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

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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 energy types among sustainable energy sources. The sun is an inexhaustible source of energy for humanity that can be used for generations. The first step in the project design process in the installation of solar farms is to determine the suitable land. Appropriate site selection is an important factor that increases the efficiency of a solar farm. In order to minimize the negative environmental, economic and social effects in the solar farms location studies, all criteria affecting the study should be taken into consideration. A good land selection and preparation of the selected land for the process are among the issues that should be considered in the first place for an efficient solar farm. This study 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. Six main criteria have been defined for the most suitable site selection in the study area. Criteria maps were prepared by GIS software using weight values determined from ANP and combined for the site suitability map. Suitability map was divided into three categories as low, moderate and high suitable with an equidistant classification method.

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 (Colak, et al., 2020). One of the most important effects of fossil fuels is the pollution and environmental problems. Many literatures point out that energy consumption and growth are the most important reasons that increase carbon dioxide emissions (Charfeddine and Kahia, 2019; Nguyen, Kakinaka, 2019; Pata, 2018; Hu, et al., 2018; Dong, et al., 2017).

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, new energy sources other than fossil fuels must be used. Therefore, developed countries are interested in the development and use of renewable energy sources such as solar, wind, tidal, geothermal, hydroelectric and biomass energy (Saidi et al., 2020). In recent years, the energy industry has focused on renewable energy sources to reduce the carbon footprint during energy generation (Qadir, et al., 2021). With the use of renewable energy, it can reduce CO_2 emissions by at least 0.4 billion tons in 2020. As of 2015, at least 146 countries have started renewable energy policies aiming to reduce CO_2 emissions. Global investment on renewable energy exceeded 214 billion US$, in 2013. As a result, global renewable energy capacity is projected to grow by 43% between 2017 and 2022. This situation is due to the nations' commitment to clean environment (Nathaniel and Iheonu, 2019).

Energy production in Turkey is not sufficient for current needs energy. In addition, it is expected that the energy need 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 (Erdin and Ozkaya, 2019).

Turkey's electricity consumption reached 327 billion kWh in 2021, an increase of 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, reaching 375.8 billion kWh in 2023 in the base scenario. By the end of 2021, the installed capacity of Turkey has reached 99819 MW. As the end of the 2018, the distribution of Turkey installed power by resources is shown Fig. 1. Additionally, as the end of the 2019, number of electricity energy generation plants in Turkey was 8069 (MENR, 2021).

Energy production in Turkey is importing a large portion of the raw material needs. This situation constitutes an important part of the current account deficit in terms of economy. It is important to search for efficient and local energy resources for for a sustainable national economy. Turkey is located in a very rich region in terms of renewable energy capacity. This situation creates a great opportunity for its. Turkey is capable of using almost all of the renewable energy sources such as biomass, wind, solar, hydro, geothermal and wave (Erdin and Ozkaya, 2019). 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 61000 MW by 2023. Turkey encourages increasing the share of renewable energy sources in electricity generation and it is striving to improve the whole capacity of renewables to approximately 61000 MW by 2023. The estimated electricity generation resource amounts until 2023 the Ministry of Energy and National Resources (MENR) strategic plan are shown Table 1 (MENR, 2021).

Table 1
The estimated renewable energy generation resource until 2023 (MENR, 2021).

RENEWABLE ENERGY SOURCES	2019	2020	2021	2022	2023
Solar (MW)	5750	7000	7750	8500	10000
Wind (MW)	7633	8883	9633	10663	11883
Hydropower (MW)	29748	31148	31688	31688	32037
Geothermal an Biomass (MW)	2678	2717	2772	2828	2884

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 (Shahsavari and Akbari, 2018). Electricity generation from solar energy has many advantages over other types of energy production, such as amortization periods, raw material (infinite), maintenance and operating costs (Uyan, 2013). 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 (Kabir, et al., 2018).

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's average annual global solar radiation of 1527 kWh/m², has a very high value. 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 to create 26 gigawatts of wind and solar power generation capacity by 2030 under the Paris Agreement (Uyan, 2017a).

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 (Erdin, and Ozkaya, 2019). Solar farms should be installed in a suitable areas 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 farms location studies, all criteria affecting the study should be taken into consideration (Uyan, 2017a). Selecting the suitable areas for a solar farm is a multi-criteria evaluation (MCE) problem.

