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AHP ve CBS Yardımıyla Kentlerde Güneş Enerji Santrali Yer Seçimi Alternatifleri: Karaman Türkiye Örneği

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ABSTRACT:

In meeting today's increasing energy needs, the use of renewable energy sources becomes widespread comparing with the thermal and nuclear power plants, which cause great harm to nature. While hydroelectric power plants are most common among renewable energy plants in Turkey, national policies towards increasing wind power plants and solar power plants are gaining momentum.
Due to its geographical location, Turkey is more advantageous position compared to many other countries in terms of solar energy potential. The region receiving the most solar energy in Turkey is Southeastern Anatolia, followed by the Mediterranean and Eastern Anatolia. It is seen that the solar energy potentials of Antalya, Karaman, Mersin and Van provinces are higher than other provinces of Turkey.
With the help of a well-known Turkey map on the solar potential of cities, it is possible to determine the advantageous cities which solar power plants (SPP) can be placed. However, there is a need for a multi-criteria decision-making method regarding where position solar power plants in these cities.
With this work; according to the solar radiation values of Turkey, it is aimed to determine the alternatives for the most suitable SPP locations in Karaman Province, which has an important potential for the establishment of a solar power plant. Appropriate locations were determined by a multi-criteria and geographic information systems (GIS) supported method. Eleven criteria with data for the city of Karaman have been identified among the criteria mentioned in the related literature. The scores obtained from these criteria (in grids of 100x100 meters) are classified into five categories. The weighted scores were then standardized to a range of 1-5 with tools to

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reclassify in GIS environment. Reclassified weighted criteria were overlapped with Weighted Overlay Analysis to determine the most suitable regions for SPP investment.

KEYWORDS: Solar Power Plant, Geographical Information Systems, Overlay Analysis, Multi Criteria Decision

ÖZ:

Günümüzde enerji ihtiyacının karşılanmasında doğaya zararlı etkilerde bulunan termal ve nükleer kaynaklara kıyasla yenilenebilir enerji kaynakları giderek yaygınlaşmaktadır. Hidroelektrik santraller Türkiye'deki yenilenebilir enerji santralleri arasında en yaygını olmakla birlikte, rüzgar santralleri ve güneş enerjisi santrallerinin artırılmasına yönelik ulusal politikaların da ivme kazandığı görülmektedir.

Coğrafi konumu nedeniyle Türkiye, güneş enerjisi potansiyeli açısından diğer birçok ülkeye göre daha avantajlı bir konuma sahiptir. Türkiye'de en fazla güneş enerjisi alan bölge Güneydoğu Anadolu, ardından Akdeniz ve Doğu Anadolu'dur. Antalya, Karaman, Mersin ve Van illerinin güneş enerjisi potansiyellerinin Türkiye'nin diğer illerinden daha yüksek olduğu görülmektedir.

Şehirlerin güneş enerjisi potansiyeline ilişkin Türkiye haritası yardımıyla, güneş enerjisi santrallerinin (GES) yer seçimi açısından avantajlı şehirleri belirlemek mümkündür. Bununla birlikte, bir şehir içerisinde güneş enerjisi santrallerinin nerede konumlandırılabileceğine ilişkin çok kriterli karar verme yöntemine ihtiyaç vardır.

Bu çalışma ile; ülkemizin güneş radyasyonu değerlerine göre bir güneş enerjisi santrali kurulması için önemli bir potansiyele sahip olan Karaman ilindeki en uygun GES yerlerine ilişkin alternatiflerin belirlenmesi hedeflenmektedir. Uygun yerler çok kriterli ve coğrafi bilgi sistemleri destekli yöntemle belirlenmiştir. İlgili literatürde bahsedilen kriterler arasında Karaman kenti için elde edilebilen verilere bağlı olarak on bir kriter belirlenmiştir. Bu kriterlerden elde edilen puanlar düşükten yükseğe doğru beş kategoride sınıflandırılmış, yeniden sınıflandırılan ağırlıklandırılmış kriterlere Ağırlıklı Bindirme Analizi uygulanarak GES yatırımı için en uygun bölgeler belirlenmiştir.

ANAHTAR KELİMELER: Güneş Enerji Santrali, Coğrafi Bilgi Sistemleri, Bindirme Analizi, Çok Ölçütlü Karar Verme.

"Alternatives to Solar Power Plant Location through GIS and AHP: Case of Karaman, Turkey"

INTRODUCTION:

The excessive consumption of petroleum-derived resources for energy caused negativities which are difficult to recover now in the ecosystem. In order to reduce and reverse these effects - explicitly called "global warming" and "climate change" - countries have made a quick start to take action on using renewable energy resources.

Solar energy is among the most invested renewable energy resources. Geographically Turkey and its southern neighbor countries have advantages in producing energy from the sun.

As the countries have begun to focus on solar energy resources considering their potentials, the question of where the optimum location is going to be in the urban area has started to discuss in terms of the types and characteristics of these resources. The selection of the optimum location as a process that requires to make multi-criteria decisions has gathered momentum and become easier thanks to the geographic information technologies that have developed exponentially in recent years. At this point, it is significant that the data in the process of making decisions is clear, updated, spatial, diverse and contributory to the process. Solar radiation levels, slope, land use, land cover, accessibility and safety distances, and environmental protection can be considered as the main criteria in the planning the optimum location of the solar power plants in the urban area.

In this study, it is aimed to determine the optimum location alternatives for the Solar Power Plant in Karaman where is one of the most advantageous cities in terms of benefiting from the sun in Turkey. The spatial data obtained from different measurement units have been reclassified and overlay analysis has been conducted.

1. Solar Energy as A Mode of Renewable Energy

Real time events such as the depletion of the resources due to ever increased needs of the population and rise of the environmentally sensitive movements , the concentration of energy resources of countries around the world turns into renewable energy in the last few years, Renewable energy is the energy obtained from the existing energy flow in continuous natural processes (URL 1). The commonly used renewable energy sources in the world are hydraulic energy, geothermal energy, biomass energy, solar energy and wind energy. (Gasparovic and Gasparovic, 2019; Harjanne and Korhonen, 2019).

Solar energy generation involves the use of the Sun′s energy to provide electricity via solar photovoltaic (PV) and concentrating solar power (CSP) systems (Ellaban, 2014). The intensity of solar energy is 1370 Watt/m^2 on the outside of the Earth's atmosphere. However, this density varies between 0-1100 Watt/m^2 values on the surface of the Earth. This energy is quite higher than humanity's current energy consumption (Koc and Senel, 2013). With technological developments, the ratio of solar energy of use is increasing in different fields. These are redressing the electrical energy needs in houses and other buildings; heating of various places such as buildings, houses and greenhouses and obtaining hot water; cooling operations; drying operations; water distillation processes; the lighting of roads and streets in garden lighting; redressing the energy needs of traffic signs; calculators and clocks; charging mobile phones and other portable devices; satellites and solar towers (Canka Kilic, 2015).

