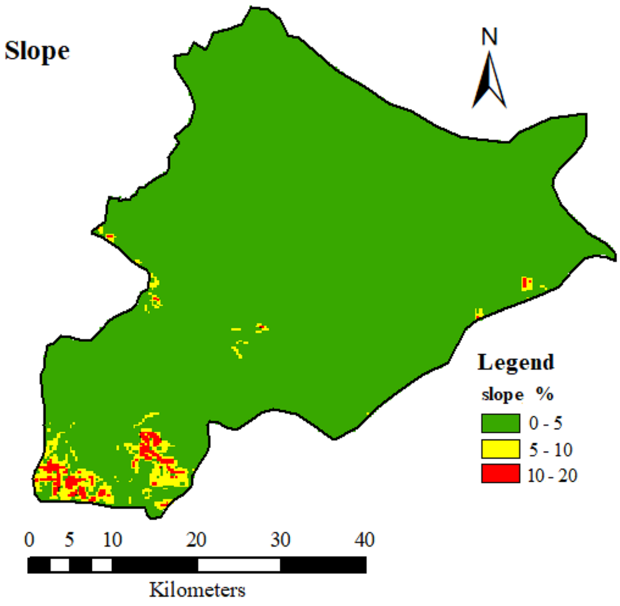

Fig. 7 Slope map of study area

was grouped into four parts. The first part is *North–North East-North West*, the second part is *West*, the third part is *East*, and the fourth part is *South-South East-South West*, respectively.

(F2) Distance from transmission lines (m)

Generated electric from a PV park must be connected to transmission lines. Therefore, a connection must be established between the solar farm and the transmission line. The proximity of the renewable energy facilities to be established to the transmission lines will both reduce the cost of establishing new lines and prevent transmission losses [44]. Distance from transmission lines is divided < 2000 m, 2000–5000 m, 5000–8000 m, 8000–10,000 m and > 10,000 m buffer zone, respectively.

(F3) Distance from surface waters (m)

Currently, water availability is rarely considered in the site assessment of solar power plants [41]. This criterion has been taken into account, albeit with a low weight, in order not to adversely affect the presence of migratory birds in the surface water areas in the study area from reflections. Distance from surface waters is divided 1000–2000 m, 2000–5000 m, 5000–7000 m and > 7000 m buffer zone, respectively.

(F4) Distance from transformer centre (m)

Positioning solar power plants close to transformer centres both reduces the installation cost and prevents energy loss. In the study, for distance from transformer centre < 2000 m, 2000–5000 m, 5000–8000 m, 8000–10,000 m and > 10,000 m buffer zone, respectively.

(F5) Distance from residential areas

A distance towards urban areas is defined to avoid development implications and visual impacts [45]. Since Cumra is a plain area in terms of landforms, it shows a rapid circular development. Therefore, in this study, it was decided to establish solar farms at least 1000 m away from the residential areas. Residential areas with 1000–2000 m, 2000–3000 m, 3000–5000 m and > 5000 m buffer zone, respectively.

(F6) Distance from roads and railways

The proximity to roads and railways will reduce the additional costs of infrastructure construction for the power plants to be established. In addition, being close to the roads for the operation and maintenance of these power plants is important in terms of ease of transportation. Distance from roads and railways with 100–1000 m, 1000–2000 m, 2000–5000 m, 5000–8000 m and > 8000 m buffer zone, respectively.

According to Gašparović and Gašparović [46], since it is not possible to build solar power plants in built-up areas, 100 m distance is defined as the constraint parameter. However, due to the circular rapid urban growth of the study area and visual effects, 1000 m buffer application was made from residential areas. A buffer of 100 m was applied from roads and railways against the possibility of widening the roads and railways. A buffer of 500 m was applied in order to prevent the migratory bird presence in the surface water areas of the study area from being adversely affected by the light reflections on the solar panels. A buffer of 1000 m was applied in order not to damage the protected areas from solar field investments. The lands are evaluated between I and VIII classes according to their land use ability in Turkey. First class lands are the lands that can be cultivated in the best, easiest and most economical way without causing erosion. On the other hand, eighth class lands are areas that are not suitable for any agriculture [47]. For this reason, grades I and II were constrained due to their high arable value. Grades III, IV, V, VI, VII and VIII were not constrained due to the lower fertility of the land.

