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RESEARCH ARTICLE

Assessing the solar PV power project site selection in Pakistan: based on AHP-fuzzy VIKOR approach

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Abstract
Pakistan has an abundant solar power potential which can be effectively utilized for the electricity generation. There are various sites across the country which have sufficient solar irradiation across the year, and thus, suitable for the installation of solar photovoltaic (PV) power projects. This study, therefore, aims to undertake research on the establishment of solar power project site selection in Pakistan. In this context, 14 promising cities of Pakistan are considered as alternatives and studied in terms of economic, environmental, social, location, climate, and orography criteria and further supplemented with 20 sub-criteria. Initially, the analytical hierarchy process (AHP) method has been used to prioritize each of the main criteria and sub-criteria. Later, fuzzy VlseKriterijuska Optimizacija I Komoromisno Resenje (F-VIKOR) method has been employed to prioritize the 14 alternatives. The present investigation reveals that Khuzdar (C2), Badin (C3), and Mastung (C7) are the most suitable cities for the installation of solar PV power projects in Pakistan. Finally, the outcome of the sensitivity analysis revealed that obtained results are reliable and robust for the installation of solar PV power projects in Pakistan. This study shall assist government, energy planners, and policymakers in making cities sustainable by establishing solar power projects in Pakistan.

Keywords Solar PV power project · Site selection · Sustainable cities · AHP · Fuzzy VIKOR · Pakistan

Introduction

Solar is one of the most powerful, sustainable, effective, clean, and accessible source of energy on the earth (Rezaei et al. 2018). Solar energy can be very useful for the cities with a strong solar irradiance throughout the year. This source of energy eliminates the need and use of fossil fuels such as coal, oil, and natural gas for electricity generation and is particularly suitable for cities which do not have access to electricity. Further, solar energy including other renewable energy (RE) sources such as wind, biomass, hydro, and geothermal energy is also considered as clean and sustainable and helps to cope with the increasing environmental concerns (Saracoglu et al. 2018). Further, climate change is a challenging issue in all over the world (Solangi et al. 2018); thus, the growing concern about the increasing levels of greenhouse gases (GHGs), environmental pollution, and the depleting reserves of fossil fuels has drawn global attention towards the utilization of RE sources specifically solar energy for electricity generation (Zameer and Wang 2018). Solar energy is an abundantly available source, and it depends on the solar irradiance with an average number of daily sunlight hours in the region (Xu et al. 2019). In case, any city which has enough global horizontal irradiance (GHI) throughout the year, then it is generally termed as favorable for the installation of solar photovoltaic (PV) power projects.

Solar power generation system has economic, social, and environmental benefits (Perpiña Castillo et al. 2016). Moreover, the selection of sites plays a significant role in efficiency, operating cost and final power output of solar power projects (Shiva Kumar and Sudhakar 2015). Recently, Pakistan has installed various renewable energy (RE) projects to harness its potential for electricity generation (Solangi et al. 2019). The government has developed RE plans which aim to install different RE-based power projects in the country. However, the key challenge related to the site selection of such projects is one of the critical decisions which require to

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consider various criteria and undertake a preliminary investigation.

Solar PV technology is very suitable to install in huge land areas, where solar irradiation is very high and available throughout the year (Al Garni and Awasthi 2017). However, there are various key barriers in the development of PV technology; one of the main barriers is the discrepancy of solar irradiation from one site to another due to the different geographical conditions of the area of the city. Therefore, to select and install a solar PV project site selection, various aspects must be considered and evaluated. For instance, the maximum power output from solar panels and minimum total cost of the solar power project, including other important aspects, must be examined.

The various criteria can influence the solar PV power project site selection; to tackle this issue, the multi-criteria decision making (MCDM) techniques are very significant in assessing the key criteria for installation and selection of a solar PV power project. Further, it is identified that MCDM techniques are effectively used in energy planning problems. A significant literature review is available on the applications of MCDM methods in RE sources planning (Al Garni and Awasthi 2017; Mateo 2012; Wang et al. 2009). Therefore, the evaluation and selection of proposed solar PV site is a crucial strategic process as suggested by the National Renewable Energy Laboratory (NREL). The solar PV power project site selection is a vital decision process; thus, several key steps should be carefully considered (Noorollahi et al. 2007). First, the restriction criteria and suitable decision criteria should be well considered for installation of solar PV projects; second, the methodology-based ranking of proposed sites; and finally, the sensitivity analysis can be conducted to draw insights into the obtained results.

The assessment of solar PV potential in Pakistan shows that solar energy is the most favorable option for electricity generation (Bhutto et al. 2012). As such, this study aims at exploring the MCDM techniques for the selection of an appropriate site of a utility-scale solar PV power projects in Pakistan. A utility-scale solar project is one which generates solar power and transmits it into the on-grid station and supplying a utility with energy. Therefore, this study has proposed a decision model that hybrids the analytical hierarchy process (AHP) and fuzzy VlseKriterijuska Optimizacija I Komoromisno Resenje (F-VIKOR) as MCDM techniques with data on sites obtained from the National Aeronautics and Space Administration (NASA) database. As such, these MCDM methods shall provide further insights into various suitable decision criteria which can aid the government and policymakers in the development of solar power project site selection.

It is also pertinent to mention that, in Pakistan, the selection and prioritization of the solar PV sites have also not been investigated appropriately in contemporary literature. In this context, 14 cities of the country have been taken into account to identify the most optimal sites for the development of the utility-scale solar PV power projects in Pakistan. These cities include Bannu, Khuzdar, Badin, Multan, Mardan, Hyderabad, Mastung, Karachi, Nawabshah, Turbat, Sahiwal, Peshawar, Quetta, and RahimYar-Khan, respectively. Further, this study has identified the 6 main criteria and 20 sub-criteria, which has been obtained from the literature review. The key MCDM methods, i.e., AHP and F-VIKOR, are used to realize the objective of this study. Here, the AHP method is used to assign the weights to criteria and sub-criteria using a pairwise comparison matrix; and, the VIKOR method is employed to classify the various alternatives. Researchers usually criticize the VIKOR method because it ignores the uncertainties and hesitancies (Tian et al. 2018). To address this shortcoming, the fuzzy set theory which addresses the uncertainties appropriately is supplemented along with the VIKOR method. It is important to mention that it is not always necessary that the criteria may have arithmetical values, but can also comprise the subjective data in linguistic variables and their significance can be depicted through a fuzzy membership (Rodríguez and Martínez 2013). This important aspect is duly covered in this study.

The rest of the paper is structured as follows: MCDM applications applied in solar power project are presented in the "MCDM applications applied in solar power project site selection" section. Potential and progress of solar power are discussed in the "Potential and progress of solar power in Pakistan" section. The research framework of the study is given in the "Research framework" section. The "Results and discussion" section presents the results and relevant discussion. Finally, the conclusions drawn based on this study are provided in the "Conclusion" section.

MCDM applications applied in solar power project site selection

In the decision-making process, the MCDM methods can aid decision-makers to prioritize suitable alternatives with several criteria for a specific goal (Afsordegan et al. 2016). The MCDM techniques have been frequently employed in RE sources planning and policies. Moreover, the various decision-makers might have dissimilar decisions about the individual criteria or alternatives, and thus, group decision-making is utilized in the decision process. The selection of different sites for RE project-based and relying on just one criterion is insufficient (Loken 2007).

The GIS-AHP based study conducted in southern Morocco to analyze the grid-connected 10 MW solar PV potential in the area and the researchers identified that 24% of the area is very suitable for the installation of solar farms (Tahri et al. 2015). A similar study conducted for eastern Morocco using AHP method and authors identified that 19% of the land is suitable for installation of large-scale solar PV plant (Alami Merrouni et al. 2018b).