The main motivation of MCE analysis methods is to explore a range of selection possibilities in light of multiple factors and conflicting goals. MCE methods provide a tool for making and supporting complex positioning decisions involving multiple criteria (Tercan, et al., 2020). 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 (Latinopoulos & Kechagia, 2015). With the integration of MCE and GIS, the analysis can be provided with speed and efficiency, 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 (Karimi, et al., 2019). The combined use of GIS and MCE in site selection studies is very common in the literature. Ahmadi, et al. (2020) 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. (2020) 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 (2020) used AHP, MCE and GIS together to determine solar energy potential on a large scale, using high resolution spatial data. Mokarram et al. (2020) 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. (2019) identified suitable areas for locating small scale wind and solar farms with GIS and AHP in southern Thailand. Figure 2 shows the percentage of using MCE methods in energy-related decision making problems in the literature (Erdin and Ozkaya, 2019).

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

Konya, Turkey's largest in terms of surface area (38873 km^2), is the seventh largest city in terms of population. Its population is 2.250.020 according to 2019 data. It consists of 31 districts. The study area is the Cumra region, one of these 31 divisions. It is geographically located between 37.25^0–37.80^0 north latitudes and 32.42^0–33.21^0 east longitudes (Fig. 3). Cumra region is located in the south of Konya Plain, which is the largest closed basin of Turkey and its area 2320 km^2. The urban population is approximately 67000. Cumra is one of the most important agricultural production regions in Central Anatolia.

Konya, the largest city in terms of area of the Turkey has a great potential for investment in solar energy, as shown in Fig. 4. Annual means of solar radiation values are between 1650–1750 KWh/m^2/year, in the study area. Figure 5 is shown solar radiation values and sunshine duration for Cumra region.

2.2. Methodology

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 (Afzali, et al., 2014; Reisi, et al., 2018). Current literature and legal regulations are very important for determining factors and constraints.

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

Goal	Factors	Sub-factors
Land Suitability	**(F1)** Slope (%)	1>
		1–2
		2–3
		3<
	(F2) Distance from transmission lines (m)	2000>
		2000–5000
		5000–8000
		8000–10000
		10000<
	(F3) Distance from surface waters (m)	500–2000
		2000–5000
		5000–7000
		7000<
	(F4) Distance from transformer center (m)	3000>
		3000–6000
		6000–9000
		9000–12000
		12000<
	(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<

Evaluation criteria including the factors and constraints were determined (Table 2 and Table 3). A factor is a criterion that increases or decreases from the suitability of a particular alternative for the activity under consideration (Motlagh and Sayadi, 2015).

Table 3
The constraints of solar farm site selection.

Constraints	Buffer of residential areas distance = 1000 m
	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

Six factors were determined for the study area based on various reasons such as literature review and expert opinions (Uyan, 2013; Uyan, 2017b; Watson and Hudson, 2015; Doorga, et al., 2019; Tahri, et al., 2015; Finn and McKenzie, 2020). Solar radiation value was not evaluated as a factor, because of the same values as 1650–1700 KWh/m^2/year for all of the study area. Considered factors were listed below for this study and shown with buffer scores at Fig. 6 (Uyan, 2017b):

(F1) Slope (%)

Land levelling is required for the deployment of solar farms and a low slope topology is ideal for minimizing costs of land levelling (Ruiz, et al., 2020). Slope factor was grouped into four parts (< 1%, 1–2%, 2–3%, > 3%) and buffer zone scored as 1, 2, 3 and 4, 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 (Mensour, et al., 2019). Distance from transmission lines is divided < 2000 m, 2000–5000 m, 5000–8000 m, 8000–10000 m and > 10000 m buffer zone scored as 1, 2, 3, 4 and 5, respectively.

(F3) Distance from surface waters (m)

Proximity to surface waters is important in terms of environmental effect. Distance from surface waters is divided 1000–2000 m, 2000–5000 m, 5000–7000 m and > 7000 m buffer zone scored as 1, 2, 3 and 4, respectively.

(F4) Distance from transformer center (m)

Positioning solar power plants close to transformer centers both reduces the installation cost and prevents energy loss. In the study, for distance from transformer center < 2000 m, 2000–5000 m, 5000–8000 m, 8000–10000 m and > 10000 m buffer zone scored as 1, 2, 3, 4 and 5, respectively.

(F5) Distance from residential areas

It is undesirable for economic investments to be very close to residential areas due to many social and environmental negative impacts. 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 scored as 1, 2, 3 and 4, 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 scored as 1, 2, 3, 4 and 5, respectively.

Economic investments are not desired to be too close to residential areas due to some social and environmental negative effects. Hence, a buffer of 1000 m was applied from residential areas. A buffer of 100 m was applied from roads and railways against the possibility of widening the roads and railways. Proximity to surface waters is important in terms of environmental effect. For this reason, a buffer of 1000 m was applied from surface waters. 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 (Tercan and Dereli, 2020). 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. Slope maps were prepared based on SRTM (Shuttle Radar Topography Mission) data.

