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GIS-based solar farms site selection using analytic hierarchy process (AHP) in Karapinar region, Konya/Turkey

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A B S T R A C T

Renewable energy is clean sources and has a much lower environmental impact than other energy sources. In Turkey, solar energy investments have been developed rapidly in recent years. Site selection for solar farms is a critical issue for large investments because of quality of terrain, local weathering factors, proximity to high transmission capacity lines, agricultural facilities and environmental conservation issues. Multi criteria evaluation methods are often used for different site selection studies. The purpose of this study was to determine suitable site selection for solar farms by using GIS and AHP in the study area. The final index model was grouped into four categories as “low suitable”, “moderate”, “suitable” and “best suitable” with an equal interval classification method. As a result, 15.38% (928.18 km^2) of the study area has low suitable, 14.38% (867.83 km^2) has moderate suitable, 15.98% (964.39 km^2) has suitable and 13.92% (840.07 km^2) has best suitable for solar farms area. 40.34% (2434.52 km^2) of the study area is not suitable for solar farm areas.

Contents

1. Introduction

Energy is a key element required for sustainable development and prosperity of a society [1]. Nowadays, more than 80% of the global primary energy demand is based on fossil fuels (coal, oil and natural gas). In the world, the main sources of the total energy consumed are crude oil contributes with 31%, coal with 28% and natural gas with 22%, respectively. However, the global oil reserves are unevenly distributed and this imbalance will inevitably lead to political and economic conflicts in future [15]. Clearly, fossil fuel resources are limited and will run out in the future. In the long term, the limited availability of fossil fuels will lead to a higher price. Global energy demand is projected to increase by 49% in the next 25 years. Global oil consumption is expected to grow from 86 million barrels per day in 2007 to 104 million barrels per day in 2030 [3].

While a majority of the world's energy supply is generated from fossil fuels, fossil fuel use has tremendous impact on the world economy, ecology and global climate. In recent years, the price of oil and others fossil fuels has quickly increased and and most of the world countries have developed new policies and major challanges to reduce the energy costs and the pollution impact. Also concerns over climate, energy security and rising fuel prices have spurred growing interest for fossil fuels [25,10,27].

The depletion of fossil fuels and the increasing awareness about environmental pollution have led to the use of renewable energy resources in the 21st century [17]. Renewable energy is very important because of the benefits it provides and will play an important role in the world's future. The energy resources can be divided into three

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categories: fossil fuels, renewable resources and nuclear resources. Renewable energy sources are those resources which can be used to produce energy again and again, e.g. solar energy, wind energy, biomass energy, geothermal energy, etc [22]. Renewable energy sources are clean sources and have a much lower environmental impact than other energy sources. Other sources of energy are finite and will someday be depleted. On the contrary, renewable energy sources will not run out and are finite. Renewable energy suffers low cost or free fuels [28]. Wind and solar power sources are undoubtedly the most used worldwide for energy production ([10]). Solar power generation has emerged as one of the most rapidly growing renewable sources in the world. Solar power generation has several advantages over other forms such as environmental advantages, government incentives, flexible locations and modularity. In Turkey, the renewable energies expand rapidly in the last decade and solar power has emerged as the most dominant contributor to renewable power generation associated with wind power.

Site selection of solar power system is a difficulty which puzzled the electricity generation enterprises, grid enterprises and government. Because the decision of power plant sites has a strong relationship with the plant's security which should meet the meteorology requirement, economics requirement, environment and society requirement [34]. The locations with the highest solar resources are not always feasible sites for solar farms. A variety of factors play a role in the site selection of solar farms. They can be categorized into: economic, ecological, etc. factors [30].

In recent years, multi criteria evaluation (MCE) methods and Geographical Information System (GIS) have become increasingly popular as a tool for different site selection studies. MCE methods were developed in the 1960 s to assist for decision-making. MCE is a concept which has wide usage in many fields, according to the literature. The combination of GIS and MCE techniques has been increasingly used as an important spatial decision support system (SDSS) for evaluating suitable locations. Using the combination of GIS and MCE techniques validated research on the site selection of solar farms is very rare. Janke [12], identified suitable areas for wind or solar farm using multicriteria GIS modeling techniques. Charabi and Gastli [6] presented a study that aimed at developing the first geographical mapping models to locate the most appropriate sites for different photovoltaic technologies in Oman using MCA. Nguyen and Pearce [21], developed and tested an algorithm in this paper which can be generalized to any region in the world in order to foster the most environmentally-responsible development of large-scale solar farms. Dagdougui et al. [8] proposed a GIS-based decision making methodology for the selection of the most promising locations for installing renewable hydrogen production systems. Based on the combination of a Geographic Information System (GIS) and tools or multi-criteria decision making (MCDM) methods in order to obtain the evaluation of the optimal placement of photovoltaic solar power plants in southeast Spain is studied by Lozano et al. [18]. In addition, there are many studies on the same subject for wind farms [2,26,7].

