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Strategic renewable energy resources selection for Pakistan: Based on SWOT-Fuzzy AHP approach

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ABSTRACT

Pakistan is facing a severe energy crisis since the last two decades, and yet the government has not been able to overcome this problem. Therefore, the various renewable energy resources of Sindh and Baluchistan province has been assessed to diversify the electricity generation from fossil fuels to renewable energy. In the study, Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis has been employed to assess the internal and external factors which affect the renewable energy technologies in Sindh and Baluchistan province. Then, the Fuzzy Analytical Hierarchy Process (Fuzzy AHP) method is used from the multi-perspective approach (i.e., economic, environmental, technical, and socio-political criteria). Therefore in the study, four criteria, seventeen sub-criteria and three renewable energy resources (i.e., solar, wind, and biomass) have been assessed as alternatives in the decision model. It is identified that economic and socio-political are the two most important criteria. Further results reveal that wind has ample potential to generate electricity in both (Sindh and Baluchistan) provinces, whereas solar and biomass energy ranked second and third, respectively. It is, therefore, suggested that the government should exploit renewable resources to mitigate the current energy crisis and increase energy security for sustainable development of the country.

1. Introduction

Increasing population and industrialization is the reason behind increasing energy consumption in Pakistan (Solangi, Tan, Mirjat, & Ali, 2019). The country is heavily dependent on fossil fuels; the estimated about 87% of total energy is produced from fossil fuels such as oil, coal, liquefied petroleum gas (LPG) and natural gas, while only 4% from renewable energy (RE) resources for total energy supply in the country. The total energy produces from different sources during the fiscal year 2017 accounts for thermal as 64%, followed by hydroelectric 26%, nuclear 6% and renewable energy 4% illustrated in Fig. 1 (HDIP, 2013). Pakistan is facing a serious energy crisis for a long time, and the electricity breakdown around 8–10 h per day (Shah, Syed Ahsan & Solangi, 2019). The energy problem indicates that the country has been not able to utilize indigenous RE resources properly for electricity generation. Many countries like China, India, Germany, and Denmark have utilized the clean RE resources for sustainable development and to be less dependence on fossil energy sources. Because the nature of fossil energy sources is very harmful to human health and the environment. Pakistan is a highly vulnerable country to climate and ranked 7th among over 180 countries by global climate risk index (Kreft & Eckstein, 2013). Thus, the country requires a massive effort to overcome this problem for sustainable development.

Luckily, Pakistan has enormous RE potential due to its best geographical location (Farooq & Kumar, 2013). But unluckily, these natural RE resources have not been harnessed in the country; however, only small RE projects have been installed in Sindh province. These RE resources include solar, wind, biomass, hydro and geothermal, but from the assessment of RE resources, solar, wind and biomass energy have ample potential to generate electricity to meet the current energy demand. Around 97 million people of Pakistan are living in rural areas, while only 46% of people have access to power even though these regions are rich with RE resources and are grid-connected transmission (Oecd & Iea, 2011). RE technologies have innumerable benefits due to its environmentally friendly nature and are very vital for eliminating the country's energy crisis, sustainable economic growth, energy security, and reduction in CO_2 emissions (Shah, Solangi, & Ikram, 2019). Thus, in this situation, the government should exploit RE resources for sustainable economic, environmental, and social development.

Pakistan has established two research institutes for the development of RE technologies, namely, Pakistan Council of Renewable Energy Technologies (PCRET) and Alternate Energy Development Board

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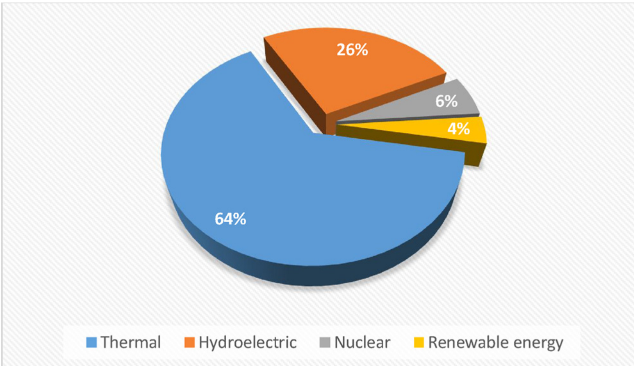

Fig. 1. The energy mix of Pakistan.

(AEDB). The country has a desire to deploy its indigenous RE resources though unlikely government policies and uncertain conditions of the state does not make it possible. Many regions in the country are far from transmission on-grid. Moreover, most of the rural regions do not have access to electricity (Xu, Wang, Solangi, Zameer, & Shah, 2019). For non-grid regions, the standalone system would be required to serve the regions where there is no access to electricity. Therefore, the country must enhance the share of indigenous and sustainable renewable resources.

The objective of this study is to assess the various RE resources (solar, wind, and biomass energy) of Sindh and Baluchistan province for sustainable electricity generation. Therefore, the SWOT analysis is used to identify the main factors that affect the RE technologies in Pakistan, especially for the deployment of RE technologies in Sindh and Baluchistan province. Then, this study employed Fuzzy Analytical Hierarchy Process (Fuzzy AHP), a famous multi-criteria decision making (MCDM) approach to evaluate significant resources based on their renewable potential, namely, solar, wind, and biomass.

The rest of the paper is structured as follows: Section 2 presents the related studies, while Section 3 presents the RE resources potential in Pakistan. Section 4 illustrates the research methodology of the study. Section 5 presents the results and discussion. Finally, Sections 6 presents conclusion and policy implications.

2. Related studies

There are various studies wherein SWOT analysis, and MCDM methods have been utilized for energy planning problem with a different aim, particular criteria, and objective (Solangi, Tan, Mirjat, Valasai et al., 2019). It is apparent from the literature that SWOT analysis and MCDM methods are often used and are famous for decision making in the sustainable energy planning issues (Solangi, Tan, Mirjat, Ali et al., 2019). Further, the MCDM method has been used in various studies with different aim and objective, such as urban renewal in southern India (Manupati, Ramkumar, & Samanta, 2018), sectoral investments for sustainable development (Suganthi, 2018), sustainable smart city (Yadav, Mangla, Luthra, & Rai, 2019), sustainable buildings for public services (Pardo-Bosch, Aguado, & Pino, 2019), social sustainability assessment for small hydropower (Wu, Wang, Chen, Xu, & Li, 2017), and sustainable urban transportation network (Mahmoudi, Shetab-Boushehri, Hejazi, & Emrouznejad, 2019). Therefore, the MCDM methods are considered as important for solving any complex decision problem.

2.1. SWOT analysis applied in sustainable energy planning

SWOT analysis is the most common and reliable strategic tool for strategic planning issues. It permits managers to assess the situation by defining internal factors and external factors to develop a policy plan (Alptekin, 2013). In the existing literature, the SWOT analysis has been widely used for energy planning issues, as it helps in providing the strategic decision on the problem. Such as, the SWOT analysis has been conducted for the renewable energy sector of Poland (Igliński, Piechota, Iglińska, Cichosz, & Buczkowski, 2016). A SWOT-MCDM based methodology has been examined for analyzing the electricity supply chain in Iran (Zare, Mehri-Tekmeh, & Karimi, 2015). In a similar study, the SWOT-Fuzzy TOPSIS combined with AHP method has been utilized to formulate a strategic plan for the electricity supply chain in Turkey (Bas, 2013). Further, the SWOT analysis has been employed to evaluate and formulate policy advice regarding the improvement of the RE system and deployment of renewable energy sources in Jordan (Jaber, Elkarmi, Alasis, & Kostas, 2015). It is identified that the SWOT analysis is a very reliable and important tool for analyzing any complex decision problem.

2.2. MCDM methods applied in sustainable energy planning

It is very difficult for decision-makers to decide on any multi-faceted decision problem because the numerous nature of uncertainties arises while analyzing the problem. These uncertainties are not only economic and technical but also social and environmental (Kassem, Al-Haddad, Komljenovic, & Schiffauerova, 2016). Thus, the MCDM methods are significant for assessing the energy sector and choosing the optimal energy alternative. While MCDM tools have been a widely used analytics method since the energy policy and planning problems are very complicated. Table 1 presents the MCDM techniques used in sustainable energy planning related studies.