GIS data sets of study area were conducted through collecting 1:50000 and 1:100000 maps from different organizations. Data collected from various institutions regarding the above-mentioned factors were converted into digital format using GIS. Aspect maps were prepared based on SRTM (Shuttle Radar Topography Mission) data. Open-source OpenStreetMap (OSM) data were used for road-railway, residential areas and surface water data.

2.3 Multi-criteria Decision-making and Analytic Network Process (ANP)

In this study, using the ANP method, which is a component of MCE methods, a model for solar energy field location

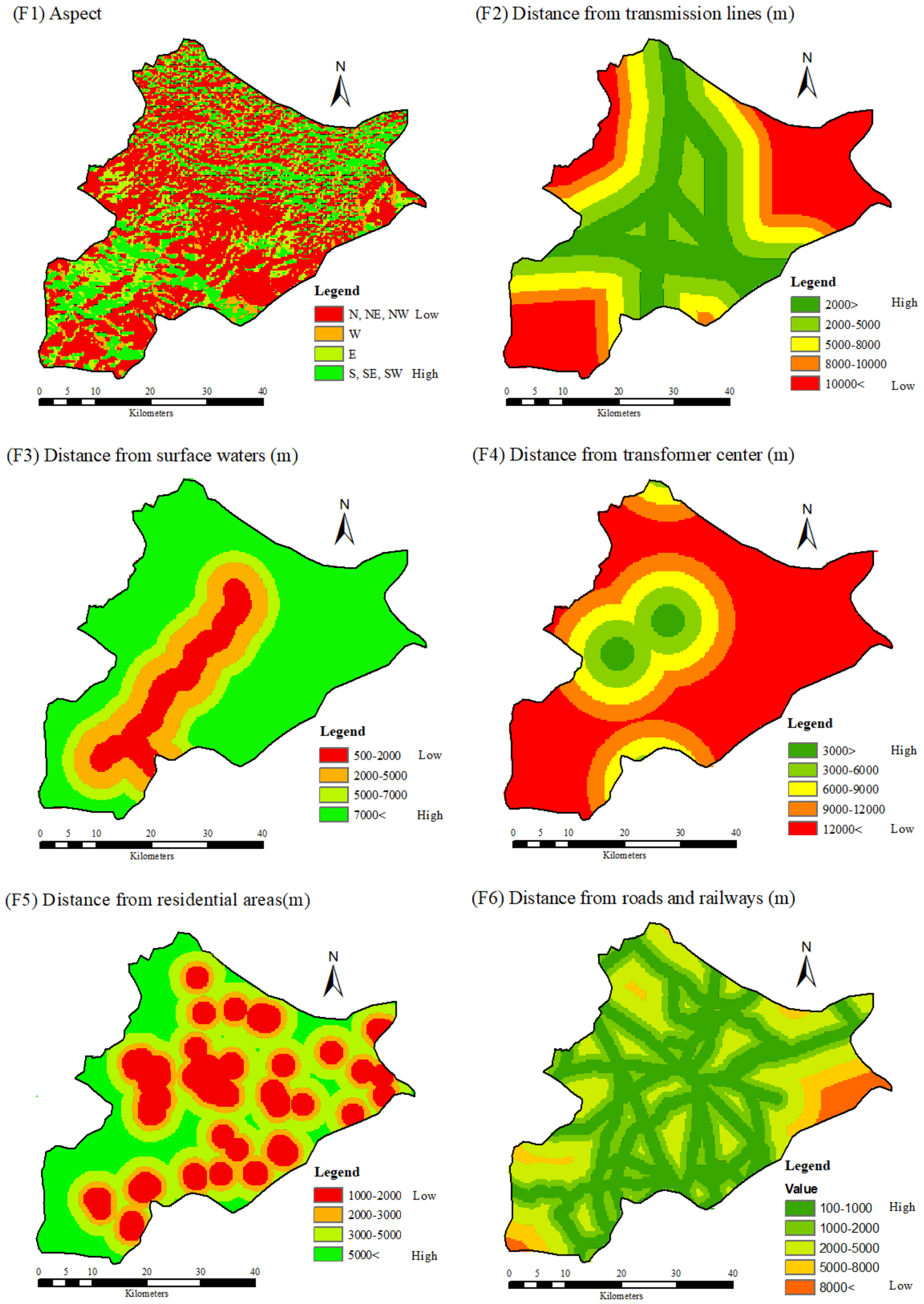

Fig. 8 Suitability index of (F1) aspect, (F2) transmission lines, (F3) surface waters, (F4) transformer centre, (F5) residential areas and (F6) roads and railways

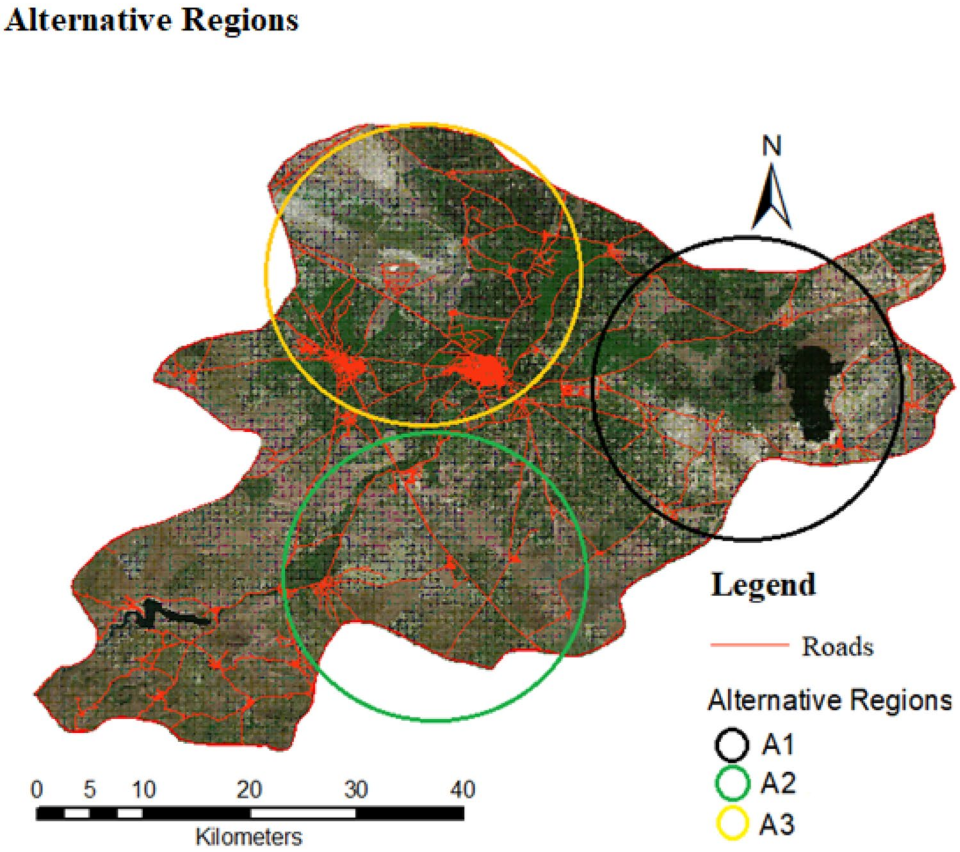

Fig. 9 Alternative regions for solar farm site selection

selection was created. MCE is a combination of analytical methods that help decision makers to solve problems by combining determined weighted criteria by experts. Various MCE approaches such as AHP, ANP, best worst method, ELECTRE and VIKOR have been developed to assist in decision-making and planning [34].

