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A Fuzzy-TOPSIS Based Evaluation of Renewable Energy Alternatives: A Case Study

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There is a pressing need to rapidly deploy Renewable Energy Sources (RES) to meet the world's power requirements in a way that is both sustainable and economically viable. Using soft computing, sustainable electricity generation can be achieved without further resources or expenses. The selection procedure of the Fuzzy Analytical Hierarchy Process (F-AHP) and Fuzzy Technique for Order of Preferences by Similarity to the Ideal Solution (F-TOPSIS) is crucial in sustainable power and soft computing. The research conducts evaluations and examinations to develop durable RES management that offers improved security against cyber-attacks. The critical criteria influencing the selection of sustainable RES are further divided into five dependent secondary elements, which are then assessed. The methods of generating Renewable Energy (RE) are seen as alternatives. The F-AHP approach is necessary because of the inherent complexity of determining the efficacy evaluation of the RES control and the components' significance. The F-TOPSIS-based approach successfully chooses the optimal option from many choices. The discovery demonstrates that wind energy is a sustainable, highly favored, and prominent form of RE. The proposed study would be innovative because it combines mixed soft computing methods and their use in the energy business.

Keywords: TOPSIS, Renewable Energy, Fuzzy, Sustainable Electricity.

1. Introduction

Renewable energy is crucial in alleviating the adverse impacts of global warming [1]. Analyses conducted by the International Renewable Energy National Agency (IRENA) indicate that 90% of the necessary carbon dioxide decreases to reach nationally accepted climate objectives are accomplished by implementing secure, dependable, and cost-effective measures using renewable energy and energy conservation. Many nations and international groups have made substantial progress in pursuing sustainable energy production options via Renewable Energy (RE) techniques [14]. Solar and wind energy proliferation has garnered significant scrutiny due to its almost limitless and readily accessible sources [2]. Other nations have derived advantages from possessing significant reserves of geothermal energy [15].

A few individuals are harnessing the energy from tidal or wave sources to produce electricity. Only a limited number of nations have sufficient wave power capabilities. In addition to the existing Renewable Energy Sources (RES), other countries are exploring hydrogen fuel production as an alternative energy source. This could be a more cost-effective method of energy creation while simultaneously lowering greenhouse gas emissions [3].

Environmental initiatives and laws substantially impact sustainable economic development at both the national and global levels. Energy generation is crucial to sustainable development and environmental regulations [4][20]. The environment, RE generation, and sustainable growth are interconnected fundamental ideas. The primary driver of global warming in the last century has been the extensive extraction and use of fossil fuel resources. Policy-makers should design novel tactics and policies about these three principles [27]. Forward-thinking approaches should include the examination of environmental impacts and the spread of technology resulting from the business operations of individual organizations [5][16][17][25].

All materials employed for energy production have detrimental environmental impacts [22]. The availability of energy sources such as petroleum-based fuels (coal, oil, and natural gas) and uranium is widely acknowledged to be limited, has more adverse environmental effects, and imposes more significant limitations on sustainable development [24]. RES has a detrimental impact on nature, albeit the harm level is lower than that of fossil fuels and nuclear power. Several sustainable RE choices provide a much more environmentally friendly system for the natural world [6]. When striving for equitable growth, it is crucial to prioritize using RES and select the specific kind of RE [19][26][28].

Soft computing methods are practical tools for enhancing the effectiveness of energy systems. Fuzzy logic decision-making procedures are utilized to select several RE choices. Soft Computing in RES is a practical manual that uses soft computing methods and mixed intelligent systems to design, model, characterize, optimize, forecast, and predict renewable energy systems [7][18]. Soft Computing Techniques for RE is a comprehensive collection of advanced technical research in computational intelligence and fuzzy logic, providing the most effective solution for environmental preservation. The field of RE study is advancing rapidly as politicians, academics, analysts, and international organizations collaborate to create alternate and sustainable energy options to address pressing financial, environmental, and social issues.

