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Ranking Renewable Energy Sources in Saudi Arabia

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Abstract

Over the few last decades, Saudi Arabia has relied on fossil fuels for electricity generation. Despite this dependency, the country has an abundance of renewable energy (RE) resources that can easily meet the energy requirements of the country. RE creates a desirable and sustainable environment in addition to reducing the fear of energy insecurity. The purpose of this paper is to examine and rank the following renewable energy sources: wind, solar, biomass, geothermal, hydroelectric, and oceanic. Analytical Hierarchy Process (AHP) was used to explore and rank the RE alternatives. Evaluation of criteria was determined based on a thorough literature review and validated by expert assessment. The weights for each criterion were calculated through pair-wise comparison. The findings indicate that solar energy is the most efficient source of renewable energy for generating electricity, while wind source is the second-most appropriate option for fulfilling the energy requirements of the country.

Keywords: Renewable Energy; AHP; Energy in Saudi Aribia; MCDA; Solar Energy

I. INTRODUCTION

Sustainable energy systems are required for long-term development [1]. Renewable energy is a beneficial form of short- and long-term sustainable energy [2-4]. Renewable energy will be proven to be a critical energy source for future electricity generation. According to M. Kumar [5], the world's 1.6 billion people who live without electricity and renewable energy sources may assist in fulfilling the energy demand [6] because these sources are environmentally friendly [7] and becoming socially acceptable [8]. These sources not only reduce the import of fossil fuels, but also improve flood control [9] and mitigate global warming [10] through careful analysis and the application of advanced technologies. In the Kingdom of Saudi Arabia, present energy generation is primarily based on crude oil, which has negative environmental consequences due to the release of carbon dioxide and other toxic gases. There are a lack of initiatives to generate electricity from renewable sources in the country. Thus, the government recently has set a target of 20 percent energy output from renewable sources.

Because of rising domestic energy use, the country's fossil-fuel generation capability will be reduced [11]. Domestic energy usage also contributes to a rise in carbon dioxide emissions, polluting the environment. Accordingly, the authority of Saudi Arabian must explore other ways to meet its energy needs. In Kingdom of Saudi Arabia (KSA), there are potential sources of renewable energy that might meet the country's energy needs. Saudi Arabia has a large capacity for renewable electricity generation, with a focus on solar energy due to its location in the "sunbelt," and wind energy due to the country's annual average onshore wind speed, which is comparatively high and far greater than the global average. One of Saudi Vision 2030's goals is to expand the renewable energy sector [12, 13]. As solar energy is a clean, sustainable source of renewable energy and also the Kingdom is located in the middle of the sunbelt with high radiation, an annual amount of radiation is 2200KWh/m^2 twice as much as in Europe [14]. This supply of renewable solar energy will not only meet the country's future energy needs but will also be environmentally friendly. Individuals can integrate photovoltaics (PV) into buildings rather than relying on large-scale initiatives. This will include measures to mitigate environmental effects and reduce carbon dioxide emissions. Encouraging individuals to use such systems can reduce domestic energy consumption from fossil fuels. Moreover, it is generated in a cleaner environment and requires less depletion of nonrenewable energy sources. Wind energy is yet another environmentally friendly, clean, affordable, abundant, and rapidly developing energy source. Wind power generation is primarily concentrated in China and the United States, but Saudi Arabia has only one wind farm in Turaif city [15]. As Saudi Arabia has 2.4 - 6.1 m/s monthly wind speed and 3.2 - 5.3 m/s annual wind speed [16], which is much higher than other countries, it leads to more power generation from wind energy in the country which ranges between 14.2 and 162.5, W m-2, 31.7 and 94.6 W m-2 for both monthly and annual wind speed, respectively [17]. As a result, future use of these two energy sources - solar and wind energy - may be beneficial to meet the energy demand.

This research aimed to assess and select the most appropriate renewable energy source in the Kingdom of Saudi Arabia, with a primary focus on exploring RE alternatives, determining the best RE source, and drawing the government's attention to alternative sources of electricity generation. Analytical Hierarchy Process (AHP) approach was used to assess various renewable energy alternatives due to its effective decision-making while solving complex problems. In addition, AHP helps identify and define the problem in detail with excellent judgment. This research is unique; it identifies eight distinct criteria, and there is no evidence that this issue has been addressed previously. Six RE alternatives that were selected included wind, solar, biomass, geothermal, hydroelectric, and oceanic. In the prioritization process, a pairwise comparison of criteria-criteria and alternative criteria was performed. Then, the consistency index (CI) and consistency ratio (CR) were calculated in order to assess consistency. The results showed that solar energy is the best RE source for producing electricity. Moreover, it showed that wind energy is the second source that can help to meet the energy demand.