ANP is a MCE method that is an improved form of AHP presented by Saaty [48]. Uyan [17] explained AHP method, widely. The ANP method can significantly simplify decision-making processes where criteria have complex relationships. It also provides the evaluation of all relationships by adding interdependencies and feedbacks to the decision system [49]. ANP models the problem as a network where nodes are grouped into clusters and the directed arcs correspond to relationships between the nodes. The purpose of the process is to prioritize all the nodes in a cluster. Normally, there is a set of corresponding alternatives for a decision problem, so the process prioritizes these alternatives to support decision-making [50]. ANP differs from AHP in that it uses a hierarchical structure rather than a top-down hierarchical structure. Steps of the ANP method are as follows [51]:

Step 1: identifying the problem
Step 2: determining relationships between factors
Step 3: performing pairwise comparison
Step 4: calculating of consistency ratio (CR)
Step 5: creating super matrices in order [52]:

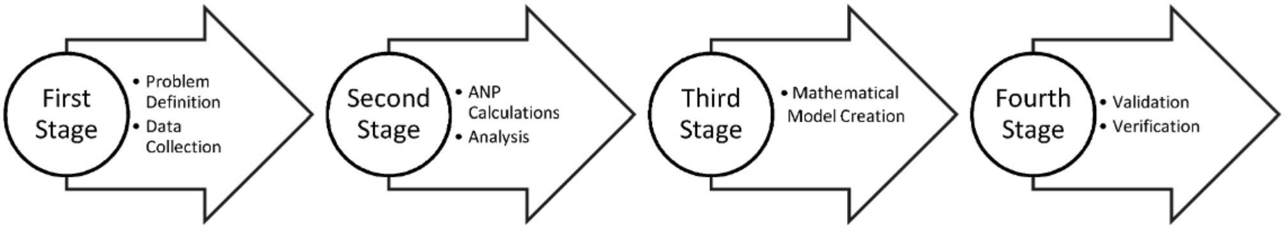

Fig. 10 Flow chart of ANP model for solar farm site selection [51]

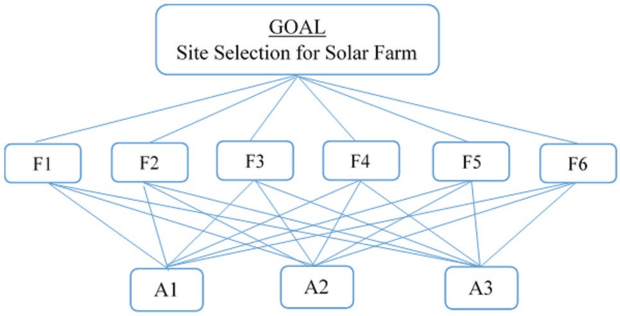

Fig. 11 The designed ANP model

Unweighted supermatrix: a supermatrix is actually a partial matrix, and each matrix section shows the relationship between two factors in a system. Each element is represented at one row and one respective column.
Weighted supermatrix: if the column sum of any column in the composed supermatrix is greater than 1, that column will be normalized.
Limit supermatrix: the weighted supermatrix is then raised to a significantly large power in order to have converged or stable values. The values of this limit matrix are the desired priorities of the elements with respect to the goal. Therefore, the importance weights of alternatives or comparable factors are determined by the limit supermatrix.

Step 6: determination of the best alternative

3 Results

A model for the solar farm site selection was based combining ANP method which is a component of the MCE methods, with GIS in Cumra Region, Konya, Turkey in this study. Firstly, the solar farm site selection problem was defined. Three alternative regions (Ismil direction (A1), Karaman direction (A2) and Karatay direction (A3)) and 6 factors were determined (Fig. 9) for solar farm site selection. Using the ANP method, criteria and alternatives were weighted and the most suitable solar farm location was selected. Figure 10 shows the flow chart to be followed in solving the problem.

At the first step, through the pairwise comparison, weight value of each factor in selected model was determined. Pairwise comparison was carried out similar to AHP method. According to the ANP model, each parameter was scored using a numerical scale ranging from 1 (least impact) to 9 (greatest impact) [48] to determine the relative weight and coefficient of importance (Fig. 11). A pairwise comparison matrix was generated as a result of pairwise comparisons and factor weights were reached as a result of these calculations. For control the consistency of the estimated weight values using a Consistency Ratio (CR). Pairwise comparison matrices should have acceptable if CR is less than 0.10, otherwise the pairwise comparison should be reconsidered [34]. *CR* values were calculated, as follows [53]:

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

in which

$$CI = \frac{\lambda_{\max} - n}{n - 1}, \tag{2}$$

where *CI* is the Consistency Index, *RI* is the Random Index, and *n* is the size of matrix the pairwise comparisons matrix. RI is a parameter derived from Saaty [54]. The RI values for different numbers of n are shown in Table 4.