During the last ten years, various systems introduced all over the world proved the effectiveness of solar energy innovations. Solar PV, as one of the solar energy systems, brings two benefits together. A centralized PV system for local energy supply has advantages in terms of optimizing installation, operating costs by bulk buying as well as providing cost-effective PV components. On a large scale, it brings a balance to the system. As a result, all of these advantages from economies of scale, and so the preferability rises (Ellaban, 2014).

Turkey has advantages of solar energy potential compared to most of the other countries because of its geographical location. The regions that receive the most solar energy are Southeastern Anatolia Region, Mediterranean Region and Eastern Anatolia Region (Figure 1).

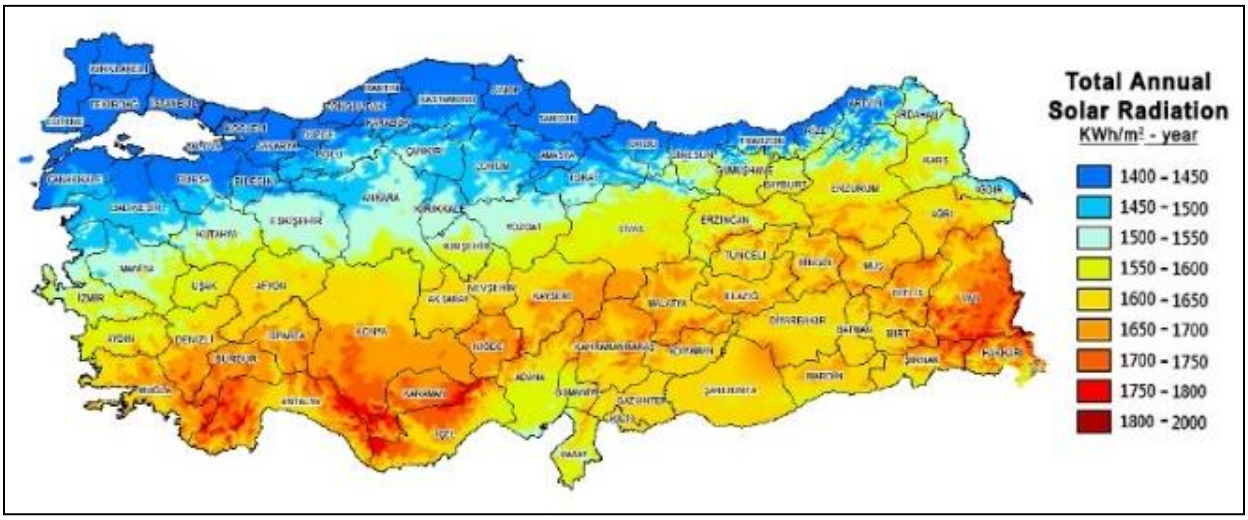

Figure 1. The solar potential of Turkey (URL 2)

To use solar energy and energy production efficiently, Turkey's Solar Energy Potential Atlas was prepared by the General Directorate of Renewable Energy, which is a subsidiary of the Republic of Turkey Ministry of Energy and Natural Resources. According to Turkey's Solar Energy Potential Atlas, the annual sunshine time is 2737 hours (daily total is 7.5 hours), and the total annual solar energy is determined as 1527 kWh/m² years (URL 3). By making the necessary investments, Turkey has a quite high solar energy potential as 110 days in a year and nearly 1100 kWh per square meter in a year.

2. Determinants of Solar Power Plant Location

The location decision of a solar power plant is a complex problem that includes multiple criteria and alternatives. Depending on their weights, topography, land use, proximity to specific facilities and infrastructure, environmental, economic, cultural and social conditions of the space determine the SPP location. To identify a suitable location for solar PV installation, a multi-criteria function spatial analysis and a decision support system are required (Yousefi et. al. 2018). Because of the spatial nature of the Multi-Criteria Decision Making (MCDM) of SPP location, Geographic Information Systems (GIS) seem to be the most operable tool for the location problem in recent years (Uyan, 2017).

In the last 30 years, GIS has been applied to the location problem of a series of land uses in an urban area. Spatial analysis through GIS increase the pace and decrease the error rates of the MCDM. Analysis and results are also effortless to be understood by decision-makers because of powerful GIS visualization tools. Nowadays, it is inevitable to use these tools for the exploitation of renewable energy sources such as SPPs (Gasparovic and Gaspariovic, 2019).

There are commonly used data in the studies on SPP location via combining GIS and MCDM. Solar radiation levels, protected areas, built-up area, water bodies, road infrastructure, distance to settlements, roads, railways, electricity network, slope, elevation and orientation of topography are the main variables in the search for a location to a solar power plant (Aydin, 2009; Uyan, 2017; Merrouni et. al. 2018; Yousefi et al. 2018; Gasparovic and Gasparovic, 2019).

Many recent studies used MCDM and GIS consecutively for the location of solar power plants. Kengpol et. al. (2012)'s Fuzzy AHP in Thailand, Asakereh et. al. (2014)'s Fuzyy AHP-GIS in Shodirvan/Iran, Elquoliti's AHP in Saudi Arabia (2015), Uyan's AHP-GIS in Karapinar/Konya (2013), Sozen et. al.'s consecutive use of Data Envelopment Analysis (DEA) and TOPSIS (2015) in 30 cities in Turkey, Sindu et. al. (2017)'s AHP-TOPSIS model in India, Chandio et. al.'s (2013) GIS-based AHP, Sánchez et al.'s (2013) optimized solar farm locations using ELECTRE and GIS, Yushchenkoa's (2018) GIS based assessment in West Africa are the examples of methods and geographies that search locations for the solar power production.

Kaya and Kahraman (2010) proposed a VIKOR-AHP methodology which combines two methods and find Catalca district as the best location in Istanbul/ Turkey to launch a renewable energy plant. Rumbayan and Nagasaka (2012) also run an AHP-GIS methods to in Indonesia in 30 different areas to find alternative locations for renewable energy investments.

Georgiou and Skarlatos (2016), developed an integrated framework to evaluate land suitability for the optimal SPP Placement in Limassol / Cyprus. The AHP has been chosen as a means of weighting the suitability criteria, with simple additive weighting (SAW) method. Evaluation layers in the study are Standardized evaluation electricity grid, road network, land value, elevation, slope, solar energy, and viewshed from primary roads.

Uyan (2017), studied SPP location method in Ayranci, Karaman/Turkey. Five criteria including Land use, distance from residential areas, slope (%), distance from roads and distance from transmission lines were determined by the author and weighted by AHP method. Overlay analysis in GIS was operated by these weighted criteria and suitability map was created. The most suitable places for the installation of SPP in Ayranci was mostly agglomerated in northern part of Ayranci and in a close proximity to highway. This study is the only study, that search suitable sites for SPP in Karaman, Turkey.

Akkas et. al. (2017) analyzed the criteria for selecting the appropriate location by the multicriteria decision making (MCDM) methods and evaluated results for 5 cities in the Central Anatolian Region of Turkey. They defined three main criteria for SPP Location which are Solar Energy Potential, Feeder Capacity of Distribution Center and Surface Slope. With the combination of 4 main MCDM methods (AHP, ELECTRE, TOPSIS, and VIKOR), it has shown that Karaman has been identified as the most suitable city for solar power plant installation for all of the methods according to three main criteria.