2.2.1. 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 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, VIKOR have been developed to assist in decision making and planning (Afzali, et al., 2014).

ANP is a MCE method that an improved form of AHP presented by Thomas L. Saaty (1996). Uyan (2013) 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 (Aghasafari, et al., 2020). 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 (Quezada, et al., 2021). 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 (Özder, et al., 2019):

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 (Ozkaya and Erdin, 2020)

Unweighted Super Matrix: 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 Super Matrix: If the column sum of any column in the composed supermatrix is greater than 1, that column will be normalized.

Limit Super Matrix: The weighted super matrix 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 super matrix.

Step 6

Determination of the Best Alternative

3. Results And Discussion

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 is defined. Three alternative regions (Ismil direction (A1), Karaman direction (A2) and Karatay direction (A3)) and 6 factors were determined for solar farm site selection (Fig. 7). Using the ANP method, criteria and alternatives were weighted and the most suitable solar farm location was selected. Figure 8 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 is determined. Pairwise comparison was carried out similar to AHP method. According to the ANP model, each parameter is scored using a numerical scale ranging from 1 (least impact) to 9 (greatest impact) (Saaty 1996) to determine the relative weight and coefficient of importance. A pairwise comparison matrix is generated as a result of pairwise comparisons and factor weights are reached as a result of these calculations. For control the consistency of the estimated weight values using a CR. Pairwise comparison matrices should have acceptable if CR is less than 0.1, otherwise the pairwise comparison should be reconsidered (Afzali, et al., 2014). In Eq. 2, CR determined with the largest eigenvector value (λmax) and consistency index (CI) of pairwise comparison matrix (Danesh, et al., 2019).

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

$$CR = \frac{CI}{RI} \tag{2}$$

where random consistency index (RI) is a parameter derived from Saaty (1980). The RI values for different numbers of n are shown in Table 4.

Table 4
RI table values (Saaty, 1980)

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

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 distance from residential areas and distance from roads and railways, with weights of 0.43 and 0.29, respectively. The CR is acceptable (0.076) at a ratio lower than 0.1. For next stage, the internal dependencies and inner weights of factors and sub-factors were calculated, since there was dependence between them.

Table 5
Comparison matrix for factors and its weights.

Factors	F1	F2	F3	F4	F5	F6	Weight
F1	1.00	0.33	1.00	0.33	0.14	0.20	0.042
F2	3.00	1.00	5.00	1.00	0.20	0.20	0.106
F3	1.00	0.20	1.00	0.33	0.20	0.20	0.043
F4	3.00	1.00	3.00	1.00	0.20	3.00	0.092
F5	7.00	5.00	5.00	5.00	1.00	3.00	0.431
F6	5.00	5.00	5.00	5.00	0.33	1.00	0.286

Supermatrix was used to analyze internal dependencies between system components. The super matrix components obtained from matrix pairwise comparison of internal dependencies were changed. Any non-zero value in the super matrix column indicates the comparative weight significance of the internal dependencies derived from pairwise comparison matrices. In fact, a super matrix is a matrix classified by components, in which each matrix division shows the relationship between the two decision making level on the total decision (Motlagh and Sayadi, 2015).

Isalou, et al., (2013) explained the ANP calculations as follows:

If ANP model has N clusters as C_1, C_2,…., C_n, in *i*th cluster, n_i elements would be existed. 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 the Eq. 3. This matrix is known as unweighted super matrix.

$$w_{ij}^{'} = \begin{bmatrix} w_{i_1}^{j_1} & w_{i_1}^{j_2} & \Lambda & w_{i_1}^{j_{nj}} \\ w_{i_2}^{j_1} & w_{i_2}^{j_2} & \Lambda & w_{i_2}^{j_{nj}} \\ M & M & \Lambda & M \\ w_{i_{ni}}^{j_1} & w_{i_{ni}}^{j_2} & \Lambda & w_{i_{ni}}^{j_{nj}} \end{bmatrix} \qquad (3)$$

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 super matrix, then weighted super-matrix (W) will be obtained (Eq. 4).

$$w^{'} = \begin{bmatrix} w_{11} & w_{12} & \Lambda & w_{1N} \\ w_{21} & w_{22} & \Lambda & w_{2N} \\ M & M & \Lambda & M \\ w_{N1} & w_{N2} & \Lambda & w_{NN} \end{bmatrix} \qquad (4)$$

The final weight of elements is achieved through Eq. 5. The matrix achieved is referred as “Limit super-matrix”. The corresponding weight of each element is placed in the corresponding raw of limit super-matrix. Hence, weights of elements of the whole clusters would be achieved.

$$\lim_{k\to\infty} W^{2K+1} \qquad (5)$$

As it was mentioned above, each of the model clusters in the ANP modeling (unweighted supermatrix, weighted supermatrix and limit supermatrix) were determined in Table 6, Table 7 and Table 8, respectively.

