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RESEARCH ARTICLE

Assessing the integration of solar power projects: SWOT-based AHP–F-TOPSIS case study of Turkey

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Abstract

Solar energy systems are a cheaper and easy solution to cope with severe energy crisis especially in emerging economies including Turkey which exerted huge efforts to enhance the existing solar power projects. However, the selection of the optimal site for the installation of solar projects needs vigorous investigation through various factors. Adequate quantitative scientific research is required for the process of site selection in Turkey. This paper categorizes various sites in Turkey through various factors such as economic, environmental, and social factors. Various major criteria have been combined through mathematical development to install the solar power project in remote areas of Turkey. The scientific evaluation of remote and rural solar projects in Turkey has been taken as a case study in the current paper. Additionally, the analytical hierarchy process (AHP) and F-VIKOR methods were used to aggregate the criteria. The results show that economic and social ratio is significant, whereas the transmission matrix, land cost, and the sun irradiance got a major score in order to generate electricity. The study results show that total sunshine time per year determined is 2741 h (a total of 7.5 h per day) and the total solar energy obtained each year is 1527 kWh per square meter per year (a total of 4.18 kWh per square meter per day).

Keywords Solar PV projects · Economic and environmental criteria · Climate Criteria · AHP · Fuzzy-VIKOR · Turkey

Introduction

Energy planning is a complex administrative issue containing numerous interconnected procedures, for example, energy production and energy distribution, in order to meet the objectives of various participants (Mohsin et al. 2018, Mohsin et al. 2019a, b, c, d). Multi-criteria decision-making is being used in energy planning studies and it can yield actual and reliable outcomes by instantaneously providing the sustaining multiple objectives. Most studies of energy development consist of investigating fossil fuel or renewable and fossil energy sources together with a relative technique. The growing energy demand has become a key problem in the world in recent decades. Urbanization, overpopulation, and industrialization have a severe impact on energy use (Topkaya 2012). Oppositely, a gap in energy demand and supply has become a major cause of concern of energy projects globally, while economic development significantly impacts the energy investments in order to satisfy the continuously rising demand of energy (Kaygusuz 2011). Various alternative options exist for handling energy demand worldwide. Inelastic and uncertain demand for various alternatives of energy, financial concerns, government policies, capacity requirements, and proper assessment for site selection are the major factors that affect the selection of suitable energy alternatives (Ayağ Z et al 2013; Márquez et al. 2014, and New Methods and Applications in Multiple Attribute Decision Making (MADM)). Today, renewable energy resources meet

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20% of the world's energy demand and also encouraged to reduce environmental losses (Mohsin et al. 2019a, b, c, d).

Turkey has taken important steps for the production of renewable energy. Turkey produced 88.81% of its electricity from local and renewable resources, and its renewable energy has reached the level of 36 GW at the end of the year 2016 (Karatas et al. 2018). This energy demand is mostly provided by hydraulic energy. Even though, currently, the renewable energy obtained from the wind and the sun is not at a satisfactory level, it increases every year (Topkaya 2012). The average duration of sunshine in Turkey is 2738 h annually, which means average sunshine of 7.5 h per day. According to recent research, it is possible for Turkey to produce 189 GWh/year of electricity from solar energy (Benli 2016). Existing reports on solar systems implementation have used multiple-criteria decision analysis methods such as analytic network process (ANP), a method for perfect arrangement comparability tilt (TOPSIS), Elimination and Choice Expressing Reality (ELECTRE), an examination of information wrap (AED), weighted linear combination (WLC), and calculation of weighted average (OWA). Geographic data framework (GIS) has been recently incorporated with the analytical hierarchy process (AHP) application, unlike other basic methodological strategies (Rediske et al. 2019). AHP is an exceptionally well-known strategy for multiple-criteria decision-making (MCDM). AHP is a four-level technique that aims to evaluate the criteria, sub-criteria, and choices for achieving the objective (Çolak and Kaya 2017) and (IEEE 2018). The AHP technique has the ability to combine subjective and quantitative factors into one model (Valasai et al. 2017). It has been used by many analysts in the field of renewable energy sources and has been the choice of renewable energy companies (Gareta et al. 2006). In the basic leadership process, MCDM strategies can help decision makers organize reasonable choices for a particular goal (Jun et al. 2014). These MCDM procedures have often been used in renewable energy strategies and arrangements. Moreover, decision makers may have different choices about individual criteria or options, and hence, the selection process is based on a cooperative choice. The determination of various locations for a renewable energy company based on a single benchmark is absolutely inadequate (Sánchez-Lozano et al. 2016). Principally, scientists have viewed AHP as an adaptable and dynamic strategy to help evaluate multifaceted choice problems (U.S. Energy Information Administration 2017). Correspondingly, in this survey, the AHP strategy will be used to resolve the site of choice issue. The F-VIKOR strategy organizes the options and recognizes the best offer. However, it is evident that such a study was not conducted in Turkey. Thus, this study employs MCDM methods in its first attempt to examine suitable sites for the installation of solar PV power in Turkey. The following sections in this paper further discuss various restriction factors and suitable decision criteria. Subsequently, AHP and F-VIKOR will be used to investigate the best site for a solar PV power project using suitable decision criteria (Cayir Ervural et al. 2018a) and (Iqbal et al. 2019). Various studies concerned with the application of the AHP and F-TOPSIS approach are shown in Table 1.

Turkey is blessed by huge potential in solar sources and faces various difficulties in developing such energy (Topcu et al. 2019; Atilgan and Azapagic 2016). The major challenge faced by Turkey is financial and technical constraints. In addition, the demand for qualified labor is also high. In this regard, it is important for the government to encourage incentives to encourage local production and investors (Cayir Ervural et al. 2018b). After the Paris conference in 2015, Turkey projected a National Determined Contribution (NDC) policy in order to minimize the dangerous impacts of climate change. Turkey's vision is to ensure the region is irrepressible to climate change through turning to a renewable economy (Nazari et al. 2018). By 2030, Turkey is committed to decreasing the carbon emissions by at a minimum 42% lower than the conventional business-as-usual (BAU) level, particularly by the large-scale installation of green energy plants. By doing so, the Turkish Energy Strategic Plan increases the installed capacity of its renewable energy by 42% in 2020 to 52% in 2030. Finally, the share of solar energy in the total national energy mix will be about 20%. While host sites are needed to be identified in the appropriate areas, not enough research has been done to recommend processing of a site for the improvement and implementation of solar energy activities in Turkey. In addition, previous studies ignored mathematical formulas for environmental, economic, social, climate, geomorphological, and locational criteria (Roinioti and Koroneos 2019; Uyan 2013a).

