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Optimal site selection for solar photovoltaic (PV) power plants using GIS and AHP: A case study of Malatya Province, Turkey

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ABSTRACT

The importance of energy needs increases substantially with the effects of scientific developments, technological improvements and human population growth. Because of excessive consumption of non-renewable energy resources and rising expenses, the vast majority of nations are in constant search of new resources. In Turkey, electricity produced from solar energy systems plays a key role in supplying energy demands because the geographic location of Turkey is suitable to benefit from solar energy systems. In this study, the construction of solar photovoltaic (PV) power plant within the Malatya Province of Turkey was identified by using Geographical Information Systems (GIS) technology. Within this framework, many effective factors were generated including solar energy potential, roads, energy transmission lines, transformer centers, slope, aspect, location of dams and rivers, natural gas pipelines, fault lines, land cover and residential areas. Using the Analytical Hierarchy Process method, factor weights were then calculated. As a result of all these processes, a map was presented demonstrating the optimal locations for solar energy plants. Finally, results were compared with existing solar photovoltaic (PV) power plants. An empirical study that produces the most optimal solution for decision makers to site selection for solar power plants has been realized.

1. Introduction

Energy is an important universal criterion for the measure of development and sophistication. Because of advances in science and technology and the rapidly growing human population, the need for energy is increasing day by day worldwide as well as in Turkey. When faced with the exhaustion of non-renewable energy sources such as fossil fuels, there is a growing threat of a sharp increase in these needs. Fossil fuels, which cover a high proportion of energy needs, are known to be the source of many negative consequences such as global warming, seasonal deviations, glacier meltdown and natural disasters resulting in environmental pollution. The industrialization process and increased energy demands have initiated and accelerated these negative effects. Because of these impacts, many people, animals and plants have been harmed and are faced with new challenges each day. Because of these problems, alternative energy sources are being sought both worldwide and in our country. To solve all these problems, renewable energy sources which are reliable and will not pollute the environment or damage living organisms must play a big role. In this context, it is clear that one of the most important sources of renewable energy is solar energy. Today, the use of solar energy has gained popularity and become widespread throughout the world, including in Turkey. Many studies have been done to calculate the amount of energy to be obtained from the sun in today's globalizing world. The International Energy Agency (IEA) has carried out many important studies for calculating the extent of solar energy and finding the most effective ways to benefit from this. Within this framework, the study conducted by the IEA calculated the sunlight reaching the earth in 90 min. The results correspond to the amount of energy used all over the world. It is claimed by the IEA that 11% of the world's energy needs will be met by solar energy in the next 30 years. However, it is expected that there will be a significant increase in renewable energy sources by 2030 and this increase is expected to be 7.6% annually [1,2].

Regarding Turkey, energy demands are increasing rapidly and this situation places the security of the energy supply, including electricity and other primary energy sources, at the top of the government agenda. Consequently, Turkey has adopted an energy

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policy aimed at strengthening energy security, using domestic and renewable resources and increasing the number of facilities [3]. Commissioning new production investments, diversifying energy sources and maximizing energy efficiency are among the most important issues for Turkey. Turkey is carrying out an innovative energy policy for the future in which renewable energy plays an important role. The annual duration of sunshine coverage in Turkey is quite a bit high. Due to the geographic location where Turkey is located 36°–42° Northern parallel with 26°–45° Eastern meridians, the potential to benefit from solar energy is quite high. Therefore, Turkey is advantageous compared to some other countries due to their geographical location and in terms of energy obtained from solar [4]. This fact in particular has brought increased energy production from solar energy to the forefront as one of the renewable energy sources in our country. According to the Solar Energy Potential Atlas of Turkey, the annual period of total sunshine has been identified as 2741 h (average 7.5 h per day) and the annual total solar energy yield as 1527 kWh/m^2 (daily average 4.18 kWh/m^2) [3]. Therefore, to convert sunlight into energy, solar photovoltaic (PV) power plants installations are needed and have been highlighted as a national policy. However, this raises the question of where to install these power plants in order to obtain the best efficiency.

In determining the most suitable location for the installation of solar PV plants, first, it is important to determine the criteria to be taken into consideration and the extent to which these criteria will affect the site selection areas. In addition, issues such as spatial analysis technology are also important for site selection. Geographic Information Systems (GIS) technologies enable the identification of factors affecting the installation of solar PV power plants and their collection in a spatial database along with the effective evaluations of relevant analyses. Thus, by identifying the factors important in the installation of solar power plants and the degree of importance of these factors, GIS technology can determine the most suitable regions for efficient and economical energy production.

Although scientific studies have been conducted in more recent years using GIS analysis to determine the most appropriate areas for renewable energy plants in the world, exemplary studies in Turkey are limited [5–8]. Thus, the lack of information on how to make use of the rapidly increasing solar energy, the work done thus likely remain missing. Lack of much study on the use of renewable energy fields on behalf of the country, restricts the use of solar energy. The international studies in the field of solar energy evaluating the criteria effective in the installation of solar PV power plants using GIS have often preferred Multi-Criteria Decision-Making Methods (MCDMs) to determine the weights of the parameters [9–20]. In these studies in particular, weights were determined according to the Analytic Hierarchy Process (AHP) method and handled with an integrated base using GIS technology [16,18,20–23]. When these studies are examined, especially those conducted in the last seven years, it can be seen that the newer studies at the international level on this subject are also limited. As a result of the literature summary, the factors used in the literature were determined and their usability was identified (Table 1).

Thus, it is obvious that there is a need for similar studies applying new methodologies to meet the needs of the country. It is important to analyze and define the most appropriate area for Solar PV power plants and make final decisions accordingly. Maximum efficiency at minimum cost is the most important goal for solar PV power plants installed at high costs. In recent years, Turkey as policy has turned to renewable energy. In this context, the question arises where these solar PV power plants should be established. This study will provide guidance on the nature of these policies be carried out as case studies for the Turkey.

This study aimed to select the most appropriate locations for the installation of solar PV power plants in order to enable Turkey to benefit from solar energy, seen as a sustainable and renewable energy source without the problems of fuel and with ease of operation. Thus, in accordance with the country's policy of supporting the installation of solar power plants, the aim was to determine the most suitable sites and to contribute to the spread of their implementation. As a sample application area, Malatya Province was selected for this study in Turkey. The average annual sunshine duration in Malatya is 7.9 h per day and therefore, in terms of global radiation values, the installation of solar PV power plants is suitable in this region [8,26]. In the study, the criteria were determined for the construction of solar PV power plants at the most suitable areas and the process steps and required analyses were investigated. In addition, by applying GIS integrated from the AHP, an important MCDM methods, spatial analysis queries were performed for the most appropriate site selection. Consequently, this study sought to define the most appropriate areas for solar PV power plants in Malatya Province and to examine their feasibility and efficiency for all of Turkey.