RES includes highly computational, non-linear, and complex strategies such as creative designs, sustainable processes, and data analysis. These systems also involve a significant level of unpredictability. Soft computing techniques, including neural science and structures, fuzzy sets and structures, genetic coding, evolutionary techniques, and machine learning, effectively handle data noise, inaccuracy, and unpredictability while providing dependable and cost-effective solutions. Soft computing and intelligent paradigms are increasingly employed in studying RES.

2. Background to renewable energy resources

Several investigations have been undertaken to assess the RE industry, using diverse methodologies and examining different aspects.

Ding et al. focused on the relationship between age and power transfer in public networks using the deterministic approach using the General Algebraic Modeling System (GAMS) software [8][29]. They considered the reduction of the overall cost of the system, the environmental constraints to mitigate CO_2 emissions, and the exploitation of energy sources. However, they suggested more investigation to examine uncertain elements associated with the energy systems. They emphasized that future studies should include the risks of the subject, resources, and the cost of fuels.

Cantarero et al. focused on developing an energy planning platform to promote renewable energy resources, establish sustainable environments, and evaluate alternative approaches for transforming the public energy mix [9][21]. This phase used geographic data structure components, an interest supply energy examination approach, and a multi-standards choice assessment method to assess sustainability.

Garduño-Ruiz et al. developed a methodology to choose viable energy options for future electricity generation in Mexico [10]. This technique considers evaluating environmental, economic, and social sustainability via investigating life cycle indicators using a multi-criteria decision analysis model (weighted averages). They disregard practical aspects, the design of the vegetation, and the concerns of managers and stakeholders.

According to Gaba et al., intelligent tiny systems have social setups because they consist of dispersed socio-specialized groups that organize a limited region with precise levels of linkages between the actors [11][23]. It is crucial to analyze the sociological perspective in connection to society for long-term acceptance and support and any energy source that impacts communities. The producers have analyzed numerous categories of actual functions using different methods while organizing and designing power systems with RE.

Alghassab et al. conducted a study on various aspects of Multi-criteria Decision-Making Analysis (MDMA) for Hybrid Renewable Energy Systems (HRES) [12]. When using MDMA in practical energy systems, there are four categories of rules that need to be considered: technical (efficiency, reliability, safety, etc.), economic (investment cost, fuel cost, net current value, etc.), environmental (CO_2 emissions, land use, noise, etc.), and social (social acceptability, job creation, social benefits, etc.).

Maisanam et al. proposed an approach for assessing the influence of sustainability concepts on the design of an HRES [13]. The approach combines environmental analysis, a study of existing literature, and the intellectual management process via expert panels and evaluations.

The literature review unequivocally illustrates that the assessment of RE is a multi-criteria issue that is effectively addressed using fuzzy sets. The challenge is the need for more hesitant fuzzy units due to their shortage. Thus, it is imperative to design an environmentally friendly structure for RE that utilizes hybrid soft computing methods to provide sustainable RE. The structure has the potential to evaluate several utility-scale RES. This study aims to provide a fuzzy multi-criteria solution by including reluctant fuzzy sets using the Fuzzy Analytical Hierarchy Process (F-AHP) and Fuzzy Technique for Order of Preferences by Similarity to the Ideal Solution (F-TOPSIS).

3. Proposed fuzzy-TOPSIS-based evaluation of renewable energy

This research presents a novel technique combining a hybrid window concept and the F-TOPSIS method to assess RE generation capacities accurately. Fig. 1 illustrates a research flow chart outlining the study's methodology. The process starts by defining the aims and objectives concurrently with selecting the appropriate Decision-Making Units (DMUs). This article examines 42 nations, referred to as DMUs in America, Europe, Asia, and Africa, that have shown exceptional proficiency in harnessing and using renewable energy sources.