In a recent study, the new easy approach to Fuzzy Preference Ranking Organization Method for Enrichment of Evaluations (NEAT F-PROMETHEE) has also surfaced recently as MCDM method based on the adjustment of mapping trapezoidal fuzzy numbers (Ziemba, 2018). PROMETHEE for sustainability assessment (PROSA) has also been used to solving wind energy decision problems (Ziemba, Wątróbski, Zioło, & Karczmarczyk, 2017). The various studies has employed Fuzzy AHP methodology to determine the optimal RE alternative for electricity generation (See Table 1). The researchers have also used various integrated MCDM tools to choose the most reliable and Significant RE resource. However, Fuzzy AHP method has been a widely employed and appropriate methodology for decision making (Xu, Shah, Solangi, & Siyal, 2019).

It is determined that the SWOT and MCDM are widely applied methods and are considered as the most suitable for solving energy planning problem. In this study, Fuzzy AHP method is applied because it converts the decision problem into a simple problem. Besides, the Fuzzy AHP method can use quantitative and qualitative data in one model. Thus, in the study taking into account to harvest the RE resources of Sindh and Baluchistan province, Pakistan based on SWOT and Fuzzy AHP method.

3. Potential of renewable energy

The total area of Pakistan is 796,095 km^2, while the total land area is 770,875 km^2. Pakistan has ample RE resources potential, which includes solar energy (2900 GW), wind energy (346 GW) and biomass energy (5 GW) (Solangi, Tan, Khan, Mirjat, & Ahmed, 2018). However, the country has been failed to utilize these RE resources despite having huge potential to generate sustainable electricity. Currently, their development level is inferior only 4% share of renewables in the total energy mix of the country (NEPRA, 2014). It is identified that Sindh and Baluchistan province has the highest RE resource in the country to generate electricity. Therefore, this study discusses and evaluates three main RE resources of Pakistan, namely, solar, wind, and biomass.

Table 1
The various MCDM methods applied in energy planning and modeling.

Focus	MCDM Method	Country	Reference
Selection of RE resources for sustainable energy planning	AHP	Pakistan	(Amer & Daim, 2011)
Selection of RES for sustainable development of electricity generation system	AHP	Malaysia	(Ahmad & Tahar, 2014)
Model of sustainable development for energy system	AHP	Iran	(Sahabmanesh & Saboohi, 2017)
Ranking of renewable resources for electricity generation system	AHP	Algeria	(Haddad, Liazid, & Ferreira, 2017)
Selection of renewable and nuclear resources for electricity generation	AHP	Kazakhstan	(Ahmad, Nadeem, Akhanova, Houghton, & Muhammad-Sukki, 2017)
Achieving renewable energy 3-E policy goals	AHP	Taiwan	(Shen, Chou, & Lin, 2011)
Sustainable assessment in energy planning and management	Fuzzy AHP	India	(Luthra, Mangla, & Kharb, 2015)
Selection among renewable energy alternatives	Fuzzy AHP	Indonesia	(Tasri & Susilawati, 2014)
Assessing energy management performance	AHP, Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), and Visekriterijumsko Kompromisno Rangiranje (VIKOR)	Turkey	(Karatas, Sulukan, & Karacan, 2018)
Selection and ranking of renewable energy technology	Modified Fuzzy TOPSIS	Turkey	(Kaya & Kahraman, 2011)
Assessment of RE resources for sustainable energy planning	Fuzzy AHP and Cumulative Prospect Theory	China	(Wu, Xu, & Zhang, 2018)

3.1. Solar energy

Pakistan has an enormous solar energy potential; the estimated 2900 GW of solar potential is available in the country. The sun shines more than 300 days in a year with around 1800–2200 kW h/m^2, annual radiation at 26-28C^o, and average annual temperature which can produce the average electricity of 5.5–6 kW h/m^2/day (Wakeel, Chen, & Jahangir, 2016). As such, the exploitable solar resources are estimated to be higher than 50,000 MW with more than 2500 h of sunlight in a year. There are excellent potential and possible conditions for deploying solar energy projects in Baluchistan and Sindh where the sun shines for 7–8 h a day or about more than 2300–2700 h/annum (Rauf, Wang, Yuan, & Tan, 2015). The solar map of Pakistan for direct normal radiation is depicted in Fig. 2.

Two well-known renewable organizations; PCRET and AEDB are working for the development of RE in Pakistan (Rauf et al., 2015); but unsuccessful in promoting solar energy technologies in Sindh and Baluchistan due to their ineffective policies and poorly managed infrastructure. Although, currently the various small solar energy projects have been installed and at under different stages of project development in Sindh province, whereas only one solar energy project is under progress in Baluchistan province. Table 2 presents the solar energy-based projects in Sindh and Baluchistan.

Moreover, solar energy generated the 26–217 gCO_2eq/kWh of greenhouse gas (GHG) emissions (Amponsah, Troldborg, Kington, Aalders, & Hough, 2014). But, this value is very lower as compared to fossil fuels energy sources; the estimated GHG emissions from energy sources are presented in Fig. 3.

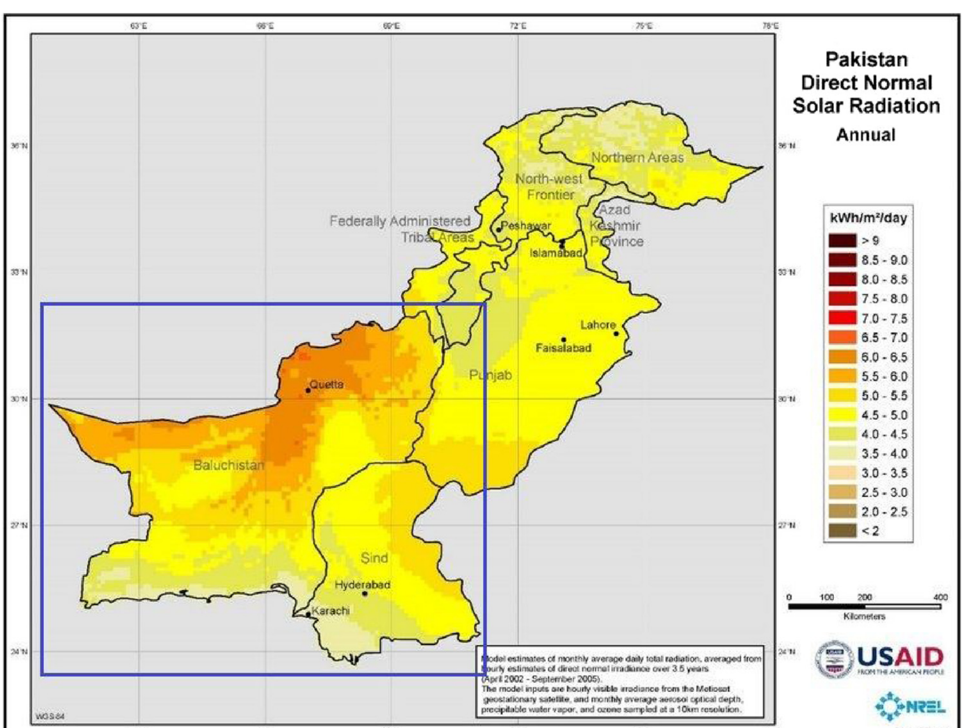

Fig. 2. Solar map of Sindh and Baluchistan province (NREL, 2007).

Table 2
Solar energy-based projects in Sindh and Baluchistan province, Pakistan ("Status of Solar Power Projects in Pakistan, 2017" n.d.).

Company name	Capacity (MW)	Location	Status
Scatec Solar	50	Goth Gagrawara Sukkur, Sindh	Under development
Ourson Pakistan Ltd.	50	Gharo, Sindh	Under development
Enertech	50	Quetta, Baluchistan	Under development
ET Solar (Pvt.) Ltd.	25	Gharo, Sindh	Under development
Forshine (Pakistan)	50	Gharo, Sindh	Under development
M/s Jafri & Associates	50	Nooriabad, Sindh	Under development
M/s Integrated Power Solution	50	Nooriabad, Sindh	Under development
M/s Solar Blue Pvt. Ltd.	50	Nooriabad, Sindh	Under development
M/S R.E Solar-I Pvt. Ltd.	20	Dadu, Sindh	Under development
M/S R.E Solar-II Pvt. Ltd.	20	Dadu, Sindh	Under development

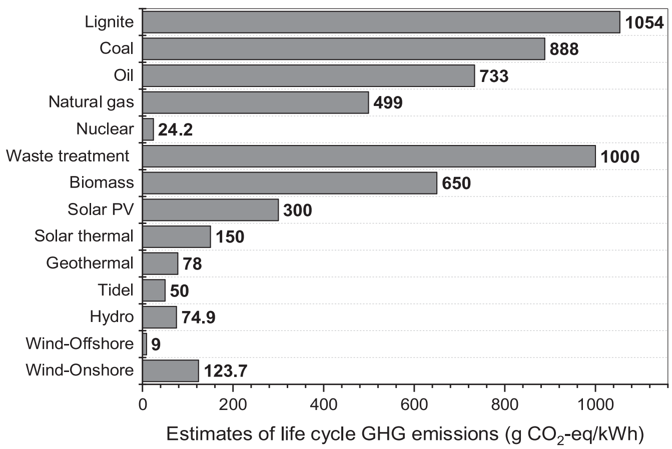

Fig. 3. Maximum GHG emissions level produced from various energy sources (Amponsah et al., 2014).