2. Material and methods

2.1. Analytic Hierarchy Process (AHP) Method

Multi-Criteria Decision-Making (MCDM) methods are tools that allows the best choice to be made from among multiple and concurrent criteria. The Analytic Hierarchy Process (AHP), one of the MCDM methods, was originally developed by Prof. Thomas L. Saaty in 1977 [27]. The AHP method has been used frequently in the solution of complex decision-making problems. Since the development of AHP, it has been used in many fields for the definition and analysis of user preferences in a vast range of application areas. Implementation of AHP is based on three basic principles: a) detecting the problem and creating a hierarchy, (b) creating a comparative decision-making preference matrix and (c) determining factor weights. AHP uses a pairwise comparison of criteria to determine which criteria is more important than the other criteria [27]. In AHP, each factor is compared as a binary value using the pairwise comparison method, and the relative values are assessed in accordance with the level of importance among themselves to each other, based on the criteria in Table 2. Finally, a paired comparison matrix is formed [27].

After creating all weight matrices, the weighted vector is normalized and the normalized weight vectors are calculated. The normalized weight vector value is obtained according to the level of importance of the used criteria [27]. From the resulting normalized vector values, the consistency ratio (CR) values are computed, and these values are used in the application to determine whether it is valid or not [27]. Referring to formula: *CR* represents the consistency ratio, *CC* represents consistency index and *RI* represents random consistency index.

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

Because of research, an upper limit ratio was set for consistency. When the limit is less than 0.1, it can be said that the binary comparisons are acceptable. If this value is greater than 0.1, it means that the binary comparisons contradict each other. In this case, the entire process must be repeated from the beginning. The factors determined for this study were found using the AHP method. The factor weights were tested for use in practice in accordance with the CR and the spatial analysis performed.

Table 1
Literature summary for factors.

Criteria	Literature Summary															
	[5]	[7]	[8]	[9]	[10]	[11]	[12]	[13]	[14]	[16]	[17]	[18]	[20]	[21]	[24]	[25]
Land Cover	×	×	×					×	×		×	×		×	×	×
Slope		×	×				×	×			×	×	×	×	×	×
Aspect		×	×										×			
Road	×		×			×	×	×	×	×	×	×	×		×	×
Solar energy potential	×	×	×	×		×		×	×	×	×		×	×		×
Energy transmission lines	×		×				×				×	×		×		×
Transformer center	×		×					×		×	×	×	×	×		
Lakes and rivers	×		×				×		×	×					×	×
Natural gas pipelines			×													
Fault lines	×		×												×	
Residential areas			×		×	×				×	×	×			×	×

Table 2
AHP binary comparison scale [27,28].

Importance level	Meaning
1	Indifferent (equal)
3	Weak preference (moderately more important)
5	Preference (more important)
7	Strong preference (strongly more important)
9	Very strong preference (extremely more important) (Intermediate values 2, 4, 6 and 8 are also possible)

2.2. *Case study*

2.2.1. *Study area*

This study was conducted in Malatya Province, located in the Eastern Anatolia Region of Turkey within an area of 12 259 km^2. Malatya Province is located between 37° 30ˊ - 39° eastern meridians and 38° - 39° north parallels. Global solar radiation distribution statistics for Malatya Province in the years 2004–2016 reported that the solar radiation distribution was above average [29]. For this reason, Malatya has been chosen as a pilot region due to its high utilization of solar energy. This region is namely one of the most sunbathing areas in the country and it is also a fairly flat area. Therefore, the construction of such a building in this section can be a very useful region both in terms of economy and in terms of its contribution to the energy of the country. This area is also important that the results obtained are coincided with the rural areas and come as close to the city center. Another reason was that in most of the region, inhabitants was not possible to obtain and distribute their own electricity from solar energy. Besides, because photovoltaic solar panels are being produced in a factory in the region, another aim of this project was to increase the number of solar plants in this region. The study area is shown in Fig. 1.

2.2.2. *Factors affecting the selection of solar PV power plant sites and obtaining spatial data*

Data are among the most basic requirements in the study of site selection for solar PV power plants. To perform an accurate analysis yielding the highest level of findings, data must be provided at the appropriate scale and resolution. The data determined for this study included spatial data for the factors necessary for the installation of solar PV power plants. The factors affecting selection for installation of solar PV power plants within the borders of Malatya Province were determined as a result of a literature research and expert opinions [5,7,17,18,24,30,31]. Since the data used in solar energy site selection are similar in the studies in the literature, this part has been integrated in order to be expressed more plainly and it has been tried to be expressed by supporting with references.

For this study, eleven different map layers were made ready for use in the GIS database. These included maps of solar energy potential, aspect, slope, roads, residential areas, energy transmission lines, fault lines, lakes and dams, transformer centers, land cover and natural gas lines. Among these data, five factor's restrictive buffer zones (100 m distances to lakes and dams, 100 m distances to road, 500 m distances to residential areas, slope areas> 20%, 7 m distances to natural gas lines) were identified and included in the analysis. These areas have been identified as prohibited areas for installation of PV power plant. In addition, since the agricultural land and forest areas are the areas to be protected in the land cover data, there is also no construction in the swamp areas. In this study, all factors effective on solar PV power plant installation were identified and the spatial data for these factors were obtained from the relevant institutions. In addition, demarcation of provincial and district boundaries was obtained from related institutions. The factors and the necessary restriction factors taken into account in determining the optimal location for solar PV power plants were shown in Fig. 2.

The Republic of Turkey State Railways 5th Regional Directorate provided provincial and county boundary (polygon) spatial data covering the province of Malatya. The factors determined as affecting selection in solar PV power plant installation with detailed information about these factors were as follows:

2.2.2.1. *Solar energy potential.*

When choosing the location for solar PV power plants, the solar potential of the region where this study will be carried out is first analyzed. Establishment of such a power plant in areas with low solar potential is in contradiction with efficiency and cost. Therefore, the situation of the solar potential of the region to be studied must be determined. Selecting regions with a high duration of sunshine time when determining solar PV power plant sites provides an important contribution to the desired efficiency. In Turkey, General Directorate of Meteorology carries out studies on solar radiation. This institution even creates solar radiation model and produces Global Solar Radiation distribution maps (Fig. 3) [29]. In studies of the calculation of the Global Solar Radiation distribution for Turkey, HELIOSAT model is used. The HELIOSAT is a hybrid model based on the analysis of a radiation transfer equation and simple statistical relationships. With this model,