The solar PV site selection problem has been evaluated in Saudi Arabia using AHP method; for this purpose, the authors computed land suitability index to identify the suitable location (Al Garni and Awasthi 2017). In another study, the solar PV natural potential was evaluated in Serbia using AHP method, and it was identified that climate, vegetation, and orography have a significant influence on sitting of ground-mounted PV (Doljak and Stanojević 2017). Wang et al. 2018 used data envelopment analysis (DEA), fuzzy AHP, and TOPSIS method to assess and rank the solar power plants in Vietnam. Further, AHP and TOPSIS method has been used in India from multi-perspectives such as economic, environmental, social, technical, and political to evaluate and rank the solar PV farms location (Sindhu et al. 2017). The various studies on the solar PV site selection are listed in Table 1. It is also identified from Table 1 that the AHP method has been extensively used for solar PV site selection. The geographic information system (GIS) application has been most often integrated with AHP application as compared with other decision-making methods. AHP method has a strength to combine the qualitative and quantitative factors in one model (Wichapa and Khokhajaikiat 2018). Therefore, this method has been considered as a most famous method of MCDM; and it has been utilized by many researchers in the field of RE sources allocation, conventional and RE planning, and RE project selection (Shah et al. 2019). In general, the AHP technique has been recognized by the researchers as a flexible and robust method to help in evaluating a multifaceted decision problem (Dehe and Bamford 2015).

It is evident that there are many studies available in the literature for the development of a solar PV power project site selection. However, this strategic decision problem for the selection of PV sites is missing in the context of Pakistan. Thus, this study has employed the MCDM methods (i.e., AHP and F-VIKOR) to investigate the suitable sites for the installation of solar PV power projects in Pakistan. To the best of our knowledge, this study is very first attempt to investigate and prioritize the solar PV power projects site selection in Pakistan. Therefore, in the study, the AHP technique is employed to determine the weights of suitable decision criteria and rank them accordingly. The second commonly employed application is fuzzy VIKOR. This method has a simple computational procedure to solve the problem under a fuzzy environment and then allows for prioritizing the alternatives and identifies the solution with compromise and closeness to the best solution. Thus, F-VIKOR method will be utilized to evaluate the various alternatives for the site selection of a solar PV power project in Pakistan.

The following section further determines the various suitable decision criteria pertaining to the development of solar PV power projects site selection.

Suitable decision criteria applied in solar power project site selection

The various decision criteria must be considered and analyzed for the establishment of solar PV power project site selection. So, it would ensure to become more significant and efficient power system, less impact on the environment and economic suitable. The obtained decision criteria and their sub-criteria for solar PV power project site selection have been derived from the study by Al Garni and Awasthi 2018. Therefore, in this study, the 6 main criteria, i.e., economic, environmental,

Table 1 Applications of MCDM methods used in solar PV project selection

RE source	Grid	Method	Country	Reference
Solar PV	On	AHP	Morocco	(Tahri et al. 2015)
Solar PV	On	AHP	Morocco	(Alami Merrouni et al. 2018b)
Solar PV	On	AHP	Saudi Arabia	(Al Garni and Awasthi 2017)
Solar PV	On	AHP	Serbia	(Doljak and Stanojević 2017)
Solar PV-CSP	On	AHP	Egypt	(Effat 2013)
Solar PV-CSP	On	AHP	Turkey	(Uyan 2013)
Solar PV-Wind	On	AHP	China	(Yunna and Geng 2014)
Solar PV-Wind	On	AHP	UK	(Watson and Hudson 2015)
Solar PV	On	DEA-FAHP and TOPSIS	Vietnam	(Wang et al. 2018)
Solar PV	On	Fuzzy-AHP	Korea	(Suh and Brownson 2016)
Solar PV	On	Fuzzy-AHP	Iran	(Noorollahi et al. 2016)
Solar PV-CSP	On	AHP	Tanzania	(Aly et al. 2017)
Solar PV	On	AHP-TOPSIS	Spain	(Sánchez-Lozano et al. 2013)
Solar PV	On	Fuzzy ANP and VIKOR	Taiwan	(Lee et al. 2017)
Solar PV	On	AHP-fuzzy TOPSIS	India	(Sindhu et al. 2017)
Solar PV-Wind	On	ELECTRE-II	China	(Jun et al. 2014)
Solar PV	On	TOPSIS-ELECTRE-III	Spain	(Sánchez-Lozano et al. 2016)
Solar PV-CSP	On	AHP-fuzzy OWA	Oman	(Charabi and Gastli 2011)
Solar PV	On	FAHP-DEA	Taiwan	(Lee et al. 2015)

Table 2 Most suitable decision criteria used in solar PV studies (Al Garni and Awasthi 2018)

Criteria	Sub-criteria	Description
Economic (EC)	Cost of land (EC1)	A huge amount of land is required for the construction of solar PV power project. Therefore, the city with low-cost land is suitable for the construction of the solar energy project.
	Infrastructural cost (EC2)	The power generation from solar projects requires a well infrastructural system, such as road facilities, on-grid transmission lines accessibility, water supply, and some other infrastructural development. Therefore, the area which requires low infrastructural cost is generally more preferable.
	Operations and maintenance (O/M) cost (EC3)	O/M cost comprises of the total cost of operating and undertaking the regular maintenance of the solar power project including the salaries of workers. Thus, the low O&M cost requirement is generally preferred during the site selection of a solar power project.
	Electricity demand (EC4)	The higher the demand for electricity, the more obligatory shall be the installation of a PV plant. Therefore, it is very important to install a solar power project, particularly in the city with high electricity demand.
Environmental (EN)	Flat terrain and without trees site (EN1)	The terrain for solar PV power project should be flat, without forest cover, and sunny dry area. Therefore, the site with these qualities is very suitable for the utilization of solar power project.
	Wildlife and habitat (EN2)	The solar panels appear as lake or water from a long distance; this deceives migrating birds to change their direction towards PV plants, which ultimately causes them fatigue and sometimes death. Thus, the selected location must be far from wildlife and habitat area.
	Carbon emissions saving (EN3)	The CO_2 emissions are generated in the solar PV project during the transportation, operation and maintenance, and replacement of solar panels. Thus, the location of a PV project which causes low carbon emissions is preferred.
Social (SO)	Public acceptance (SO1)	The residents may dissent the installation of RE project due to lack of awareness about the socio-economic and environmental benefits. Thus, this aspect must be considered before the deployment of the solar power project.
	Employment opportunities (SO2)	Solar power project must act to provide jobs to local people in the area. Therefore, the selected solar PV power project must create employment for residents.
	Effect on local economic development (SO3)	The installation of a solar power project develops the infrastructural conditions. Thus, this improves the living standards of the people and adds to local economic development in the area.
Location (LO)	Distance to residential areas (LO1)	The installation of the solar PV power project must not be within the surroundings of urban and rural areas. Else it may create an obstacle to residents and impact on the urban growth of the area. Therefore, it is recommended that PV power projects must be at least 500 m away from the urban and rural areas (Uyan 2013).
	Distance to main roads (LO2)	The solar power project must have a lower distance to main roads so that it may provide the lower infrastructural cost. Thus, it is recommended that the solar power project should be at the lowest distance and must not exceed 500 m from the main roads (Uyan 2013).
	Distance to on-grid transmission lines (LO3)	The on-grid transmission lines must be closed to the solar PV project. Thus, the location of a solar plant must be within 3 km to on-grid transmission lines, or else, it may be regarded as practically uneconomical and unacceptable (Uyan 2013).
	Population density (LO4)	The installation of PV power project has pertinent inferences on nearby populated density cities, such as emissions and pollutants. So, the proposed site should be a little far from the populated density areas, in order to avoid any delay in project or conflict with residents (Janke 2010).
Climate (CL)	Solar irradiation (CL1)	The amount of solar irradiation received from the sun depends on dust, humidity, sun angle, latitude, and longitude of the area (Sabziparvar and Shetaee 2007). Therefore, the area with higher solar irradiation is considered to be more appropriate for the deployment of a solar PV project.
	Relative humidity (CL2)	The areas having high relative humidity and water vapor have a low potential for deploying solar energy (Zoghi et al. 2015). The efficiency of the solar PV is high when the humidity is low; therefore, the area with low relative humidity increases the performance of a solar PV system.
	Annual air temperature (CL3)	Annual air temperature affects the efficiency of solar PV power plant system. It indicates that the efficiency of solar panels depends on its temperature, which itself is dependent on the intensity of the solar irradiation and ambient temperature received (Noorollahi et al. 2016).
Orography (OR)	Elevation (OR1)	The atmosphere layer from the above ground level reduces the thickness and receives more solar irradiation and increases the efficiency performance of the solar panels due to the decrease in temperature at high elevation. However, the cost of the solar power project increases by increasing the height. Therefore, the installation of the solar PV power project is not suggested at high elevation.
	Slope (OR2)	The city or area must be mild steep slope, so it will help in avoiding the high construction cost required in high slope regions. Thus, the higher or steep slope cities should be avoided in order to minimize the construction cost of the solar power project.
	Aspect (OR3)	The aspect of solar panels plays a significant role in maximizing the amount of solar irradiation during the sunny days (Sánchez-Lozano et al. 2013). The ideal direction for the installation of solar PV panels is to the south-facing slope. Nevertheless, other directions can also be suitable for the installation of solar panels.

social, location, climate, and orography, would be assessed. Each criterion has several sub-criteria with overall 20 sub-criteria. Table 2 presents the decision criteria and sub-criteria for the solar PV project site selection.