Table 6
Unweighted supermatrix.

Unweighted supermatrix	A1	A2	A3	F1	F2	F3	F4	F5	F6	Goal
A1	0.0	0.12500	0.25000	0.33333	0.10473	0.63699	0.10473	0.10473	0.10473	0.10473
A2	0.12500	0.0	0.75000	0.33333	0.25828	0.25828	0.25828	0.25828	0.25828	0.25828
A3	0.87500	0.87500	0.0	0.33333	0.63699	0.10473	0.63699	0.63699	0.63699	0.63699
F1	0.02570	0.02538	0.02670	0.0	0.05169	0.04380	0.05089	0.06552	0.05869	0.04175
F2	0.17990	0.16026	0.25450	0.11567	0.0	0.08793	0.14118	0.17884	0.17489	0.10576
F3	0.29790	0.32654	0.10490	0.04620	0.05693	0.0	0.05212	0.06100	0.06028	0.04338
F4	0.09930	0.08063	0.25450	0.09182	0.11198	0.08793	0.0	0.15573	0.15185	0.09234
F5	0.09930	0.08063	0.10490	0.27198	0.48542	0.48519	0.44587	0.0	0.55429	0.43125
F6	0.29790	0.32654	0.25450	0.47432	0.29399	0.29515	0.30994	0.53891	0.0	0.28551
Goal	0.0	0.0	0.0	0.0	0.0	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	0.06250	0.12500	0.16667	0.05237	0.31849	0.05237	0.05237	0.05237	0.05237
A2	0.06250	0.0	0.37500	0.16667	0.12914	0.12914	0.12914	0.12914	0.12914	0.12914
A3	0.43750	0.43750	0.0	0.16667	0.31849	0.05237	0.31849	0.31849	0.31849	0.31849
F1	0.01285	0.01269	0.01335	0.0	0.02585	0.02190	0.02544	0.03276	0.02934	0.02088
F2	0.08995	0.08013	0.12725	0.05784	0.0	0.04397	0.07059	0.08942	0.08744	0.05288
F3	0.14895	0.16327	0.05245	0.02310	0.02846	0.0	0.02606	0.03050	0.03014	0.02169
F4	0.04965	0.04032	0.12725	0.04591	0.05599	0.04397	0.0	0.07786	0.07592	0.04617
F5	0.04965	0.04032	0.05245	0.13599	0.24271	0.24260	0.22293	0.0	0.27715	0.21563
F6	0.14895	0.16327	0.12725	0.23716	0.14699	0.14758	0.15497	0.26945	0.0	0.14275
Goal	0.0	0.0	0.0	0.0	0.0	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	0.08721	0.08721	0.08721	0.08721	0.08721	0.08721	0.08721	0.08721	0.08721	0.08721
A2	0.16405	0.16405	0.16405	0.16405	0.16405	0.16405	0.16405	0.16405	0.16405	0.16405
A3	0.24874	0.24874	0.24874	0.24874	0.24874	0.24874	0.24874	0.24874	0.24874	0.24874
F1	0.01995	0.01995	0.01995	0.01995	0.01995	0.01995	0.01995	0.01995	0.01995	0.01995
F2	0.08457	0.08457	0.08457	0.08457	0.08457	0.08457	0.08457	0.08457	0.08457	0.08457
F3	0.06539	0.06539	0.06539	0.06539	0.06539	0.06539	0.06539	0.06539	0.06539	0.06539
F4	0.07102	0.07102	0.07102	0.07102	0.07102	0.07102	0.07102	0.07102	0.07102	0.07102
F5	0.11802	0.11802	0.11802	0.11802	0.11802	0.11802	0.11802	0.11802	0.11802	0.11802
F6	0.14105	0.14105	0.14105	0.14105	0.14105	0.14105	0.14105	0.14105	0.14105	0.14105
Goal	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Finally, the importance degree of factors, which is the resultant of this study, is presented in Table 9. According to these results, A3, which is one of the alternative areas, became the most preferred with a ratio of 49.75%. Although the slope factor (F1) is important, it took a low weight value in this study. The reason for this is that almost all of the land is flat. Proximity to transmission lines and transformer centers has been identified as one of the most effective factor in renewable energy sources location selection problems. In this study, proximity to transmission lines (F2) and transformer centers (F4) is weighted with a total of 31.11%. Since the agricultural production in the region is at a high level, the factor of proximity to water resources (F2) has taken a weight of 16.91% for the protection of water resources. It is undesirable for economic investments to be very close to residential areas due to many social and environmental negative impacts. Weight of proximity to residential areas (F5) is 23.60%. Proximity to roads and railways was weighted with 28.21%, as an important factor due to infrastructure construction, operation and maintenance of solar farms.