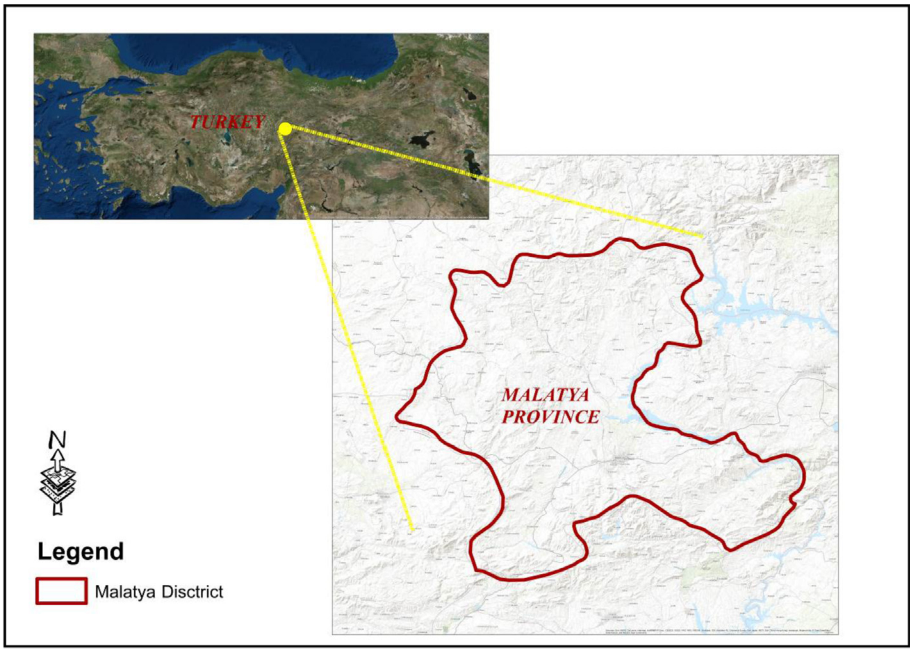

Fig. 1. Study area.

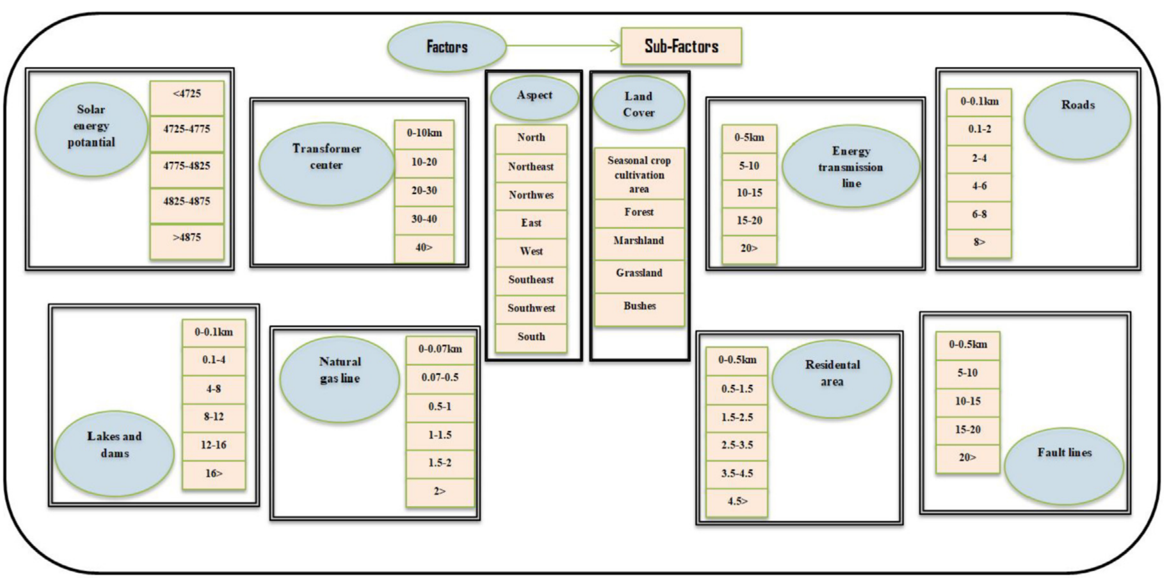

Fig. 2. Factors and restrictions for solar PV power plant site selection.

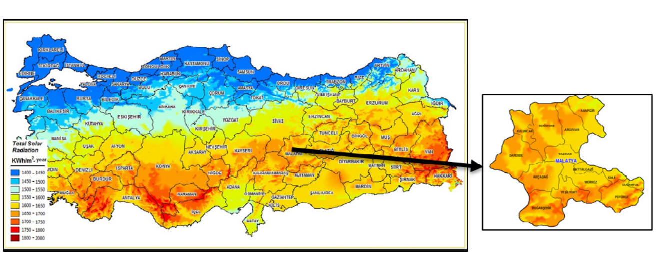

Fig. 3. Malatya Province solar energy potential map [33].

radiation value data can be obtained according to the current weather conditions and produced as daily data by using hourly data. For this study, daily global solar radiation measurements for 2004–2016 period were obtained from General Directorate of Meteorology in excel format with the spatial information of the measured points. Then, the measured points are associated with the spatial information and integrated into ArcGIS 10.6 program. The data associated with the location were subjected to interpolation analysis to reflect the whole province and a solar energy potential raster surface was created. Inverse Distance Weighted (IDW) interpolation method was used here the result raster here was produced. IDW is a type of deterministic method used for multivariate interpolation with known scattered points. The assigned values to unknown points are calculated with a weighted average of the values available at the known points [32].

2.2.2.2. Aspect. Depending on the slope of the terrain, the aspect is another factor for site selection of solar PV power plants. In determining slope orientations, an aspect map is important. An aspect map is derived from elevation maps showing the topography of the terrain. To produce the aspect map, the contours of Malatya were obtained from the General Directorate of Maps. The map containing height information in the form of linear data was obtained from vector data in the GIS database and a digital elevation model was produced in raster form from this data. The aspect map was then produced using GIS 3-D spatial modeling analysis.

2.2.2.3. Slope. Terrain that is extremely sloping and rough is one of the factors to be considered in solar PV power plant installation. If the land does not meet the slope requirement, excavation or filling operations in the area cause losses in terms of both time and cost [34]. At the same, time, it is also important that the facility be established in a stable area. In this context, no criteria for the land slope best suited for solar PV power plant installation are included in relevant legislation. In this study, areas with a slope of less than 20% were the subject of study for optimal solar PV power plant site selection. In the analysis, areas with land slope above 20% were evaluated as unsuitable. To produce the slope map, the contours (as contour lines) of Malatya were obtained from the General Directorate of Maps and then added to the geographic database using the polyline feature. From contour data added to the database, a slope surface map was produced to be used in the analysis, the slope map was then produced using GIS 3-D spatial modeling analysis. By not specifying the weight value in the AHP-based location selection analysis, the spatial slope data were considered as a restrictive criterion in the study.

2.2.2.4. Transformer centers and energy transmission lines. When distributing electricity generated from power plants, electricity is transmitted to substations via power transmission lines and then the distribution is performed. The greater the distance to the substations and the energy transmission lines, the greater the cost that will be created by new lines and new substations. Thus, the total construction cost will increase. Considering the distance to substations and power transmission lines in the selection of locations, i.e., lowering the cost, will provide an advantage in reducing energy loss. The spatial data for transformer centers and energy transmission lines of Malatya Province were obtained from the 13th Elazig Regional Directorate of Turkey Electricity Transmission Corporation. These spatial data were obtained in the CAD system. The energy transmission line data (lines) and transformer center data (polygons) were then transferred to the GIS database.