The stated-above decision criteria and sub-criteria are very significant and provide sufficient insight towards rational decision-making for the establishment of solar PV power project site selection in Pakistan.

Potential and progress of solar power in Pakistan

Pakistan is located in South Asia, with 210 million residents (Government of Pakistan n.d.). Pakistan is the 33th largest country in the world and having an area of 796,095 km^2. The country is geographically located between the latitudes 33.73 north and longitudes 73.08 east. The country has an ample potential of RE sources such as solar (2,900,000 MW), wind (360,000 MW), hydro (60,000 MW), geothermal (100,000 MW), and biomass energy (5000 MW) (Mirjat et al. 2017).

As such, Pakistan has an immense RE potential to meet its electricity demand, in specific, solar. The solar power potential is estimated to be 2,900,000 MW in the country (Sheikh 2009). However, the installed capacity of solar power is only 200 MW in Pakistan (Zafar et al. 2018). While Pakistan receives the highest solar irradiation with more than 300 sunlight days with around 1800–2200 kWh/m^2 annual irradiation, which can generate average electricity of 5.5–6 kWh/m^2/day (Wakeel et al. 2016). As such, the usable solar resources are estimated to be greater than 50,000 MW. The highest values of GHI can be found in Sindh and Baluchistan provinces, where the sunlight about 2300–2700 h/year (Rauf et al. 2015). The annual sums of GHI for each of the province are presented in Fig. 1 (World Bank 2016). The highest values of GHI can be found in Baluchistan, Sindh, and Punjab, while the lowest sums of GHI have been estimated for Khyber Pakhtunkhwa (KPK) province of Pakistan.

The development of solar power is at very early staged in spite of outstanding potential and geographical conditions of Pakistan. The lack of energy planning and commitment of concerned authorities are the key barriers in the utilization of solar energy potential. In the meantime, with penetration of solar-based technology in the market, various electricity consumers in both rural and urban have installed PV units of 100–500 W for the electricity generation (Shahzad et al. 2017), although these individual efforts can be short-lived with the availability of spares, operational maintenance requirement, and other challenges. Given the potential of solar PV power taken into consideration, with the annual mean sunlight duration is about 8–8.5 h a day, thus, it is projected that around 40,000 villages in the country can be electrified (Rehman et al. 2017).

On the other hand, the development of the Quaid-Azam solar PV power project at Bahawalpur district of Punjab is the only substantial effort by the government of Pakistan (Khaliq et al. 2015). At completion, the total installed capacity of this solar project shall be 1000 MW (Ali 2018). It is evident from these analyses that the share of solar power for electricity generation is insufficient and requires huge efforts for the development of solar power sector. This will help country to address the supply-demand gap and ensure energy security.

Geographical coordinates and solar data of 14 cities of Pakistan

The geographical conditions of Pakistan are very favorable as most of the areas or cities receive sufficient solar irradiation throughout the year. It is therefore in the study, 14 sunny cities of Pakistan, i.e., Bannu, Khuzdar, Badin, Multan, Mardan, Hyderabad, Mastung, Karachi, Nawabshah, Turbat, Sahiwal, Peshawar, Quetta, and Rahim Yar Khan are considered as selected cities have the highest sunny days and good weather conditions for the deployment of soal PV power project. The GHI map of Pakistan is presented in Fig. 2.

The geographical coordinates and solar data of the 14 cities have been acquired from NASA power project data sets ("NASA-POWER Project Data Sets," 2018); NASA Earth Science's program supports the project. The data is very easily accessible on the database of NASA. The data about latitude (LAT), longitude (LONG), average GHI (kWh/m^2/year), annual average GHI (kWh/m^2/day), annual average air temperature (T °C), and annual average relative humidity (RH %) have been collected. As such, the obtained geographical

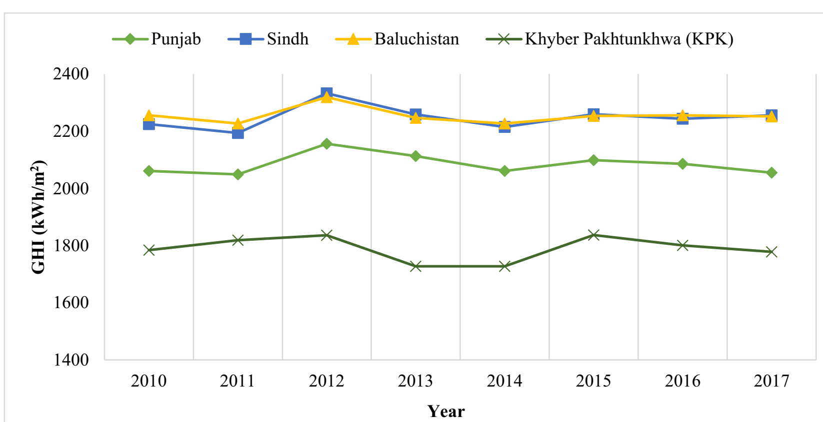

Fig. 1 Annual sums of GHI (kWh/m^2) for 4 provinces of Pakistan from the year 2010–2016

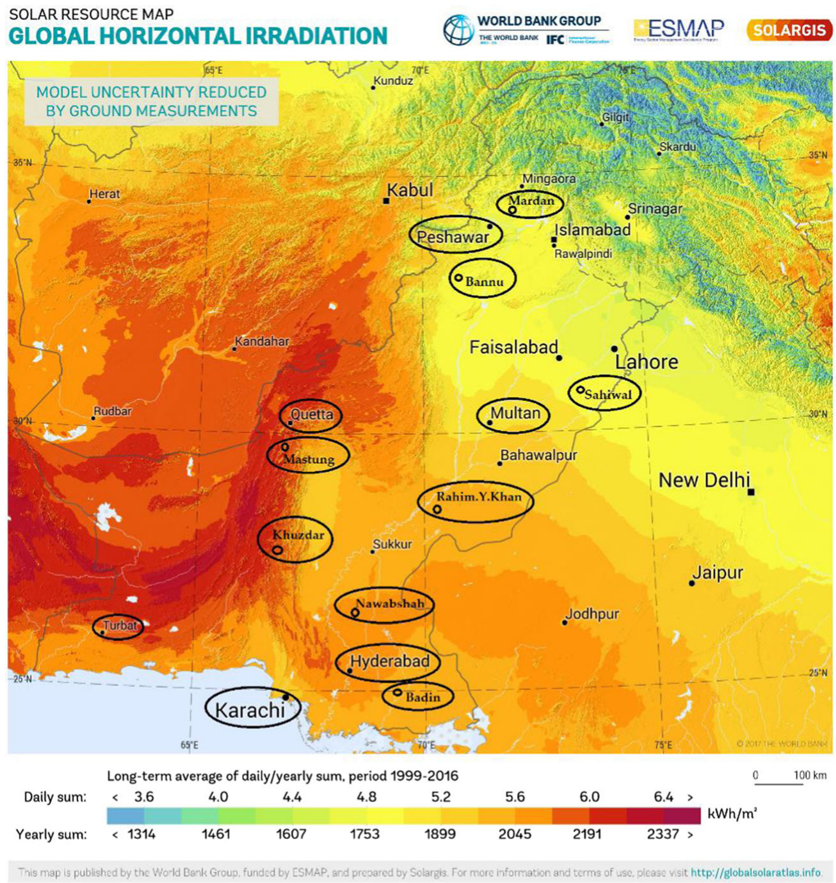

Fig. 2 The GHI map of 14 cities of Pakistan (World Bank Group 2017)

coordinates and solar data of 14 cities of Pakistan are presented in Table 3.