3.2. Wind energy

The country has the vast potential of wind energy, which is estimated to be 346 GW (Aman, Jasmon, Ghufran, Bakar, & Mokhlis, 2013). Most of the wind energy potential is available in Sindh and Baluchistan province. According to the Pakistan Meteorological Department, the average wind speed 7 to 8 m/s has been recorded in the coastal areas of Sindh and Baluchistan (Bhutto, Bazmi, & Zahedi, 2013). Wind resource map of Sindh and Baluchistan province is presented in Fig. 4. Wind energy is considered as cleanest energy technology and the second highest source to provide electricity in the world (Baloch, Kaloi, & Memon, 2016). Pakistan has the option to utilize wind technology, besides it would be significant for the development of the country, reducing CO_2 emissions which are currently emitted from nonrenewable, and also useful to overcome energy shortfall. The wind energy generated 8–20 g per kWh greenhouse gas (GHG) emissions, which is only 2.2% of the emissions produced by the coal (Duan, 2017).

Sindh has high wind power potential, as can be seen in Table 3. About 12.55% of its land falls into the moderate to excellent wind power class. The estimated electricity generation is 88,460 MW; however, no region of Sindh province lies within wind power classes 6 and 7. Tremendous wind power potential also exists in Baluchistan province. About 8.41% of the land falls into the moderate to excellent wind power class can be seen in Table 3. The total electricity generation capacity in this province is around 146,145 MW. Baluchistan province lies within wind power classes 6 and 7; but regrettably, no significant move has been taken to deploy this source of energy for electricity generation. While Sindh province has promoted wind power technology for electricity generation, and thus the various small wind farms are currently operational, and some of the projects are under development phase. Table 4 presents information about wind energy projects in Sindh province.

3.3. Biomass energy

Biomass is a sustainable RE resource to generate electricity (Awan & Khan, 2014). The various resources like industrial, agriculture, and forestry residues, have declared under the definition of biomass by the European Union. The biomass types suggested for biomass assessment are listed in Table 5. Pakistan is an agricultural country with around 62% of the population of the country living in rural areas; thus around 5000 MW biomass is available for generating electricity (Ghafoor, Rehman, Munir, Ahmad, & Iqbal, 2016). Government of Sindh has established some biomass energy projects but there producing electricity capacity is very small and not enough to meet the current energy demand. Besides, it is also apprised that there is no single biomass energy project has been installed in Baluchistan province. Table 6 shows the biomass energy-based projects at their different level of project development in Sindh province.

Furthermore, the GHG emissions from biomass energy are less than the nonrenewable energy sources; however, it is much higher than other RE resources. The GHG emissions generated from waste to energy and biomass were 97–1000 gCO_2-eq/kWh and 14–650 gCO_2-eq/kWh (Amponsah et al., 2014).

4. Research methodology

This study employed a SWOT analysis to identify the factors behind slow progress in RE technologies. Then, Fuzzy AHP utilized to obtain the weights of the criteria and sub-criteria, these criteria have been determined through five experts from academia, industry, and energy department feedback using a pairwise comparison matrix. Finally, to select and rank the optimal RE resource utilizing the Fuzzy AHP technique. The research methodology is presented in Fig. 5.

4.1. SWOT analysis

SWOT analysis is a vital tool for the scanning of the environment. It can synthesize all the conceptual framework together (Marttunen, Lienert, & Belton, 2017). In the study, these internal factors (strengths and weaknesses) and external factors (opportunities and threats) have been identified from the RE policy, 2006, Energy Security Plan and Energy Power Policy, 2013 (Rauf et al., 2015). This method establishes the factors that maximize the strengths and opportunities and minimize the weaknesses and threats of the organization. This method provides an excellent opportunity for the development of any strategic plan. Fig. 6 depicts the structure of SWOT analysis for this study.

Thus, this analysis can help in identifying the various other factors on the development of RE resources.

4.2. Fuzzy set theory

The fuzzy set theory was first proposed by Lofti A. Zadeh in 1965 (Klir, 2001). The method can be used when there is a vague, incomplete

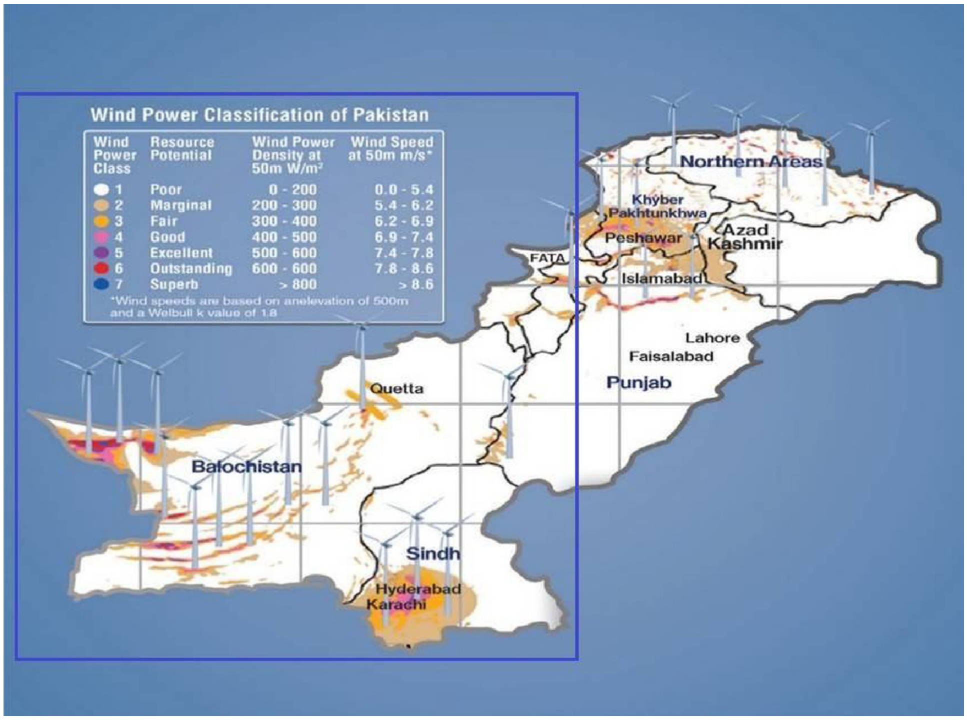

Fig. 4. Wind resource map of Sindh and Baluchistan province (NREL, 2007).

and uncertain knowledge of the decision-problem. Fuzzy set theory is a general form of a crisp set, 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 are very helpful (Shukla, Garg, & Agarwal, 2014). The TFNs rating scale frequently employed in MCDM problems is shown in Table 7.

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

$$\mu_X(x) = \begin{Bmatrix} 0, \ x < 1 \\ \dfrac{x - x}{y - x} \, if \ x \le x \le y \\ \dfrac{z - x}{z - y} \, if \ y \le x \le z \\ 0, \ x > 0 \end{Bmatrix} \tag{1}$$

The rest of the fuzzy set theory procedure is explained in the literature (Kim & Chung, 2013).

4.2.1. *Fuzzy analytical hierarchy process*

AHP is a very significant approach of MCDM (Solangi, Shah, Zameer, Ikram, & Saracoglu, 2019). However, in this study, the Fuzzy based AHP is employed to spoil the decision problem into a very small problem. The pairwise comparison is then operated in a matrix using TFNs to evaluate and prioritize the RE resources for sustainable electricity generation in Pakistan. (Gogus & Boucher, 1998) developed a method for calculating the inconsistency ratio of fuzzy pairwise comparison matrices, which its steps are given as follows.

Step 1: Transform a fuzzy triangular matrix into two independent matrices. At this step, a fuzzy triangular matrix is divided into two matrices, assuming that the triangular fuzzy number is presented as follows.

$$X_i = (l_i, m_i, u_i) \tag{2}$$

Then, the first matrix can be created by middle numbers of the fuzzy triangular matrix, that is:

$$X_m = [x_{ijm}] \tag{3}$$

The second matrix can be created by the geometric mean (GM) of the upper and lower bounds of the fuzzy triangular matrix, that is:

$$X_g = [\sqrt{x_{iju} x_{ijl}}] \tag{4}$$

Step 2: Compute the weight vector based on the Saaty method and calculation of lamda max (λmax).