II. THE MODEL DESCRIPTION AND METHODOLOGY OF ANALYSIS

II.I Analytical Hierarchical Process

AHP is a sophisticated decision-making tool [18] developed by Saaty to handle complicated problems and make decisions when several objectives are available. AHP locates the ranking and most appropriate options based on several criteria [19]. The goal is established and located at the top of this hierarchical process with the alternatives at the bottom. At the intermediate level, the criteria on which a choice must be made are placed. The decision makers follow a structural procedure, which is outlined below step-by-step, for the successful implementation of the AHP [20].

1) Determine the aim, which is then placed at the top of the structure process, followed by the establishment of criteria at the second level. A collection of attributes is assigned to the criteria, allowing the priority of the criteria to be set. The alternative is found at the end of the procedure, and a suitable solution is found for the optimum decision.

2) Different numerical values are assigned to each of the criterion based on the decision maker's preferences. Many of the researchers have confirmed a scale proposed by the Saaty [21] for selecting numerical values for criteria and illustrated in Table 1.

3) After determining the priorities and assigning the relative rating quantitatively from a Saaty's scale, a pairwise comparison was constructed. A matrix C was created in this way with the elements c_{ij}, where c is the numerical value and I, j are the placement values of each element. The c_{ij}'s reciprocal value is stored in the c_{ji} position. The unity values are assigned throughout the main diagonal as illustrated in equation (1).

$$C = \begin{bmatrix} 1 & c_{12} & c_{13} & \cdots & c_{1n} \\ 1/c_{12} & 1 & c_{23} & \cdots & c_{2n} \\ 1/c_{13} & 1/c_{23} & 1 & \cdots & c_{3n} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ 1/c_{1n} & 1/c_{2n} & 1/c_{3n} & \cdots & 1 \end{bmatrix} \quad (1)$$

4) Next, the sum of each column was computed in matrix C by adding the components of matrix C along the column. After obtaining the column sum, the element of each column in the matrix was divided by the sum of that column. As a result, the normalized matrix is the final matrix obtained.

5) The evaluation matrix was obtained by taking the average value of each row of the matrix. Finally, a single column matrix known as the evaluation matrix of Row Averages emerges, which is used to evaluate the criteria and alternatives (based on each criterion).

6) The consistency ratio must be determined to verify the judgment for the current decision model. The weighted sum vector was found by multiplying the pairwise comparison matrix with the evaluation matrix in this perspective.

7) Each element of the weighted sum matrix was then divided by the respective elements of the row average or evaluation matrix, yielding a consistency vector as a result. The average value of the consistency vector is then used to determine the *lambda* (λ). The value of the lambda (λ) should be greater than or equal to the size of the original pairwise matrix (n); otherwise, the calculation needs to be repeated.

Table 1. Saaty's scale of importance for rating the criteria

Numerical Rating	Saaty's Scale of Importance	Reciprocal Rating
9	Extremely Important	1/9
8	Very Strong to Extremely	1/8
7	Very Strong Importance	1/7
6	Strongly to very Strong	1/6
5	Strong Important	1/5
4	Moderately to Strong	1/4
3	Moderate Importance	1/3
2	Equally to Moderate	1/2
1	Equal Importance	1

8) The following formula was used to calculate the consistency index (CI) [22].

$$CI = \frac{\lambda - n}{n-1} \quad (2)$$

9) The final step was to divide the consistency index obtained from equation (2) by the random consistency index (RI), yielding the consistency ratio.

$$CR = \frac{CI}{RI} \quad (3)$$

10) Table 2 shows how the value of the Random Consistency Index (RI) is a direct function of the size of the original pairwise matrix and RI was selected from Table 2 to calculate the consistency ratio [23].

Table 2. The random consistency index with respect to size of the original pairwise matrix

Size of the original Pairwise matrix (n)	1	2	3	4	5	6	7	8	9	10
Random Consistency Index (RI)	0	0	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.49

II.II Establishment and Prioritization of Criteria and Alternatives

Multi-criteria and alternatives were chosen after a thorough literature analysis of energy planning initiatives, particularly renewable energy (RE), and a brief discussion with experts of the same field. A panel of specialists from academia, researchers, practitioners working in the renewable energy sector, and regulators such as regional administrative bodies were contacted to give opinions about the alternatives and criteria. Following responses from 25 experts, a preliminary list of eight criteria and six RE alternatives was proposed in accordance with Saudi conditions. The criteria under consideration were efficiency [24], reliability [25], safety [26], social acceptance [25], environmental impacts [27], installed capacity [28], estimated potential [28] and cost [26]. These criteria along with their symbols are represented in Table 3.