The existing literature reveals that the perfect value of GHI should be greater than or equal to 1500 kWh/m^2/year, 5 kWh/m^2/day; the air temperature should be less than or equal to 25 °C; and the optimal percentage of relative humidity must be between 44 and 52% (Chakraborty et al. 2014; Sindhu et al. 2017). Thus, it is revealed that all the selected cities considered in this study have optimal values for the utilization of solar PV power projects in the country. Therefore, in this study, a comprehensive investigation has been undertaken to rank the selected cities systematically.

Research framework

The structure of this study consists of AHP and F-VIKOR approach to assess and select the optimal site for solar PV power project development in Pakistan. The research framework of the study is illustrated in Fig. 3. In the first instant, the AHP methodology has been employed with the help of decision-makers to determine the weights of the main criteria and sub-criteria using pairwise comparison matrix. Then, the F-VIKOR method has been used to realize the optimal sites for the development of a solar energy project in Pakistan. In the following sub-section, the AHP and F-VIKOR methods have been described in detail.

Analytical hierarchy process

AHP is a significant method of MCDM used to solve the complex decision-making problem. Thomas L. Saaty developed this technique in the 1970s (Harker 1987). The basic feature of AHP includes the pairwise comparison matrix, and thus, the development of the comparison matrices for which their consistency can be duly checked and maintained appropriately (Solangi et al. 2018). As such, this technique facilitates all decision-makers to rationally select and prioritize the complicated decision problem. The key AHP methodology steps are described as follows (Saaty 1990).

Step 1. Development of the hierarchal structure of the decision-problem.
Step 2. Development of pairwise comparison matrix of the decision problem using Saaty's 1–9 point scale.
Step 3. Calculating the consistency index (CI)

In this step, CI can be used to measure the consistency of the pairwise comparison of the matrix. CI can be presented as (Franek and Kresta 2014).

Table 3 Geographical coordinates and solar sites data of Pakistan

Code	City	Province	LAT	LONG	Avg. GHI (kWh/m^2/year)	Avg. GHI (kWh/m^2/day)	Avg. T (°C)	Avg. RH (%)
C1	Bannu	KPK	32° 59′ N	70° 36′ E	1777	5.0	20.0	47.0
C2	Khuzdar	Baluchistan	27° 48′ N	66° 37′ E	2190	5.47	22.3	51.3
C3	Badin	Sindh	24° 39′ N	68° 50′ E	2026	5.24	25.0	46.8
C4	Multan	Punjab	30° 10′ N	71° 28′ E	1849	5.09	25.0	44.0
C5	Mardan	KPK	34° 11′ N	72° 02′ E	1748	5.31	14.3	50.2
C6	Hyderabad	Sindh	25° 22′ N	68° 20′ E	2074	5.27	26.5	44.0
C7	Mastung	Baluchistan	29° 48′ N	66° 51′ E	2184	5.52	19.0	46.0
C8	Karachi	Sindh	24° 52′ N	67° 06′ E	1967	5.34	26.0	51.2
C9	Nawabshah	Sindh	26° 14′ N	68° 24′ E	2058	5.24	26.4	44.0
C10	Turbat	Baluchistan	26°00′ N	63° 03′ E	2108	5.18	24.7	52.0
C11	Sahiwal	Punjab	30°40′ N	73°06′ E	1801	5.01	24.0	45.0
C12	Peshawar	KPK	34°00′ N	71° 33′ E	1774	5.16	22.7	44.3
C13	Quetta	Baluchistan	30°10′ N	66° 59′ E	2179	5.54	15.7	44.5
C14	Rahim Yar Khan	Punjab	28°18′ N	70° 07′ E	1991	5.20	25.0	44.0

LAT, latitude; *LONG*, longitude; *Avg. GHI*, average global horizontal irradiance; *Avg. T*, average temperature; *Avg. RH*, average relative humidity

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

where λ_{max} are the eigenvalue and n is the no. of main criteria

Step 4. Computing the consistency ratio (CR)

$$CR = \frac{CI}{RI} \quad (2)$$

where RI is the random consistency index, which is presented in Table 4. During the pairwise comparison, the consistency ratio (CR) must be within the limit of 0.1; if it exceeds above 0.1, then the results could be inconsistent.

In the study, AHP method has been used to obtain the weights of the main criteria and sub-criteria, later, the F-VIKOR method has been utilized to prioritize the proposed 14 cities (i.e., alternatives) for solar PV site selection.

Fuzzy set theory

Lofti A. Zedah proposed fuzzy set theory in 1965 (Klir 2001). This method provides the more reliable and robust results when there is a vague, incomplete, and uncertain knowledge of the decision problem. Fuzzy set theory is a general form of crisp sets, while the fuzzy set numbers only consider the values in the range of 0 and 1. The value 0 represents the non-membership function, and 1 represents full membership function. There are various triangular fuzzy numbers (TFNs) which can be employed for multiple purposes and situations. In a fuzzy situation, the use of TFNs is very helpful (Shukla et al. 2014). The TFNs rating scale frequently employed in MCDM problems is shown in Table 5.

A fuzzy number ã is defined by a trio $X = (x, y, z)$. The membership function of TFN is described as:

$$\mu_X(x) = \left\{ \begin{array}{ll} 0, & x < 1 \\ \frac{x-x}{y-x} & if \quad x \leq x \leq y \\ \frac{z-x}{z-y} & if \quad y \leq x \leq z \\ 0, & x > 0 \end{array} \right\} \quad (3)$$

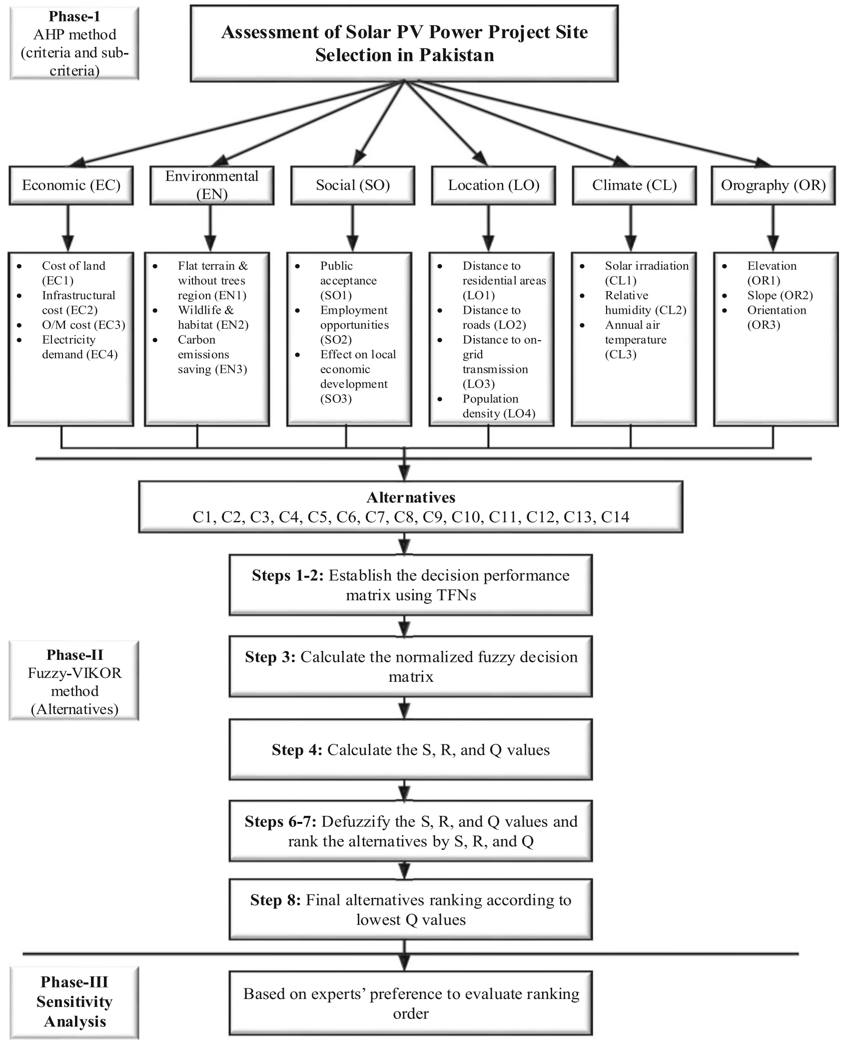

Fig. 3 Research framework of the study

The rest of the fuzzy set theory is presented in ref. (Kim and Chung 2013).