This paper is focused on the combining AHP with GIS for the most appropriate solar farms site selection in Karapinar Region, Turkey. The Analytic Hierarchy Process (AHP) is one such multi-criteria decision-making method and can be used to analyze and support decisions which have multiple and even competing objectives [11,4]. The integration of GIS and AHP is a powerful tool to solve the site selection for solar farms problem.

2. Materials and method

2.1. Study area

The field of the study includes Karapinar region of Konya Province in the Central Anatolia region of Turkey. The city of Konya is geographically situated between 36.5° and 39.5° north latitudes and 31.5° and 34.5° east longitudes and it is the largest province of Turkey. Study area is 6035 km^2. It is located east in Konya (Fig. 1) and exposed high rates soil erosion and desertification. Region generally consists of arid lands and is located in the part of the country with least rainfall, where the continental climate conditions prevail with summers that are hot and arid while winters are cold and snowy.

Fig. 1. The geographical position of study area.

As shown in Fig. 2, Konya has the biggest potential for solar energy investments within the regions of Turkey. In the study area, solar radiation annual means were between 1650 KWh/m^2/year and 1700 KWh/m^2/year. At 08/01/2011, Ministry of Energy and Natural Resources announced the regions and cities in which solar energy investments would take place in Turkey. According to newly-prepared and put forth map, only 38 cities in 27 areas were allowed to produce electricity based on solar power.

In terms of solar energy, founded power would not be able to exceed 600 MW throughout Turkey. Nearly 2 billion Euro investments are expected. The maximum capacity of 92 MW applicant right to Konya was given. Accordingly, 22% of the total investment will have been given Konya at the end of 2013 in Turkey. 46 MW applicant right to Karapinar region was given to Konya by Ministry of Energy and Natural Resources. There are large and unsuitable land for agriculture in Karapinar region and this region is seen as the most suitable for solar energy investments in Turkey. Solar radiation values and sunshine duration for Karapinar region are shown in Fig. 3.

2.2. Hierarchy model development

Hierarchy model for site selection of solar farms is shown in Fig. 4. In this study, five criteria and nineteen sub-criteria were selected for evaluating site selection suitability. The proposed model for site selection of solar farms has been made possible through the integration of environmental and economic factors.

Before defining the required criteria for the selection of solar farm, firstly, constraints were masked for the environmentally unsuitable sites. The list of constraints sites were as indicated

- Buffer of residential (urban and rural) areas distance = 500 m,
- Buffer of roads = 100 m,