Step 3: Compute the consistency index (CI) for each matrix; the CI can be computed based on the following Eq.:

$$CI_m = \frac{\lambda_{max}^{m} - n}{n - 1} \tag{5}$$

Table 3
Sindh and Baluchistan province wind resource assessment (Shami, Ahmad, Zafar, Haris, & Bashir, 2016).

Class	Potential	Installable capacity (MW)		Land area (km^2)		Windy area (%) of the total area	
		Sindh	Baluchistan	Sindh	Baluchistan	Sindh	Baluchistan
3	Moderate	61,745	82,435	12,349	16,487	8.76	4.75
4	Good	23,200	38,545	4640	7709	3.29	2.22
5	Excellent	3515	13,610	703	2722	0.50	0.78
6	Excellent	–	9,455	–	1891	–	0.54
7	Excellent	–	2100	–	420	–	0.12
Total		88,460	146,145	17,692	29,229	12.55	8.41

Table 4
Wind-based energy projects in Sindh province (Kamran, 2018; Status of Wind Power Projects in Pakistan, 2015).

Company name	Capacity (MW)	Location	Status
Hydro China Dawood Wind Farm	50	Jhimpir, Sindh	Operational
UEP Wind Farm	100	Gharo, Sindh	Operational
Sachal Wind Farm	50	Jhimpir, Sindh	Operational
Sapphire Wind Power Company Ltd.	52.80	Jhimpir, Sindh	Operational
Foundation Wind Energy I&II Ltd.	100	Gharo, Sindh	Operational
Three Gorges Pakistan (Pvt.) Ltd.	49.5	Jhimpir, Sindh	Operational
Zorlu Enerji Pakistan (Pvt.) Ltd.	56.40	Jhimpir, Sindh	Operational
Fauji Fertilizer Company Ltd.	49.50	Jhimpir, Sindh	Operational
Gul Ahmed (Pvt.) Ltd.	50	Jhimpir, Sindh	Under development
Master Wind Energy Ltd.	49.5	Jhimpir, Sindh	Under development
United Energy Pakistan Ltd.	50	Jhimpir, Sindh	Under development
Yunus Energy Ltd.	50	Jhimpir, Sindh	Under development
Metro Power Company Ltd.	50	Jhimpir, Sindh	Under development
Tapal Energy (Pvt.) Ltd.	30	Jhimpir, Sindh	Under development
Tenega Generasi Ltd.	49.5	Gharo, Sindh	Under development

Table 5
Biomass type and conversion technology suitable for electricity generation in Pakistan (Biomass Resource Mapping in Pakistan, 2016).

Supply sector	Biomass type	Conversion technology
Industry	Food processing residues (rice husk, sugarcane bagasse, sugar beet pulp)	Combustion/co-generation, gasification, biogas
	Wood processing residues (chips generated in sawmills, slabs, sawdust)	Combustion/co-generation, gasification
Agriculture	Livestock residues	Biogas, biogas to electricity, biogas to electricity and heat
	Crop residues	Combustion/co-generation, gasification
Forestry	Wood fuel, harvesting residues	Combustion/co-generation, gasification

$$CI_g = \frac{\lambda_{max}^{g} - n}{n - 1} \tag{6}$$

Step 4: Compute the consistency ratio (CR) of the matrices in Problem. To calculate the CR, the consistency index (CI) of each matrix is divided by its random index (RI).

$$CR_m = \frac{CI_m}{RI_m} \tag{7}$$

$$CR_g = \frac{CI_g}{RI_g} \tag{8}$$

If the values of CR_m and CR_g are less than 0.1, the matrices are consistent; if it surpasses 0.1, then, the method may not provide meaningful results. The values of the random indices (RI) given by Gogus and Boucher method are different from those in the Saaty method. Gogus and Boucher redeveloped the RI Table for fuzzy pairwise comparison matrices with creating 400 random matrices. Table 8 shows the values of the RI for each matrix of Gogus and Boucher method.

4.2.2. Fuzzy AHP decision model

The Fuzzy AHP application generally involves four steps, following the main decision-problem, a top-down decision hierarchy is structured. The structure of the hierarchy starting with a goal (upper level), criteria/sub-criteria (middle level), and alternatives (bottom level). In step-1, the goal is set to evaluate and prioritize an optimal RE resource for electricity generation in Sindh and Baluchistan province, Pakistan. The multi-perspective approach is used to identify 4 criteria, namely, economic, environmental, technical, and socio-political. The model comprised 17 sub-criteria and 3 alternatives. The decision model of the study is depicted in Fig. 7.

In step-2, the pairwise comparison matrices would be conducted at each level of the Fuzzy AHP model. For this motive, a team of five experts' were consulted to make a pairwise comparison matrix. The consulted experts' were very professional, experienced, and notable with the current energy system of Pakistan. The detailed information of the experts' is presented in the Appendix section of the paper. In step 3–4, the random consistency index is used to check the pairwise comparison matrix.

The Fuzzy AHP method is implemented for ranking the RE resources of Sindh and Baluchistan province. In the study, the criteria namely, economic, environmental, technical, and socio-political has been identified from the literature review (Table 9). Moreover, the quantitative data and information on various RE resources are shown in Table 10.

The selected criteria and sub-criteria are very important for the selection of RE resources in Sindh and Baluchistan province, Pakistan. Therefore, this study has utilized a Fuzzy AHP method to undertake and solve this complex decision-problem.

Table 6
Bagasse/biomass energy-based projects in Sindh province, Pakistan (Current status of bioenergy, 2013).

Company name	Capacity (MW)	Location	Status
JDW Sugar Mills (Unit-III)	26.35	Ghotki, Sindh	Operational
Alliance Sugar Mills Ltd.	30	Ghotki, Sindh	Under development
Faran Power Ltd.	26.5	Tando Muhammad Khan, Sindh	Under development
Mehran Energy Ltd.	26.5	Tando Allah Yar, Sindh	Under development
Habib Sugar Mills Ltd.	26.5	Shaheed Benazirabad, Sindh	Under development
Gotki Power Pvt Ltd.	45	Ghotki, Sindh	Under development
TAY Powergen Company Pvt Ltd	30	Tando Allah Yar, Sindh	Under development
Ranipur Energy Pvt. Ltd	60	Khairpur, Sindh	Under development

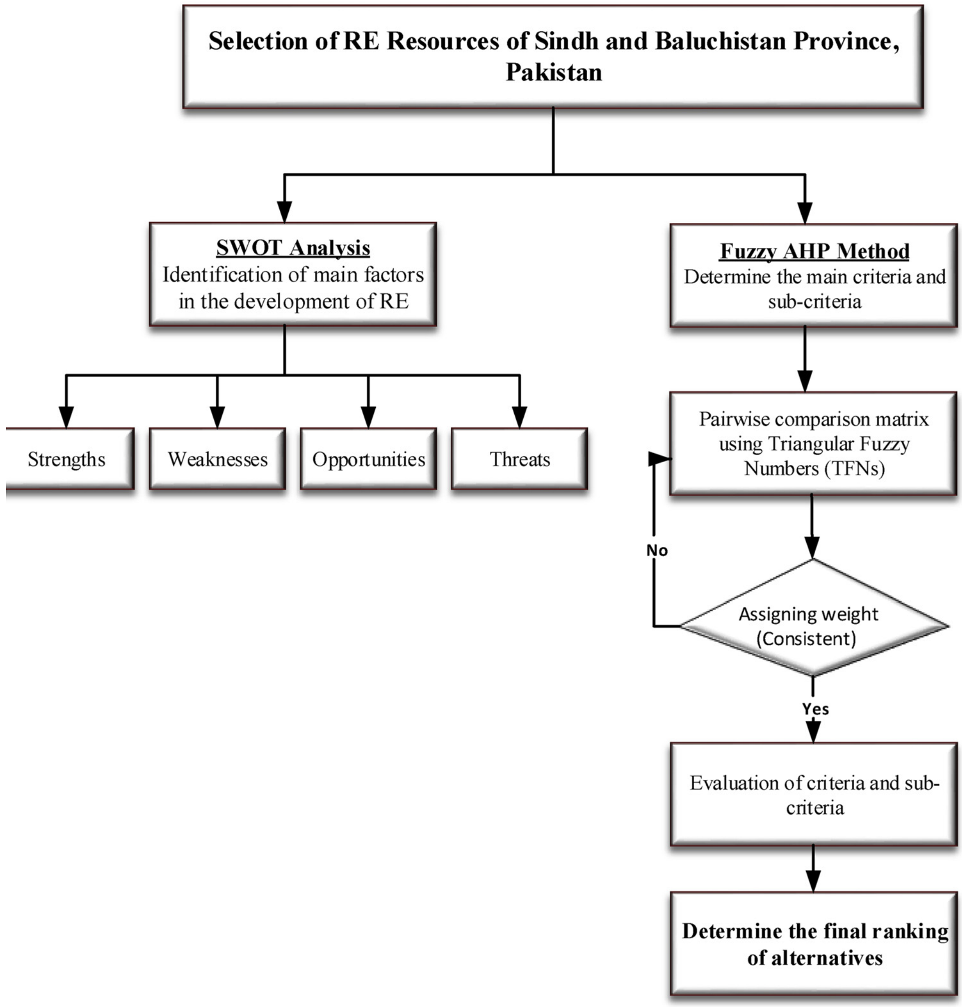

Fig. 5. The research methodology of the study.