Khemiri et. al. (2018) developed a framework for locational analysis of SPPs' in Makkah/Saudi Arabia. They prepared five weighted layers (Solar Radiation, Topography, Land use, Accessibility and Proximity to electric transmission) to determine optimal locations by AHP-GIS.

Guaita-Pradas et. al. (2019) analyze the sustainable territory for the Solar Power Farms Location in Valencia/Spain. They defined the criteria for deciding on one location or another by examining the literature on accessibility, grid connection orientation and slope, land cover, latitude and longitude, temperature and soil properties. The combination of AHP and GIS is used as the analysis method.

Koc et. al. (2019) proposed a GIS-AHP based approach to analyse wind-solar site selection problem in the Eastern Turkey. They identified nine criteria which are elevation, topography, land cover, aspect, inclination, solar irradiance, temperature, wind speed, and transmission line for the Iğdır Province.

Tunc et. al. (2019) also worked on the decision of best location for the solar power plant location in İstanbul/ Turkey. They define criteria such as Solar Irradiance, Sunshine Duration, Temperature Ratio, Land Use, Distance to Other Plants, Distance to North Anatolian Fault, Distance to Prohibited Areas, Slope, Wind Speed and Disytance to Transmission Lines. By using AHP to calculate criteria weights, they found that areas from Buyukcekmece to Sile are suitable for the SP plants.

Yalcin and Yuce (2020) determined the potential SPP investment areas of Burdur Province in Turkey by AHP-GIS based approach. They identified slope, aspect, energy transmission lines, and roads as the input features and found out that areas between Burdur ity center to Golhisar, Aglasun, Celtikci, Yesilova and Bucak districts are the alternative locations for SPP plant installation.

As a recent study on SPP location, Mokarram et. al. (2020) proposed a framework to determine the optimal location for constructing PV farms. To locate the suitable areas for PV farms Fuzzy analytical hierarchy process (FAHP) and Fuzzy Dempster-Shafer (FDS) methods were independently used in Fars Province in Iran by considering eleven parameters including solar radiation intensity, air temperature, distance to power transmission line (PTL), distance to major roads, land slope, distance to residential areas, land elevation, number of cloudy days, relative humidity (RH), land use, and number of dusty days as input parameters.

In contrast to the agreement on the criteria in the field of SPP location, the acceptable levels of these criteria are not clear and exact in the case studies. Distances to natural areas, built-up areas and technical infrastructure, slope ratio, protected areas, etc., depend on the national legislation and policies. So, it is not possible to clearly define levels of satisfaction to these criteria.

On the other hand, it is possible to describe prohibitions for the installation of SPP. Levels of prohibitions to the above-mentioned criteria in technical terms and legislation are as follows:

- Precious agricultural lands, plant and forest areas or areas close to these lands

- Areas with a slope of land greater than 3 degrees
- Settlement areas and areas within 500 meters safety strip
- Areas within 100 meters safety strip by road and railways
- Airports and areas within 3 km safety strip
- Environmental protection areas, national parks and natural areas and areas within 500 meters safety strip
- Lakes, rivers, dam lakes and wetlands
- Preservation forests, afforestation areas, private forests, nurseries, reeds and marshes, protection forests, etc. (Gucluer, 2010; Uyan, 2017; Eroglu, 2018).

3. Material and Methodology

The study aims to adopt GIS-Overlay Analysis to MCDM of candidate SPP sites. Overlay analysis is a group of methodologies for optimum site selection. It is a technique used to apply a common criterion of values using various inputs to create an integrated analysis. Overlay analysis identifies the best or most desirable locations for a particular situation. Process steps for overlay analysis are as follows; problem must be defined, the problem should be subdivided, important layers should be identified, reclassification or transformation data within a layer, the input layers should be weighted, the layers should be added or combined, and the final analysis stage will begin (URL 4).

MCDM is a solution for situations where more than one criterion should be evaluated together. The main method in this solution is to divide the problem into small pieces and to make a connection so that a meaningful result can be obtained from these pieces (Gucluer, 2010).

As one of the most widely accepted MCDM method, Analytical Hierarchy Process (AHP) is applied in this study. AHP enables participants to evaluate key criteria using the Pairwise Comparison between criteria (Saaty, 1990). With this approach, an expert specifically compares only two criteria at a time. She/he decides with this method and determines the preference weights of all criteria one by one. Comparisons can be made using objective measurements or subjective evaluations. Expert groups or participants can also discuss and / or evaluate the criterion they have chosen during this comparison phase (Brunner et al., 2011).

Whether the issues to be solved are simple or complex, this method produces meaningful results. The relationship between the AHP and the main objective, criteria, qualifications, sub-criteria and options related to the problem is constructed in a hierarchical order. One of the most important features of this process is that objective and subjective preferences are simultaneously included in the decision-making process. AHP method is based on the principle that knowledge of people or experience is at least as valuable as the data used to make a decision (Khemiri et al. 2018). With the AHP, knowledge, experience, subjective thoughts and predictions of the expert are brought together within a certain logic. With the AHP, instead of forcing experts to use a method about how they should make their decisions, it is aimed to discover their own decision-making mechanisms and make more efficient decisions in this way (Akad and Gedizlioğlu, 2007; Kırlangicoglu 2016).

In this context, 11 criteria that are prominent in the SPP site selection literature are chosen due to their data availability. These criteria also constitute the layers of the Overlay Analysis.
1. Slope
2. Aspect
3. Distance to Energy Transmission Lines
4. Distance to Electricity Transformer Centers
5. Distance to Highways
6. Distance to Railways
7. Distance to Settlements
8. Solar Radiation Rate
9. Distance to Waterways and Water Bodies
10. Distance to Bird Migration Routes
11. Land Use / Land Cover

These criteria are extracted mostly from the case studies of Aydin, (2009), Uyan, (2017), Merrouniet al. (2018); Yousefi et al. (2018); Gasparovic and Gasparovic, (2019) and summarized in the following part.

The slope of the SPP region is expected to be less than 5%. The region where the SPP is planning to be installed is in the northern hemisphere, and the Sun rays should come from the south. Therefore, the aspect characteristics are expected to be in the south, the southeast, and the southwest directions.

To reduce the cost of connecting distribution lines of the energy produced by the power plant, it is expected the power plant be close to power transmission lines and transformer substations. Power plants should also be close to roads and railways in order to be able to access the plants in case of a need for construction and maintenance. On the other hand, according to the regulations in Turkey, SPPs cannot be installed closer than 100 meters to the railways and roads (Uyan, 2017; Eroglu, 2018).

Furthermore, the panels should not be too close to the roads. Because of the dust created by the movement of vehicles may contaminate the solar panels and cause the falls in efficiency. The fact that power plants are close to the residential areas also positively affects their sustainability. However, plants should be at an optimum safety distance of 1000 m from the settlement areas (Uyan, 2017; Eroglu, 2018). In terms of water resources, panels should be at maximum distance from water sources. So, solar panels and other vehicles do not corrode due to moisture.