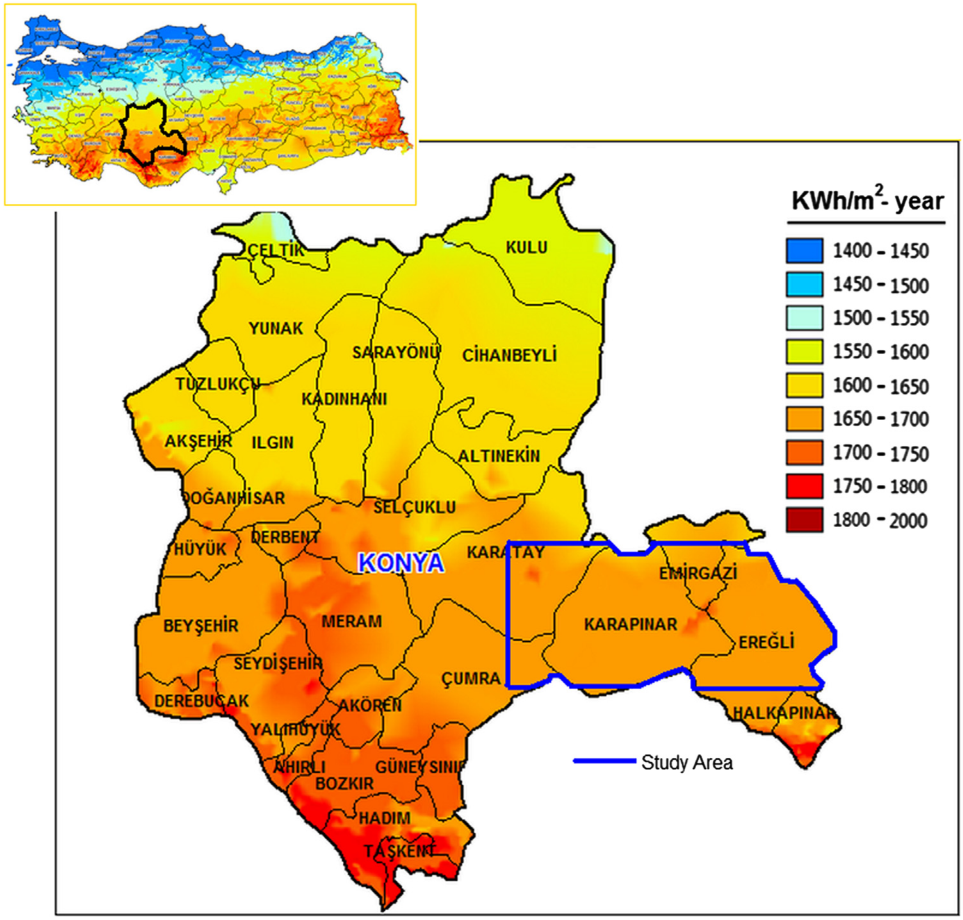

Fig. 2. Konya city solar radiation annual means [32].

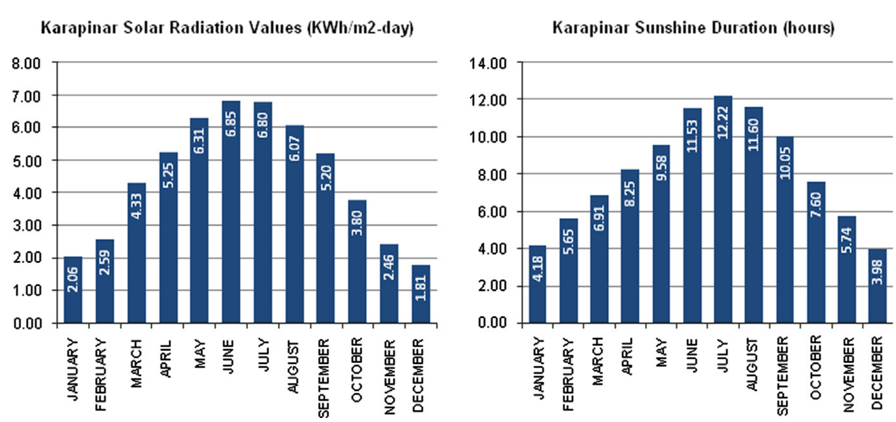

Fig. 3. Solar radiation values and sunshine duration for Karapinar region [32].

- Rivers, lakes, wetlands, and dams,
- Buffer of protection areas (archeological sites, military areas, forest land, wildlife protection areas, biologically significant areas and environmental protection area) distance = 500 m.

In the first step, GIS data sets of study area (residential areas, land use, roads, slope and transmission lines) were collected for study area from different sources. Residential areas, roads and transmission lines maps of the scale 1:25,000 were digitized and converted to raster and vector files. Land use maps were obtained from Environmental Master Plan (scale:1:100,000) for the Provinces of Konya and digitized and converted to raster file. Elevation maps were prepared based on the SRTM (Shuttle Radar Topography Mission) data. All of the digitization, convertion and analysis processes of the maps were performed using GIS software; Arc GIS Desktop 9.3. The AHP weights were calculated using Microsoft Excel.

In the next step, the weights for each of identified environmental and economic objectives were calculated with AHP which is one of the MCDM methods using Microsoft Excel and performed overlay analysis using a GIS for site selection of solar farms.