5. Results and discussion

Making a decision on the complex problem is not an easy task. In this study, the SWOT analysis has been used to determine the internal and external factors behind slow progress and development of RE in Sindh and Baluchistan province. SWOT analysis has identified the various significant strengths and opportunities of the RE technologies, while it has also identified the weaknesses and threats in the development process of RE technologies in the country. Furthermore, this study obtained the results from the energy experts by using Fuzzy AHP methodology. The pairwise comparisons matrix at each level is shown in the Appendix section of the paper. In the following sections, the results of main-criteria, sub-criteria, overall sub-criteria, and RE alternatives will be presented.

5.1. Results of main criteria

The Fuzzy AHP approach has been employed to determine the weights of each criteria with respect to the goal and is presented in Fig. 8. It can be seen that economic (ECC) is considered as the most important criteria and got the highest 0.2990 wt for the selection and prioritization of RE resources of Sindh and Baluchistan province. Socio-political (SPC) ranked second important criteria obtaining 0.2880 wt. While the technical (TEC) criteria considered as a third significant option with 0.2110 wt. Environmental (ENC) criteria were ranked fourth with the respective weight of 0.2020.

The analysis implies the development of RE resources should consider and evaluate whether the economic conditions are enough to install and implement RE sources power plant project in Sindh and Baluchistan province. It is very important to measure the capability of power generation from RE resources to decrease the dependence on conventional energy sources. The influence of the government and people is another important factor which should be well-considered. Otherwise, it may create a problem for the stakeholders to invest in the development of RE technologies. The technical criteria is also an important factor in making efficient RE power projects for electricity generation. The environmental criteria are also becoming increasingly vital due to climate change and the rise of environmental protection awareness among the many countries.

The obtained results are partially matched to a recently published study, in which the researchers identified that the economic criteria are the most important, followed by the environment and, lastly, the social criteria (Büyüközkan, Karabulut, & Güler, 2018).

5.2. Results of sub-criteria

Fig. 9 presents the results of economic sub-criteria. The prioritizing order of sub-criteria within economic (ECC) criteria is as follows: ECC2 > ECC4 > ECC1 > ECC3 > ECC5. Research and Development (R&D) cost (ECC2) is reported as the most important economic sub-barrier by obtaining 0.2450 wt. Pakistan is an under developing country having limited R&D funding, which is a major concern as most RE technologies are capital intensive; thus, experts' ranked ECC2 sub-criteria as most important sub-criteria. Therefore, ECC1 is a very

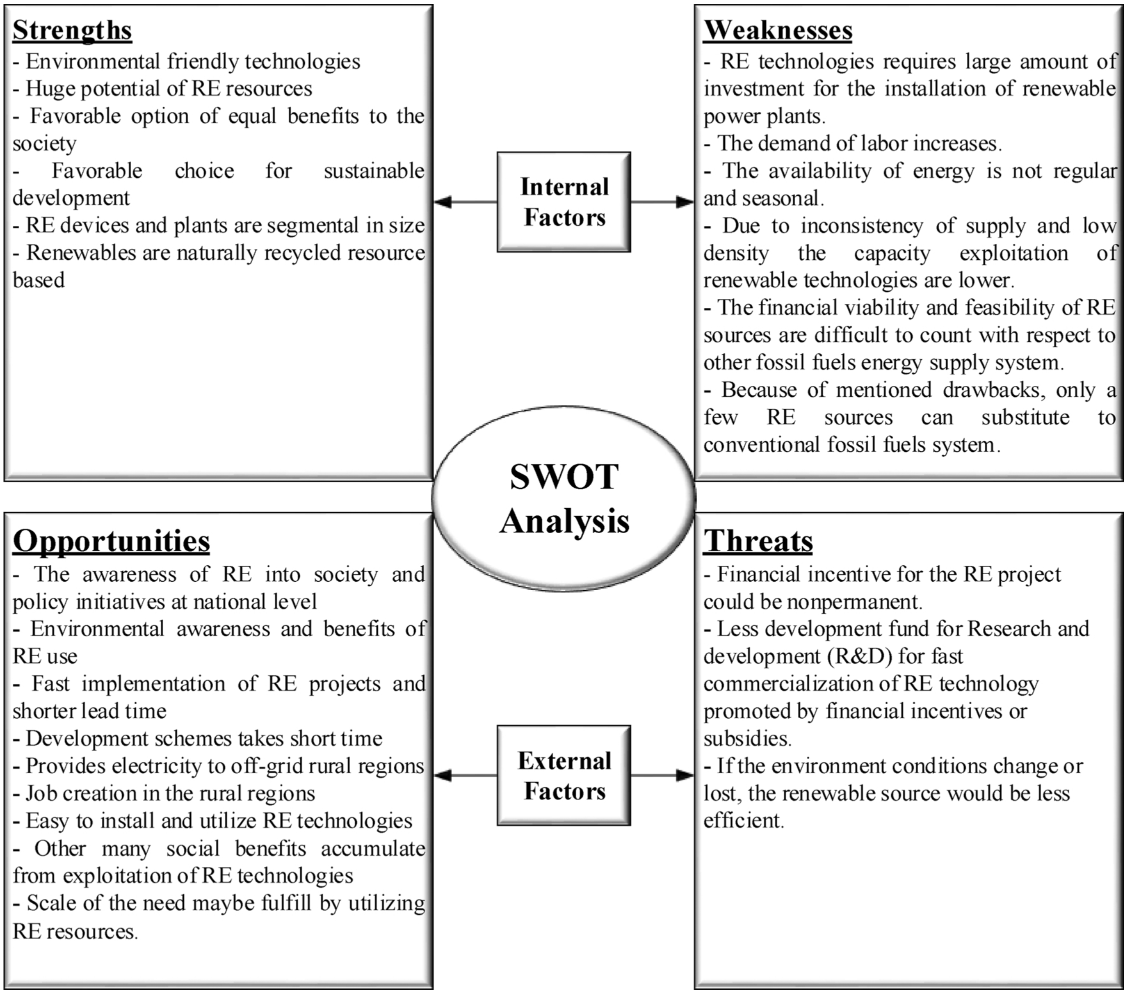

Fig. 6. SWOT analysis.

Table 7
Linguistic variable and triangular fuzzy numbers (Kaganski, Majak, & Karjust, 2018).

Number	Linguistic variable	TFNs
1	Equally significant	(1,1,1)
2	Equally to average significant	(1,2,3)
3	Averagely significant	(2,3,4)
4	Averagely to strongly significant	(3,4,5)
5	Strongly significant	(4,5,6)
6	Strongly to very strongly significant	(5,6,7)
7	Very strongly significant	(6,7,8)
8	Very strongly to extremely significant	(7,8,9)
9	Extremely significant	(9,9,9)

Table 8
RI for each matrix.

n	RI_m	RI_g
1	0	1
2	0	2
3	0.4890	0.1796
4	0.7937	0.2627
5	1.0720	0.3597
6	1.1996	0.3818
7	1.2874	0.4090
8	1.3410	0.4164
9	1.3793	0.4348
10	1.4095	0.4455
11	1.4181	0.4536
12	1.4462	0.4776

important aspect of implementing any RE project in the country. The second highest sub-criteria within ECC is resource potential (ECC4) with 0.2390 wt. The Sindh and Baluchistan region has an enormous potential of RE resources, especially solar, wind, and biomass energy. Capital cost (ECC1) has also got a considerable weight of 0.22280 because it is very important for the effectiveness of RE development project. While O/M cost (ECC3) and power generation cost (ECC5) obtained the respective weights of 0.1540 and 0.1340.