The purpose of this study is to propose and identify different sites in the four provinces of turkey which have sufficient solar energy potential. In addition, several criteria have been combined through mathematical formulation namely SWOT-based AHP and F-TOPSIS of economic, environmental, social, location, climate, and geomorphological criteria introduced to install the solar power project in the different regions of Turkey. The AHP strategy relates extensively to the criteria and sub-criteria of the choice system using peer review networks. A pairwise comparison matrix in the AHP and F-TOPSIS was proposed (Krejčí and Stoklasa 2018).

Methodology

The case study consists of seven cities (Finike, Alanya, Manavgat, Serik, Kemer, Kumluca, Gazipaşa) of the Antalya province of Turkey. The four provinces are climatologically and geographically different from each other as shown in Fig. 1 (Sevkli et al. 2012). The area of Antalya province is protected by the northerly winds through the Taurus Mountains. Antalya has a Mediterranean climate, hot summer hacking dry and hot weather, and also slight and rainy

Table 1 Application of AHP and F-TOPSIS

No.	Restricted factor	Reference
1	AHP dynamic strategy	(Anwarzai and Nagasaka 2017) and (González-Prida et al. 2014)
2	ELECTRE-TRI	(Sánchez-Lozano et al. 2016)
3	MCDM strategy	(Effat 2013), (Kaya et al. 2019), and (Tsai et al. 2010)
4	AHP technique	(Si et al. 2020)
5	VIKOR technique	(Hung et al. 2011), (Mardani et al. 2016), and (Alinezhad and Khalili 2019)
6	AHP pairwise comparison	(Liu et al. 2017), and (Gnanavelbabu and Arunagiri 2018)
7	F-VIKOR	(Samanlioglu and Ayağ 2019), (Opricovic 2011)
8	AHP and F-VIKOR	(Samanlioglu 2013), and (Kaya and Kahraman 2010)
9	AHP-CCI Index	(Franek and Kresta 2014)
10	Triangular fuzzy number	(Gao et al. 2020), and (Lah and Arbaiy 2019)

winters. Generally, Antalya province is sunny for about 300 days/year, having approximately 3000 h of sunlight/year, and it can be considered as an ideal site for solar installation. Average temperature lies between 16 °C during the winter season and 27 °C during the summer season (Kabak et al. 2016). The air temperature shows the highest record at 45.4 °C on 1 July 2017 (averages temperature was 34.4 °C during the season), whereas the lowest temperature was − 4.6 °C in February. Thus, the Antalya province's characteristics justify Antalya as the country's greatest significant region for solar power plant installation.

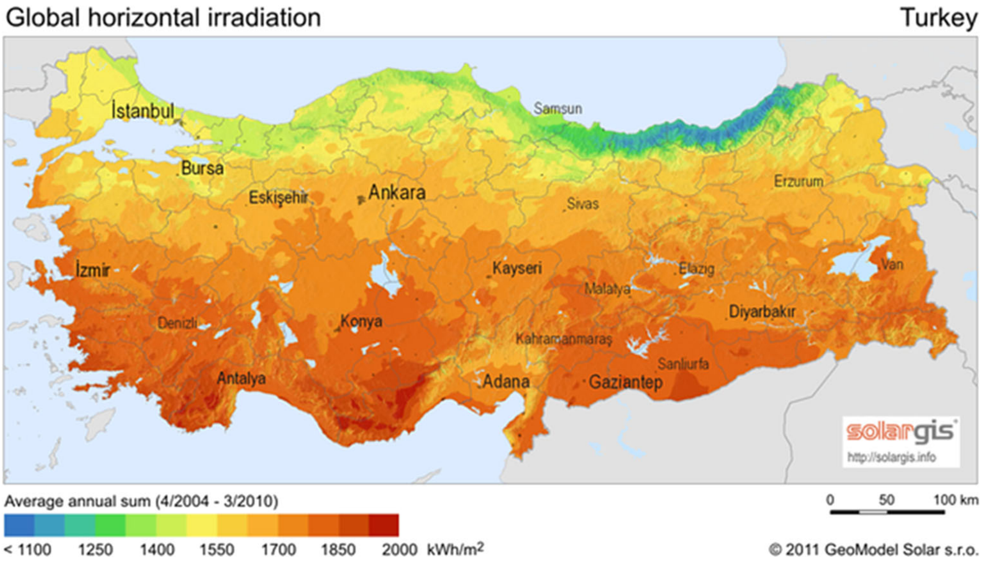
Methodology for installation criteria

Environmental criteria

A project of solar PV contains numerous solar panels that convert sunlight directly into electricity as presented in Fig. 2. These solar PV panels contain direct effects on the environment, particularly animals and plants (Lovich and Ennen 2011). Therefore, injuries and death occurred to nature and livestock because of accidents with mirror panels and they are also a probable problem that should be measured (Sindhu et al. 2017). Decrease of carbon emissions is also considered with the purpose of assessing the environmental advantages of the activities in the region of a solar PV power project installation (Liu et al. 2017). Thus, the regions that generate low carbon emissions are preferred (Mohsin et al. 2018; Mohsin et al. 2019a, b, c, d; Shiva Kumar and Sudhakar 2015).