Another criterion is a safe distance from bird migration routes in the places that are on these routes. Since the bird droppings will reduce the efficiency of solar panels, and in order to avoid the disorientation problems that birds may face in the reflections of the mirrors, solar power plants are required to be at maximum distance from the bird migration routes (Atak et al. 2019; Aydin et al. 2013; Ozdemir and Sahin, 2018).

According to the Law No. 5403 on Soil Protection Act, the soil cannot be used outside the wetland destinations in Turkey. Furthermore, it is not possible to install such a facility in forest areas, however; it is possible to build the SPP facilities in non-irrigated agricultural lands, marginal agricultural lands, and pastures.

According to the announcement published by the Ministry of Energy and Natural Resources in the Official Gazette dated 11 August 2011 and numbered 28022, the annual total solar radiation value must be equal to or higher than 1650 KWh/m^2 - year to install a solar-based electricity generation facility (URL 5).

Following the extraction of mostly suitable criteria from the studies, a pairwise comparison form of was prepared and asked to fifteen experts. The participants compared every criteria with each other in the form that enables participants to score between ±9. The experts determined in the study are academics from the disciplines of environmental engineering, architecture, civil engineering, geomatics engineering and urban planning. Eleven of the experts have completely filled the form. The responses of the experts who completely filled out the pairwise comparison form were analyzed through Expert Choice software, and the weight of each criterion was calculated (Table 1.).

4. Study Area: Karaman Province

Considering the map in Figure 2, the middle and southern parts of Turkey gets desirable rates of solar energy. Installing an SPP in these areas adds a significant contribution to the country’s renewable energy production.

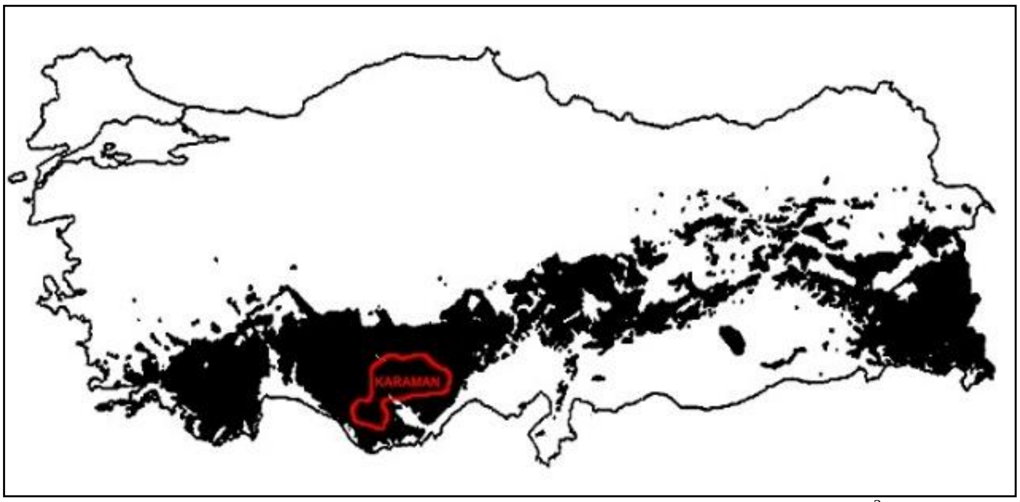

Figure 2. Places with annual total solar radiation value is higher than 1650 kwh/m^2-year

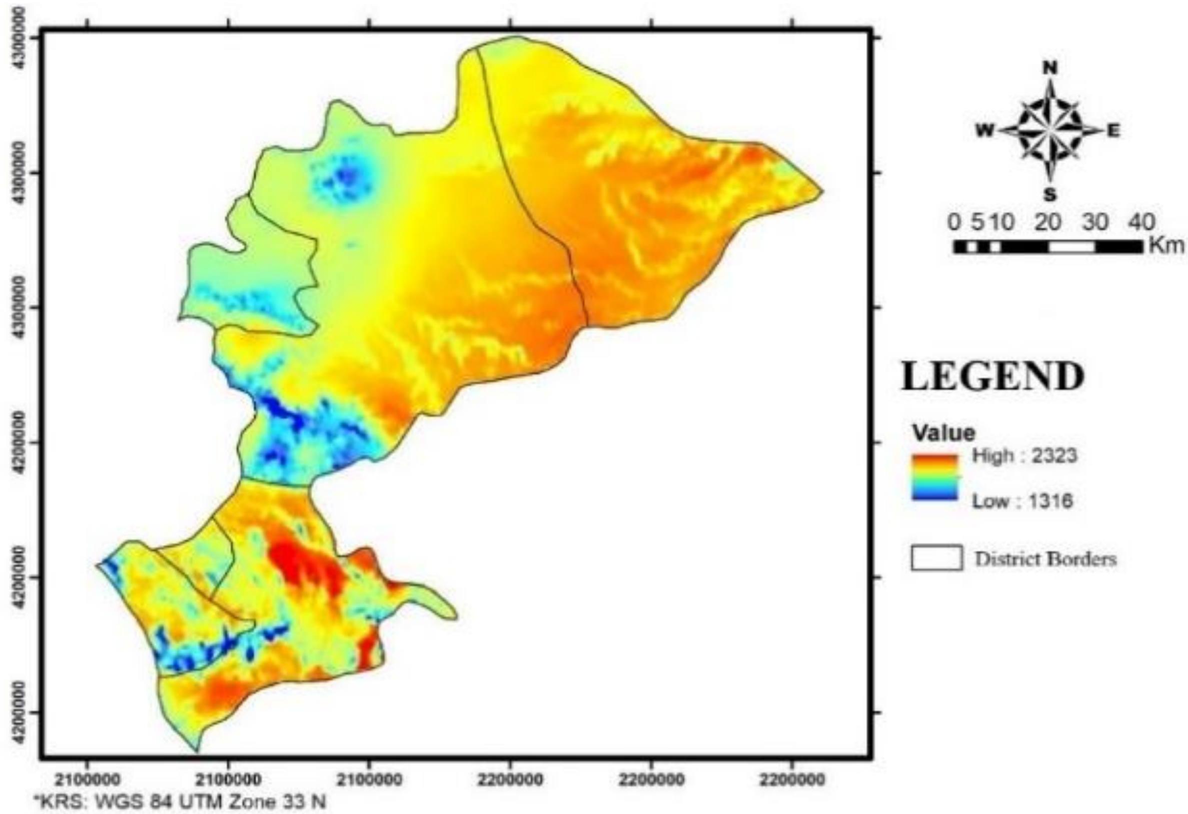

Figure 3. Karaman's DNI potential maps and study area

Karaman Province is one of the provinces that has the highest sunshine hours in Turkey. There are twelve (12) active SPPs in Karaman with power ranging from 0.04 MW to 3 MW (URL 6). Besides, it is planned to install a 33 MW power plant (URL 7). Karaman's DNI potential which indicates watts of sunlight per square meter is shown in Figure 3. The solar radiation is above 1600 KWh/m^2-year. Basyayla and Ayranci districts have the highest solar potential. Karaman Province, is in the southern part of Turkey. It is a province with 251.913 people and six districts.

As seen in the literature review there is no city-wide study for Karaman that analyze alternative locations for a solar power plant installation. However, Uyan (2017) worked on district level study in Ayranci which is one of the districts in Karaman.