Fuzzy VIKOR method

S. Opricovic developed the VIKOR approach in 1980 (Opricovic and Tzeng 2007). This method focuses on prioritizing the set of alternatives and obtains the compromise solutions of a decision problem with contradictory/conflicting criteria, which may help the decision-makers to reach a final decision. Here, the compromise solution is a feasible solution, which is the closest to the ideal, and a compromise means an agreement established by mutual concessions (Liu et al. 2013). The key steps of F-VIKOR are as follows:

Step 1 & 7. Establish the fuzzy performance matrix and the weight vector:

$$\tilde{D} = \begin{matrix} \\ O_1 \\ \vdots \\ O_n \end{matrix} \begin{bmatrix} & C_1 & C_2 \cdots C_n & \\ & \tilde{p}_{11} \tilde{p}_{12} \cdots \tilde{p}_{1n} & & \\ & \tilde{p}_{21} \tilde{p}_{22} \cdots \tilde{p}_{2n} & & \\ \vdots & \vdots & \vdots & \vdots \\ & \tilde{p}_{m1} \tilde{p}_{m2} \cdots \tilde{p}_{mn} & & \end{bmatrix} \quad (4)$$

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

where O_i represents the alternative i, i.e., i = (1, 2, 3, …, m); C_j denotes the criteria j, i.e., j = (1, 2, 3, …, n); $\tilde{p}_{ij}$ represents the fuzzy performance rating of alternative O_i with respect to criteria C_j; and $\tilde{W}_j$ denotes the fuzzy weight for each criterion. Thus, TFN can be presented as $\tilde{p}_{ij} = (x_{ij}, y_{ij}, z_{ij})$.

Step 2 & 7. Determine the values of all benefit criteria $\tilde{p}_i^+ = \left(x_i^+, y_i^+, z_i^+\right)$ and the cost criteria $\tilde{p}_i^- = \left(x_i^-, y_i^-, z_i^-\right)$: The set of benefit criteria is denoted as I^b and set of cost criteria is indicated as I^c.

Table 4 Random index (RI)

n	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.058	0.90	1.12	1.24	1.32	1.41	1.45	1.49

$$\overset{+}{p}_i = max_j p_{ij}, \quad \overset{-}{p}_i = min_j p_{ij} \quad \text{for} \quad i \in l^b$$
$$\overset{+}{p}_i = min_j p_{ij}, \quad \overset{-}{p}_i = max_j p_{ij} \quad \text{for} \quad i \in l^c. \tag{5}$$

Step 3 & 7. Calculate the normalized fuzzy decision matrix D_{ij}:

$$D_{ij} = \frac{\overset{+}{p}_i (-) p_{ij}}{z_i^+ - l_i} \quad \text{for} \quad i \in l^b$$
$$D_{ij} = \frac{p_{ij} (-) \overset{+}{p}_i}{z_i^- - l_i^+} \quad \text{for} \quad i \in l^c. \tag{6}$$

Step 4 & 7. Calculate the values $S_j = \left(S_j^x, S_j^y, S_j^z\right)$ and $R_j = \left(R_j^x, R_j^y, R_j^z\right)$:

$$S_j = \sum_{i=1}^{n} W_i (\times) D_{ij} \tag{7}$$

$$R_j = \max_i W_i (\times) D_{ij} \tag{8}$$

Step 5 & 7. Calculate the values $Q_j = \left(Q_j^x, Q_j^y, Q_j^z\right)$:

$$Q_j = v \frac{S_j (-) \overset{+}{S}}{S^{-z} - S^{+x}} (+) (1-v) \frac{R_j (-) \overset{+}{R}}{R^{-z} - R^{+x}} \tag{9}$$

where $S^+ = min_j S_j$; $S^{-z} = \max_j S_j^z$; $R^+ = \min_j R_j$; $R^{-z} = \max_j R_j^x$.

Table 5 Linguistic variables fuzzy number

Number	Linguistic variables	TFNs
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)

Moreover, v is presented as a group strategy weight for the majority of criteria S_j; whereas, $(1-v)$ is the individual weight of R_j.

Step 6 & 7. Defuzzify S_j, R_j, and Q_j values, respectively: Prioritize the alternatives according to the shrinking order of crisp values, and the results are three prioritizing results $\{O\}_S$, $\{O\}_R$, and $\{O\}_Q$, referring to the crisp values of S, R, and Q.

Step 8. Propose a solution to the alternative $O^{(1)}$ which is the optimal solution of the measure Q, if the subsequent two conditions are satisfied:

Condition 1: suitable benefit: $Ben \geq DQ$

where $ben = \frac{[Q(O^{(2)}) - Q(O^{(1)})]}{[Q(O^{(m)}) - Q(O^{(1)})]}$ is the benefit rate of alternative $O^{(1)}$ placed first compared with the alternative with the second-ranked $O^{(2)}$ in $\{O\}_Q$ and the threshold $DQ = \frac{1}{(m-1)}$

Condition 2: suitable stability in decision-making:

Alternative $O^{(1)}$ should also be the optimal prioritized by S or Q.

If any of the condition (C1 and/or C2) are not satisfied, then a set of comprising solution is suggested, which comprises the following:

Condition satisfied 1: Alternative $O^{(1)}$ and $O^{(2)}$ if only (condition 2) is not satisfied, or:

Condition satisfied 2: Alternative $O^{(1)}$,$O^{(2)}$, …, $O^{(M)}$ if (condition 1) is not satisfied; $O^{(m)}$ is determined by the relation:

$$\frac{[Q(O^{(M)}) - Q(O^{(1)})]}{[Q(O^{(m)}) - Q(O^{(1)})]}$$

$< DQ$ for maximum M.

The locations of the alternatives are in closeness.

Experts for AHP and fuzzy VIKOR approach

It is most difficult task to evaluate and select the suitable site of a solar power project. Thus, this study has consulted with experienced experts for employing the AHP and F-VIKOR methodology, since the weights scored by the individuals are always doubtful and conflicting (Vafaeipour et al. 2014). Usually, academic professors, research analysts, policymakers, stakeholders, and managers are asked to analyze and score the weights (Janke 2010). To achieve the motive, 12 professionals from academic institutes, energy research institutes, and stakeholders were consulted. The consulted experts have more than 15 years' work experience, and they were very familiar with the country's overall techno-economic and socio-environment conditions. The 12 experts' responses were collected through webmail service. However, 10 experts' results were found validated by using CI and RI proposed by Saaty (Saaty 1980). The AHP has been employed for the pairwise comparison matrix of the main criteria and sub-criteria. Then, the F-VIKOR method was used to prioritize the suitable sites for installation of solar PV project. The information of the experts is attached in Appendix, Table 8.

Therefore, the outcome of this study may help in reaching to the ideal site of a solar PV power project by employing the research framework of the study.