From the environmental (ENC) perspective, the ranking order of sub-criteria is ENC2 > ENC1 > ENC3, which is presented in Fig. 10. Emissions (ENC2) ranked priority by obtaining 0.4240 wt. The greenhouse gases (GHGs) are very dangerous and unhealthy for the people, habitat, and overall environment. Due to this reason and climate change, the world is moving towards less or zero pollutant corban emission technologies. The second highest sub-criteria within ENC criteria is a land requirement (ENC1) with 0.3650 wt. The ENC1 is very crucial sub-criteria for installation of the RE power project such that for the wind power project, the land can also be utilized for farming and cultivation. However, for the solar power project, the land cannot be used for other purposes. While the impact on the environment (ENC3) was considered as least important sub-criteria with 0.2110 wt.

The ranking of sub-criteria within technical (TEC) criteria is presented in Fig. 11. The ranking of sub-criteria orders as TEC4 > TEC1 > TEC3 > TEC4 > TEC2. On-grid access (TEC4) has been identified as the most important sub-criteria with 0.2530 wt. On-Grid

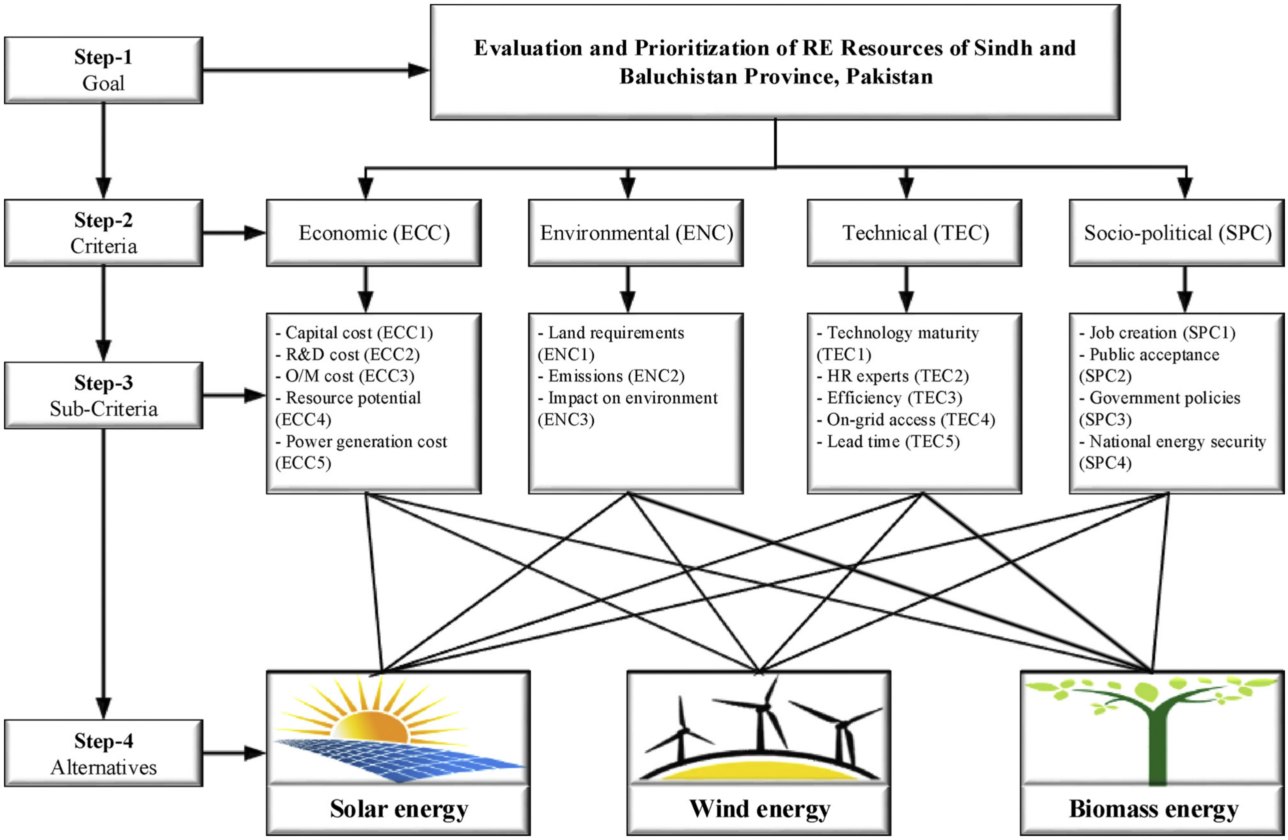

Fig. 7. The Fuzzy AHP model.

access is very important for the successful implementation of the RE project. Technology maturity (TEC1) has found as second important sub-criteria with 0.2450 wt. The importance of TEC1 presents that RE technologies are commercially not introduced; thus, it must be in mature form for the deployment of renewable technology in Pakistan.

Fig. 12 shows the ranking of sub-criteria within socio-political (SPC) criteria. The importance of each of the sub-criteria shows as SPC3 > SPCS4 > SPC2 > SPC1. Government policies (SPC3) holds the first position by obtaining 0.2950 wt. While national energy security (SPC4) comes second significant sub-criteria by obtaining 0.2590 wt. Within these criteria, the results show that SPC3 and SPC4 are the most important aspects of the development of RE technologies. The government policies must be well-established, effective, and beneficial for the stakeholders in order to increase the national energy security of the country. Whereas, public acceptance (SPC2) and job creation (SPC1) ranked third and fourth important sub-criteria with 0.2290 and 0.2160 wt.

Table 9
Criteria and sub-criteria employed in assessing RE resources for electricity generation (Ahmad & Tahar, 2014; Ahmad et al., 2017; Amer & Daim, 2011; Solangi, Tan, Mirjat, Valasai et al., 2019).

Criteria	Code	Sub-Criteria	Code	Description
Economic	(ECC)	Capital cost	(ECC1)	Power plant cost and supplementary equipment
		R&D cost	(ECC2)	The research and development expenses occurred in renewable technology.
		O/M cost	(ECC3)	The cost incurred during production, operation, and maintenance of renewable power plant.
		Resource potential	(ECC4)	Availability of locally RE resource for electricity generation
		Power generation cost	(ECC5)	The expected cost of the power generated by the renewable energy plant
Environmental	(ENC)	Land requirements	(ENC1)	Area of land required for RE power plant
		Emissions	(ENC2)	The ability of a RE technology to decrease or eliminate greenhouse gases
		Impact on the environment	(ENC3)	The extent of the impact of a RE technology on the biodiversity and visual of the region
Technical	(TEC)	Technology maturity	(TEC1)	Renewable technology that is commercially and economically available
		HR experts	(TEC2)	Experts available in the area to install, operate and maintain the renewable power plant
		Efficiency	(TEC3)	RE technology with better technical efficiency is more reliable
		On-grid access	(TEC4)	The availability of on-grid access to generate electricity
		Lead time	(TEC5)	Time elapsed in making approval and establishing of a RE plant
Socio-political	(SPC)	Job creation	(SPC1)	Potential of RE technology to create jobs
		Public acceptance	(SPC2)	Public attitude towards each technology
		Government policies	(SPC3)	Government policies regarding each RE technology
		National energy security	(SPC4)	Enhance and increase energy security by utilizing ample RE resources

Table 10
Summary of quantitative data for RE resources (Amer & Daim, 2011; Solangi, Tan, Mirjat, Valasai et al., 2019).

Unit	Solar	Wind	Biomass
O&M cost ($/MW h)	12.1	9.6	13.7
Capital cost ($/MW h)	194.6	83.9	55.3
Efficiency (%)	80	96	33
Average power generation cost (US c/kWh)	8	10	35
Job creation (employees/500 MW)	5370	5635	36055
Land requirement (km^2/1000 MW)	35	100	5000
Public acceptance in favor %	80	71	55

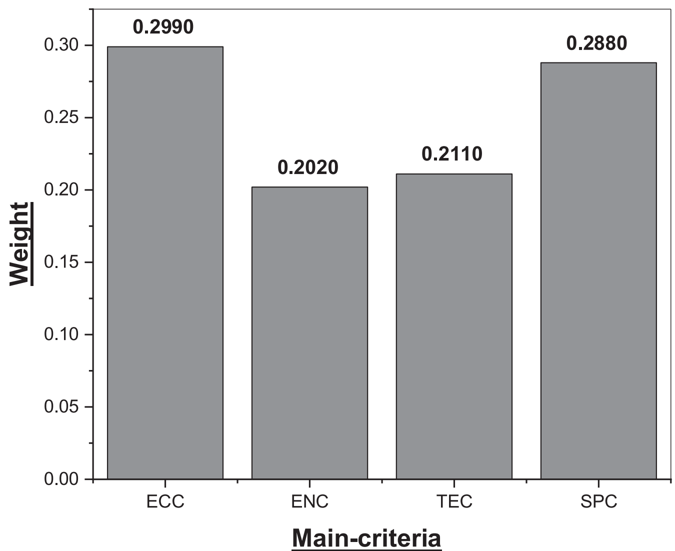

Fig. 8. Ranking of main criteria respect to the goal.