5. Results

4.1. Data Preparation

In order to obtain the above-mentioned layers, open data on the Web are generally used. The digital elevation model (DEM), which is necessary to produce slope and aspect layers, was used in the 30 m spatial resolution ASTER images that the United States Geological Research Institute (USGS) provided for use in the Earth Explorer portal. The five images obtained as mosaics were made into a single image using the "Mosaic to New Raster" tool in ArcGIS software (Figure 4).

Power transmission lines (Figure 5), transformer stations, highways (Figure 6), railways, waterways and water bodies, which are generally used to determine distance criteria, were obtained from the free and open-source map provider called Open Street Map (OSM). All data in the frame of the OSM base map - opened in QGIS software - was downloaded as a vector, and all related layers were created. The water resources layer created in line format was converted to a polygon.

The map representing bird migration routes was not obtained online as a vector layer. Since the migration routes of birds served in the web site (URL 8) were not downloadable, the OSM was drawn according to their approximate location on the base map and obtained in vector format (Figure 7). In this study, the CORINE land cover map published by Copernicus Land Monitoring Service in 2012 was used to determine the settlements (Figure 8) and to obtain land use (Figure 10). The study area clipped using the Karaman provincial border as a mask layer.

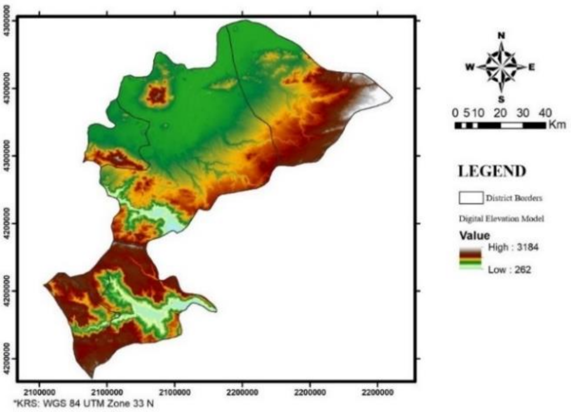

Figure 4. Digital elevation model

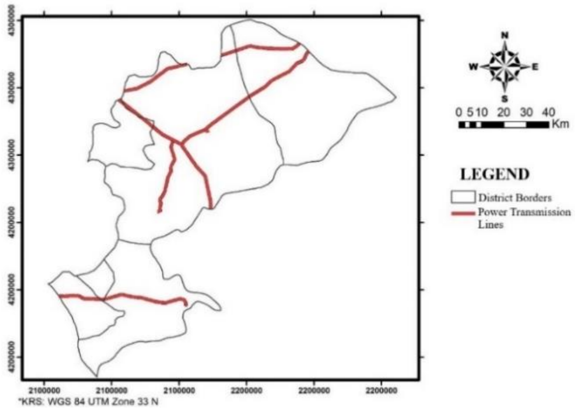

Figure 5. Power transmission lines

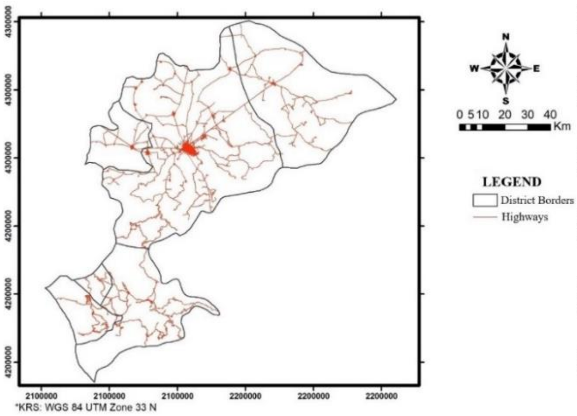

Figure 6. Highways

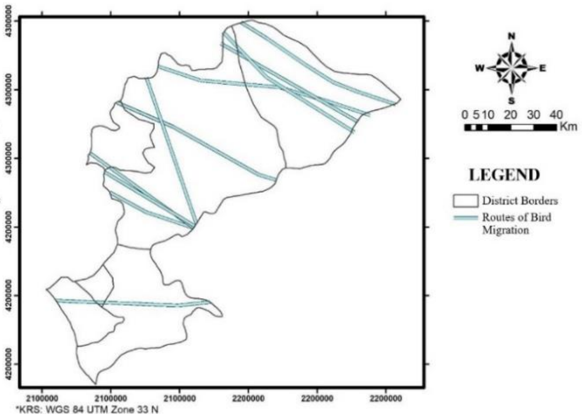

Figure 7. Bird migrations routes

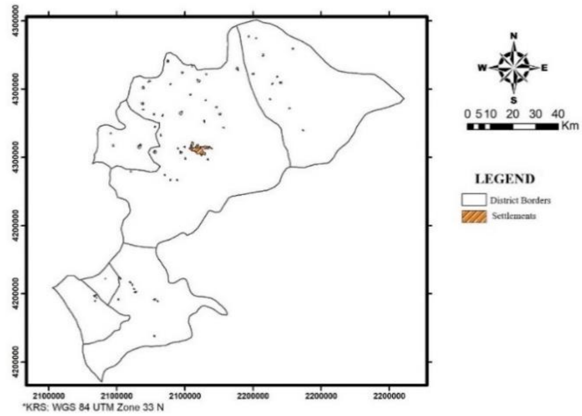

Figure 8. Residential settlements

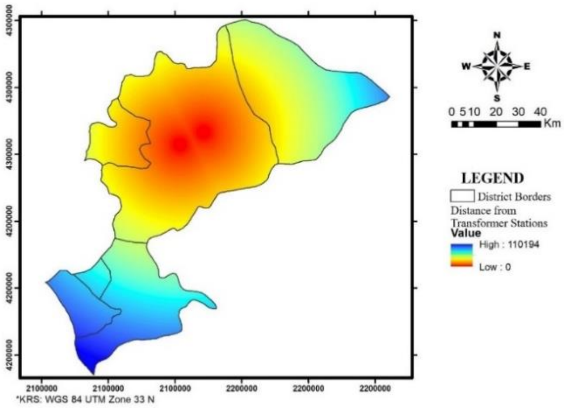

Figure 9. Distance to transformer stations

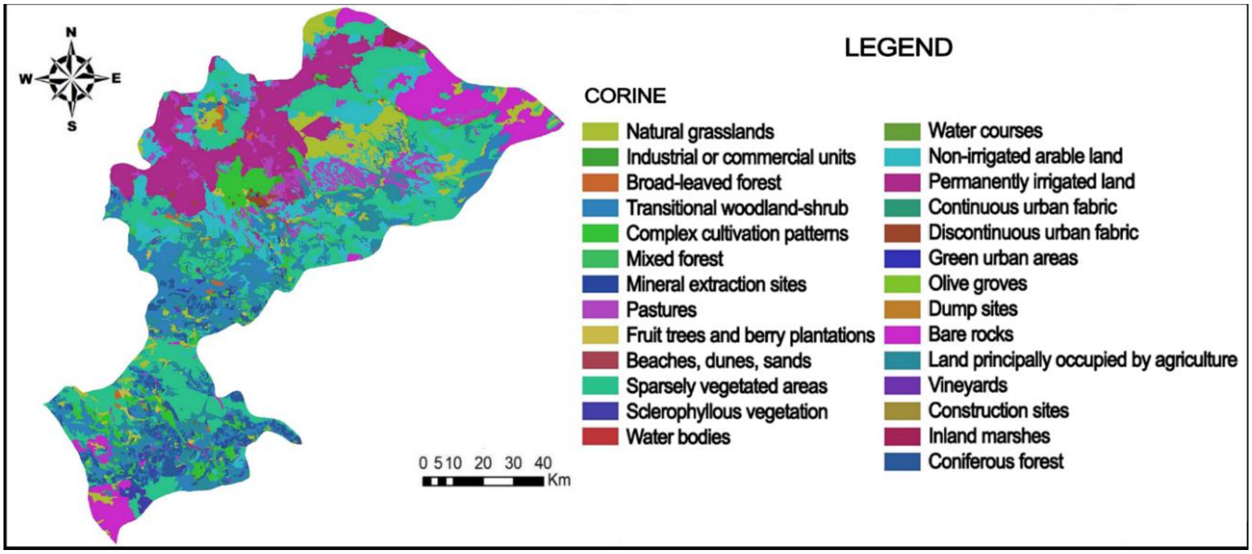

Figure 10. Land use of Karaman