MCE is a device which enables people to make the most appropriate choice among many criteria and it is a widely used concept [13,31,20,9]. The AHP, which is a mathematic technique for multicriteria decision making [19]. The AHP, which is used as a decision analysis device [23], is a mathematical method developed

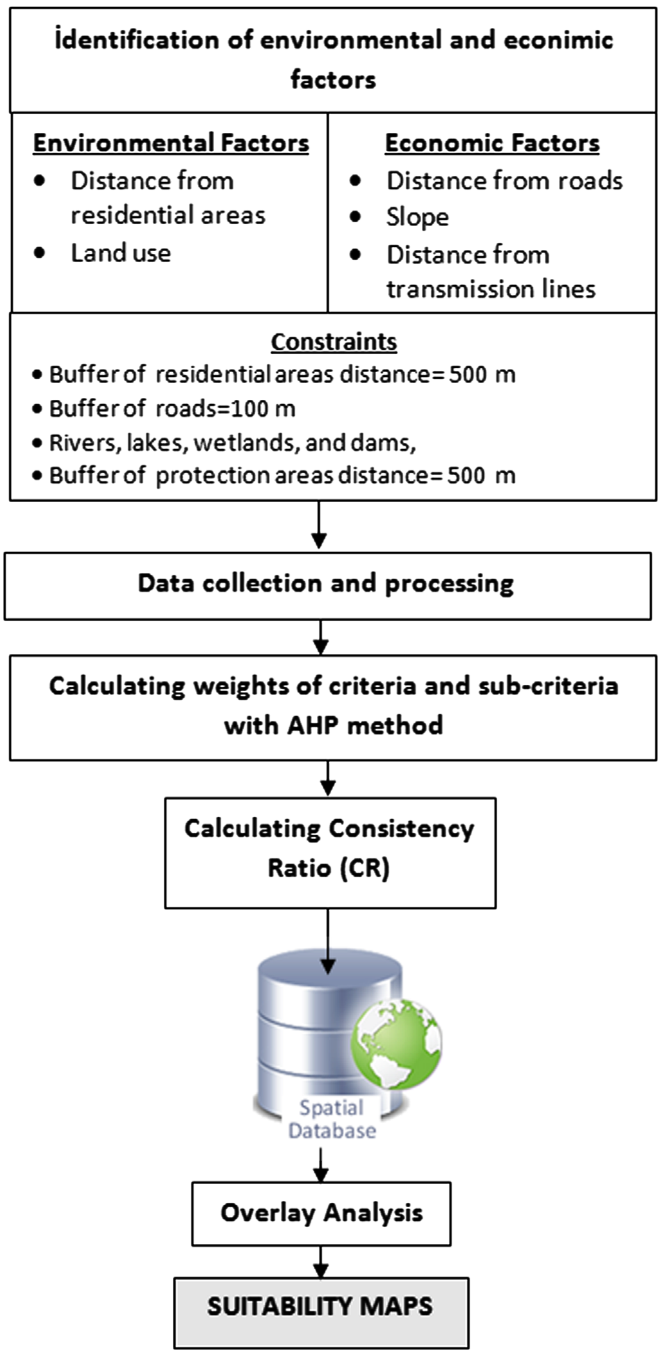

Fig. 4. Hierarchical model of land suitability.

Table 1
AHP evaluation scale.

Numerical value of P_{ij}	Definition
1	Equal importance of *i* and *j*
3	Moderate importance of *i* over *j*
5	Strong importance of *i* over *j*
7	Very strong importance of *i* over *j*
9	Extreme importance of *i* over *j*
2,4,6,8	Intermediate values

by Saaty in 1977 for analyzing complex decisions involving many criteria [16].

Pairwise comparison, which is applied within the scope of the AHP technique, provides a comparison of criteria which are used in decision analysis and determines values for each of these criteria [29]. In AHP, a matrix is generated as a result of pairwise comparisons and criteria weights are reached as a result of these calculations. Also, it is possible to determine the consistency ratio (CR) of decisions in pairwise comparison. CR reveals the random probability of values being obtained in a pairwise comparison matrix [33].

If n number criteria are determined for comparison, the specific procedures are as following for AHP performs [19]:

(1) To create $(n \times n)$ pairwise comparison matrix for multiple factors, let $P_{ij}=$ extent to which we prefer factor i to factor j. Then assume $P_{ij}=1/P_{ij}$.
The possible assessment values of P_{ij} in the pairwise comparison matrix, along with their corresponding interpretations, are shown in Table 1.
(2) A normalized pairwise comparison matrix is found. For this;
  a. Compute the sum of each column,
  b. Divide each entry in the matrix by its column sum,
  c. Average across rows to get the relative weights.