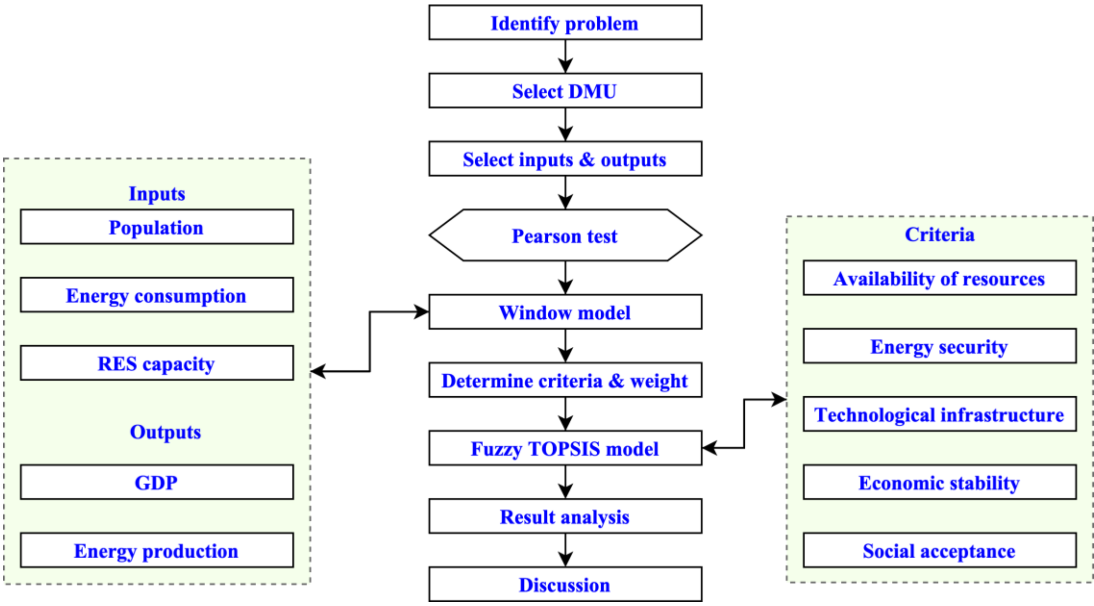

Figure 1. Research workflow

The first phase involves using the window concept to select a set of prospective candidate nations. It is essential to differentiate between the input and output elements since these aspects significantly impact the approach. They are considering the purpose of the article and the compilation of typical input and output criteria used in previous research to evaluate the possibility of RE. This article examines three factors: populace, overall usage of energy, and overall RE capability. It also analyzes two outcomes: Gross Domestic Product (GRP) and overall power generation. The information will undergo a Pearson correlation analysis to verify whether the values in the input and output components align with the stochastic criterion.

The Window method was used to assess the technical effectiveness of the DMUs throughout a specific period. This will allow the author to determine the efficiency of the DMUs throughout different years. Regarding the Window outcomes, the number of nations will be reduced from 42 to 10. The selected ten nations have attained the most excellent efficiency ratings compared to the others.

Using the Window paradigm, F-TOPSIS is employed in the following phase to prioritize all prospective nations. The study takes into account several parameters, such as the accessibility of resources, energy security, technical infrastructure, financial stability, and societal acceptability. When conducting energy capacity evaluations, conventional main system measures include the availability of assets, safety of energy, and technical infrastructure.

Sustainable development has been emphasized, making financial stability and social acceptability crucial for profitable growth and resilience. The proposed final optimum ranking is determined based on the most petite geometric length from the fuzzy positivity ideal solution and the most significant geometric length from the fuzzy harmful ideal solutions values. This approach will accurately identify the three nations with the highest proficiency in generating renewable energy.

3.1 Fuzzy TOPSIS methodology

The 'M' option in numerical arithmetic mean layout corresponds to the 'M' point and the 'N' layered region. The TOPSIS system is used in MCDM for ranking. The TOPSIS processes are primarily based on determining the absolute and farthest distance from the favorable, unfavorable, and lowest ideal solutions. The TOPSIS technique is important for assessing the performance of different alternatives and components based on specific criteria. TOPSIS incorporates fuzzy numbers to represent the tendency and effectively addresses the significance of models to provide consistency in an uncertain setting. The research chooses the crossover technique of F-AHP and F-TOPSIS to apply the collective choice dynamic technique in a fuzzy setting. F-TOPSIS techniques include the following steps:

Stage 1: The weight of the components and the flow of technique were assessed using the F-TOPSIS and F-AHP techniques to evaluate further the placements of the parameter and the chosen choices.