The efficiency of a renewable energy alternative refers to how much energy is taken from the renewable energy source and then converted into electricity or heat. The probability of a power plant working under particular design specifications and conditions is known as reliability. Safety is followed by the minimization of accident scenarios and the effective completion of operations in terms of workers' protection. The lack of social acceptance is a major impediment to the RE source's implementation, and encompasses both political and public opposition. Environmental pollution is a serious threat not only to humans but also to the ecosystem, which is why the existing model should be considered in terms of environmental impacts. The system's installed capacity is the power plant's maximum output under certain conditions for efficient operation of the system. The estimated potential is a prediction of how far the RE source will advance based on its current performance. The cost per kilowatt hour is considered as well, and it is an important consideration in power plant selection.

Table 3. Symbolical representation of the criteria

Symbol	Criteria
C_1	Efficiency
C_2	Reliability
C_3	Safety
C_4	Social Acceptance
C_5	Environmental Impacts
C_6	Installed Capacity
C_7	Estimated Potential
C_8	Cost

The important alternatives are prioritized and then the most suitable are selected, which are suggested in this study after a wide literature review. The most sustainable RE sources are considered to be wind energy, solar energy, geothermal energy, ocean energy, biomass energy and hydro energy [29-32]. The six RE alternatives along with their symbols are represented in Table 4.

Table 4. Symbolical representation of the re alternatives

Symbol	RE Alternatives
A_1	Wind Energy
A_2	Solar Energy
A_3	Geothermal Energy
A_4	Ocean Energy
A_5	Biomass Energy
A_6	Hydro Energy

The Fig. 1 depicts a hierarchical network with the goal at the top, criteria in the middle, and RE alternatives at the bottom. A pairwise comparison was carried out to rate and prioritize the criteria. This was done after a thorough assessment of the literature regarding renewable energy planning initiatives and debate with the same group of experts. RE alternatives related data were also evaluated from several other sources. The King Abdullah Petroleum Studies and Research Center (KAPSARC), Saudi Aramco, Meteorology and Environment Protection Administration (MEPA), King Fahd University of Petroleum and Minerals (KFUPM), King Abdul Aziz City for Science and Technology (KACST), and Energy Research Institute (ERI) are among these sources.

Table 5. A pairwise comparison of criteria to criteria

Criteria Name	Efficiency	Reliability	Safety	Social Acceptance	Environmental Impacts	Installed Capacity	Estimated Potential	Cost
Efficiency	1	7	2	4	3	9	3	9
Reliability	1/7	1	1/5	1/3	1/4	1	1/5	3
Safety	1/2	5	1	1	1/2	6	1/2	6
Social Acceptance	1/4	3	1	1	1/3	4	1/2	5
Environmental Impacts	1/3	4	2	3	1	7	1	8
Installed Capacity	1/9	1	1/6	1/4	1/7	1	1/7	1
Estimated Potential	1/3	5	2	2	1	7	1	7
Cost	1/9	1/3	1/6	1/5	1/8	1	1/7	1

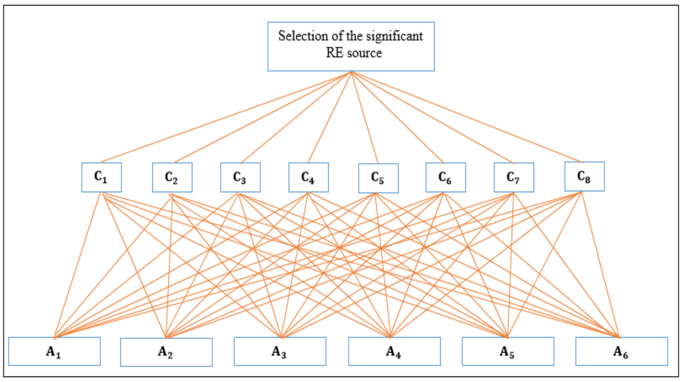

Fig. 1. Hierarchical network for the selection and prioritization of significant RE sources