Sunlight produced sustainable energy power. Therefore, policy makers are planning to install solar photovoltaic systems in the rural areas, so that the crude oil should be eliminated and thermal-based energy sources should be minimized to ensure zero emissions (Jabeen et al. 2014). Consequently,

Fig. 1 Solar roadmap for Turkey



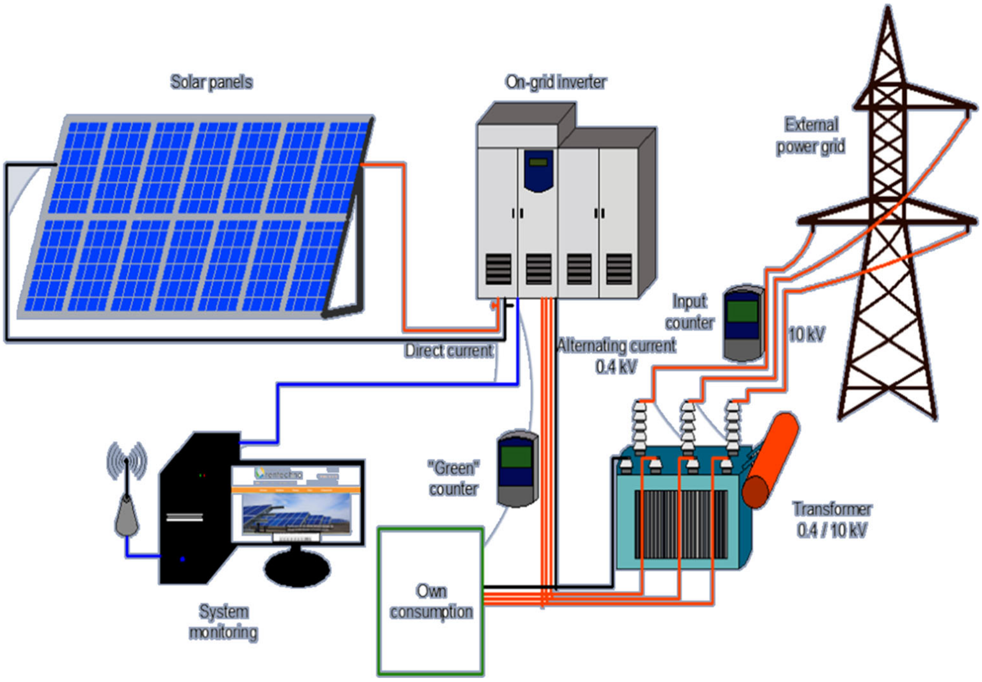


Fig. 2 Schematic diagram of a solar power plant

solar PV systems can significantly decrease CO_2 emissions (Anwarzai and Nagasaka 2017; Asbahi et al. 2019).

$$F_k = S_{pv} \times F_R \tag{1}$$

where F_R shows fuel needed to produce energy of approximately 1 kWh. Amount of dangerous gases saved and might be kept, EM_k, is derived as follows:

$$EM_k = S_{pv} \times \left(C_d - C_{pv}\right) \tag{2}$$

where C_d demonstrates the emitted carbon in kilograms (Sun et al. 2019).

Economic criteria and environmental criteria

Generally, levelized costs of energy (LCOE) can be considered to assess and compare energy costs generated from various sources (Sun et al. 2019; Iram et al. 2019). It provides energy options relying on cost efficiency. Therefore, the current paper used the case study of the system of off-grid solar photovoltaic and it measured levelized costs of energy to assess the electricity cost in kilowatt-hour. The levelized costs of energy can be evaluated as LCOE:

$$LCOE = \frac{\sum_{\alpha=1}^{n} \frac{I_\alpha + M_\alpha + F_\alpha}{(1+d)^\alpha}}{\sum_{\alpha=1}^{n} \frac{e_\alpha}{(1+d)^\alpha}} \tag{3}$$

where M_i characterized the cost of maintenance, I_α characterizes the cost of investment, F_i indicates the cost of fuel, α shows the number of years, e_i shows the amount of electricity generated in kilowatt-hour, d symbolizes the rate of discount being used, and n displays the duration of the working life of the alternative equipment. Infrastructure supply contains the lines of network transmission, street offices, and water supply (Jun et al. 2014; Babatunde et al. 2019).

Social, economic, and environmental criteria

Local community acceptance is considered as the major characteristic of any renewable energy project (Sütterlin and Siegrist 2017). Two major features can be considered in advance to install the project of solar power (Azizkhani et al. 2017). Installation of the projects of solar PV generates the opportunities of employment for the community and it contains the infrastructural situations of the region (Sindhu et al. 2017; Su et al. 2017). The technology of photovoltaic converts sunshine into electrical energy, which can be measured as

$$I_G^T = I_B^T + I_R^T + I_D^T \tag{4}$$

where I_B^T is the direct beam, I_R^T is the reflected rays of the quantity of solar energy on the surface of tilt, and I_D^T is the diffuse irradiation.

Assume G_B can be taken as the ratio for the horizontal surface mean daily direct beam while the average tilted surface direct beam, then I_B^T otherwise it can be shown as

$$I_B^T = G_B I_B \tag{5}$$

where G_B denotes the geometric parameter and it depends on the height and straight tilt. Liu and Jordan

(1961) suggested the classic of comprehensively engaged to measure G_B,

$$G_B=\frac{\cos(L_1{-}T_1).\cos Dsh.\sin i_{ss}+i_{ss}.\sin(L_1{-}T_1).\sin Dsh}{\cos L_1.\cos Dsh.\sin i_{ss}+i_{ss}.\sin L_1 Dsh} \tag{6}$$

where L_1 demonstrations the latitude, T_1 signifies the tilt angle, i_{ss} and Dsh symbolize the decreasing angles while during the day sunshine hours correspondingly (Behravesh et al. 2018). For straightforwardness, it is given as

$$I_D^T=I_D\frac{(\cos(\lambda)+1)}{2} \tag{7}$$

The reflected beam is considered to measure as

$$I_D^T=\omega(I_B+I_D)\frac{(-\cos(\lambda)+1)}{2} \tag{8}$$

Location criteria

Moreover, the available land area can help to increase the solar power RE capacity (Cherp et al. 2017; Roddis et al. 2018). Consequently, it can be concluded that the solar PV power projects should be at a minimum 500 m away from residential areas (Sun et al. 2020), as natural disasters can cause a disturbance in the solar energy supply through energy transmission distribution, thereby placing the society in a high risk. Consequently, an unconditional factor for distance was used, rather than variable of simple distance. The transmission distance and distribution factor have been employed to assess the risks at off-grid areas. Therefore, "distance risk" has been used as a variable which is calculated as follows:

$$\mathrm{DTD}=\sum\nolimits_j \mathrm{RS_j}\times\left(\frac{\mathrm{D_j}}{\mathrm{D_{max}}}\right) \tag{9}$$

where DTD means transmission and distribution distance between local territory j, $D_j$represents the remoteness for solar power, and $D_{max}=D_{max}\{\mathrm{D}_j\}$ shows the largest distance, whereas $D_j=1$ can be taken as when it is not more than 500 km, $D_j=2$ when the distance is between 1000 and 1500 km, and $D_j=3$ when it is larger than 2000 km (Uyan 2013b; Janke 2010).