Stage 2: When using F-TOPSIS, the first step is identifying the table containing the phonetic phrases used in the contributing variables and options.

Stage 3: Equation (1) is used to evaluate the normalized fuzzy choice grids, represented by ($\widehat{P}$). Equation (2) determines the normalization.

$$\widehat{P} = \left[\widehat{P}_{xy}\right]_{n\times n} \tag{1}$$

$$\widehat{P_{xy}} = \frac{a_{xy}}{v_y^+}, \frac{b_{xy}}{v_y^+}, \frac{c_{xy}}{v_y^+}, \text{and } v_y^+ = \max\{v_{xy}\} \tag{2}$$

The optimal value for the level v_y^+ It is 1, whereas the worst value is 0. The equivalent progressions govern the normalization cycles of FCMs.

Stage 4: The weighted normalized fuzzy choice structure ($\widehat{Q}$) is determined by Equation (3).

$$\widehat{Q} = \left[\hat{q}_{xy}\right]_{n\times n} \tag{3}$$

Stage 5: The concepts of the fuzzy favorable idealized explanation, denoted as A^+ and $A^-$the fuzzy unfavorable idealized explanation are found independently based on Equations (4) and (5). This is achieved by avoiding the occasional annoyance of estimating.

$$A^+ = \{\hat{q}_{1+}, \hat{q}_{2+}, \cdots, \hat{q}_{n+}\} \tag{4}$$

$$A^- = \{\hat{q}_{1-}, \hat{q}_{2-}, \cdots, \hat{q}_{n-}\} \tag{5}$$

Equations (6) and (7) choose the choice units separately.

$$\hat{l}_x^+ = \sum_{y=0}^{N-1} l\left(\hat{q}_{xy+}\right) \tag{6}$$

$$\hat{l}_x^- = \sum_{y=0}^{N-1} l\left(\hat{q}_{xy-}\right) \tag{7}$$

Stage 6: The Closeness Factor, denoted as C_x^*, is calculated to determine the overall proximity of the alternatives used in ranking RES. Closeness factors determine the optimal proximity. The closeness factors assess the degree of fuzziness in the first stage of fuzzy closeness to recover the options. The highest and lowest quality selections units have been identified, as shown in Equation (8).

$$C_x^* = \frac{\hat{l}_x^-}{\hat{l}_x^- + \hat{l}_x^+} \tag{8}$$

The divisions use the locations of the unresolved matter in Equation (8). The safety and durability of renewable energy sources are evaluated using specific components and selected parameters.

4. Simulation analysis and outcomes

This research outlined the critical obstacles to adopting RE technologies and proposed ways to address these obstacles and promote the long-term growth of RES. The study demonstrates that using the AHP and F-TOPSIS methods allows energy planners to adopt RES to achieve sustainable power production effectively. The F-AHP technique calculates the RE barrier weights using an approximate geometric technique. Making decisions as a group has included using the pairwise comparative matrix derived from the F-AHP outcomes. The comprehensive matrix for comparing pairs in the F-AHP technique, specifically for evaluating RE barriers (criteria) and sub-barriers (sub-criteria), is found in the supplemental part of the work. During the following stages of the F-AHP technique, seven obstacles to requirements engineering and twenty-nine sub-barriers were examined and ranked according to their importance.

4.1 F-AHP results

The F-AHP approach was used to assess the weight of each RE sub-barrier relative to its corresponding barrier. The weights were calculated using the pair-wise comparison matrix and then ranked appropriately.

According to Fig. 2, the sub-barriers for the high capital cost (EFB-1) and an absence of financing method (EFB-4) are considered the most significant in the setting of the Economic & Financial Barriers (EFB). The elevated operating and maintenance cost (EFB-2), absence of subsidies (EFB-5), and inadequate transmission and distribution networks (EBF-3) are regarded as sub-barriers with medium to lowest rankings. These sub-barriers are essential for implementing RE Technologies. The survey findings indicate that financial and economic variables are the primary obstacles to implementing renewable energy in the nation. Hence, government agencies must focus on urban and rural areas to implement RE and provide financial assistance to customers via subsidies.