Table 9
Final factors weight for the solar farm site selection.

Factor	Weight	%
A1	0.087	17.44
A2	0.164	32.81
A3	0.249	49.75
F1	0.020	3.99
F2	0.085	16.91
F3	0.065	13.08
F4	0.071	14.20
F5	0.118	23.60
F6	0.141	28.21

Figure 10 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. 6 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. Therefore, Cumra region is one of the most fertility areas of Turkey, majority of the constrained areas are lands of grades I-II. It was suggested four candidate sites in A3 alternative direction for site selection of solar farms due to land size in the Fig. 10.

4. Conclusion

Access to energy is critical to human's welfare, economic development, and poverty reduction. 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. Fossil fuels are the most intensely used energy sources today. However, the damages caused by fossil fuels to the nature and the health of living things show increasingly. Their waste continue to pollute the air, water and soil. It also causes global warming and climate change, threatening all life in the world. Today, as in many countries of the world in Turkey, as energy needs of future generations and damage to the environment to minimize interest was increased to 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. The generation of electricity from solar power is an important energy alternative in very sunny countries such as Turkey. 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, which require very high installation costs.

In this study, it present 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 belong to that region. Different factors may arise for different fields. Final suitability map was created for combined all factors. These studies can offers different methodologies and different decision support to the decision maker for solving site selection problems.

Declarations

-Funding: *The authors declare that no funds, grants, or other support were received during the preparation of this manuscript.*

-Conflicts of interest/Competing interests: *The authors have no relevant financial or non-financial interests to disclose.*

-Ethics approval/declarations: *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*

-Availability of data and material/ Data availability: *Not available*

-Code availability: *Not available*

-Authors' contributions: *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.*

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Figures

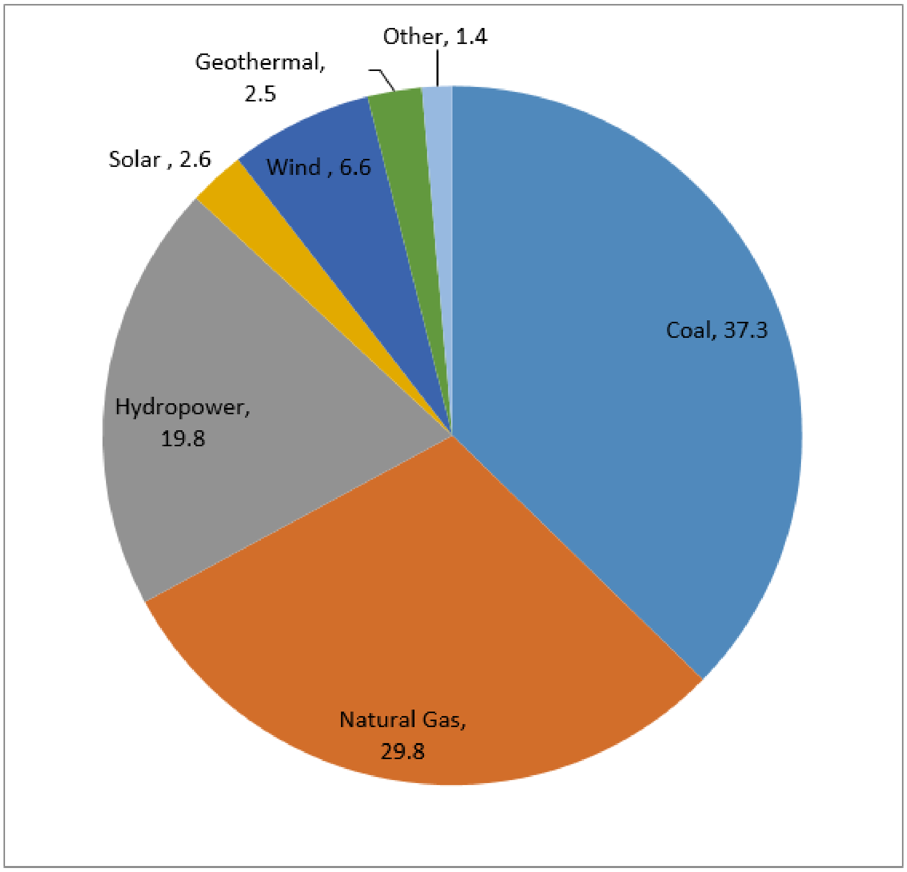

Figure 1

Installed energy capacity shares (%) of Turkey in 2018 (MENR, 2021).