2.2.2.5. Roads. Transportation is an important criterion for investments in a region. The installation of solar PV power plants will require a high amount of transport to the region. New roads will bring new costs in areas where there are no existing transportation systems. Therefore, the road network is an important criterion for solar energy plant installation. Highway data for Malatya was

Table 3
Factors, sub-factors and factor weights for solar PV power plant installation.

Factors	Sub-factors	Points	Weights	Normalized weights	Factors	Sub-factors	Points	Weights	Normalized weights
Solar energy potential	<4725	**1**	**0.2184**	**22**	Fault lines	0–5 km	**1**	**0.0259**	**3**
	4725–4775	**4**				5–10	**4**		
	4775–4825	**6**				10–15	**6**		
	4825–4875	**8**				15–20	**8**		
	>4875	**10**				20>	**10**		
Aspect	North	**0**	**0.1439**	**14**	Lakes and dams	0–0.1 km	**0**	**0.0454**	**5**
	Northeast	**0**				0.1–4	**10**		
	Northwest	**0**				4–8	**8**		
	East	**1**				8–12	**6**		
	West	**1**				12–16	**4**		
	Southeast	**6**				16>	**1**		
	Southwest	**6**							
	South	**10**							
Roads	0–0.1 km	**0**	**0.0639**	**6**	Transformer centers	0–10 km	**10**	**0.0991**	**10**
	0.1–2	**10**				10–20	**8**		
	2–4	**8**				20–30	**6**		
	4–6	**6**				30–40	**4**		
	6–8	**4**				40>	**1**		
	8>	**1**							
Residential areas	0–0.5 km	**0**	**0.0668**	**7**	Natural gas lines	0–0.07	**0**	**0.0318**	**3**
	0.5–1.5	**10**				0.07–0.5	**1**		
	1.5–2.5	**8**				0.5–1	**4**		
	2.5–3.5	**6**				1–1.5	**6**		
	3.5–4.5	**4**				1.5–2	**8**		
	4.5>	**1**				2>	**10**		
Energy transmission lines	0–5 km	**10**	**0.1011**	**10**	Land cover	Seasonal crop cultivation area	**0**	**0.2039**	**20**
	5–10	**8**				Forest	**0**		
	10–15	**6**				Marshland	**0**		
	15–20	**4**				Grassland	**10**		
	20>	**1**				Bushes	**10**		
Restricted areas									
Slope- areas >20% slope									
Road – Distance to 0-0.1 km									
Residential area-Distance to 0-0.5 km									
Lakes and dams- Distance to 0-0.1 km									
Natural gas lines- Distance to 0-0.07 km									
TO* = *0.05854207									

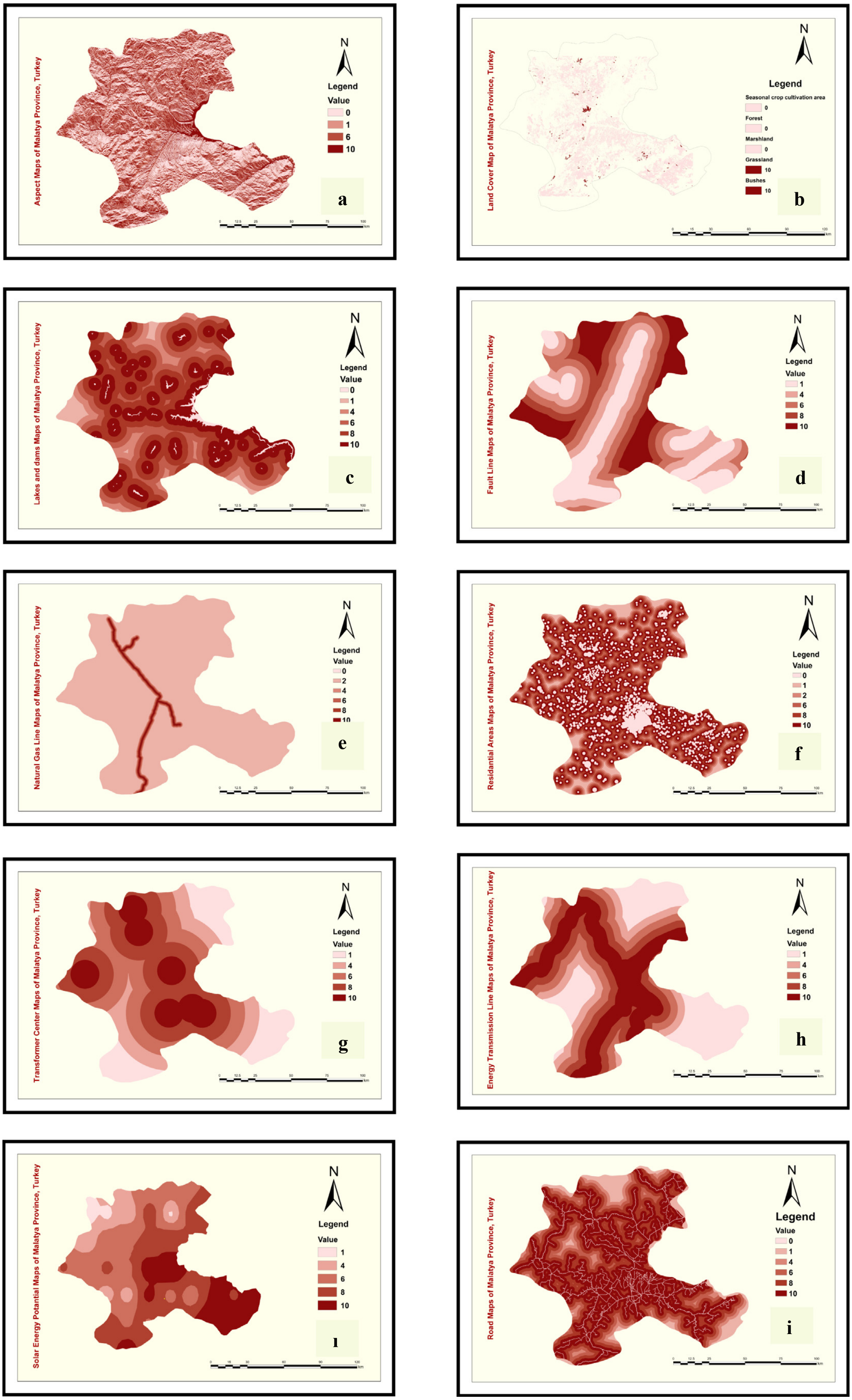

Fig. 4. Classified spatial data used in the analysis.

obtained from the Malatya Metropolitan Municipality in the CAD system format and the spatial data (lines) were then transferred to the GIS database.