$$M_C = \begin{bmatrix} 1 & 7 & 2 & 4 & 3 & 9 & 3 & 9 \\ 1/7 & 1 & 1/5 & 1/3 & 1/4 & 1 & 1/5 & 3 \\ 1/2 & 5 & 1 & 1 & 1/2 & 6 & 1/2 & 6 \\ 1/4 & 3 & 1 & 1 & 1/3 & 4 & 1/2 & 5 \\ 1/3 & 4 & 2 & 3 & 1 & 7 & 1 & 8 \\ 1/9 & 1 & 1/6 & 1/4 & 1/7 & 1 & 1/7 & 1 \\ 1/3 & 5 & 2 & 2 & 1 & 7 & 1 & 7 \\ 1/9 & 1/3 & 1/6 & 1/5 & 1/8 & 1 & 1/7 & 1 \end{bmatrix} \quad (4)$$

A pairwise comparison between criteria to criteria is detailed in Table 5. Manual calculations were carried out using the priority ratings of the criteria listed in the preceding Table, and a matrix M_C of size n=8 was created using Table 5 to make the calculations simple and easier.

The process then moved to determining the normalized matrix after the criteria were rated. To find a normalized matrix M_N, the elements of each column in matrix M_C were added, and then each element of a given column inside the matrix were divided by the sum of that column in matrix M_C. Similarly, the original pairwise matrix M_C had eight columns and eight rows, resulting in a normalized matrix of the same size and represented by equation (5). The elements of each row in the normalized matrix were added and then divided by the total number of elements in each row to get the average value of that row. The average row matrix $M_{R_{avg}}$ was obtained by repeating these steps for each row of the matrix. The average row matrix, known as the factor evaluation matrix, as the $M_{R_{avg}}$ matrix, prioritizes the value of the criterion. The matrix is eight rows by one column in size and is shown in equation (6). The computations were then carried out to determine if the ratings given to the criterion were consistent. The consistency vector must be determined for this purpose. The weighted sum vector was calculated first to determine the consistency vector.

$$M_N = \begin{bmatrix} 0.359 & 0.266 & 0.234 & 0.340 & 0.472 & 0.250 & 0.463 & 0.225 \\ 0.051 & 0.038 & 0.023 & 0.028 & 0.039 & 0.028 & 0.031 & 0.075 \\ 0.180 & 0.190 & 0.117 & 0.085 & 0.079 & 0.167 & 0.077 & 0.15 \\ 0.090 & 0.114 & 0.117 & 0.085 & 0.052 & 0.111 & 0.077 & 0.125 \\ 0.120 & 0.152 & 0.234 & 0.255 & 0.157 & 0.194 & 0.154 & 0.200 \\ 0.040 & 0.038 & 0.019 & 0.021 & 0.23 & 0.028 & 0.022 & 0.025 \\ 0.120 & 0.190 & 0.234 & 0.170 & 0.157 & 0.194 & 0.154 & 0.175 \\ 0.040 & 0.013 & 0.020 & 0.170 & 0.020 & 0.028 & 0.022 & 0.025 \end{bmatrix} \quad (5)$$

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$$M_{R_{avg}} = \begin{bmatrix} 0.326 \\ 0.039 \\ 0.131 \\ 0.096 \\ 0.183 \\ 0.027 \\ 0.174 \\ 0.023 \end{bmatrix} \quad (6)$$

The weighted sum vector M_W was obtained by multiplying the original pairwise comparison matrix M_C with the factor evaluation matrix $M_{R_{avg}}$, and the resulting matrix ($M_C \times M_{R_{avg}}$) is referred to as the weighted sum matrix (M_W) and is represented by equation (7).

$$M_W = \begin{bmatrix} 2.770 \\ 0.321 \\ 1.065 \\ 0.797 \\ 0.155 \\ 0.222 \\ 1.466 \\ 0.188 \end{bmatrix} \quad (7)$$

Next, each element of the weighted sum vector M_W was divided by the respective element in the factor evaluation matrix. The results are elaborated with the help of matrix $M_{C.V}$ as shown below.

$$M_{C.V} = \begin{bmatrix} 8.495 \\ 8.168 \\ 8.158 \\ 8.267 \\ 8.434 \\ 8.238 \\ 8.409 \\ 8.198 \end{bmatrix} \quad (8)$$

The matrix $M_{C.V}$ is known as the *consistency vector* or *consistency matrix*. We can simply take the average value of the consistency vector to discover the value of lambda. The lambda value was bigger than the size of the original pairwise matrix ($\lambda > n$), indicating that the calculation is correct where n equals 8 and lambda (λ) equals 8.296.