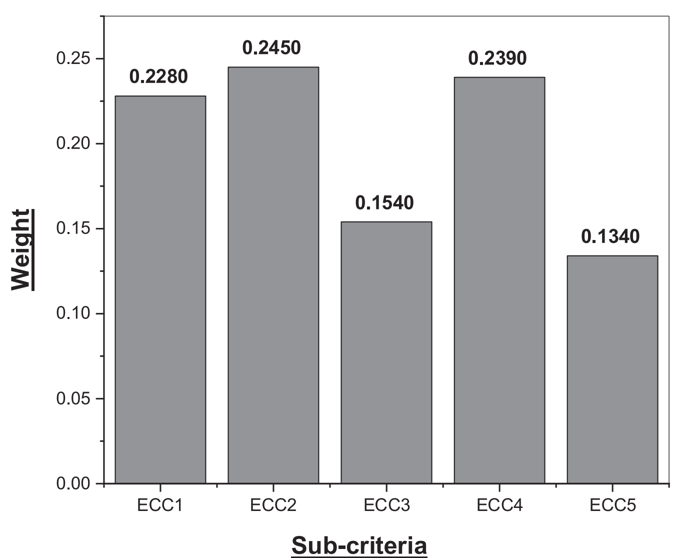

Fig. 9. Ranking of economic (ECC) sub-criteria.

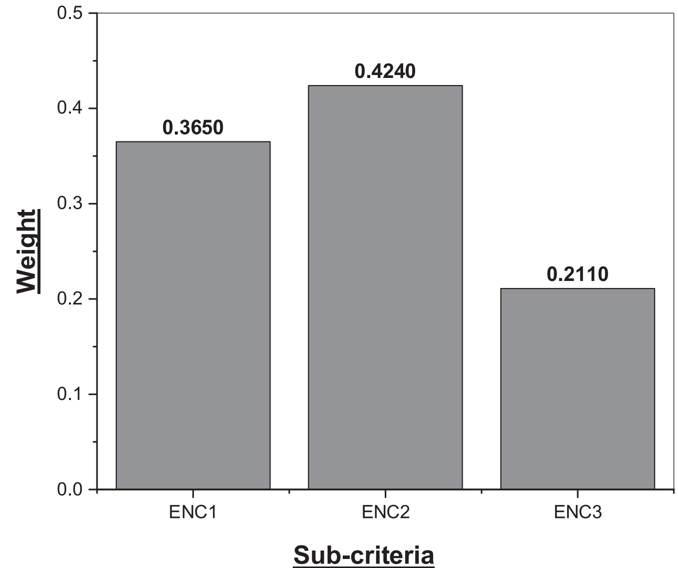

Fig. 10. Ranking of environmental (ENC) sub-criteria.

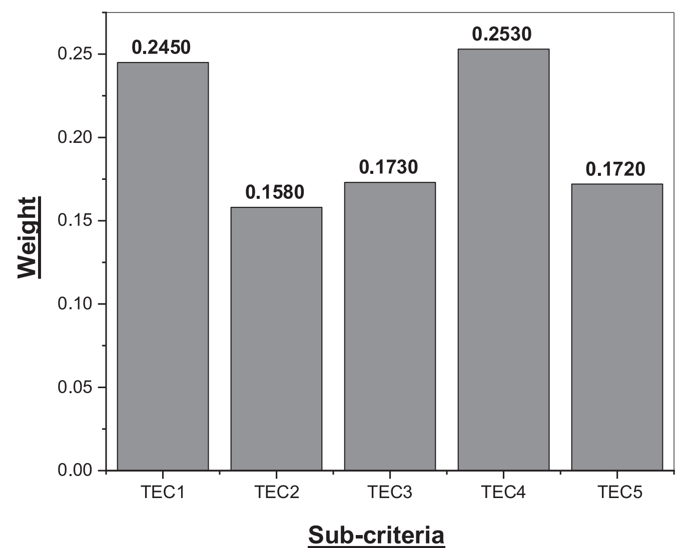

Fig. 11. Ranking of technical (TEC) sub-criteria.

5.3. Results of overall sub-criteria

The final weight and ranking of sub-criteria were determined by multiplying each sub-criterion priority weight of its respective main criteria. The evaluation and ranking of 17 sub-criteria performed with respect to the goal. This step develops the overall priority of the 17 sub-criteria. Fig. 13 presents the overall ranking of sub-criteria, which is based on the final weights obtained. Emissions (ENC2) has obtained the highest 0.0856 wt among all sub-criteria, followed by Government policies (SPC3) with 0.0840 wt, and national energy security (SPC4) with the respective weight of 0.0745.

The study conducted by (Theodorou, Florides, & Tassou, 2010) found that investment cost, efficiency, and technological implementation are the most important sub-criterion. Another study indicated that energy efficiency is ranked the most significant sub-criteria, whereas land use and social acceptance criteria are less significant sub-criteria (Ahmad & Tahar, 2014).

5.4. Results of RE alternatives

From the alternatives point of view, the wind ranked first followed by solar and biomass. The priority weight of wind is 0.4460, followed by 0.4020 for solar, and 0.1520 for biomass, respectively. The ranking of the three RE resources evaluated concerning the goal is presented in Fig. 14. It is evident from Fig. 14 that wind energy alternative has attained highest overall weight under Fuzzy AHP methodology and thus determined as most suitable RE resource for electricity generation in Sindh and Baluchistan province followed by solar energy and biomass

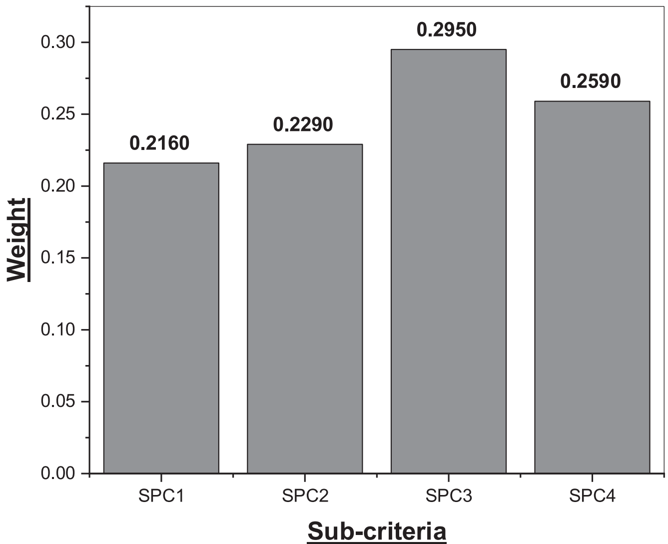

Fig. 12. Ranking of socio-political (SPC) sub-criteria.

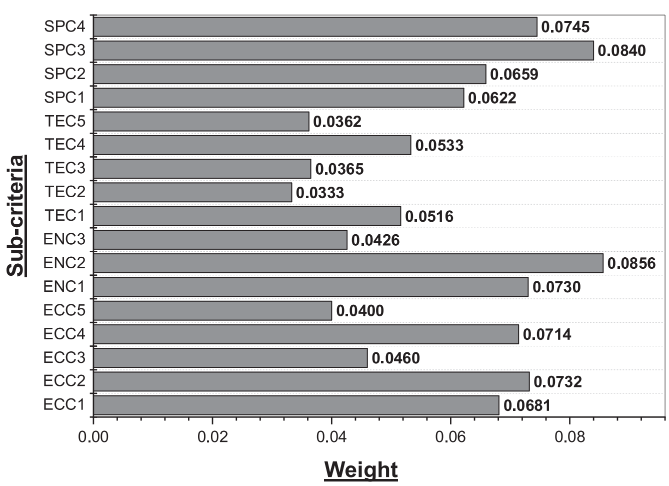

Fig. 13. Ranking of overall sub-criteria.