2.2.2.6. Lakes and dams. Solar energy operates independently of non-renewable energy sources and does not require additional costs other than those of installation, and thus can contribute to the energy needed for irrigation in agriculture. To avoid any negative effects from water overflow, such as flooding when precipitation is high during the year, areas maintaining a maximum water level should not be used. In this context, spatial data on lakes and dams in Malatya provided by the 9th Regional Directorate of State Hydraulic Works in the CAD system format were then transferred to the GIS database using the polygon feature.

2.2.2.7. Natural gas lines. Factors which pose a danger must be considered when choosing solar PV power plant sites and therefore, the infrastructure network is another criterion. When selecting the most appropriate solar PV power plant sites, the routes of pipelines like natural gas lines should not be selected, as they can be affected by the risk of leakage or explosion. For this reason, spatial data on the natural gas pipelines were obtained from the Malatya Yesilyurt Municipality and added to the geographical database in a polyline format.

2.2.2.8. Fault lines. In selecting the location for installation of a solar PV power plant, areas with low earthquake risk should be selected. Therefore, another factor for selecting solar PV power plant site is the presence of earthquake fault lines. Fault line spatial data were obtained by digitizing the fault map prepared by the General Directorate of Mineral Research and Exploration and then adding the data in a polyline format to the designed geographic database.

2.2.2.9. Land cover. Land cover data is one of the most important criteria for installation of a solar PV power plant. It is very important that the PV power plant land to be installed must not hit the existing protected areas and to the point that will create restrictions on the use. Therefore, PV power plant site selection areas should be installed as far away as possible from existing land. In this study, land cover data was obtained from General Directorate of Mapping of Turkey for 2018 and added to the geographical database in a polygon format.

2.2.2.10. Residential areas. Building a solar PV power plant within a future settlement area can be prevented by considering the developmental direction of residential areas. At the same time, the solar power plants will be close to the settlement to ensure that the energy needs of the region as well as the costs are met. In this study, the spatial data of residential areas was identified via the Google Earth program and current orthophoto maps and these data were then added to the geographic database using the polygon feature.

2.3. Spatial database design

In this study, the eleven data layers required for analysis and

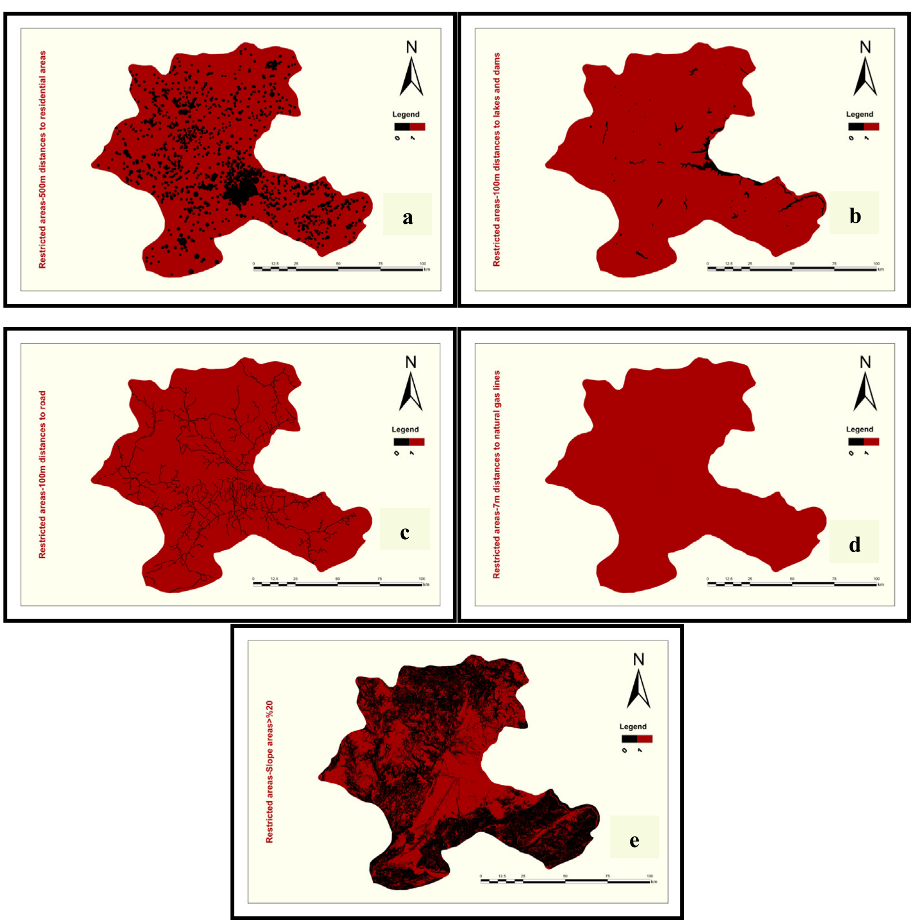

Fig. 5. Restricted areas.

also the administrative boundary layer (for district boundaries) were obtained from the related institutions. Obtained data were arranged in three different vector data formats, which included the point, line and polygon. All spatial data were then converted to the TUREF_TM39 coordinate system and the integrated geographic database for use in ArcGIS 10.6. Data held in separate layers in the database were then converted to raster format to be analyzed by the AHP MCDM process.

2.4. Determining priorities among criteria with AHP, creating binary comparison matrices and determination of factor weights

Since multiple factors are effective on solar PV power plant sites, it is important to determine the method to be used by the decision makers. When determining which parameters to prioritize during application, the importance of factors with regard to each other was decided and analyzed. The most important factors and the order of priority were determined using the AHP method. Because the criteria used in this context were not evaluated separately, opinions of experts in this field and previous studies conducted in Turkey were used in determining the weights, priority levels and classification of the factors among themselves [5–7]. These criteria were then subjected to a pairwise comparison matrix and the factor weight of each criterion was determined. To ensure the accuracy of the procedures, the consistency ratio (*CR*) was calculated for the determination of the weights, and it was established that the *CR* should be less than 0.1. Following this calculation, it was determined whether the factor weights were consistent with the *CR* to be put into practice. Factor weights obtained as a result of the binary comparison matrix are shown in Table 3.

2.5. Data processing

2.5.1. Optimal site selection for solar photovoltaic (PV) power plants for Malatya Province, Turkey

To determine the most suitable areas to install solar PV power plants in Malatya Province, each factor was evaluated within itself. Appropriate ranges for each parameter were determined by experience gained from consulting academic studies highlighted Table 1 and raster buffer surfaces were formed by scoring according to these ranges. The data were classified and prepared for scoring. Weights of these classes were scored ranging from the most appropriate value of “10” to the least appropriate value of “1”, with restricted area values not to be included in the analysis as “0” (Fig. 4).

Factor areas not to be used were transformed into raster surfaces and restricted to buffer zones (Fig. 5). As a result, all used and restricted data layers were classified as 20 m resolution and produced as raster data surfaces and used in the analysis.

These weighted raster buffer surfaces were combined in ArcGIS 10.6 using weights determined via the AHP method, spatial analysis was performed (Fig. 6), and a map of the most suitable areas for solar PV power plants was obtained (Fig. 7).