Figure 2

Percentage of using MCE methods in energy-related decision making problems in the literature ((Erdin and Ozkaya, 2019).

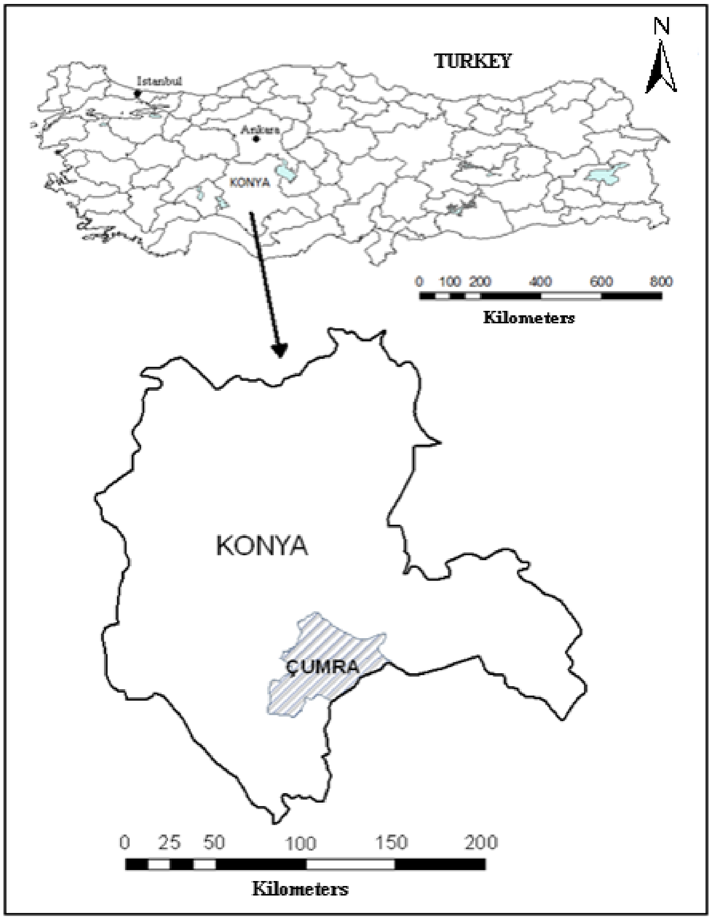

Figure 3

Study area for solar farm site selection.

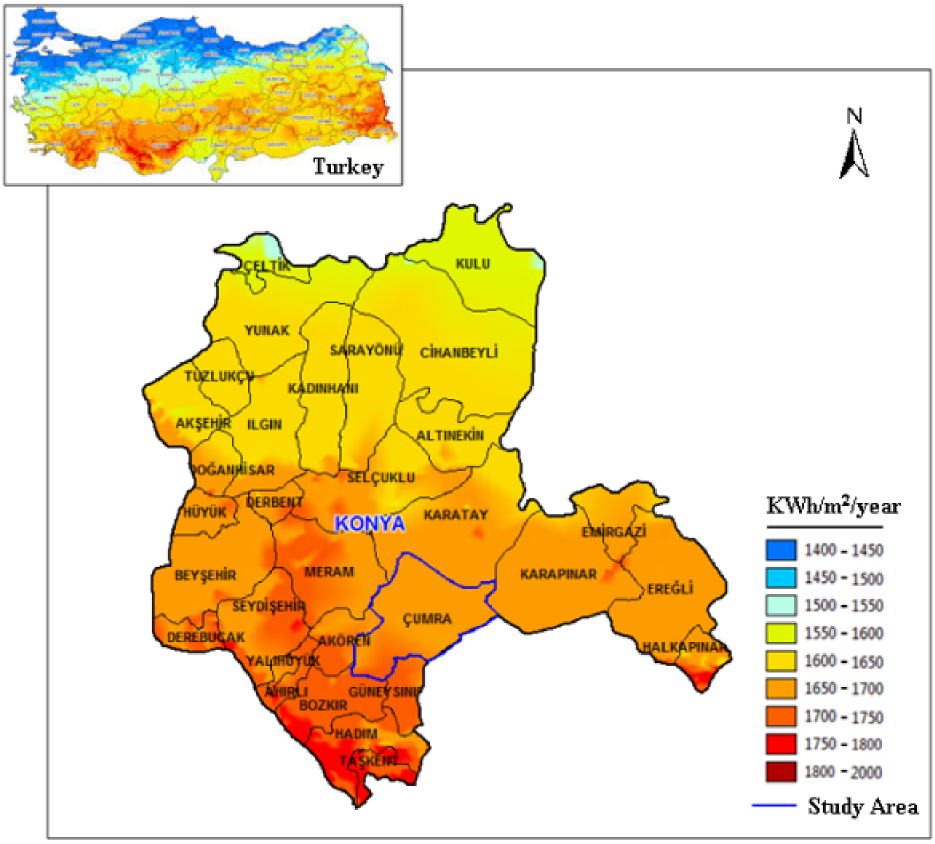

Figure 4

Konya city solar radiation annual means (Uyan, 2017b).