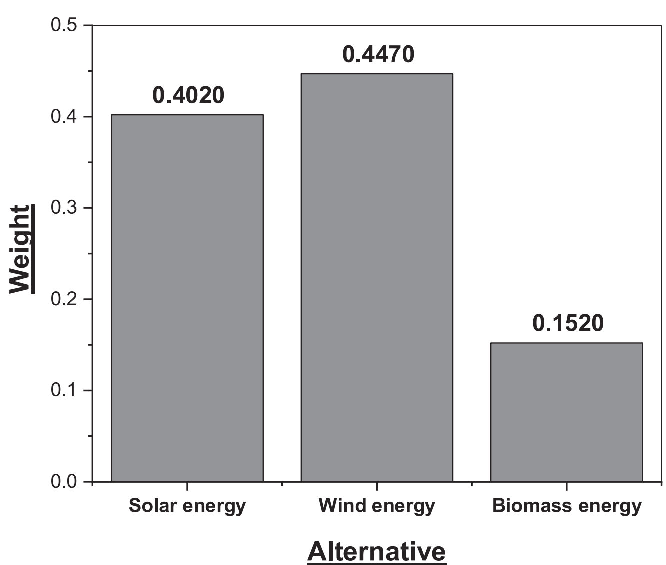

Fig. 14. Ranking of RE alternatives based on priority weight with respect to the goal.

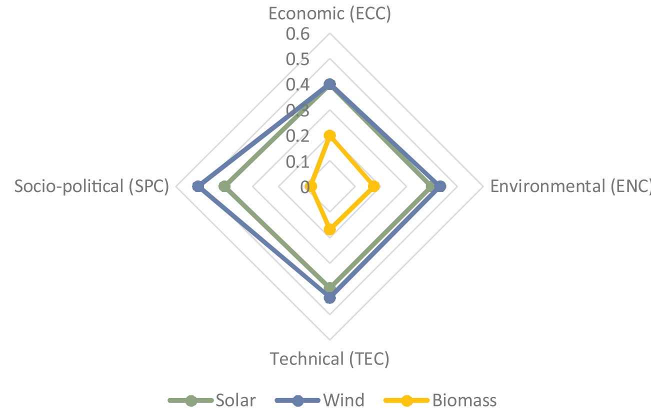

Fig. 15. Performance of RE alternatives with respect to criteria.

energy respectively. Moreover, further analysis reveals that wind energy outshines on all criteria (economic, environmental, technical, and socio-political) followed by solar and biomass energy. In the study conducted by (Ahmad & Tahar, 2014), wind energy technology also performed the finest on environmental criteria for the case study in Malaysia. The highest weight for wind technology is due to low GHG emissions. Therefore, it is identified that the wind is the most suitable options and commercially viable for electricity generation. However, the biomass technology is currently not as mature as wind and solar technologies; therefore, the experts ranked as least important RE alternative. Fig. 15 depicts the performance of RE resources with respect to criteria.

These findings align with a recent study conducted by (Solangi, Tan, Mirjat, Valasai et al., 2019), in their study authors identified that economic is the most important criteria and the wind is the optimal option for sustainable electricity generation in Pakistan.

5.5. *Sensitivity analysis*

The sensitivity analysis is conducted to check the robustness of the obtained results. It is used to analyze any major or minor variation in the obtained results. Therefore, it is important to analyze the stability of prioritization of RE alternatives because a minor variation in weight may lead to major variations in the obtained results (Mangla, Govindan, & Luthra, 2017). Further, the sensitivity analysis can confirm the changes in the final prioritization of minor changes in priority weights of criteria. Therefore in the study, the weight of the main criteria has been changed to examine the impact of criteria weights on ranking values of RE alternatives. For this purpose, the 4 cases are determined by changing the weights of the main criteria. In each case, only one criterion is set as important (0.400 wt), while others are kept constant (0.200). The priority weights used are shown in Table 11. The final ranking of RE alternatives determined from sensitivity analysis with respect to each case is shown in Table 12.

The results reveal that wind energy is considered as the most

Table 11
Criteria weight employed for sensitivity analysis.

	Economic (ECC)	Environmental (ENC)	Technical (TEC)	Socio-political (SPC)
Case-1 Economic (ECC)	0.400	0.200	0.200	0.200
Case-2 Environmental (ENC)	0.200	0.400	0.200	0.200
Case-3 Technical (TEC)	0.200	0.200	0.400	0.200
Case-4 Socio-political (SPC)	0.200	0.200	0.200	0.400

Table 12
Ranking of RE resources with priority weight.

		Solar energy	Wind energy	Biomass energy
Case-1	Priority weight	0.4160	0.4520	0.1630
Economic (ECC)	**Rank**	**2nd**	**1st**	**3rd**
Case-2	Priority weight	0.4090	0.4490	0.1590
Environmental (ENC)	**Rank**	**2nd**	**1st**	**3rd**
Case-3	Priority weight	0.4130	0.4510	0.1620
Technical (TEC)	**Rank**	**2nd**	**1st**	**3rd**
Case-4	Priority weight	0.4050	0.4480	0.1550
Socio-political (SPC)	**Rank**	**2nd**	**1st**	**3rd**

significant RE alternative for electricity generation in Sindh and Baluchistan Province, Pakistan. While solar energy is ranked second important RE alternative, and biomass energy is observed as the least important RE alternative option for electricity generation. After performing sensitivity analysis, it can be clarified that the obtained results of Fuzzy AHP method are reliable and robust, and there is no notable change in the results; therefore it is insignificant to change the weights. The results of the study are very useful for policy and decision-makers in implementing RE resources for electricity generation in Sindh and Baluchistan.

6. Conclusion and policy implications

Pakistan is an energy deficient country, and it is expected that in future energy demand will increase due to increasing population and industrialization. Thus, it is very important to exploit RE resources of Pakistan. This study has identified main factors through SWOT analysis that impede the utilization process of RE resources. These have been identified as the internal and external factors behind this core issue. It is identified that economic and socio-political are the most appropriate criteria for selecting and ranking of various RE resources.

Therefore, the Fuzzy AHP method is employed to prioritize suitable RE resources of Sindh and Baluchistan province for sustainable electricity generation. The results of Fuzzy AHP reveal that wind resource is ranked first followed by solar and biomass, respectively. It is identified that wind has enormous potential to generate electricity in both provinces, which could be enough to meet the country's energy demand. The utilization of wind energy can reduce dependence on conventional energy sources, and it would also improve energy security and produce new jobs in rural regions. Wind energy can also play a pivotal role in reducing the energy shortage because there are many rural regions where there is no electricity; thus, this source of energy is very useful for energy generation. Therefore, it is recommended that the country should consider the use of wind for sustainable development. In the study, authors have also suggested energy planning and policies for sustainable development.

6.1. Financing and incentives for RE used in Sindh and Baluchistan province

The favorable system of RE in Pakistan already exists for the development of RE resources. But yet, renewables have not been promoted successfully, so, it is essential to help RE and focus on research & development (R&D) capacity, complete ongoing projects and install new big renewable projects. Government subsidies may support the financing system for RE project, and financial incentives as briefly pointed below:

- Accelerated depreciation
- Capital subsidy
- Concessional custom duty
- bank facilities and loans
- Sales tax benefits
- Exemption of electricity tax

6.2. Strategy for the exploitation of RE in Sindh and Baluchistan province

The share of RE is very limited in the total energy mix of Pakistan. The strategy is to increase the share of RE in the total energy mix of Pakistan. These strategies include:

- A suitable policy plan and package should be introduced in the country for both private and public sectors to establish the RE power plants.
- To provide financial incentives to stakeholders with low tax and tariffs.
- The RE development should be considered from various aspects such as energy augmentation and tool for social justice.
- The development of RE through the social network of the people and communized based to introduce awareness programs and knowledge about renewable resources.
- The country must have a well-established entrepreneurship system for the development of RE technologies.
- To establish a significant renewable energy policy, which addresses the use of RE and covering all the legal features.

6.3. Limitations and future research directions

This research has been conducted comprehensively, but still there have some limitations which need to be assessed in future work. This study was undertaken in the context of Sindh and Baluchistan provinces; therefore it is vital to research other provinces of Pakistan. In the study, only five experts' were consulted to provide their feedback; thus, more inclusions of experts' would provide significant results. This study has used SWOT and Fuzzy AHP methodology for assessing RE resources of Sindh and Baluchistan provinces of Pakistan. In future research studies, the Fuzzy based MCDM methods such as ANP, DEA, ELECTRE, TOPSIS, and VIKOR can be applied to the similar-type of decision-problem; and compare the results of the current study and then determine the feasible RE option for sustainable electricity generation. It is believed that this research shall be assessed as a solution for sustainable development by utilizing the RE resources of Pakistan; however, further research can shed much more light on this topic.

Declaration of Competing Interest

The authors declare that there is no conflict of interest with anyone else.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.scs.2019.101861.

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