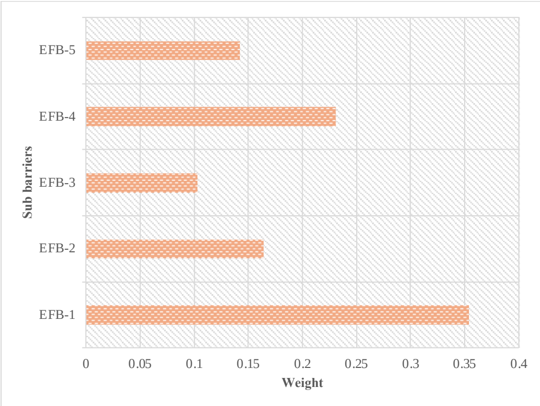

Fig. 2. EFB ranking analysis

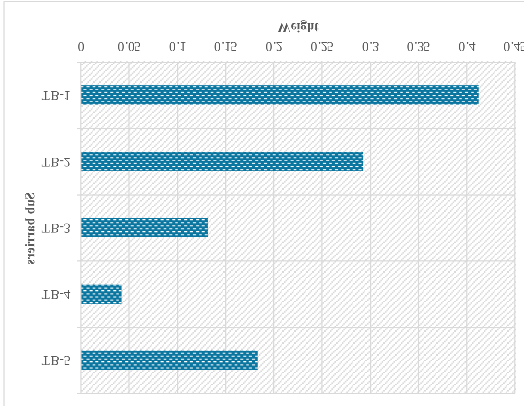

Fig. 3. RB ranking analysis

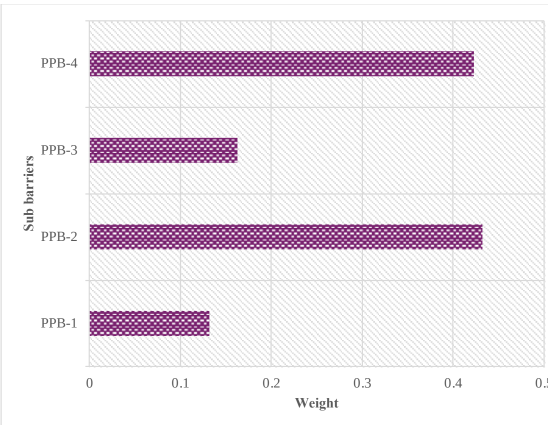

Fig. 4. PPB ranking analysis

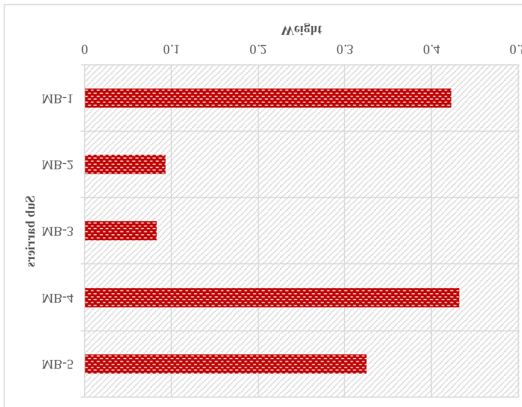

Fig. 5. MB ranking analysis

According to the Political And Policy Barriers (PPB) viewpoint, as shown in Fig. 2, nepotism, corrupt practices, and favoritism (PPB-2), as well as the absence of a cohesive renewable energy strategy (PPB-4), were identified as the most significant sub-barriers to the growth of renewable energy technologies. The sub-barriers of lack of transparency in the decision-making process (PPB-3) and unstable politics (PPB-1) are considered less important in the RE context. Establishing a consensus amongst lawmakers and political parties about implementing renewable energy is essential. Decision-makers, policy-makers, and stakeholders must prioritize and devote attention to addressing energy policy issues to prepare and formulate energy policy effectively.

Analysis of the Technical Barriers (TB) shows that the most significant sub-barrier to renewable energy (RE) growth is the need for more research and development (R&D) capacity (TB-1). This is followed by the absence of on-grid availability (TB-2), lack of technological advances (TB-5), and unpredictability and risk (TB-3), as shown in Fig. 4. The sub-barrier lacking infrastructure (TB-4) was evaluated as the least important. A substantial investment is necessary for R&D efforts, making it a significant sub-barrier.