In this study, a raster-based accumulated cost surface map (Fig. 7) was produced using GIS and the AHP method analysis using ArcGIS 10.6 with 300 dpi resolution. Pixels having higher numerical values were taken as appropriate for the most suitable areas for solar power plants. Based on the resulting map, it was possible to decide the most appropriate sites for installation of solar PV power plants. The raster surface map obtained was divided into 10 classes (Fig. 7). Pixels with the highest value are classified as the most suitable; pixels with the lowest pixel value are classified as the most unsuitable area. In addition to the 10th grade, the 9th grade was accepted as an appropriate value and the sections corresponding to the two classes have been tried to be selected as the suitable field.

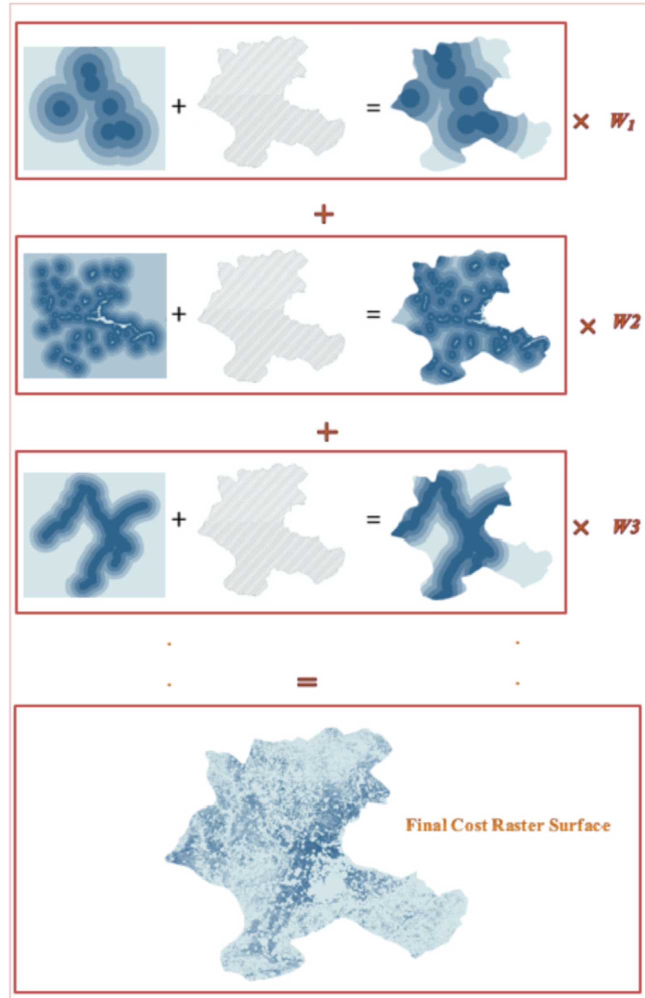

Fig. 6. Raster result surface creation stages.

The resulting map obtained using the AHP method was created using criteria such as solar energy potential, aspect/slope, roads, residential areas, energy transmission lines, fault lines, transformer centers and natural gas lines. According to the obtained map, it was concluded that the appropriate level of solar energy potential factors for the establishment of solar PV power plants was not only sufficient. Therefore, it was deduced that different criteria have to be taken into consideration.

3. Results

Studies conducted in Turkey and worldwide were analyzed, and although academic studies have been carried out in terms of solar PV power plants in general, it was observed that studies need to be performed in specific regions by considering multiple factors in the determination of the most suitable sites for solar PV power plants. In accordance with the Turkish national vision for 2023, the aim is to increase electricity production from solar energy to higher levels. In this context, the question of where to establish these power plants comes to the fore. In this study, an applied method was used to answer this question. Studies have shown that solar power plant sites should have a maximum of 2 ha for each MW project to be installed [35].

In addition, in accordance with the Regulation on the Protection,

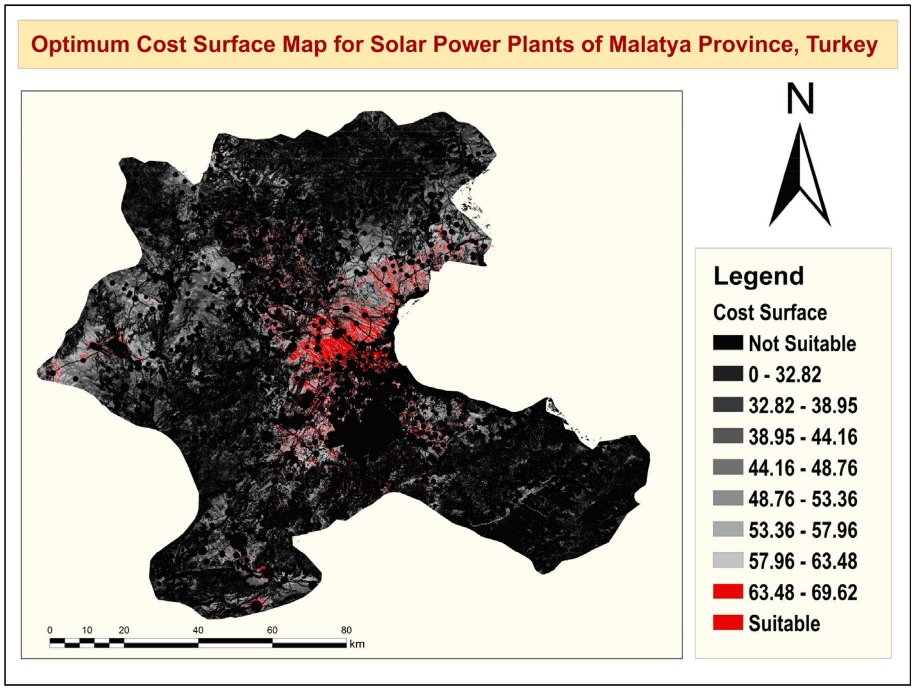

Fig. 7. Cost surface map for solar PV power plant sites.