Due to a reduction in the volume of calculations, only comparison matrix for factors and its weights is shown in Table 5, which indicates the importance of aspect and distance from transmission lines, with weights of 0.338 and 0.338, respectively. The CR was acceptable (0.056) at a ratio lower than 0.10. For next stage, the internal dependencies and inner weights of factors and sub-factors were calculated, since there was dependence between them.

Supermatrix was used to analyse internal dependencies between system components. The supermatrix components obtained from matrix pairwise comparison of internal dependencies were changed. Any non-zero value in the supermatrix column indicates the comparative weight significance of the internal dependencies derived from pairwise comparison matrices. In fact, a supermatrix is a matrix classified by components, in which each matrix division shows the relationship between the two decision-making levels on the total decision [36].

Isalou et al. [55] explained the ANP calculations as indicated below:

If ANP model has N clusters as $C_1, C_2, \ldots, C_n$, in *i*th cluster, there are n_i elements. If two clusters, C_i and C_j are selected, comparing all elements of C_i together with all elements of C_j, and obtaining their specific vectors would result in the Eq. (3) matrix. Building up this matrix for all of the clusters will give Eq. (4). This matrix is known as unweighted supermatrix.

Table 4 RI table values [54]

n	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Table 5 Comparison matrix for factors and its weights

Factors	F1	F2	F3	F4	F5	F6	Weight
F1	1.00	1.00	9.00	5.00	7.00	3.00	0.338
F2	1.00	1.00	9.00	5.00	7.00	3.00	0.338
F3	0.11	0.11	1.00	0.20	0.33	0.20	0.027
F4	0.20	0.20	5.00	1.00	3.00	0.33	0.090
F5	0.14	0.14	3.00	0.33	1.00	0.20	0.048
F6	0.33	0.33	5.00	3.00	5.00	1.00	0.158

$$w'_{ij}\begin{bmatrix} w_{i_1}^{j_1} & w_{i_1}^{j_2} & \cdots & w_{i_1}^{j_{nj}} \\ w_{i_2}^{j_1} & w_{i_2}^{j_2} & \cdots & w_{i_2}^{j_{nj}} \\ \vdots & \vdots & \cdots & \vdots \\ w_{i_{ni}}^{j_1} & w_{i_{ni}}^{j_2} & \cdots & w_{i_{ni}}^{j_{nj}} \end{bmatrix}. \tag{3}$$

If the weight of clusters (C_i) is calculated by comparing each other through even comparison between effectible clusters with effective clusters, and multiply in weight of each of the corresponding elements of clusters in unweighted supermatrix, then weighted supermatrix ($w^{'}$) will be obtained (Eq. (4)).

$$w'\begin{bmatrix} w_{11} & w_{12} & \cdots & w_{1N} \\ w_{21} & w_{22} & \cdots & w_{2N} \\ \vdots & \vdots & \cdots & \vdots \\ w_{N1} & w_{N2} & \cdots & w_{NN} \end{bmatrix} \tag{4}$$

The final step in obtaining the global priority vector is to reach synthesis by raising the weighted supermatrix to large powers, as follows [53]:

$$w_{limit} = \lim_{x\to\infty} (w_{weighted})^{x} \; or \; (w_{weighted})^{2k+1}, \tag{5}$$

in which k is an arbitrarily large number. Raising the weighted supermatrix to these large powers is necessary to obtain stabilization or convergence. As it was mentioned above, each of the model clusters in the ANP modelling (unweighted supermatrix, weighted supermatrix and limit supermatrix) is determined in Table 6, Table 7 and Table 8, respectively.

Finally, the importance degree of factors, which was the resultant of this study, is presented in Table 9.