Climate criteria

The sky radiance distribution and global horizontal and diffused horizontal irradiance are considered as important indicators between the sun and sky (Pattanasethanon et al. 2007; Santbergen et al. 2017) which stated that solar power capacity to generate energy is mainly reliant on radiation absorption, inter reflection, and the increasing and decreasing radiations because of adjacent impairment, as calculated by Santbergen et al. (2017). The mean value of solar incident radiation, Q_R (W/m^2), is evaluated by the value of irradiance Q_I (W/m^2), from the total incident solar radiation surface area A (m^2) (Lou et al. 2016; Alonso-Montesinos et al. 2015).

$$Q_R=\sum\left(Q_{I,j}A_j\right)/A \tag{10}$$

and

$$P_{gen}=\eta_{\mathrm{gen}}\times A_\mathrm{c}\times E_\mathrm{s} \tag{11}$$

whereas the efficiency of radiation absorption is articulated through η_{gen}, whereas A_c characterizes the getting part of solar panels while E_s shows the irradiation of global solar. The solar generator efficiency is as follows:

$$\eta_{gen}=\eta_{\mathrm{mod}}\times\eta_{\mathrm{dc/ac}}\times P_\mathrm{f}\times N_{\mathrm{mod}} \tag{12}$$

The solar module efficiency is η_{gen}, electrical efficiency can be represented through DC/AC, η_{mod} can be shown through solar modules, while P_f shows the factor of the full module (Sabziparvar and Shetaee 2007; Zoghi et al. 2015; Noorollahi et al. 2016). Carbon dioxide and water vapor are considered as the most significant solar irradiation. Therefore, regions containing greater relative humidity and water vapor contain lower capacity for deploying solar energy.

Geomorphological criteria, climate criteria, location criteria, social criteria, economic criteria, and environmental criteria

The high slope regions are not suitable for solar power projects due to very low economic viability (Charabi and Gastli 2011). The sunlight angle's height (h), the horizontal surface, and the sun elevation from 0° to 90°, in the direction of the zenith can be evaluated as follows.

$$Sin(Sh)=Sin(\delta)Sin(\theta)+Cos(\delta)Cos(\theta).Cos(Ah) \tag{13}$$

where zenith represents the angle concerning perpendicular raise while the sun direction can be evaluated as

$$Coz(Z)=Sin(\delta).Sin(\theta)+Cos(\delta).Cos(\theta).Cos(Ah) \tag{14}$$

Azimuth angle shows the angle among the location of the perpendicular superficial transient over the sun and the zenith.

$$Sin(\varphi)=\frac{\cos(\delta)*\sin(Ah)}{Cos(h)} \tag{15}$$

In order to ensure the expansion of energy capacity; variety of alternative energy sources; cost efficiency and other factors can be considered such as the social, technical, economic, political and numerous other goals and restrictions. Essential decisions while multi-dimensional and every novel principle make it increasingly more intricate and complex.

Aggregation through integrated AHP and F-VIKOR method

Analytical hierarchy process technique

This theory was first proposed by Klir (2001). Several triangular fuzzy numbers (TFN) could be used for various assessment purposes. The use of triangular (during a fuzzy situation) fuzzy numbers is useful (Shukla et al. 2014). Rating scale of TFN often used in MCDM applications is given in Table 4. The investigative methodology was proposed for the problem of energy planning. By keeping in mind the considerable escalation in the investment and strategic planning assesses the problem by engaging a F-TOPSIS methodology for the case of Turkey as a descriptive example. A definition of a fuzzy number ã can be expressed through the factors of $X = (x, y, z)$. The fuzzy number as a function of TFN is defined as

$$\mu_X(x) = \left\{ \begin{array}{ll} 0, & x < 1 \\ \frac{x-x}{y-x} & if \quad x \le x \le \mathrm{y} \\ \frac{z-x}{z-y} & if \quad y \le x \le z \\ 0, & x > 0 \end{array} \right\} \tag{16}$$

The application of other fuzzy techniques can be used consistent with the ways provided by (Kim and Chung 2013).

Fuzzy AHP and VIKOR method

The greatest problematic task is to assess and choose the suitable site selection needed to qualify the experts' criteria which have been consulted (Fig. 3); meanwhile, the weights measured by individuals are mostly uncertain and controversial (Vafaeipour et al. 2014). Generally, academia's research forecasters, policy makers, professors, stakeholders, and executives are asked to investigate the weights score (Janke 2010). With the intention of attaining the objective of this research, authors have consulted with 10 professionals from an academic background, energy researchers, government energy institutes, and related stakeholders. These experts have experience in their field of specialization, and they are aware of the country's current situation and environment. The 10 experts' outcomes and opinions were authenticated by means of consistency index and random consistency index, proposed by (Saaty 1980). The software YAAHP (V. 10.5) has been utilized for obtaining weightages of the proposed criteria of the study. Table 2 shows the variables for fuzzy numbers.