For controlling the consistency of the estimated weight values, the consistency ratio (CR) is calculated as following:

a. First, calculate the eigenvector and the maximum eigenvalue for each matrix,
b. Then, calculate an approximation to the consistency index (CI)

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

where λ_{max} is the eigenvalue of the pairwise comparison matrix,
c. Finally, to ensure the consistency of the pairwise comparison matrix, the consistency judgment must be checked for the appropriate value of n by CR [35], that is,

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

where RI is the random consistency index. The RI values for different numbers of n are shown in Table 2.

If $CR \le 0.10$, the degree of consistency is satisfactory. If $CR > 0.10$, there are serious inconsistencies. In this case, the AHP may not yield meaningful results [5].

Weights were calculated for all of criteria by AHP and were summarized in Table 3. Nineteen criteria were used in the computation process, which were divided into two main groups. The CR values of all comparisons were lower than 0.10. This means that the weights were suitable.

As a result, the overall score of alternatives in the GIS environment and land suitability of the study area were determined by calculating the land suitability index (LSI) [24]:

$$\boldsymbol{LSI} = [(A) \times ((A_1 c_{wi} \times A_1 sc_{wi}) + (A_2 c_{wi} \times A_2 sc_{wi}] + [(B) \times ((B_1 c_{wi} \times B_1 sc_{wi}) + (B_2 c_{wi} \times B_2 sc_{wi})) + (B_3 c_{wi} \times B_3 sc_{wi}))]$$

where, LSI: land suitability index; $A_1 c_{wi}$; weight index of distance from residential areas criteria, $A_1 sc_{wi}$; weight index of distance from residential areas sub-criteria, $A_2 c_{wi}$; weight index of land use criteria, $A_2 sc_{wi}$; weight index of land use sub-criteria, $B_1 c_{wi}$; weight

Table 2
RI table values [23].

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

Table 3
Weights of all criteria used in site selection.

Goal	Obj.	Weight	CR	Criteria	Weight	CR	Sub-criteria	Weight	CR	∑Weight
Land suitability	**Environmental factors (A)**	0.550	0.000	Distance from residential areas(m)	0.250	0.000	500 >	0.042	0.065	0.006
							500–2000	0.133		0.018
							2000–5000	0.267		0.037
							5000 <	0.558		0.077
				Land use	0.750		Barren	0.990	0.000	0.408
							Agriculture	0.010		0.004
	Economic factors (B)	0.450		Distance from roads (m)	0.071	0.025	100 >	0.033	0.070	0.001
							100–1000	0.454		0.015
							1000–3000	0.256		0.008
							3000–5000	0.160		0.005
							5000 <	0.096		0.003
				Slope (%)	0.180		1 >	0.390	0.059	0.032
		0.5								
							1–2	0.390		0.032
							2–3	0.184		0.015
							3 <	0.036		0.003
				Distance from transmission lines (m)	0.748		3000 >	0.574	0.062	0.193
							3000–6000	0.291		0.098
							6000–10,000	0.090		0.030
							10,000 <	0.044		0.015

index of distance from roads criteria, B_1sc_{wi}; weight index of distance from roads sub-criteria, B_2c_{wi}; weight index of slope criteria, B_2sc_{wi}; weight index of slope sub-criteria, B_3c_{wi}; weight index of distance from transmission lines criteria, B_3sc_{wi}; weight index of distance from transmission lines sub-criteria.

In this study, land suitability map was prepared as five map layers including distance from residential, land use, distance from roads and distance from transmission lines. ArcGIS software was used in this process for overlay analyses. Determined numerical values from LSI divided into four grades (low suitable, moderate, suitable and best suitable) according to criteria and buffer zones were built. The higher score is more suitable area for solar farm areas.

2.3. Criteria description

The following factors were considered in the site selection for solar farm process for this study: Distance from residential areas, land use, distance from roads, slope and distance from transmission lines. In the study, solar potential was not evaluated as a criterion, because it is between 1650 KWh/m^2/year and 1700 KWh/m^2/year throughout study area. Selection criteria may change from one region from another based on local conditions and circumstances [24]. Determinates criteria were divided into two main groups. The first group was environmental factors. The second group was economic factors. Five criteria and nineteen sub-criteria were determined into two main groups for site selection process for study area.

Each criteria is explained below.