Results and discussion

This study presents how the integration of AHP and F-VIKOR approach can enable energy planners and policymakers to implement and assess a strategic decision-making process. It is the first kind of study in Pakistan, which has evaluated the regional sites for the development of solar PV projects using AHP and F-VIKOR technique. Therefore, the present investigation lays a foundation for government and decision-makers to determine the research framework of this study, which would provide a suitable rationalization of a solar PV power project site selection.

AHP results

The AHP method is an excellent way to determine the experts' score using a geometric mean approach (Forman and Peniwati 1998; Krejčí and Stoklasa 2018). In this study, a group decision-making approach has been employed to determine the weight of the main criteria and the sub-criteria. Six main criteria were considered, such as economic, environmental, social, location, climate, and orography, to pursue the AHP model analysis. In the first part of the AHP method, 6 main criteria weights were analyzed, and in the second part, 20 sub-criteria of the study were assessed.

The ranking of main criteria

AHP method provides the weight of each main criteria at the hierarchy level. Therefore, the main criteria results reveal that the location is the most significant criteria with a weight of (0.2773), followed by economic (0.2609), climate (0.1869), environmental (0.1120), orography (0.1067), and social (0.0563) criteria, respectively. Further, the detailed each main criteria weights are provided in Fig. 4. The location plays a crucial role

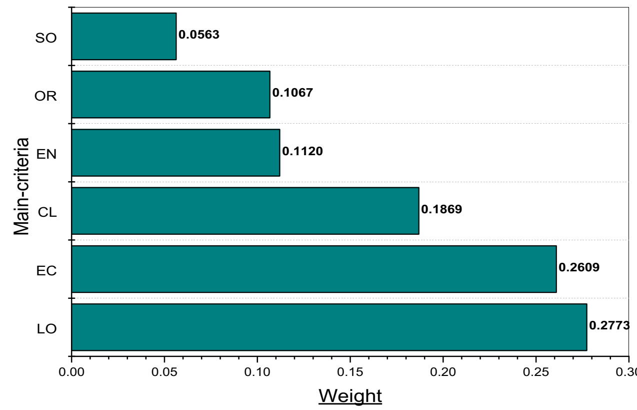

Fig. 4 Ranking of main criteria in solar PV project site selection in Pakistan

in the installation of a solar power project, which makes the solar power project more efficient to generate electricity. Moreover, the economic criterion is considered to be the second main criteria of the study because it is obvious from the perspectives of Pakistan, wherein, the limited funding source is a key challenge to install the solar PV project. The climate and environmental conditions are considered as a third and fourth important criterion of the study because every city and the specific site has its climate and environmental conditions; thus, these criteria play an important role to identify the potential of solar energy such as solar irradiation and subsequently flat terrain for the development of solar PV power plant. The orography criteria are identified as fifth important criteria since, for each site, the elevation, slope, and aspect must be evaluated to determine the potential of solar power. Lastly, the social criteria are although not inspiring criteria from the obtained results, yet reflect the rights of the local community, which impact on the national level decision-making. However, every city has its economic context, location, and climate conditions that may lead to variations in results obtained in this study, which would require different approaches to overcome the problem based on the region's specific needs.

Next, the 20 sub-criteria of the study were evaluated through the pair of experts' feedback using pairwise comparison matrix of AHP.

The ranking of sub-criteria

Within the economic criteria, cost of land (EC1) is found to be the highest ranked sub-criteria for establishing solar PV power project in Pakistan, followed by infrastructural cost (EC2), O/M cost (EC3), and electricity demand (EC4) (Fig. 5).

For the environmental criteria, as can be seen in the results shown in Fig. 6, carbon emissions saving (EN3) was cited to

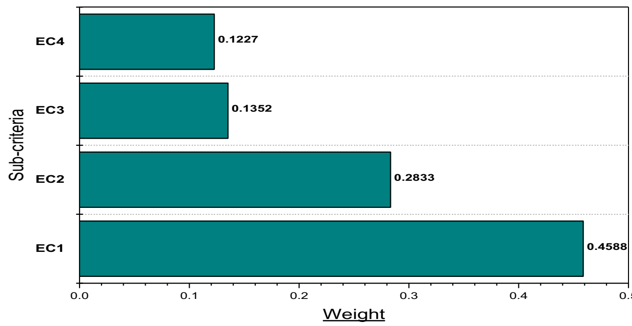

Fig. 5 Ranking of economic (EC) sub-criteria

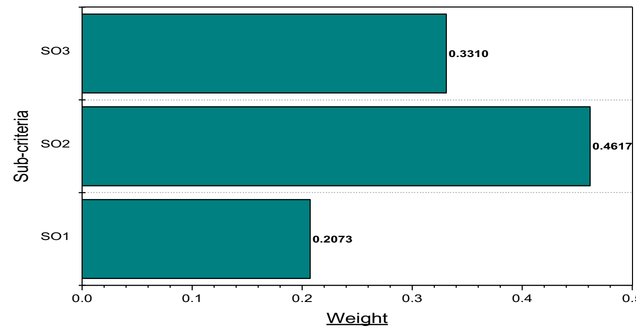

Fig. 7 Ranking of social (SO) sub-criteria

be the vital sub-criteria followed by flat terrain and without trees site (EN1), and wildlife and habitat (EN2).

Within the social criteria, employment opportunities (SO2) were identified as the highest important sub-criteria for the establishment of a solar PV power project in Pakistan, followed by the effect on local economic development (SO3), and public acceptance (SO1), as presented in Fig. 7.

As can be seen in Fig. 8, distance to on-grid transmission lines (LO3) was found to be the optimal sub-criteria for the development of solar PV power development within the location criteria, followed by distance to main roads (LO2), distance to residential areas (LO1), and population density (LO4).

Figure 9 presents that solar irradiation (CL1) was cited as a vital sub-criteria within the climate condition criteria for the selection of a solar PV power project in Pakistan, followed by relative humidity (CL2), and annual air temperature (CL3).

As seen in Fig. 10, aspect (OR3) was identified to be the most influential sub-criteria within the orography criteria, followed slope (OR2) and elevation (OR1).

The overall ranking of sub-criteria

The final weight scores and ranking of sub-criteria are depicted in Fig. 11. The overall ranking of sub-criteria results reveals that distance to on-grid transmission lines (LO3), cost of land (EC1), and solar irradiation (CL1) as top-ranked sub-criteria, respectively. The sub-criteria ranking of on-grid transmission, cost of land, and solar irradiation is all insights of a very robust outcome. Moreover, the overall obtained sub-criteria are very significant in the decision-making of a solar power project site selection.

Fuzzy VIKOR results

In this section, the ranking of 14 potential solar areas/cities for deployment of solar PV project has been analyzed using F-VIKOR approach. The analysis made by a group of experts; therefore, a group decision-making approach has been used to determine the results. The fuzzy decision matrix and weighted normalized decision matrix using TFNs rating scale have been obtained after the comparison of the alternatives against each sub-criterion. All the criteria of this study have been considered as cost criteria.

In the implementation of F-VIKOR method, the area having the lowest Q_i value has been prioritized as the highly suitable site for the installation of a solar PV power project. The obtained S, R, and Q values are given in Table 6, whereas the summary ranking of the alternatives is presented according to the lowest value of Q in Table 7. Consequently, results recommend Khuzdar (C2) as best-suited site followed by Badin (C3), Mastung (C7), Hyderabad (C6), Sahiwal (C11), Karachi (C8), Peshawar (C12), Turbat (C10), Quetta (C13), Rahim Yar Khan (C14), Nawabshah (C9), Multan (C4), Bannu (C1), and