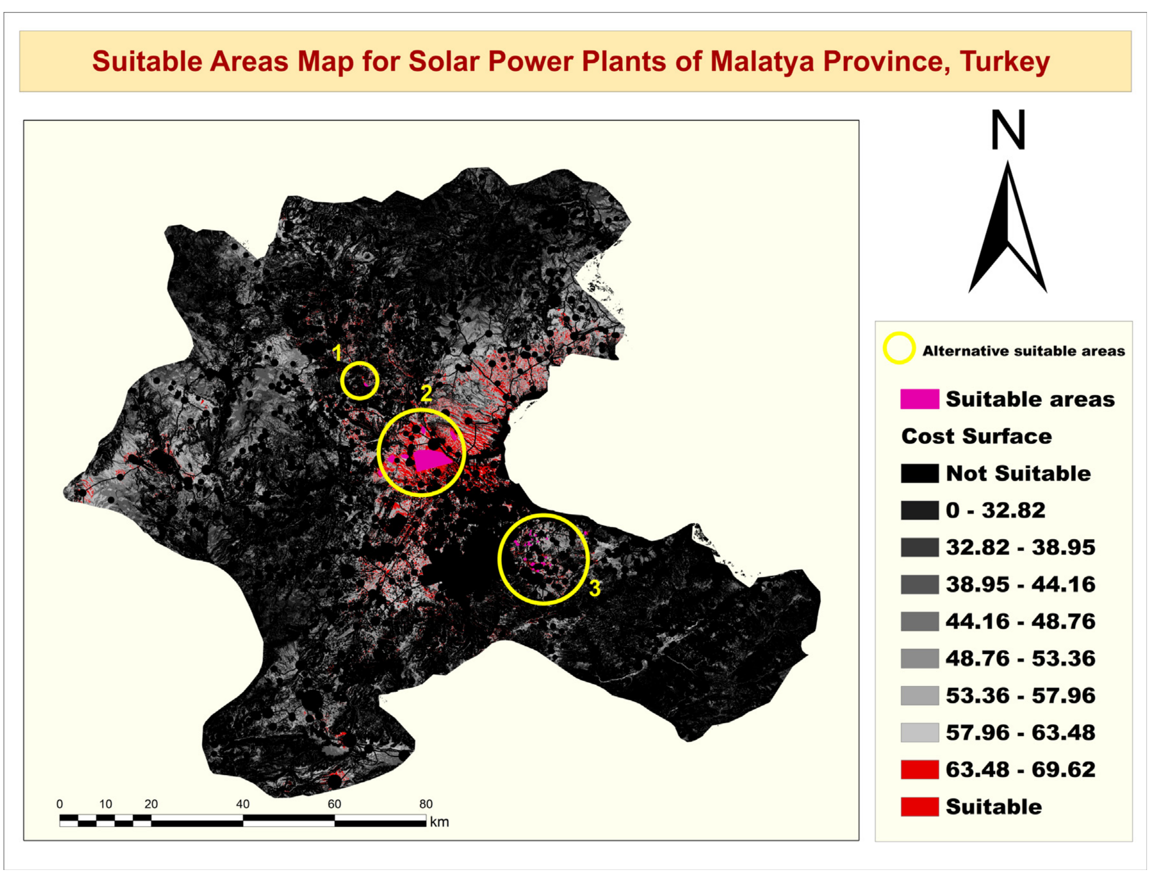

Fig. 8. Alternative solar PV power plant installation areas.

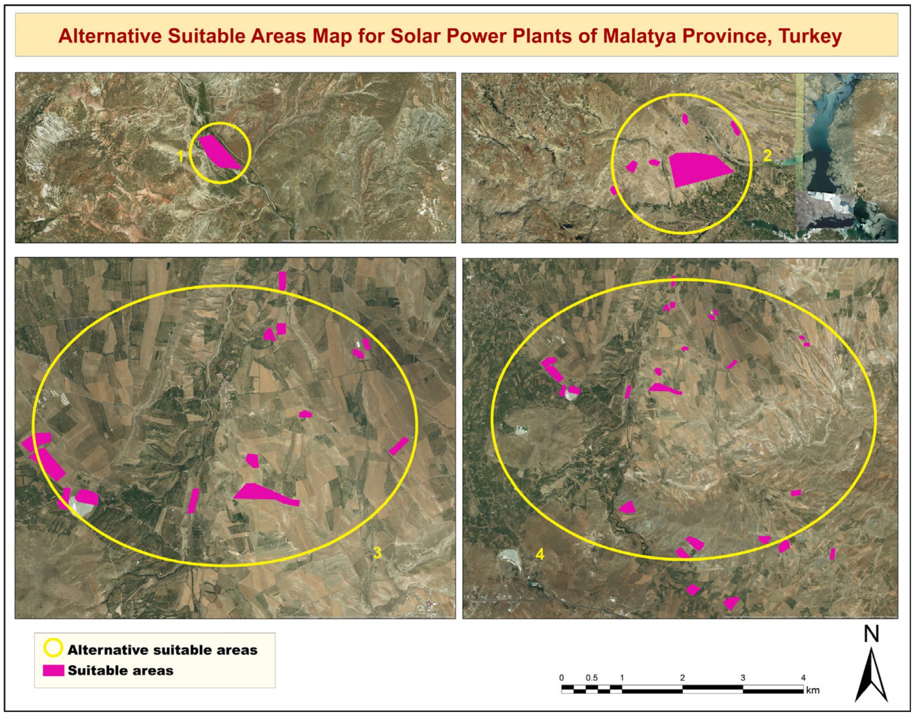

Fig. 9. Satellite image of alternative solar PV power plant installation areas.

Use and Land Consolidation of Agricultural Land, it was determined that production facilities based on solar energy could not be established in areas where the integrity of agricultural use would be disrupted, or on environmental lands, absolute farmland, special product lands, sown farmland or irrigated farmland [36]. Therefore, based on these criteria, the most appropriate site selection analysis was conducted for the installation of solar PV power plants. Since Malatya Province has a significant potential for generating electricity from solar energy, this region was selected for the study. In this study, relevant spatial analyses were performed and appropriate areas were determined. Using the AHP method, factors effective in determining the most suitable areas for solar PV power plant installation were evaluated and weighted according to each other. Using these weight values, GIS technology and spatial analyses were used to determine the most suitable locations, which were then presented on maps. As a result of the analysis, a raster-based cost surface map was generated. The identified alternative points selected by suitable pixel values are shown in Figs. 8 and 9. These areas were selected by red values with different areas by digitizing polygon on the cost surface raster. These figures are produced by ArcGIS 10.6 program with 300 dpi resolution.

The solar energy map of Malatya Province shows that solar energy is at a maximum level in the southeast and east. However, in determining the most suitable locations considering other factors (aspect, solar energy potential, transformer center distance, etc.), a total of 34 suitable areas were found in the Malatya Province districts of Ipekyolu, Yazihan, Civril, Misirdere, Fethiye, Yarimcahan, Eskimalatya, Karakasciftligikoyu, Karakoy, Goller, Bulgurlu and Sisman. While seven of identified areas cover less than 2 ha, the rest is more than 2 ha. In order to reduce the number of detected areas, the conditions of the existing land were taken into consideration. For this purpose, the areas that are close to the solar PV power plants currently being built and planned to be built are concentrated. The majority of these sites correspond to the districts of Yarimcahan, Karakasciftligikoyu, Karakoy and Goller. In particular, the presence of pre-existing PV power plant sites in this region has helped to obtain evidence that this region is quite suitable (Fig. 10). In addition, the area in Yazihan has been chosen among the alternatives since it is a very close land to the city center (Fig. 10).

4. Conclusions

In recent years, energy demands have increased in parallel with the growth in population and rapid increase in technology in our country. Due to the rapid exhaustion of non-renewable energy sources, rising costs and dependence on foreign energy, energy generation from renewable energy sources is important for our country. Turkey has a rich potential for renewable energy sources as a location and, as in developed countries, has adopted the issue of energy production from renewable resources as a national policy. In this context, legislation has been developed for licensed and unlicensed installation of solar power plants.