Figure 12 shows the logical location of solar farms site map which created by combining raster criteria maps weighted by ANP with overlay analysis, and reclassified according to suitability levels in Cumra Region, Konya, Turkey. Evaluation factors weighted with ANP in Fig. 8 were used to calculate the suitability map. Six site selection factors were selected according to the characteristics of the study area. Each factor map was prepared using ArcGIS with weight values obtained from ANP and combined for the land suitability map. The classification was made in three categories as low suitable, moderate suitable and high suitable with an equidistant classification method.

4 Discussion

A3, which was chosen as one of the alternative areas, was the most preferred region with a rate of 52.39% as a result of the evaluation made by using the ANP method. The reason of selection of this region with the highest rate was that the amount of fertile land in the region is less than other regions. The establishment of solar power plants on

Table 6 Unweighted supermatrix

Unweighted supermatrix	A1	A2	A3	F1	F2	F3	F4	F5	F6	Goal
A1	0	0.125	0.25	0.104729	0.104729	0.104729	0.104729	0.104729	0.104729	0.104729
A2	0.166667	0	0.75	0.258285	0.258285	0.258285	0.258285	0.258285	0.258285	0.258285
A3	0.833333	0.875	0	0.636986	0.636986	0.636986	0.636986	0.636986	0.636986	0.636986
F1	0.415238	0.341305	0.341305	0	0.514824	0.362093	0.370077	0.362749	0.396947	0.341305
F2	0.311233	0.341305	0.341305	0.514824	0	0.362093	0.370077	0.362749	0.396947	0.341305
F3	0.024872	0.026478	0.026478	0.036445	0.036445	0	0.029984	0.028695	0.031155	0.026478
F4	0.078712	0.086403	0.086403	0.132075	0.132075	0.076201	0	0.081806	0.116511	0.086403
F5	0.038548	0.044941	0.044941	0.064936	0.064936	0.038924	0.055075	0	0.05844	0.044941
F6	0.131396	0.159568	0.159568	0.251719	0.251719	0.160689	0.174787	0.164	0	0.159568
Goal	0	0	0	0	0	0	0	0	0	0

Table 7 Weighted supermatrix

Weighted supermatrix	A1	A2	A3	F1	F2	F3	F4	F5	F6	Goal
A1	0	0.0625	0.125	0.052365	0.052365	0.052365	0.052365	0.052365	0.052365	0.052365
A2	0.083333	0	0.375	0.129142	0.129142	0.129142	0.129142	0.129142	0.129142	0.129142
A3	0.416667	0.4375	0	0.318493	0.318493	0.318493	0.318493	0.318493	0.318493	0.318493
F1	0.207619	0.170652	0.170652	0	0.257412	0.181046	0.185038	0.181375	0.198473	0.170652
F2	0.155616	0.170652	0.170652	0.257412	0	0.181046	0.185038	0.181375	0.198473	0.170652
F3	0.012436	0.013239	0.013239	0.018223	0.018223	0	0.014992	0.014348	0.015578	0.013239
F4	0.039356	0.043202	0.043202	0.066037	0.066037	0.038101	0	0.040903	0.058255	0.043202
F5	0.019274	0.022471	0.022471	0.032468	0.032468	0.019462	0.027538	0	0.02922	0.022471
F6	0.065698	0.079784	0.079784	0.12586	0.12586	0.080345	0.087394	0.082	0	0.079784
Goal	0	0	0	0	0	0	0	0	0	0

Table 8 Limit supermatrix

Limit supermatrix	A1	A2	A3	F1	F2	F3	F4	F5	F6	Goal
A1	0.069463	0.069463	0.069463	0.069463	0.069463	0.069463	0.069463	0.069463	0.069463	0.069
A2	0.168590	0.168590	0.168590	0.168590	0.168590	0.168590	0.168590	0.168590	0.168590	0.169
A3	0.261947	0.261947	0.261947	0.261947	0.261947	0.261947	0.261947	0.261947	0.261947	0.262
F1	0.162873	0.162873	0.162873	0.162873	0.162873	0.162873	0.162873	0.162873	0.162873	0.163
F2	0.160000	0.160000	0.160000	0.160000	0.160000	0.160000	0.160000	0.160000	0.160000	0.160
F3	0.014914	0.014914	0.014914	0.014914	0.014914	0.014914	0.014914	0.014914	0.014914	0.015
F4	0.049353	0.049353	0.049353	0.049353	0.049353	0.049353	0.049353	0.049353	0.049353	0.049
F5	0.025693	0.025693	0.025693	0.025693	0.025693	0.025693	0.025693	0.025693	0.025693	0.026
F6	0.087168	0.087168	0.087168	0.087168	0.087168	0.087168	0.087168	0.087168	0.087168	0.087
Goal	0	0	0	0	0	0	0	0	0	0