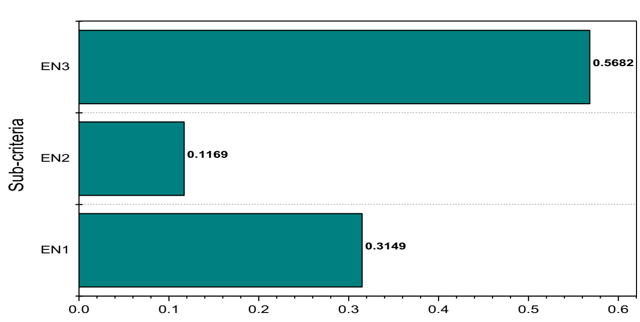

Fig. 6 Ranking of environmental (EN) sub-criteria

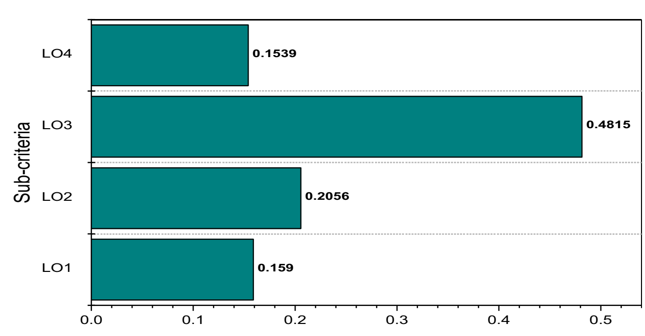

Fig. 8 Ranking of location (LO) sub-criteria

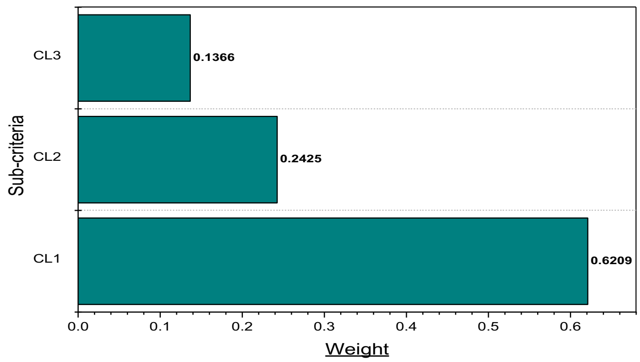

Fig. 9 Ranking of climate (CL) sub-criteria

Mardan (C5) city/area, respectively. The ordered ranking of different sites is very significant since it has provided the best and worst sites for the installation of solar PV power projects in Pakistan. The Khuzdar (C2), Badin (C3), and Mastung (C7) are considered as the ideal sites for the development of solar PV power project. It is a matter of fact that all these cities have enormous solar PV potential across the year to generate electricity. Moreover, the regions are ideally suitable because undertaken criteria are matched with its potential and easily accessible to on-grid with low infrastructural cost, availability of main roads, flat terrain region, and other significant criteria of the study.

The AHP and F-VIKOR method has been used effectively and systematically to address and analyze the selection of a solar PV power project. The results of the study are not only supported by the research framework, yet the experts' feedbacks and related work have also been utilized appropriately. Thus, this study can help government and policymakers in the selection of feasible sites and installation of solar PV power projects in the country.

Sensitivity analysis

In this study, the sensitivity analysis has been conducted to check the robustness of the obtained results, for instance, to discover the new ranking results of alternatives by changing

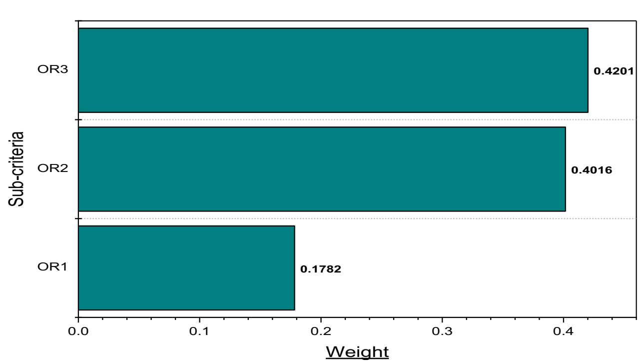

Fig. 10 Ranking of orography (OR) sub-criteria

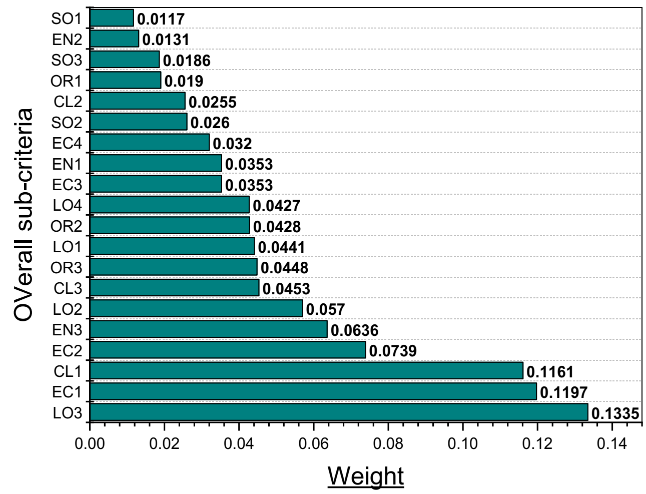

Fig. 11 The overall prioritizing order of sub-criteria

the decision information. The experts' feedbacks are not always consistent because of various other factors that affect the decision problem. Thus, to examine the impact on the ranking results of the alternatives, this study analyzed the sensitivity analysis by changing the experts' feedbacks.

The alternative results have been obtained by F-VIKOR technique, and the parameter v has been employed as group strategy weight for the ranking of the alternatives. The parameter v plays a crucial role in the group decision-making; usually, the value of parameter v is set to 0.5 to weight the alternatives. However, one can use any value of v between 0 and 1. In group decision-making, it is a matter of fact that various feedbacks of the experts can provide different prioritizing orders. Thus, it is significant to conduct the sensitivity analysis on the parameter v according to the experts' preference to

Table 6 *S*, *R*, and *Q* values

Code	City	S_i	R_i	Q_i
C1	Bannu	0.350	0.045	0.157
C2	Khuzdar	0.235	0.034	0.019
C3	Badin	0.209	0.041	0.062
C4	Multan	0.263	0.048	0.142
C5	Mardan	0.255	0.051	0.159
C6	Hyderabad	0.287	0.038	0.074
C7	Mastung	0.272	0.038	0.066
C8	Karachi	0.284	0.042	0.104
C9	Nawabshah	0.281	0.047	0.140
C10	Turbat	0.274	0.044	0.117
C11	Sahiwal	0.258	0.043	0.100
C12	Peshawar	0.274	0.044	0.113
C13	Quetta	0.274	0.047	0.137
C14	Rahim Yar Khan	0.270	0.047	0.138

Table 7 Final alternatives ranking according to the lowest Q values

Code	City	Q_i	Rank
C2	Khuzdar	0.019	1st
C3	Badin	0.062	2nd
C7	Mastung	0.066	3rd
C6	Hyderabad	0.074	4th
C11	Sahiwal	0.100	5th
C8	Karachi	0.104	6th
C12	Peshawar	0.113	7th
C10	Turbat	0.117	8th
C13	Quetta	0.137	9th
C14	Rahim Yar Khan	0.138	10th
C9	Nawabshah	0.140	11th
C4	Multan	0.142	12th
C1	Bannu	0.157	13th
C5	Mardan	0.159	14th

investigate the robustness and validity of the existing results. This study has taken parameter v between 0 and 1 to determine the values of Q_i on different parameters. The prioritizing order trend of the alternatives by employing parameter values between $v = 0$ and $v = 1$ is depicted in Fig. 12. It can be determined from Fig. 12 that the prioritizing order trend of eight alternatives is hardly influenced by the utility group strategy (v value). Particularly, the prioritizing order of C2, C3, and C7 is constantly the ideal alternatives, which are not impacted by the v value at any stage between 0 and 1.

It can be seen in Fig. 12 that prioritizing the order of alternatives remains the same when the value of v ranges from 0 to 0.5. In case the value of v increases from 0.6 to 1 then the several less favorable alternatives rank slightly changed, and we can find that alternatives vary their ranking order from C11>C8 to C8>C11, C14>C13 to C13>C14, and C9>C4 to C4>C9, respectively. The results reveal some influence of the experts' feedbacks changes on the decision results; however, ideal and worst alternatives remain at the same ranking order. Therefore, it is revealed that the achieved results are reliable and robust.