According to Fig. 5, the main obstacle to the growth of RE is the absence of a large enough market base (MB-4) from a Market Boundaries (MB) viewpoint. The elevated upfront cost (MB-1), inability to fulfill power demand alone (MB-5), insufficient consumer understanding of technology (MB-3), and absence of customer willingness to pay (MB-2) have been identified as medium to least sub-barriers that hinder the spread of RE technologies. Therefore, the government still needs to offer a robust market foundation for stakeholders to participate in the energy industry. The investment cost is significantly elevated due to importing RE technology; likewise, customers need more information about the proper use of RE technology. Additionally, the electricity demand cannot be adequately met by only depending on petroleum and coal.

The absence of coordination and collaboration among officials (IAB-1) has been determined to be the primary sub-barrier to the growth of RES within the Institutional and Administrative Barriers (IAB), as shown in Fig. 6. The remaining rankings of the sub-barriers are the following: the insufficiency of human assets and training institutions (IAB-4), the delivery method (IAB-3), and the absence of institutional capability (IAB-2). The collaboration between energy institutions and the government is essential for advancing RE as they develop and implement approaches to enhance the energy planning landscape. It is necessary to eliminate all obstacles to facilitate sustainable energy planning and growth.

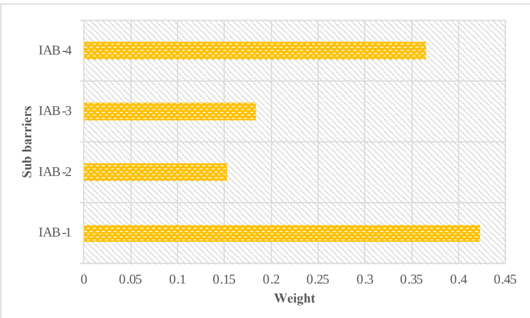

Fig. 6. IAB ranking analysis

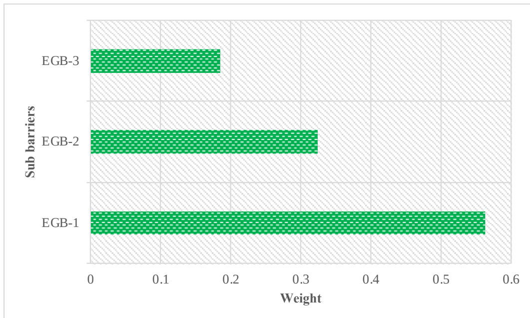

Fig. 7. EGB ranking analysis

According to the Ecological and Geographical Barriers (EGB) viewpoint, as shown in Fig. 7, environmental difficulties (EGB-1) were identified as the most significant sub-barrier to developing RE technologies in Pakistan. The government is implementing off-grid RE initiatives in isolated rural areas lacking electricity from the central power system. The implementation of RE is accompanied by significant expenses, driven mainly by elevated transmission costs, limited road accessibility, and challenges in transporting resources to distant locations. RE is employed when focusing on isolated rural areas and is primarily used for electrification goals. Access to electricity is limited to daytime hours only. As a result, RE growth initiatives in these regions need to generate more revenue to be considered economically viable. The transportation issues (EGB-2) were determined to be the second most significant factor affecting the implementation of RES. The focus of real estate growth is on distant rural areas. The high transportation costs associated with this endeavor significantly impact project completion timelines. The dispersed homes (EGB-3) were identified as the least significant.