agriculturally unproductive lands was encouraged. Another reason for preference was that its location was in an area very close to the city centre of Konya. Operation, maintenance, transportation, etc. Proximity to central areas was important in terms of costs. Restricted areas were less in the A3 region. Among the alternative areas, A1 was the least preferred area with 13.89%. The biggest reason for this was that the restricted areas have very limited the appropriate areas. This region had also very limited roads in terms of transportation. A2 region also has a high suitability with a preference rate of 33.72%. Regional transmission lines were preferred in terms of proper routing and road lines. While solar radiation values and slope were accepted as the most important criteria for many studies, they were not considered criteria in this study because the study area consists of flat plains and the solar radiation value was approximately the same. According to the analysis values of the F1, F2, F3, F4, F5 and F6 criteria, it was seen that F1 and F2 have the most suitable positions for the construction of solar power plants with the values of 32.57% and 32%, respectively. Aspect ratio of selected region is a really important criteria for the efficiency of solar panels. In terms of installation costs, proximity to transmission lines was also seen as very effective criteria. Proximity to roads and railways was weighted with 17.43%,

Table 9 Final factors weight for the solar farm site selection

Factor	Weight	%
A1	0.069	13.89
A2	0.169	33.72
A3	0.262	52.39
F1	0.163	32.57
F2	0.160	32.00
F3	0.015	2.98
F4	0.049	9.87
F5	0.026	5.14
F6	0.087	17.43