For the distance-based analysis, the Euclidean Distance tool in ArcGIS software was implemented. The distance to the railways determined as a result of the analysis shows only one railway passes through the northern part of Karaman. In the distance layer to the power transmission lines, it is seen that the furthest region is the eastern part of Ayranci district. The distance map to bird migration routes shows that the southern region of the Ermenek district is located farthest away from bird migration routes, and thus it is the most suitable region for this criterion. The distance map to the water resources also shows that the district of Ayranci is the farthest from the water resources. On the other hand, the eastern part of the Ayranci district is the most inappropriate in terms of distance to the settlements. Figure 9 shows the distance values to two transformer stations in Karaman city center by colored. Therefore, when we look at only this feature, it is seen that Karaman city center will be the most suitable area for the installment of SPP. It is seen that the transportation network is nearly homogenous throughout the province, so this criterion may not have a major impact.

4.2. Reclassification of the Layers

All the layers included in the study have their measurement units ranging very differently from each other. For the sake of weighted overlay analysis, all these layers have to be standardized. At this stage, the Reclassify tool of ArcGIS software was implemented to reclassify the pixels in order to standardize the data. The new values of the pixels in the layers are given in Table 1, and reclassified maps are shown in Figure 11.

All layers in the analysis were transformed into the World Geodetic Datum (WGS) 1984 Universal Transversal Mercator (UTM) 33 North (EPSG:32633) coordinate system. Pixel sizes of raster layers were determined as 100x100m, and bilinear resampling was performed.

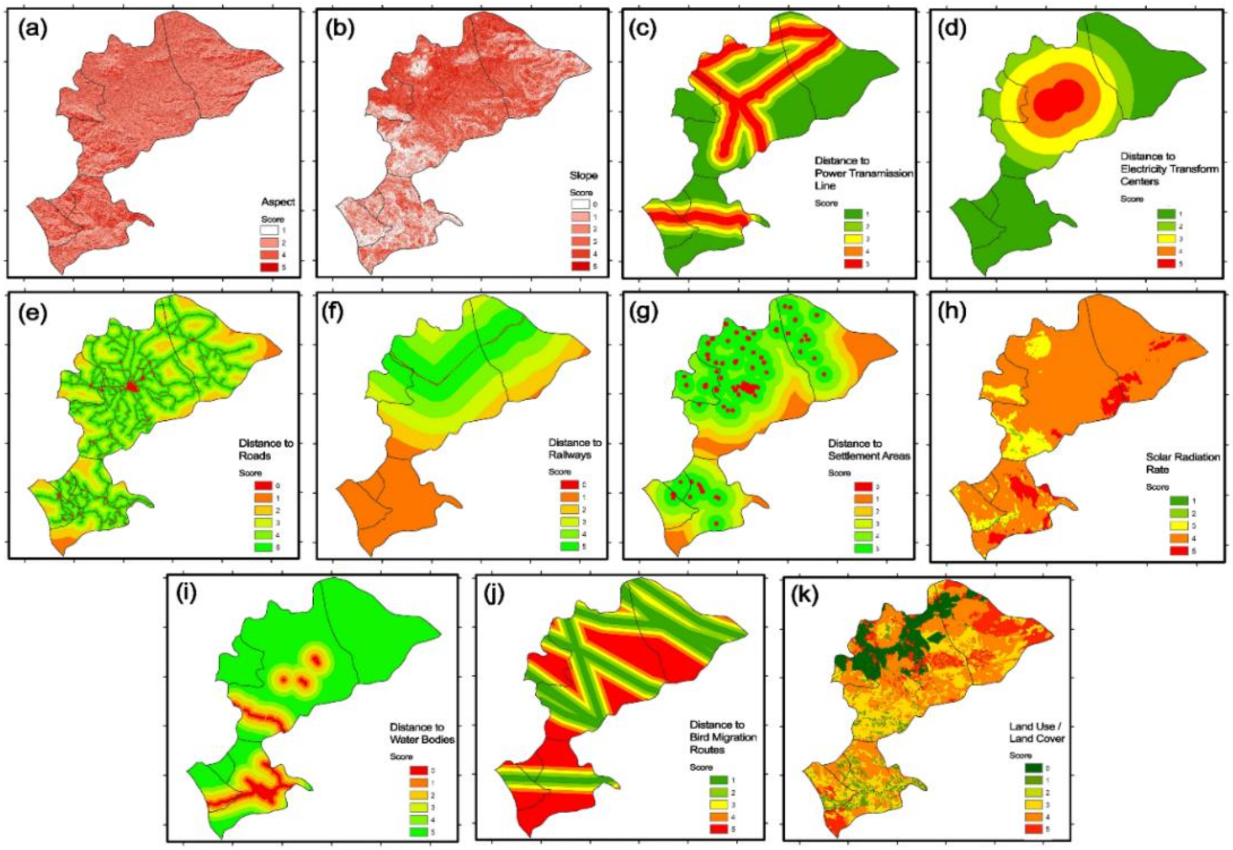

Figure 11. Reclassified analysis of each criteria in the study

4.3. Potential Locations through Weighted Overlay Analysis

By using layers with different importance, it is aimed to obtain a raster layer with total scores in the overlay analysis. Therefore, an input layer should be scored due to its criterion weight. As explained in the methodology of the study, the weights of the layers in this study is determined by AHP technique. Resulted weights calculated in Expert Choice software are as follows:

Table 1. Weights of the Criteria determined by AHP in the Expert Choice Software and Reclassification Procedures