Step 1. Construct the fuzzy performance matrix and weight vector and as follows:

$$\widetilde{D} = \begin{array}{c} \\ O_1 \\ \vdots \\ O_n \\ \\ \\ \end{array} \left[\begin{array}{cccc} & C_1 \; C_2 \cdots C_n & & \\ & \widetilde{p}_{11}\widetilde{p}_{12}\cdots\widetilde{p}_{1n} & & \\ & \widetilde{p}_{21}\widetilde{p}_{22}\cdots\widetilde{p}_{2n} & & \\ \vdots & \vdots \quad \vdots & & \vdots \\ & \widetilde{p}_{m1}\widetilde{p}_{m2}\cdots\widetilde{p}_{mn} & & \end{array} \right] \tag{17}$$

$$\widetilde{W} = (w_1, w_2, w_3), \sum_{j=1}^{n} w_j = 1$$

where O_i represents the substitute choices, for example, i, i.e., $i = (1, 2, 3, \ldots, \mathrm{m})$; C_j shows the proposed choices O_i regarding standards C_j, $\widetilde{W}_j$ signify the fuzzy weight every one planned obtainable criteria. Consequently, TFN measured as through $\widetilde{p}_{ij} = (x_{ij}, y_{ij}, z_{ij})$.

Step 2. Estimate mathematical numbers for benefit criteria $\widetilde{p}_i^+ = (x_i^+, y_i^+, z_i^+)$ along with the cost criteria $\widetilde{p}_i^- = \left(x_i^-, y_i^-, z_i^-\right)$. The set of vector is accessible through l^b while cost criteria are articulated asl^c.

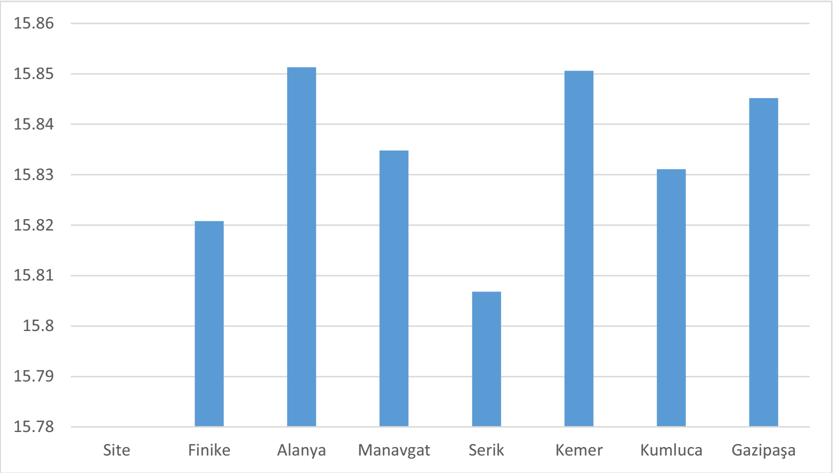


Fig. 3 Site S_i score based on AHP and F-TOPSIS

$$\overset{+}{\widetilde{p}_i} = max_j\, \widetilde{p}_{ij}, \overset{-}{\widetilde{p}_i} = min_j\, \widetilde{p}_{ij} \text{ for } i \in l^b$$
$$\overset{+}{\widetilde{p}_i} = min_j\, \widetilde{p}_{ij},\ \ \overset{-}{\widetilde{p}_i} = max_j\, \widetilde{p}_{ij} \ \text{ for } \ \ i \in l^c \tag{18}$$

Step 3. Done the fuzzy decision matrix $\widetilde{D}_{ij}$ normalization

$$\widetilde{D}_{ij} = \frac{\overset{+}{\widetilde{p}_i}(-)\widetilde{p}_{ij}}{z_i^+ - l_i^-} \quad \text{for} \quad i \in l^b$$
$$\widetilde{D}_{ij} = \frac{\widetilde{p}_{ij}(-)\overset{+}{\widetilde{p}_i}}{z_i^- - l_i^+} \quad \text{for} \quad i \in l^c \tag{19}$$

Step 4. Compute standards values as follows:

$$\widetilde{S}_j = \left(\widetilde{S}_j^x, \widetilde{S}_j^y, \widetilde{S}_j^z\right) \text{ and } \widetilde{R}_j = \left(\widetilde{R}_j^x, \widetilde{R}_j^y, \widetilde{R}_j^z\right)$$
$$\widetilde{S}_j = \textstyle\sum_{i=1}^n \widetilde{W}_i(\times)\, \widetilde{D}_{ij} \tag{20}$$

$$\widetilde{R}_j = max_i\, \widetilde{W}_i(\times)\, \widetilde{D}_{ij} \tag{21}$$

Step 5. Determine standard numerical values of $\widetilde{Q}_j = \left(\widetilde{Q}_j^x, \widetilde{Q}_j^y, \widetilde{Q}_j^z\right)$:

$$\widetilde{Q}_j = v\frac{\widetilde{S}_j(-)\overset{+}{\widetilde{S}}}{S^{-z} - S^{+x}}(+)(1-v)\frac{\widetilde{R}_j(-)\overset{+}{\widetilde{R}}}{R^{-z} - R^{+x}} \tag{22}$$

here, $\overset{+}{\widetilde{S}} = min_j\, \widetilde{S}_j$; $S^{-z} = max_j S_j^z$; $\overset{+}{\widetilde{R}} = min_j \widetilde{R}_j$; $R^{-z} = max_j R_j^x$

Additionally, represents the group strategic weight against the proposed criteria $\widetilde{S}_j$, whereas $(1 - v)$ represents the dissimilar weight of $\widetilde{R}_j$.

AHP and Fuzzy-VIKOR valuation

The technique of the paper is determined to construct an important mathematical model through the proposed framework achieved through measuring the most optimal location for solar PV power projects, as accessible in the following section.

Table 2 Fuzzy numbers factors

Sr. number	Linguistic variables	TFN
1	Very bad (VB)	(0, 0.05, 0.15)
2	Bad (B)	(0.1, 0.2, 0.3)
3	Fairly bad (FB)	(0.2, 0.35, 0.5)
4	Fairly (F)	(0.3, 0.5, 0.7)
5	Fairly good (FG)	(0.5, 0.65, 0.8)
6	Good (G)	(0.7, 0.8, 0.9)
7	Very good (VG)	(0.85, 0.95, 1)

Results and discussion

The AHP framework that prioritizes the fuzzy-VIKOR factors affecting the location of the Turkish solar power plant can be divided into three parts: geomorphological criteria; climate criteria; and location criteria, social criteria, economic criteria, and environmental criteria.