After finding the lambda (λ), the consistency index was calculated by using equation (2) and its value was 0.0423; further, this value was divided by Random Consistency Index RI to obtain the Consistency Ratio CR. The value of CR was 0.0299. The measurement of CR is imperative in AHP. The pairwise comparison is related to the permissible value of CR in the optimal decision model. The value of the CR is only acceptable if it is less than 10%; otherwise, the relevant judgment must be amended. The present model's CR value was 0.0299, which is less than 10% or 0.1, and thus the experts' judgment to rate the criteria is consistent.

The same type of computation is done for the alternatives based on each criterion to compute the factor valuation matrix and Consistency Ratio. To complete the present decision model, eight calculations were performed in this manner. Fig. 2 shows the Consistency Ratio of each evaluating matrix of the alternatives.

Finally, a matrix M_E was created that evaluated each RE alternative based on the criteria chosen. This was obtained by merging the evaluating matrices of alternatives, which were formed based on each criterion. Equation (9) shows the evaluating matrix M_E for the alternatives. This evaluating matrix further uses to find the overall ranking of the RE alternatives.

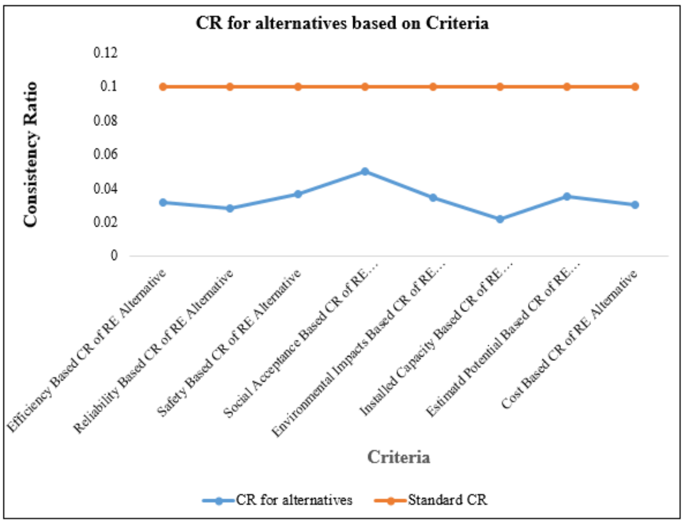

Fig. 2. Consistency ratio for 8 evaluating matrix for the alternatives based on each criterion.

The overall ranking of the RE alternatives was obtained by multiplying the alternative to criteria evaluating factor matrix M_E with the evaluating factor matrix of the criteria to criteria comparison $M_{R_{avg}}$, after evaluating each criterion and the RE alternative based on each criterion. The resulting findings reflect the RE alternative's overall rating under conditions of the Kingdom.

$$M_E = \begin{bmatrix} 0.177 & 0.287 & 0.300 & 0.407 & 0.264 & 0.450 & 0.262 & 0.049 \\ 0.094 & 0.205 & 0.391 & 0.286 & 0.407 & 0.267 & 0.424 & 0.032 \\ 0.028 & 0.043 & 0.0414 & 0.068 & 0.045 & 0.049 & 0.072 & 0.278 \\ 0.043 & 0.026 & 0.030 & 0.039 & 0.073 & 0.0312 & 0.031 & 0.212 \\ 0.328 & 0.147 & 0.093 & 0.166 & 0.026 & 0.135 & 0.177 & 0.314 \\ 0.330 & 5 & 0.144 & 0.034 & 0.184 & 0.068 & 0.034 & 0.113 \end{bmatrix} \quad (9)$$

$$M_{\text{Rank}} = \begin{bmatrix} 0.2546 \\ 0.2738 \\ 0.0514 \\ 0.0473 \\ 0.1875 \\ 0.1854 \end{bmatrix} = \begin{bmatrix} \text{Wind Energy} \\ \text{Soalr Energy} \\ \text{Geothermal Energy} \\ \text{Ocean Energy} \\ \text{Biomass Energy} \\ \text{Hydro Energy} \end{bmatrix} \quad (10)$$

The alternative matrix is on the right side of equation (10), while their ranking matrix is on the left side. These findings were then employed to assess and prioritize renewable energy alternatives for the KSA. The CR for each alternative is also computed, which is less than 10% for each alternative, indicating that the results shown in equation (10) are consistent.

III. RESULTS AND DISCUSSION

Energy insecurity is a genuine threat towards the high cost and low quality of energy for end users, and it has rendered the country incapable of meeting its major energy needs. In the perspective of the increasing energy demand, the Saudi government has set a goal of meeting 20% of its total energy demand from renewable sources by 2030. However, no substantial measures have been taken to meet the energy demand. This study not only examines different renewable energy sources available to meet energy demand, but it also evaluates the optimum renewable energy source for Saudi conditions.