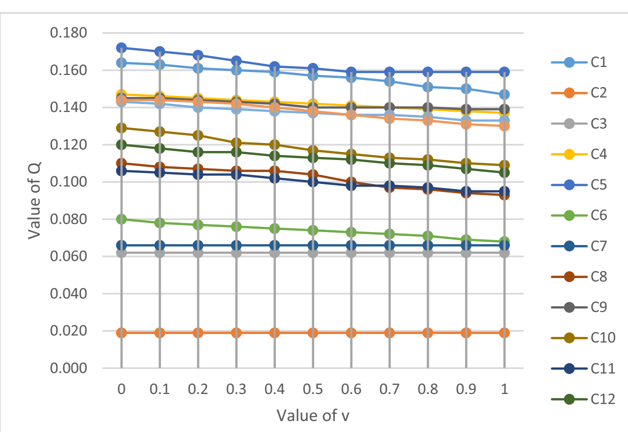

Fig. 12 Sensitivity analysis

Discussion

Earlier it was difficult to analyze and decide which criteria are more important in solar PV power project site selection in Pakistan. However, ranking of these criteria made it more significant, helpful, and logical for decision-makers. Solar PV power project site selection is a crucial problem in PV installation; thus, it has been investigated by AHP and F-VIKOR method. Therefore, the integration of both MCDM methods (i.e., AHP and F-VIKOR) has been determined suitable for carrying out this research. The extensive literature review and experts' opinion have been utilized to make a comparative assessment of feasible locations for deployment of solar PV power projects in Pakistan. The evaluation process in real life decision-making is often very difficult, not exact and contains uncertainties, fuzziness, and hesitancies. This research put up a systematic research framework for comparative evaluation of feasible cities of solar PV with capability towards handling shortcoming, uncertainty, imprecise, and vague data appropriately. The results of the study have been listed and discussed below.

Among the economic (EC), environmental (EN), social (SO), location (LO), climate (CL), and orography (OR) criteria, the CL criteria have been found to be the most important and leading criteria, following EC, CL, EN, OR, and SO proved to be the least important criteria. On-grid transmission lines (LO3) are identified to be the first rank sub-criteria, and cost of land (EC1) and solar irradiation (CL1) are prioritized as second and third rank important sub-criteria. Moreover, the other top sub-criteria rankers are as follows: EC2>EN3>LO2>CL3>OR3>LO1>OR2>LO4> and the least sub-criteria rankers are EC3<EN1<EC4<SO2<CL2<OR1<SO3<EN2<SO1. Then, the lowest obtained value of Q may be selected as an optimal city (site) for the deployment of the solar PV power project. Therefore, according to the investigation, Khuzdar (C2), Badin (C3), and Mastung (C7) are prioritized as first, second, and third most significant sites for the installation of the solar project, while Mardan (C5) city is considered as the lowest important site. This decision-making will confidently help policymakers and decision-makers for selecting a suitable site for solar PV installation.

There is no research work identified in the literature on the solar PV site selection in Pakistan. However, there are some previous studies around the globe, which has done similar research to identify the optimal location for the installation of the solar PV projects. In most of the previous studies, authors have only used the simplest AHP method to obtain the suitable location for solar power project such as Al Garni and Awasthi 2017; Alami Merrouni et al. 2018a, b; Aly et al. 2017; Doljak and Stanojević 2017; Effat 2013; Noorollahi et al. 2016; Suh and Brownson 2016; Tahri et al. 2015; Uyan 2013; Watson and Hudson 2015; Yunna and Geng 2014. It is also identified that previous studies have used limited or insufficient criteria for the selection of solar PV power plants; however, the problem is even more crucial in selecting the feasible site. Therefore, this study has undertaken more important criteria relating with every aspect of solar PV project selection. Further, in the study, a hybrid framework (i.e., AHP and fuzzy VIKOR) was used to amalgamate the decision criteria and sub-criteria results with alternatives for identifying the feasible site of a solar PV project development.

This study is unique and effective in terms of selecting and prioritizing potential sites for solar PV power project installation in different cities of Pakistan. The suitable prioritization of solar projects sites has become a challenge. In this regard, the proposed AHP and F-VIKOR can be a very effective method for selecting and ranking the solar PV sites. This study has compared the results of the proposed research framework with the previous studies, and it is found that the results of AHP and F-VIKOR approach are more rational than the previous method results. Therefore, this study presents a decision-support tool for policymakers and decision-makers to rank the feasible locations in deployment solar PV technology in Pakistan.

Conclusion

Solar energy has a gigantic potential to generate electricity for sustainable development of Pakistan. This clean energy technology has various benefits, such as shifting the energy mix from fossil fuels to solar energy, growing employment opportunities, and growing regional and national economic development of the country. Therefore, it is very significant to rank the sites for the installation of solar PV power project in Pakistan. The site selection for the solar power project is a complex decision problem. Taking into consideration, the fact that there is no comprehensive study in Pakistan, for investigating the solar power project site selection. Thus, this study has attempted to address this research gap and proposed a hybrid research framework for the solar PV project site selection in Pakistan.

Therefore, this study considered various suitable sites for the establishment of solar PV power projects and applied AHP and F-VIKOR approach to find out the optimal site. For the implementation of AHP and F-VIKOR technique, the experts from the government, academia, and stakeholders were participated to provide their insightful judgment relating to decision criteria and alternatives. First, the AHP method was used for determining the 6 main criteria and 20 sub-criteria weights obtained from the various experts' through pairwise comparison matrix. Location (LO), economic (EC), and climate (CL) were emerged as top-ranked criteria, while on-grid transmission lines (LO3), cost of land (EC1), and solar irradiation (CL1) were ranked as top sub-criteria of the study. Later, the fuzzy-based VIKOR method was employed for prioritizing the 14 areas/cities (i.e., alternatives) to enhance and validate the consistency of the results. According to the final results of the F-VIKOR methodology, Khuzdar (C2) has been ranked as a most suitable site for the development and installation of solar PV power project followed by Badin (C3), Mastung (C7), Hyderabad (C6), Sahiwal (C11), Karachi (C8), Peshawar (C12), Turbat (C10), Quetta (C13), Rahim Yar Khan (C14), Nawabshah (C9), Multan (C4), Bannu (C1), and Mardan (C5), respectively. A sensitivity analysis of alternatives was also conducted to validate the robustness of the decision results. The alternatives C2, C3, and C7 have remained the ideal cities in all experiments from 0 to 1. Thus, it is proved that this technique is valid and robust and can be applied to any region which has the potential to install solar PV power projects.

This study can be further refined and extended to explore the site selection for other RE sources like wind, hydro, geothermal, and biomass energy. Further, in this study, only six criteria and twenty sub-criteria were employed from the available literature; however, the number of criteria can be increased by taking into account the other associated parameters. Also, various other MCDM techniques like OWA, DEA, ANP, WLC, WASPAS, DEMATEL, TOPSIS, and ELECTRE can be used in future and compare the results of this study.

Acronyms *GHI*, global horizontal irradiation; *NASA*, National Aeronautics and Space Administration; *NREL*, National Renewable Energy Laboratory; *RE*, renewable energy; *MCDA*, multi-criteria decision analysis; *AHP*, analytical hierarchy process; *F-VIKOR*, Fuzzy VlseKriterijuska Optimizacija I Komoromisno Resenje; *CI*, consistency index; *CR*, consistency ratio; *RI*, random index; *TFNs*, triangular fuzzy numbers

Appendix

Table 8 List of experts

No.	Designation	Qualification	Age	Department
1	Professor	PhD	40	MUET, Jamshoro
2	Professor	PhD	48	UoS, Jamshoro
3	Energy expert	Graduate	52	AEDB, Islamabad
4	Energy expert	PhD	42	PAEC, Islamabad
5	Chairman	Graduate	50	PCRET, Islamabad
6	Director	Graduate	40	MoPW, Islamabad
7	Deputy-Director	Graduate	45	PPIB, Islamabad
8	Executive director	PhD	55	AEB, Hyderabad
9	Secretary	Graduate	52	Energy Department, Sindh
10	Deputy-secretary	Graduate	51	Energy Department, Sindh

Names of the experts not disclosed at the request of them

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