Fuzzy-VIKOR application for Turkey's solar energy integration

Therefore, the research outcomes are aligned with the goal of a suitable target for both a transportation hub and a hub. The problem of performance source planning has become important across the country. Because of their strategic importance, governments are working to mitigate negative consequences; they need to plan energy policy integration.

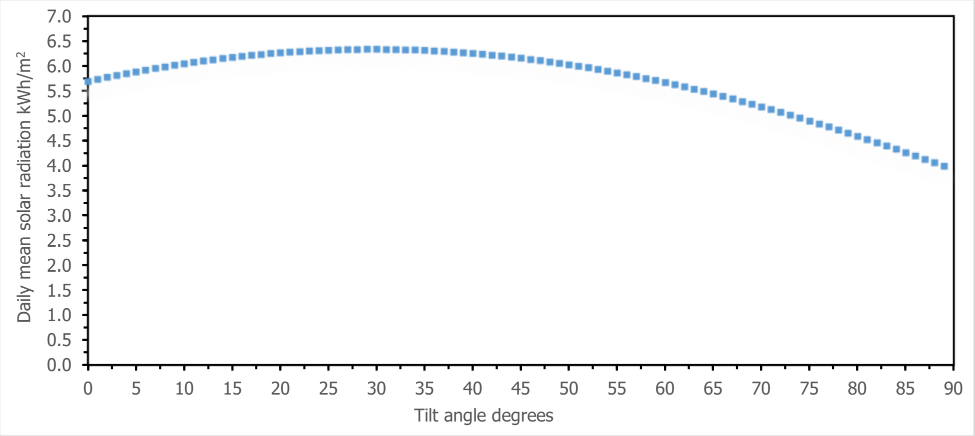
The oil sector provides resource diversity. The measures needed to decrease import risks and use nuclear energy technology in the energy supply. One of the salient points of the results is that the strategy has the lowest priority. In this study, six criteria were developed which strongly affect the solar power site selection. These criteria contain geographical criteria, climate criteria, location criteria, economic criteria, social criteria (SC), and environmental criteria. The ranking of each criterion has been conducted through the expert's opinion in order to attain an Eigenvalues. The values of RI (1.12) from Table 1 and CI (0.0716398) from Table 3 were utilized which lastly guides to 0.0640 value of CR in a satisfactory range.

Six fuzzy-VIKOR factors consisting of twenty sub-criteria were measured. Further AHP method has been done on sub-criteria to obtain the local properties and ranking of each

Table 3 Criteria for Turkey's solar site selection

Criteria dimension	SSA	TTA	EEC	EEN	PPA	Global priority weighting	Rank
SA	2	0.5	1	0.33	0.5	0.099	5th
TA	1	1	1	1	0.5	0.184	3rd
EC	2	2	0.5	1	0.5	0.242	2nd
EN	1	0.5	1	2	0.5	0.156	4th
PA	1	2	2	2	1	0.318	1st

Fig. 4 Solar irradiation from 0 to 90 tilt angle degree



standard, and subsequently, local priorities and ranking were attained. The results show ranking, weights, CI, and maximum Eigenvalues of each sub-criteria. Turkey is considered as the largest solar power source and they presented the results of solar energy potential assessment. The survey assessment shows that Turkey owns the per year mean overall insolation of 2640 h (7.2 h/day) while the yearly mean solar energy of Turkey is 1480 kWh/m^2/year. Furthermore, TSMS demonstrated the model of Turkey's solar power potential by the duration of insolation radiation while the data gathered by 157 weather stations of TSMS (Fig. 4). The design of solar energy potential presented by TSMS findings shows the average annual insolation of Turkey's is 2494 h (7 h/day). Turkey has an annual average duration of insolation of 2738 h (7.5 h/day) and yearly mean solar energy of 1527 kWh/m^2/year (4.2 kWh/m day). SEPA used the area and types of PV and the quantity of solar energy generated by sunshine, and they declared that Turkey is the best and suitable country for solar energy mix.

Table 4 shows site selection through criteria dimension. Turkey's solar power plants have a capacity of 5995 megawatts (MW), geothermal target to increase the capacity up to 2000 MW by 2020, and biomass capacity is about 800 MW. Increased population, economic development, and suburbanization are forcing administrations to re-strategize to counter growing power demand.

Table 4 Site selection through ranking of sub-criteria (dimension 2)

Criteria dimension	SA1	SA1	SA3	SA3	SA4	Global priority weighting	Rank
SA1	2	1	2	0.33	1	0.099	5th
TA2	1	0.5	1	2	1	0.184	3rd
EC3	2	2	0.5	2	0.5	0.242	2nd
EN4	1	0.5	1	1	0.5	0.156	4th
PA5	1	1	2	2	1	0.318	1st

Table 5 shows site selection through technical aspects. Solar energy is obtained by collecting sunlight from solar or photovoltaic cells and then focusing it on a mirror to generate a high-intensity heat source that operates a generator to generate electricity. Solar energy can be used for cooling, lighting, heating, and other energy needs. Turkey has high solar potential due to its geographical location. According to the Turkish solar energy map drawn by the General Administration of Renewable Energy, the total sunshine time per year has been determined to be 2741 h. This corresponds to 4% of the total potential. In 2017, solar power generation reached 2684 GWh, of which 0.91% of electricity came from solar energy (http://www.enerji.gov.tr/zh-CN/Pages/Solar, 02.07.2018).

In order to arrest these multi-dimensional and complex difficulties, various mathematical methods have been introduced. Results show that political and environmental factors (Table 6) have directed to the development of new complications towards the problems of energy-planning. These complications require instantaneous assessment. The studies concentrating merely on the sources of renewable energy and overall advantages are quite inadequate, in spite of the current intensification in renewable energy and interest in this area. Most importantly, very few studies focused on the planning of Turkey's renewable energy since the models of energy planning are established which might be reliant on the local source diversity and energy policies.