2.3.1. Environmental factors

2.3.1.1. Distance from residential areas. Placing a solar farm near rural and urban residential areas can cause negative environmental impacts on the urban growth and population. Therefore, solar farms area at a distance less than 500 m from urban areas must not be established. In this study, a 500 m buffer zone was masked for rural-urban residential and industrial areas. Residential and industrial areas with a < 500 m buffer zone was scored as 1, 500–2000 m buffer zone was scored as 2, 2000–5000 m buffer zone scored as 3 and > 5000 m buffer zone scored as 4 (Fig. 5a). Separately in all buffer zones were weighted by AHP. The criterion map was obtained by ArcGIS software with weighted value of each buffer zone in Table 3.

2.3.1.2. Land use. Land requirement is one of the most critical factors for the energy investment [14]. The land use is considered as an environmental factor for site selection of solar farms. In this study, land use was evaluated for two criteria as barren areas and agricultural areas. Barren areas were scored as 1 and agricultural areas were scored as 2 (Fig. 5b). Separately in all areas were weighted by AHP. The criterion map was obtained by ArcGIS software with weighted value of each buffer zone in Table 3.

2.3.2. Economic Factors

2.3.2.1. Distance from roads. Proximity to major roads can give an idea about construction costs. In this study, < 100 m buffer zone was scored as 1, 100–1000 m buffer zone was scored as 2,1000–3000 m buffer zone scored as 3,3000–5000 m buffer zone scored as 4 and > 5000 m buffer zone scored as 5 (Fig. 5c). Separately in all buffer zones were weighted by AHP. The criterion map was obtained by ArcGIS software with weighted value of each buffer zone in Table 3.

2.3.2.2. Slope (%). Slope must less than 3% for all aspects for suitable solar farms site. Slope was divided into four parts. < 1% buffer zone was scored as 1, 1–2% buffer zone was scored as 2, 2–3% buffer zone scored as 3 and > 3% buffer zone scored as 4 (Fig. 5d). Separately in all buffer zones were weighted by AHP. The criterion map was obtained by ArcGIS software with weighted value of each buffer zone in Table 3.

2.3.2.3. Distance from transmission lines (m). Proximity to existing electrical transmission lines are important economically. In the study, < 3000 m buffer zone was scored as 1,3000–6000 m buffer zone was scored as 2,6000–10,000 m buffer zone scored as 3 and > 10,000 m buffer zone scored as 4 (Fig. 5e). Separately in all buffer zones were weighted by AHP. The criterion map was obtained by ArcGIS software with weighted value of each buffer zone in Table 3.