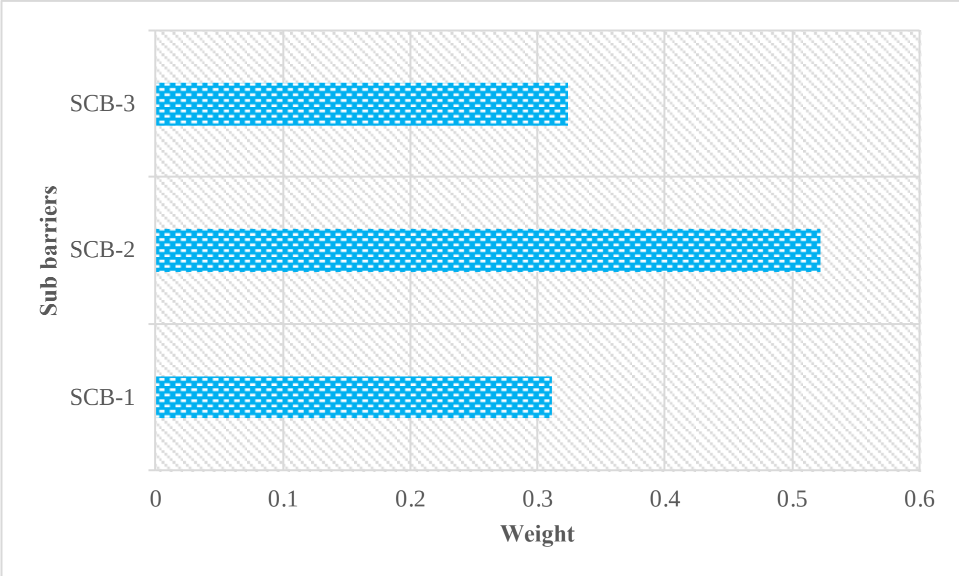

Fig. 8. SCB ranking analysis

Fig. 8 shows that among the Social and Cultural Boundaries (SCB), the most significant sub-barrier is the absence of public awareness and information (SCB-1), next to the lack of public interest (SCB-1), and the absence of public acceptability (SCB-3) in the implementation of RE technologies in Pakistan. The acquired data reveal a significant disparity and misunderstanding among individuals about implementing the RE project. The government needs to initiate training programs, seminars, and guides to educate individuals about the applications and advantages of using RE technology.

4.2 F-TOPSIS results

Table 1. RES energy factor analysis

Alternatives	Ref-8	Ref-9	Ref-10	Ref-11	Ref-12	Ref-13	Proposed
A-1	0.037	0.074	0.055	0.064	0.046	0.045	0.032
A-2	0.045	0.079	0.076	0.083	0.049	0.056	0.002
A-3	0.045	0.031	0.041	0.031	0.095	0.033	0.028
A-4	0.065	0.027	0.088	0.081	0.022	0.032	0.013
A-5	0.094	0.031	0.038	0.027	0.097	0.098	0.006

The various soft computing techniques have been compared, and their quantitative results are shown in Table 1. Soft computing techniques in sustainable RE enable organizations to assess aspects and explore alternative options before creating resources. The need for RE is growing tremendously in the current development phase. According to the statistics published by the International Statistics Corp, using soft computing can eliminate one billion metric tons of carbon dioxide by 2024.

The reason for this is that soft computing reduces reliance on energy-intensive methods. In addition, the fast network and understanding of energy use result in higher profits. Therefore, the efficient use of resources in soft computing environments is now a critical concern. Over the next ten years (2013-2025), a server farm will use around 1000 terawatt-hours of energy. The server complexes and cooling systems will account for 5% of worldwide energy consumption. Energy use leads to operational costs and environmental consequences, such as global warming. Evaluating RE variables using soft computing techniques is of great significance.

5. Conclusion and findings

The objective is to mitigate the problem of supporting long-term, beneficial, and environmentally friendly RES. Emphasizing the development of item durability from the beginning of the enhancement process will increase the product's significance level. This paper used the soft computing method for the evaluation. Sustainable RE characteristics are characterized by their practical functionality. The calculations for sustainable RE using cross-sections are inherently complex. However, the research simplifies these calculations in the future. This quantitative exploratory assessment relies on the existing sustainable RES and anticipates future challenges based on relevant research. The evaluation findings indicate that wind energy is the most favored RE. Wind energy is the optimal resource for generating electricity in distant areas where it is not feasible to establish conventional power lines due to ecological or economic constraints. Soft computing technique models are being studied to enhance sustainable RE development. The research has analyzed the upcoming challenges and strives to assess them successfully by applying a combined strategy of several independent systems, namely "F-AHP and F-TOPSIS."

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