Table 5 Site selection through ranking of sub-criteria (dimension 3)

Technical aspect	TTA1	TTA2	TTA3	Local priority weight	Rank
TA1	2	2	1	0.4934	1st
TA2	0.5	1	0.5	0.1958	3rd
TA3	2	2	2	0.3108	2nd

Table 6 Site selection through ranking of sub-criteria (dimension 4)

Economical aspect	EEC1	EEC2	EEC3	Local priority weight	Rank
EEC1	2	1	1	0.1634	3rd
EEC2	1	2	0.5	0.297	2nd
EEC3	3	1	0.33	0.5396	1st

Tables 7 and 8 show the global weights and the ranking of the six criteria used in this study. The overall importance of the fuzzy-VIKOR factor and the associated sub-factors was measured by multiplying the global weight and the local weight of the sub-criteria, in which political criteria are ranked as No. 1 and its global weight value is 0.3181. After finding the global weight of each factor, the factors are arranged according to their rank.

With these conditions in mind, the Turkish government plans to meet 30% of Turkey's electricity demand through RES in 2023. Therefore, for Turkey, the important decision is whether to establish a renewable energy system and decide which renewable energy or multiple energy combinations is the best choice. In addition, because the investment cost of building a renewable energy structure is high, it is important to choose the best alternative among different renewable energy sources from the perspective of long-term planning. The results can be changed by changing the weights of different criteria and expert opinion. Tables 9 and 10 show the ranking of the alternative location for a solar farm.

Conversely, taxes on batteries and solar inverters are still greater, approximately 50%. Moreover, the decision makers and policy makers failed to deliver encouragements intended in place of households to connect the system of solar power, demonstrating the disadvantage of policies. Carbon-free energy through the solar source is the main method to deal with the economic and environmental and challenges instigated through climate change. Accumulative monetary expansion and decreasing CO_2 emissions level are mutual goals important for low-carbon economy (Mathiesen et al. 2011; Sun et al. 2019). Therefore, there is a dire need to measure the installation criteria of solar power and it is an appreciated appliance for policy makers. Meanwhile, a cumulative amount of CO_2 emissions threaten the environment, sustainability, and living life at a global level.

Table 7 Site selection through ranking of sub-criteria (dimension 5)

Environmental aspect	EN1	EN2	EN3	EN4	Local priority weight	Rank
EEN1	2	1	1	1	0.1205	4th
EEN2	1	0.333	0.5	1	0.4182	1st
EEN3	3	1	2	2	0.1906	3rd
EEN4	2	0.5	1	0.50	0.2707	2nd

Table 8 Site selection through ranking of sub-criteria (dimension 6)

Political aspect	PA1	PA2	PA3	PA4	Local priority weight	Rank
PA1	1	0.3333	0.5	0.5	0.1205	4th
PA2	3	1	2	2	0.4182	1st
PA3	2	0.5	1	0.5	0.1906	3rd
PA4	2	0.5	2	1	0.2707	2nd

Globally feed-in tariffs have largely determined the huge success especially in Germany as a global example in renewable energy like solar and wind, thanks to its known renewable Energy Act (EEG), which was introduced in the 1990s, which is benchmarked by many countries globally. Liew et al. (2017) says that FITs are plausible to boost renewable capacity and must be adjusted periodically according to the pricing model suggested in their study. Another study by Maulidia et al. (2019) says FITs are the known tools used to promote investment in the renewable sector as they guarantee long-term contracts with investors in the renewable energy sector. Inversely, Yu et al. (2020) in their study came out with contrasting results, which says FITs may lead to wind energy capacity curtailment in China. That is, an intended loss of wind energy generated or wasted energy generated. Energy demand also proves to be significant from the model. It explains the total energy needs of the country. Turkey has an annual energy demand that explains that energy demand has a direct impact on wind energy capacity in addition to the country. As energy demand increases, solar energy demand increases. When energy demand increases by one unit, solar energy capacity will increase. Based on the above, after interacting wind capacity and licensing duration, the results from the model do not change. FITs, energy demand, RPO, licensing duration, and GDP are still significant. And percent of wind on the grid and sown area are not significant. One thing worthy of note is the "cross" variable that shows solar capacity × licensing duration is perfectly significant. Therefore, the duration of getting a license and solar capacity is a very key determinant of solar energy capacity addition in Turkey.

Sensitivity analysis

In order to investigate the impact degree/strength, we use different levels of standard weights to measure changes in results. Table 11 gives the advanced SWOT factor weights (used as standard weights in the case of inspections), and Table 12 shows the strategy sensitivity results obtained from the sensitivity analysis.

The interest laid the foundation because proper involvement in integration requires energy planning which has

Table 9 Weights of priority and ranking of site selection

Scopes of barriers	Dimension's weight	Positions of dimensions	Sub-criteria	Local weight of sub-barriers	Global weights of barriers	Overall rankings of barriers
Social aspect (SA)	0.099	5th	Impact on agriculture, employment, and travel (SA1)	0.1155	0.0114	18th
			Outcome of the financial progress of the adjacent region (SA2)	0.1634	0.0161	17th
			General acceptance (SA3)	0.231	0.0229	15th
			Distance from housing area (SA4)	0.4901	0.0485	9th
Technical aspect (TA)	0.1844	3rd	Solar energy data accessibility (TA1)	0.4934	0.091	3rd
			Skilled manpower (TA2)	0.1958	0.0361	13th
			Climatic conditions (TA3)	0.3108	0.0573	7th
Economical aspect (EC)	0.2522	2nd	Substructure cost (EC1)	0.1634	0.0396	11th
			Transmission grid accessibility (EC2)	0.297	0.0719	5th
			Road accessibility (EC3)	0.5396	0.1307	2nd
Environmental aspect (EN)	0.2162	4th	Graphic impact (EN1)	0.1205	0.0188	16th
			Wildlife and endangered species impact (EN2)	0.4182	0.0653	6th
			Sound impact (EN3)	0.1906	0.0298	14th
			Harmful toxin emission (EN4)	0.2707	0.0423	10th
Political aspect (PA)	0.3181	1st	Public policies (PA1)	0.1689	0.0537	8th
			Supervisory boundaries (PA2)	0.119	0.0379	12th
			Acquisition of land (PA3)	0.4511	0.1435	1st
			Relocation and reintegration (PA4)	0.2609	0.083	4th

become a critical challenge for countries, starting with domestic/national resources and then external importing resources to meet energy plans. Table 12 shows the sensitivity analysis.