Figure 5

Solar radiation values and sunshine duration for Karapinar region (Uyan, 2017b).

Figure 6

Suitability index of (F1) slope, (F2) transmission lines, (F3) surface waters, (F4) transformer center, (F5) residential areas and (F6) roads and railways.

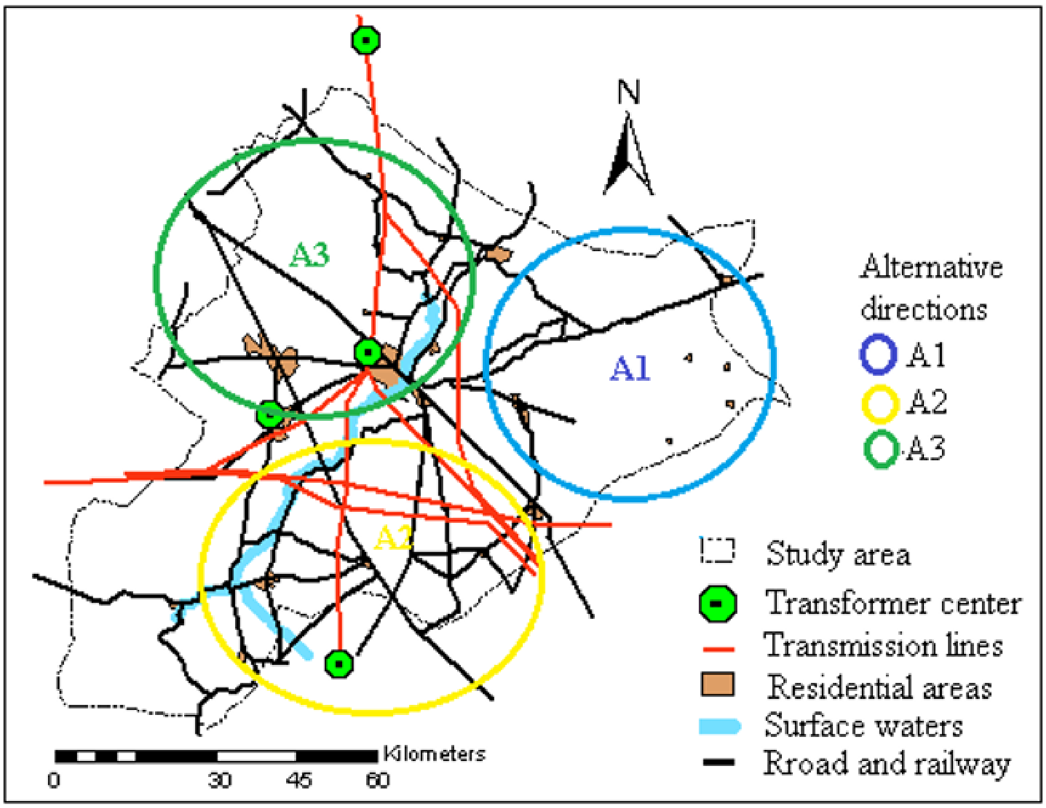

Figure 7

Three alternative regions and study area for solar farm site selection

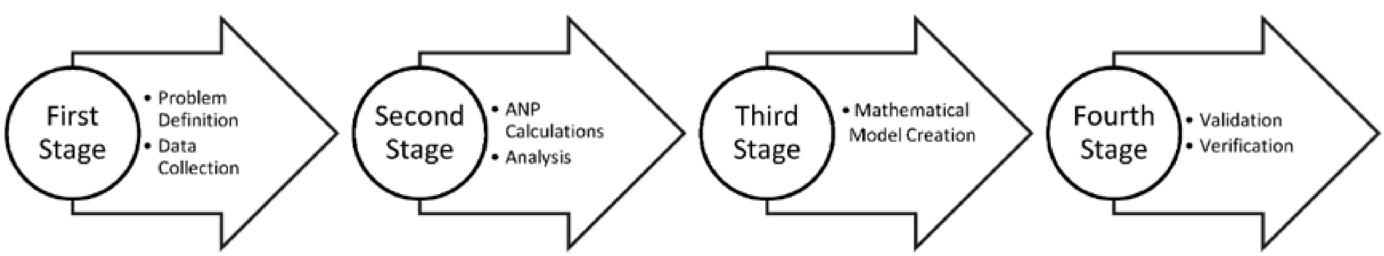

Figure 8

Flow chart of ANP model for solar farm site selection (Özder, et al., 2019).