This empirical study was carried out to determine where solar (PV) power plants should be established in order to meet the energy needs in Turkey and which factors should be considered when determining these areas. With the AHP method used, the aim was to develop an exemplary model for Turkey. For this application, a pilot study was conducted in Malatya Province. Malatya Province was selected because of its suitability among the provinces in Turkey to produce solar energy and generally because of the roughness of the terrain. Consequently, the spatial data of the factors for location selection using AHP were included in the analysis according to the weight significance levels, and the most suitable areas for solar power plants were identified. As a result of analysis, a total of 34 suitable areas were found in the Malatya Province districts of Ipekyolu, Yazihan, Civril, Misirdere, Fethiye, Yarimcahan, Eskimalatya, Karakasciftligikoyu, Karakoy, Goller, Bulgurlu and Sisman. Seven of the selected areas are less than 2 ha while others are more than 2 ha. The solar (PV) power plants that were previously built and planned to be built near these areas have come to the fore as an alternative depending on the existing land conditions. These alternatives correspond to the districts of

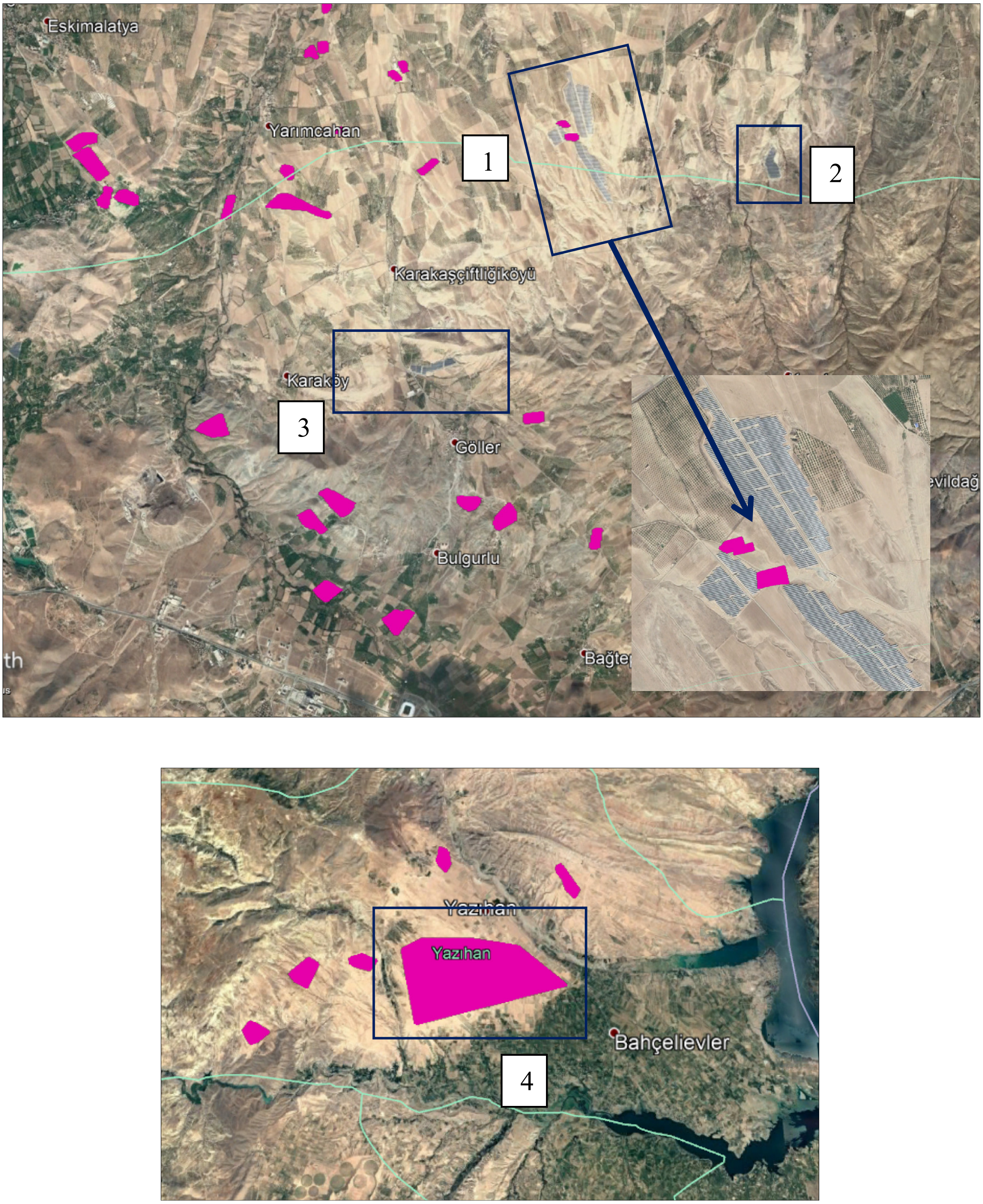

Fig. 10. Areas suitable for solar PV power plants and sites of pre-existing solar (PV) power plants (Google Earth Program).

Yarimcahan, Karakasciftligikoyu, Karakoy and Goller. In addition, because of its size and proximity to the city center, Yazihan was also included in the alternatives.

As a result of this study, some areas having the potential for solar energy in the province of Malatya Province were identified as being in close proximity of settlements or wetlands or as areas of insufficient aspect. Therefore, it was observed that those areas would not be suitable in terms of solar power plant installation. On the other hand, when other factors were considered such as distance to energy transmission lines, transformer centers, highways and railways, it was observed that the results changed for determining the most appropriate sites. The fact that the analyzes are tested with the current state of the land shows the accuracy of the findings. Because the results indicate that the facilities planned for the region coincide exactly. Determined areas will be able to provide energy needs especially for this region of the country, which will contribute to the country's economy and contribute to the provision of new energy resources on behalf of the country. This study will also be able to set an example for both national and international studies by analyzing and testing the results one to one in the field. A new study area and also solar energy, which has become a source of energy for the country, will help the optimal the site selection studies based on multi-criteria. Because in recent years as Turkey policy toward renewable energy and consequently the question arises where solar PV plants should be installed, this study will serve as an example to answer this question for decision making support system. In order to benefit from renewable energy at the highest level, GIS should be used more effectively and the study area should be expanded in the future work to be done.

Author contributions section

H. Ebru Colak: In this study, H. Ebru Colak has contributed to the editing of literature; decide what should be in the general framework of the manuscript, implementation of the analysis and selection of alternative areas.

Tugba Memısoglu: In this study, Tugba Memisoglu has contributed to the editing of literature information, writing of the manuscript, organizing the collected data, implementation of the analysis, selection of alternative areas, and production of maps.

Yasin Gercek: In this study, Yasin Gercek working in the municipality of Malatya has contributed to do literature research, the collection of data, the questioning of the appropriate areas identified in the existing land.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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