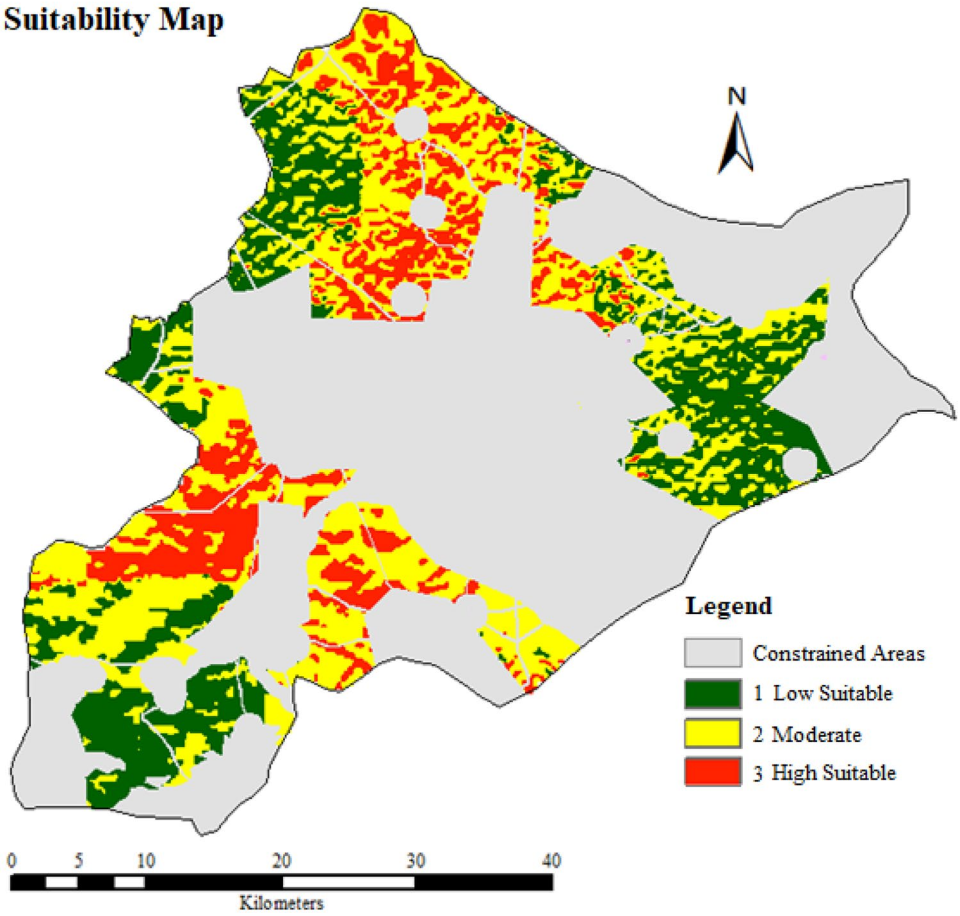

Fig. 12 The classified suitability map for solar farms

as an important factor due to infrastructure construction, operation and maintenance of solar farms. The weights of proximity to residential areas (F3) and proximity to water resources (F5) were quite low. The reason for this was that solar energy farms had no negative environmental effects. In addition, the fact that these criteria had no negative effects in terms of installation costs and efficiency was effective in keeping the criteria weights low. The criteria set for this field of study might not be valid in different fields of study. For example, it is inevitable to use this criterion in mountainous regions where the slope changes a lot. Criteria will differ according to regional characteristics.

5 Conclusion

Making it possible for everyone to have adequate access to energy is an increasingly important challenge. There have been great wars to capture energy resources from the past to the present. Even now, energy is the main cause of most conflicts in the world. Today, as in many countries of the world, in Turkey, to meet energy needs and to minimize environmental concern, it was focused on increase energy production from sustainable energy sources. In 2020, while renewable energy became the largest source of electricity in the European Union, for the first time it managed to outpace fossil fuels. Solar energy is evaluated in the form of light, heat and electricity. Photovoltaic systems convert solar energy directly into electricity. Electricity generation from solar energy is an important energy alternative in countries such as Turkey, where the sunshine duration is long. But, among these countries, mostly, there are no serious criteria determined for the establishment of solar farms that generate electrical energy. However, different criteria must be taken into account in order to reduce the initial facility costs and increase their efficiency of solar farms. The amount of unit energy produced in solar power plants requires a very large area when compared to that of other power plants. In order to establish these structures, vegetation such as trees, maquis, bushes and reeds must be destroyed. For reducing the installation costs, it is the generally preferred to install such solar farms in the pasture areas also this situation prevent the continuation of animal grazing activities. The transfer of agricultural lands to investors cannot be prevented because there is not sufficient legal legislation. Site selection of protected archaeological, urban and historical sites and solar power plants in or near the impact area of these areas should be avoided. The ecological system can be protected with site selection studies carried out by determining scientific criteria.

In this study, it presents the application of combining ANP, which is one of the MCE methods, with GIS, in order to determine the most suitable locations for solar power plants in Cumra Region, Konya, Turkey. The determined factor for the study area belongs to that region. Different factors may arise for different fields. Final suitability map was created for combined all factors. These studies can offer different methodologies and different decision support to the decision maker for solving site selection problems. Konya, where the study area is located, is one of the leading regions of Turkey in terms of its current situation and potential in the solar energy sector. It has significant advantages in terms of its potential to support these investments due to factors such as high solar radiation values, availability of suitable lands and having many companies operating in the solar energy sector. When it is considered the solar radiation values, the amount of electrical energy to be obtained from any solar farm to be established on the determined lands will be approximately 70% more than the Bavarian Region of Germany.

Author Contribution MU performed the final evaluation and was a major contributor in writing the manuscript. OLD analysed and interpreted spatial data. All authors read and approved the final manuscript.

Data Availability Not available.

Code Availability Not available.

Declarations

Ethics Approval This is an observational study. Konya Technical University Research Ethics Committee has confirmed that no ethical approval is required.

Consent to Participate Not applicable.

Consent for Publication Not applicable.

Conflict of Interest The authors declare no competing interests.

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