Layer	Weight of Layer	0 (Restricted Zone)	5	4	3	2	1
Distance to Energy Transmission Lines	0,040	-	0-2500m	2500-5000m	5000-7500m	7500-10000m	>10000m
Distance to Electricity Transformer Centers	0,046	-	0-10000m	10000-20000m	20000-30000m	30000-40000m	>40000m
Slope	0,020	>25	0-2	2-4	4-5	5-6	6-25
Aspect	0,040	-	Flat- S	SE-SW	-	NE-NW	N
Distance to Roads	0,053	0-100m	100-1000m	1000-2500m	2500-5000m	5000-10000m	>10000m
Distance to Railways	0,061	0-100m	100-10000m	10000-20000m	20000-30000m	30000-40000m	>40000m
Distance to Settlement Areas	0,073	0-1000m	1000-5000m	5000-10000m	10000-15000m	15000-20000m	>20000m
Distance to Waterways and	0,135	0-1000m	1000-2500m	2500-5000m	5000-7500m	7500-10000m	>10000m

Water Bodies							
Solar Radiation Rate	0,138	-	2200-2323	2000-2200	1800-2000	1500-1800	1316-1500
Distance to Bird Migration Routes	0,178	-	>8000	6000-8000m	4000-6000m	2000-4000m	0-2000m
		Water bodies	Pastures	Non-irrigated arable land	Transitional woodland-shrub	Natural grasslands	Broad-leaved forest
		Watercourses	Sparsely vegetated areas	Land principally occupied by agriculture, with significant areas of natural vegetation.	Complex cultivation patterns	Industrial or commercial units	Mixed forest
Land Use / Land Cover	0,216	Continuous urban fabric	Bare rocks		Beaches, dunes, sands	Fruit trees and berry plantations	Mineral extraction sites
		Green urban areas			Sclerophyllous vegetation	Discontinuous urban fabric	Olive groves
		Inland marshes				Construction sites	Dump sites
							Vineyards
							Coniferous forest

The calculated relative weights have shown that the land use criteria acquire the most important weight of 0.216, followed by the distance to bird migration routes criteria with a weight equal to 0.178. Overall Inconsistency Ratio – CR is 0.15 shows the results are acceptable for the analysis according to Wedley (1993). CR depends mainly on the matrix size which consists of the number of criteria included in the study. When the number of criteria is beyond the 6 or 7, it is nearly impossible to get CR smaller than 0.1 that Saaty (2013) suggests. In addition, it depends on the sample characteristics and the analysis, for individual experts, CR is restricted to 0.10 or 0.15, while for group responds CR could be relaxed to 0.20 to allow for non-expert responds following the recommendations of Ho et al. (2005).