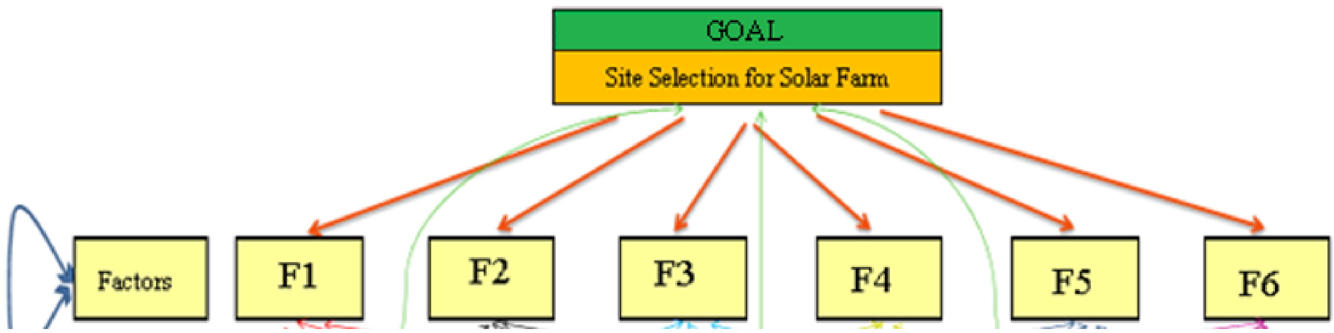

Figure 9

The designed ANP model.

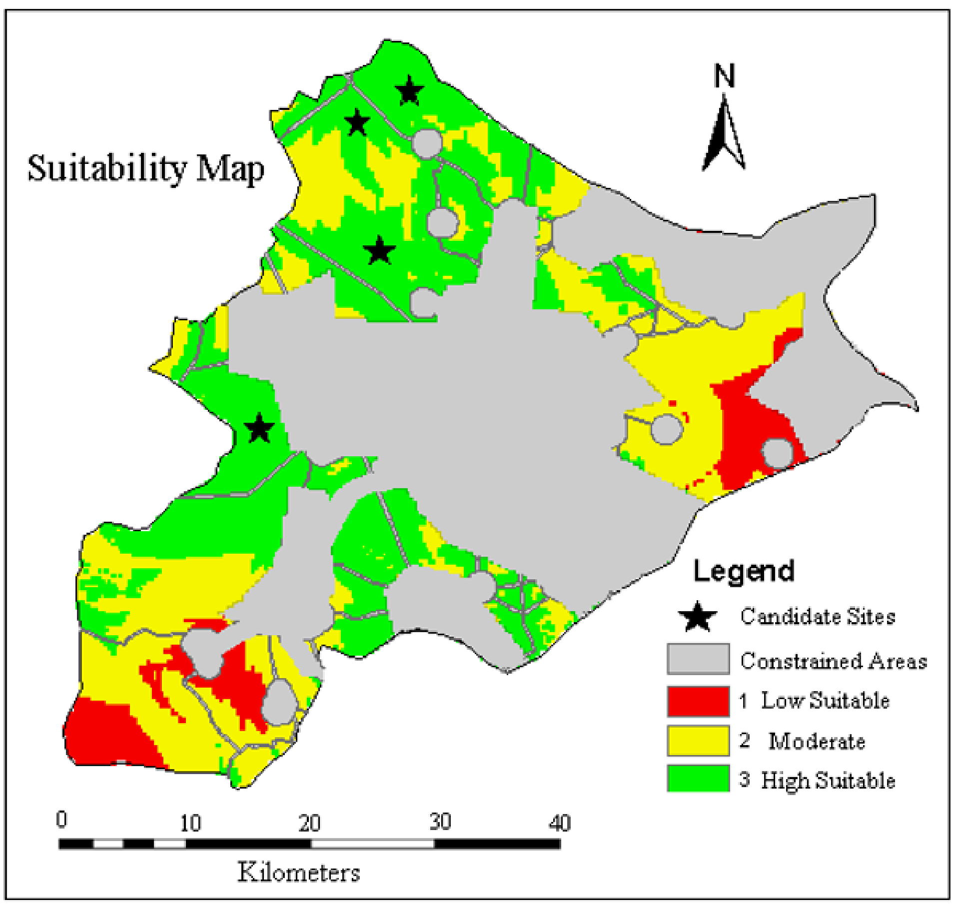

Figure 10

The classified suitability map for solar farms