The Turkish government has proposed some quite energy policies to cope with the growing demand for energy in order to avoid medium and long-term energy bottlenecks. With the purpose of decreasing energy reliance on foreign resources, certain key applications have been undertaken. Turkey's main energy strategy is to achieve established energy goals. It should be noted that technology investment is a crucial and comprehensive framework. The strategic position of transforming the country into an energy hub and energy terminal is a top priority. On the one hand, Turkey is in between the major oil-producing regions in the Middle East and the Caspian Sea. On the other hand, it is a natural "energy bridge" between European consumer markets. The region is important not only geographically but also economically. Levelized cost explains the cost per unit produced by a plant of its entire lifespan. It is used to compare and choose the best

Table 10 Ranking of the alternative location for a solar farm

Code	Solar plant	S_i	R_i	Q_i	Rank
A1	Finike	0.4119	15.8208	0.8633	4
A2	Alanya	0.3762	15.8513	0.8652	6
A3	Manavgat	0.3988	15.8348	0.864	5
A4	Serik	0.433	15.8068	0.8621	2
A5	Kemer	0.375	15.8506	0.8653	7
A6	Kumluca	0.366	15.8311	0.8623	3
A7	Gazipaşa	0.303	15.8452	0.8613	1

Table 11 SWOT analysis

Strengths (+)	**Weaknesses (−)**
1. National laws and regulatory	1. Poor grid system framework
2. Availability of experienced workforce	2. Poor culture of maintenance
3. Potential of uranium deposits	3. Lack of investment will
4. Minor history of seismic events	4. Lack of adequate financing
5. Huge renewable potential	5. Huge capital cost
6. Favorable choices for sustainable development	6. Demand of technical labor
Opportunities (+)	**Threats (−)**
1. Increasing energy demand	1. Dominance of fossil fuels
2. Regional interconnection	2. Porous security system
3. Increasing global awareness of climate change	3. Corruption
4. Availability of foreign investors	Discontinuity of energy
5. Policies	5. Nonpermanent financial incentives

Table 12 Sensitivity analysis of fuzzy-VIKOR method

Experiment	AA1	AA2	AA3	AA4	AA5	AA6	AA7
1	0.9883	0.9904	0.9903	0.9878	0.9899	0.9832	0.988
2	0.9895	0.9912	0.99	0.9903	0.9885	0.9821	0.9751
3	0.988	0.99	0.9856	0.9895	0.9751	0.9901	0.985
4	0.9856	0.9904	0.9881	0.9882	0.985	0.988	0.9854
5	0.9884	0.9905	0.9859	0.9854	0.988	0.9751	0.9885
6	0.9751	0.9885	0.9852	0.9757	0.9751	0.985	0.9896
7	0.9747	0.9852	0.9769	0.9852	0.985	0.9854	0.9882
8	0.9906	0.9902	0.9908	0.9883	0.9854	0.9885	0.9882
9	0.9879	0.989	0.986	0.9746	0.9885	0.9896	0.9882
10	0.9884	0.9905	0.9859	0.9854	0.9896	0.9882	0.9847
11	0.9883	0.9901	0.9888	0.9897	0.9882	0.9882	0.9896
12	0.9896	0.9756	0.9857	0.9893	0.9882	0.9882	0.9882
13	0.9879	0.9754	0.985	0.9764	0.9882	0.9847	0.9906
14	0.9895	0.9912	0.99	0.9903	0.9847	0.9896	0.99
15	0.9896	0.9885	0.9888	0.9854	0.9896	0.9882	0.988

technologies available that are efficient and effective in producing electricity. Generally speaking, it comes in handy in making economic decisions regarding projects and the utility rates being offered in electricity project development. It is, however, worthy of note that one negative side of using the LCOE is that it does not address likely social and environmental externalities and the long-term consequences of conventional generational technologies that are hard to capture in the measurement.

Conclusion and policy implication

Turkey has been the fastest-growing country in OECD having the reliance on energy imports coupled with increased energy costs, and the severe negative impact of high energy consumption on the environment has increased the importance of renewable energy. As reported by the General Administration of Renewable Energy, the total sunshine time per year determined to be 2741 h (a total of 7.5 h per day) and the total solar energy obtained each year of 1527 kWh per square meter per year (a total of 4.18 kWh per square meter per day) show potential of Turkish solar energy. This corresponds to 4% of the total potential. Turkey is taking serious actions to better utilize the resources of renewable energy. Consistent with the vision of 2023, they have plans to enhance renewable energy shares in its national electricity production at a minimum of 30%.

For decades, relying on foreign oil and gas for energy production (still so, although not so serious), a new generation of policymakers has been keen to explore the potential of new alternatives (since Turkey seems to be one of them). Countries with a lot of renewable/sustainable/green energy opportunities (such as wind, solar, hydropower) have the potential to reduce economic pain/reliance on external resources while improving environmental impacts. Limitation of the study contains the regional insights specific for Turkey whereas the techniques of AHP, F-TOPSIS, and ELECTRE can be used for the integration of wind and solar hybrid renewable energy installation.

1. The Turkish government should install numerous projects of renewable energy in order to fully utilize the opportunities for renewable energy.
2. 2. In the region, there should be a roadmap for cross-border electricity trade.
3. The Turkish government should launch a plan of 100% renewable energy to progress the energy security of the country.
4. There should be a major regulatory framework in order to install RE projects, for basic options including beginner exams.
5. The wide range of ozone-depleting substances (GHGs), environmental changes, natural pollution, and depleted reserves of non-renewable energy sources should become an issue of increasing concern to the government.
6. A renewable energy utilization policy should be formulated, which should focus on solar and sufficient global irradiance.

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