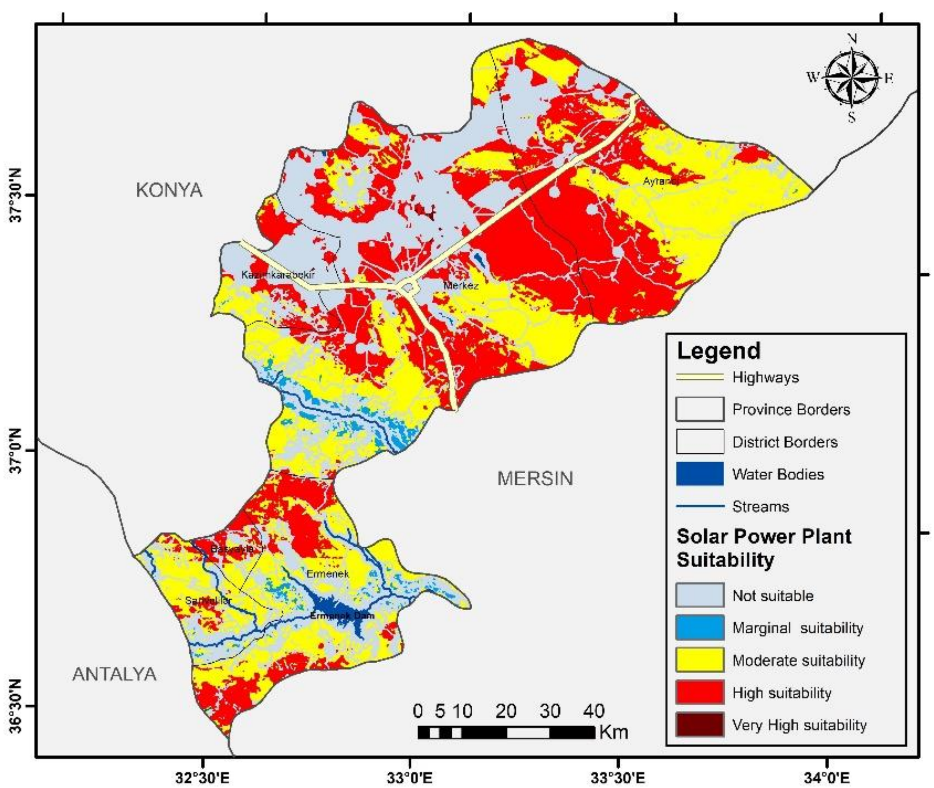

Figure 12. Result of the Weighted Overlay Analysis

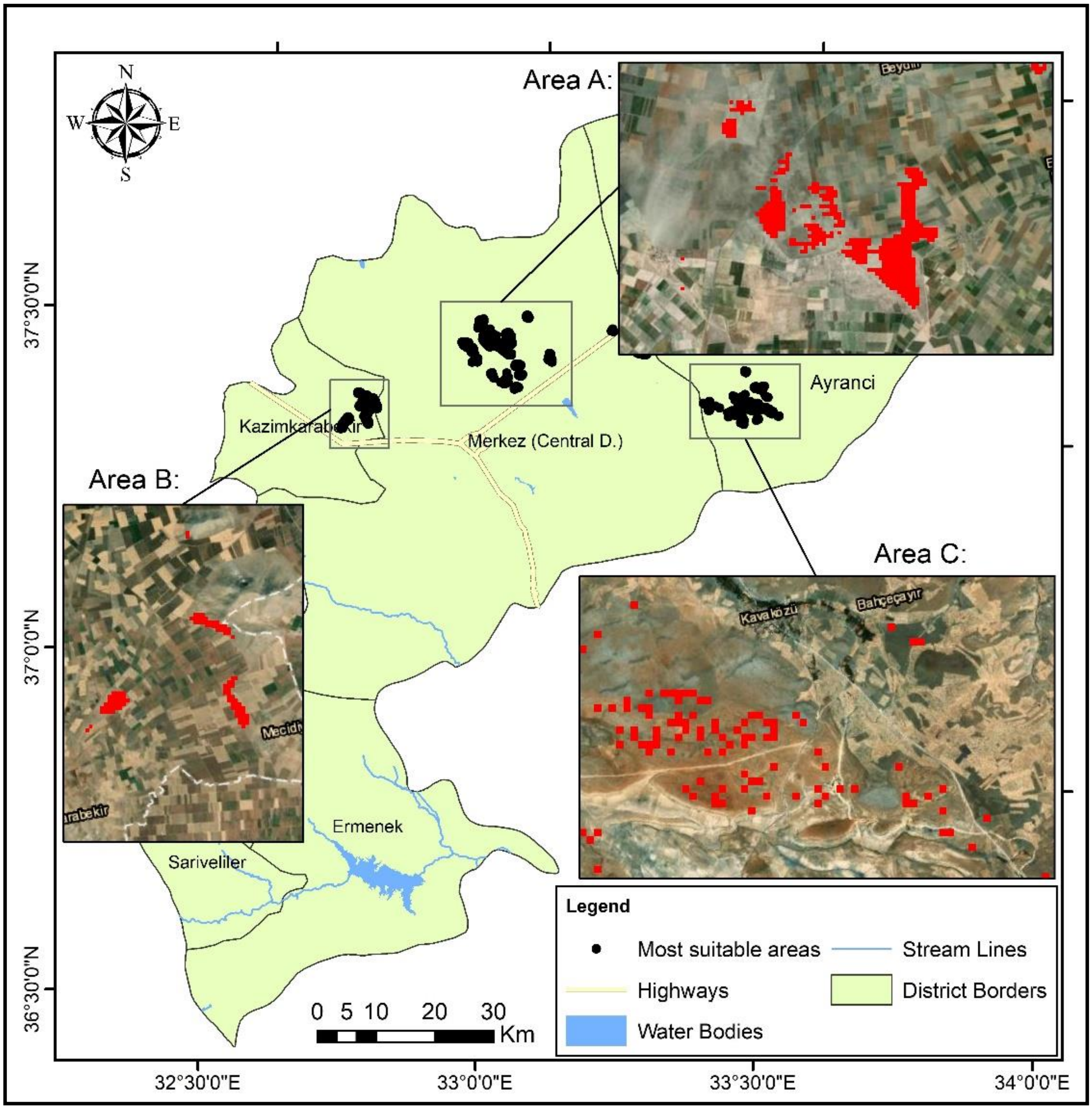

Figure 13. Representation of highest scores for SPP in Karaman

Consecutively, weighted overlay analysis was performed using eleven layers' weighted scores. Results show that Karaman Merkez (central district) is the most suitable district for solar farming except restricted areas (Figure 12). Also, Ayranci district has moderate suitable areas on southern and southwestern regions. The weighted overlay analysis' result shows that very high suitable areas for installing SPP cover 12.23 square kilometres area and clustered in Karaman Merkez (Area A), Kazımkarabekir (Area B) and Ayranci Districts (Area C). High suitable areas cover 2975.75 square kilometres. Moderate and marginal suitable areas cover 2689.31 and 147.76 square kilometres respectively. There are 3329.34 square kilometres resticted area which covers 36.37% of whole province (Table 2.).

Table 2. Suitability Statistics

Suitability level	**Pixel Count**	**Coverage Area (km^2)**	**Coverage Rate (%)**
Very High	1223	12.23	0.13
High	297576	2975.76	32.51
Moderate	268931	2689.31	29.38
Marginal	14776	147.76	1.61
Restricted	332934	3329.34	36.37

Most of the highest scores in districts (except Ayranci) are clustered in close proximity to highways. The forests located in the northern part of the Karaman city center is not suitable for SPP because the area is for irrigated agriculture. Sariveliler, Basyayla and Ermenek districts located on the south of Karaman generally do not have highest suitable areas for the construction of SPP.

CONCLUSION:

In Turkey which has high potential to benefit from solar energy due to her geographical location, energy consumption for production, service and housing ever increases in parallel to growing population and new demands of today's world. The exhaustion of fossil energy resources and theirs harmfulness to the environment direct humanity to alternative energy sources. It is possible to meet the increasing energy need by switching the energy use to renewable energy sources and energy efficiency policies. Thus, as clean production and an inexhaustible alternative energy source, solar energy production is a critical research and practice area for Turkey.

Therefore, the number of upcoming studies from the perspective of the location of solar power plants is increasing in Turkey. Kum et al. (2019) in Gaziantep, Koc et. al. (2019) in Igdir, Uyan, (2013) in Konya, Kaya and Kahraman (2010) in Istanbul, Tunc et al. (2019) in Istanbul, Yalcin and Yuce (2020) Burdur, Akkas et al. (2017) in five Turkish cities including Karaman, Ayday et al. 2016, Eskisehir, Uyan, 2017 in Ayranci, Karaman are the Pioneer studies that investigate the SPP location alternatives in Turkish cities. Although most of the studies are designed to use AHP and GIS combination, the criteria set of the studies vary depending on the characteristics of the research unit in these studies undoubtedly.

Among these studies, any study is analyzed entire city of Karaman in terms of SPP location. A previous study to include only one district of the city of Karaman was conducted by Uyan (2017). Five criteria were used in Uyan's study. The criteria in our study include those in this study. Our study also expands the research unit to include the whole of Karaman. In Uyan's (2017) study, while the locations close to the highway in the northern part of Ayranci stand out as the most suitable location, three different points in different districts stand out in our study. The cluster of very highly suitable areas on Ayranci in our results is different from Uyan's work. Highly suitable areas in our study and the most suitable areas of Uyan's coincide. However, our study's very highly suitable areas fall only into the suitable areas of Uyan's. This shows that increasing the number of spatial criteria gives much more high resolution to the outputs.

On the other hand, many criteria that stand out in the literature section are also included in our study, and AHP-GIS integration which is the most used method recently, has been achieved.

The combined use of GIS and MCDM methods has provided great advantages in terms of management of multi-layered geographic data, regulation of benchmark weight and presentation of result product in appropriate format.

As a result of this study aiming to the alternatives to SPP locations in the urban area by AHP and GIS (Weighted Overlay Analysis), Karaman's city border has been narrowed in terms of being a candidate for the SPP. Within the scope of investment and feasibility studies, potential areas to focus on considering instruction and engineering are quite limited and concentrated mostly in the three part of the city, which is quite the opposite of solar radiation values.

The fact that the data which represent the criteria can be found in the given grid detail is a subject that directs the success of all kind of spatial studies. Although there is a small amount of data ready for analysis, it is aimed to represent many more criteria in this study by transforming the existing data following the objectives of the study. It should not be forgotten that the criteria for SPP site selection are still developing compared to other conventional energy investments. Theory will be further enriched with new criteria that can be added to SPP site selection from different fields. Naturally, as new criteria added, results would also would change.

The main subject of this study is not to suggest a methodological comparison. However, a study would be designed with an approach to include comparison between different MCDM-GIS methods and evaluation of high-resolution results due to these methods in Karaman in further studies as Akkas et al.'s (2017) comparison of different MCDM methods in five Turkish cities.

Compliance with Ethical Standard

Conflict of Interests: The authors declare that for this article they have no actual, potential or perceived conflict of interests.

Ethics Committee Approval: Ethics committee approval is not required for this study.

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WEB Resources:

URL 1: http://www.yegm.gov.tr/genc_cocuk/Yenilenebilir_Enerji_Nedir.aspx/

URL 2: http://www.yegm.gov.tr/MyCalculator/iller/TR.png

URL 3: https://enerji.gov.tr/bilgi-merkezi-enerji-gunes

URL 4: http://desktop.arcgis.com/en/arcmap/10.3/tools/spatial-analyst-toolbox/understanding-overlay-analysis.htm

URL 5: http://www.resmigazete.gov.tr/ilanlar/eskiilanlar/2011/08/20110811-4.htm#%C3%A707/

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