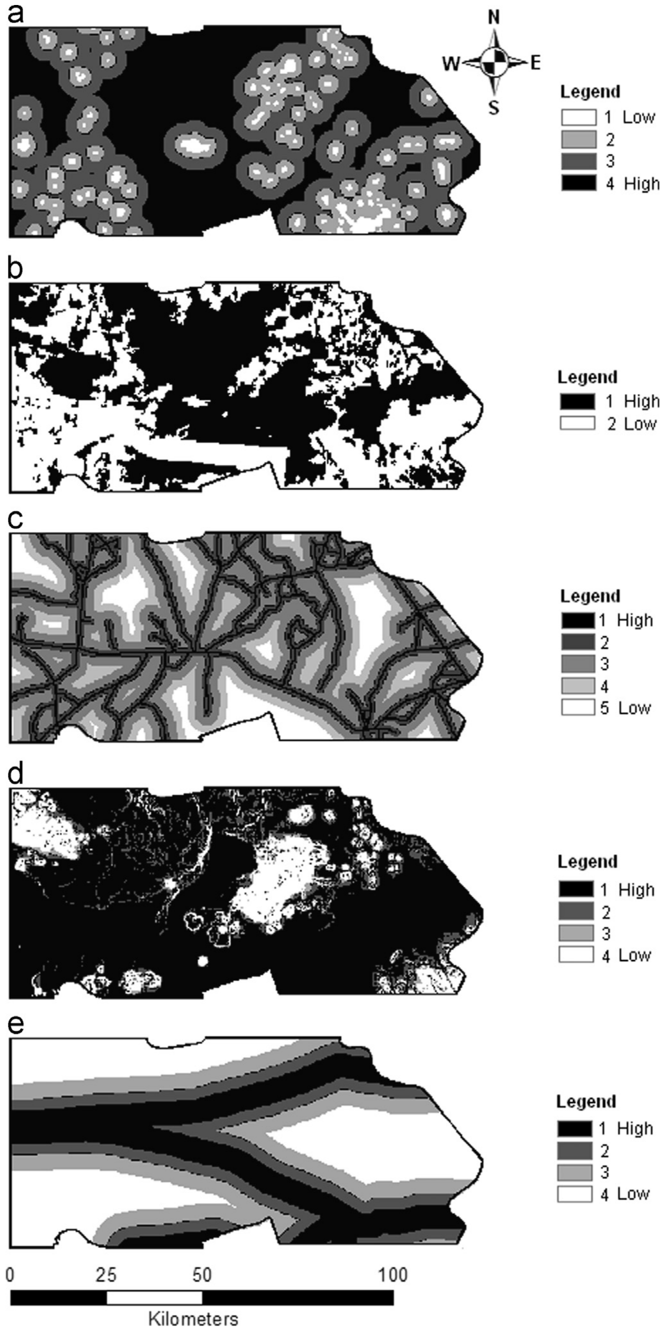

Fig. 5. Suitability index of (a) residential areas, (b) land use, (c) roads, (d) slope and (e) transmission lines.

3. Results and discussion

A land suitability index map was determined by combining AHP with GIS for the logical location of solar farms site in Karapinar region, Konya, Turkey in Fig. 6. In order to calculate the suitability indexes, the evaluation criteria (Fig. 5) were used. Five site selection criteria were chosen according to attributes of study area. Each criterion map was prepared using ArcGIS with weight values obtained from AHP and combined for land suitability map by the LSI. The final index model was grouped into four categories as "low suitable", "moderate", "suitable" and "best suitable" with an equal interval classification method. As a result, 15.38% (928.18 km^2) of the study area has low suitable, 14.38% (867.83 km^2) has moderate suitable, 15.98% (964.39 km^2) has suitable and 13.92% (840.07 km^2) has best suitable for solar farms area. 40.34% (2434.52 km^2) of the study area is not suitable for solar farm areas.

In the study area, a lot of regions can be determined to be high suitability according to Fig. 6. We suggested two candidate sites as 1 and 2 for site selection of solar farms due to land costs and size in Fig. 6. To avoid the problem of property, candidate sites were selected public lands.

The results of such study directly depend on the selected criteria. Therefore, selected criteria must be arranged for study area. In this study, based on the expertise and decision maker views, the evaluation criteria were determined and categorized.

4. Conclusions

Energy is fundamental force to and affects all aspects of development social, economic, and environmental. Fossil fuels that main sources for sustainable development are limited and will run out or become too expensive in the future. Fossil fuels also cause air, water and soil pollution, and produce greenhouse gases that contribute to global warming. Renewable energy resources, such as wind and solar are a form of energy that comes from a source that is not going to run out and offer clean alternatives to fossil fuels. The sun is our most powerful source of energy and solar energy can be used for generating electricity, heating, lighting and cooling buildings, water heating and a variety of industrial processes.

This paper presents an application of combining AHP with GIS for site selection of solar farms in Karapinar region, Konya, Turkey. The AHP is used to evaluate the importance and determinate weights of criteria. The AHP methodology integrated with GIS are remarkably important for the effective and quick evaluation of the solar farms site selection. Environmental and economic factors were all together considered in the computation process including five criteria categorized in two factors. Final suitability map was

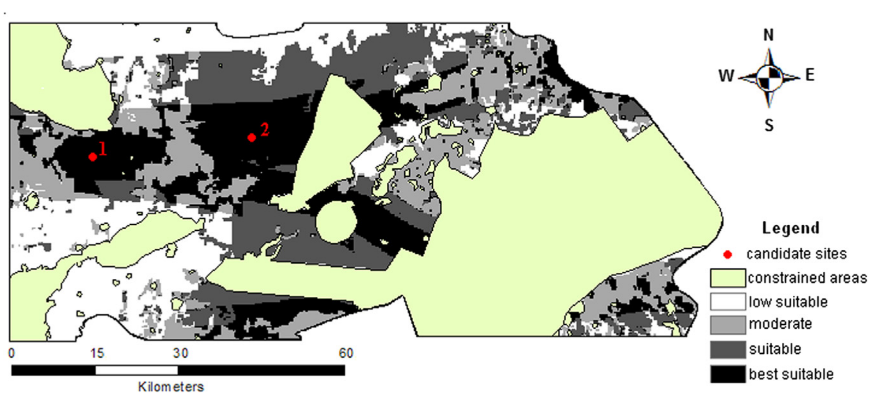

Fig. 6. Land suitability index map in the study area.

created for combined all criteria. This study can offers a methodology and decision support to the decision maker for solving the solar farms site selection.

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