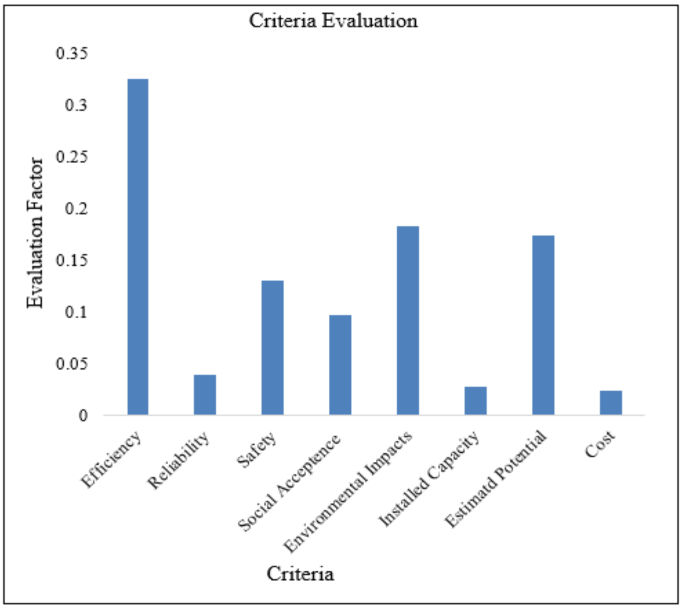

Fig. 3. Evaluation of criteria with respect to each other

The results are achieved with the consistency of alternatives based on each criterion after assessment of the criteria and RE alternative with respect to criteria. The criteria evaluation, RE alternatives rating, and evaluation basis of each criterion are further explored with the use of bar charts. Fig. 3 shows the result for the evaluation of criteria with respect to other criteria which has been considered in this study.

The efficiency of the renewable energy source is the most important factor to consider. A more efficient RE source will give better output. Environmental impacts are the second key criterion, indicating that improvement and protection of the environment have more intention than others. The other important factor in considering the RE source is estimated potential, which is an important element to consider when choosing a renewable energy source because it helps forecast and offers long-term direction to the economy. The safety of the workers and the end user is also more desirable, which is why the safety component is ranked fourth. The safety factor motivates employees to work safely and decreases the risk of failure. Social acceptance comes after the safety factor, and plays a key role in the selection of the RE source; it includes both general and local acceptance. In the implementation of a RE source, social acceptance is a significant barrier. Social acceptance not only reduces the development of the RE source, but also delay many of the RE projects. Another factor such as reliability, installed capacity and cost have relatively less significance. The graph in Fig. 4 depicts the relationship between each RE source and each criterion. The criteria on the horizontal axis and the evaluation factor of the RE alternative related to the given criteria on the vertical axis are used to create this relationship.

From the Fig. 4, hydro energy has the highest efficiency (0.329), while biomass is the second-most efficient (0.328). Wind energy has the highest efficiency (0.177), followed by biomass. The solar energy efficiency assessing factors is 0.094. Ocean energy and geothermal energy have efficiency evaluation factors of 0.043 and 0.028, respectively. Because of its vast storage capacity and flexibility, hydro has the highest efficiency factor, as shown in the graph. Conversely, geothermal energy has the lowest efficiency factor.

As mentioned previously, environmental impact is another key factor. Solar energy has the greatest environmental impact evaluation factor (0.407), demonstrating that solar energy is one of the cleanest renewable energy sources available. In terms of the environment, it is incredibly efficient, effective, and sustainable. Wind energy is ranked second in terms of environmental impact, with a significant evaluation factor (0.264). Wind energy has fewer environmental consequences, but it is far superior to other renewable energy options. Wind turbines, however, have spinning blades that pose a serious threat to flying creatures such as birds. Overall, it is about competitiveness and environmental sustainability.

For estimated potential, solar energy has the highest evaluation factor (0.424). When solar radiation reaches its highest levels on the earth's surface, a large amount of solar energy is produced. Saudi Arabia has much potential for renewable energy generation due to its location in the "sunbelt," with a focus on solar power. The evaluating factor for wind energy is also sufficient (0.262) and comes after solar energy. The annual average onshore wind speed in Saudi Arabia is comparatively high and significantly higher than the average for most countries, indicating a strong potential for wind energy.

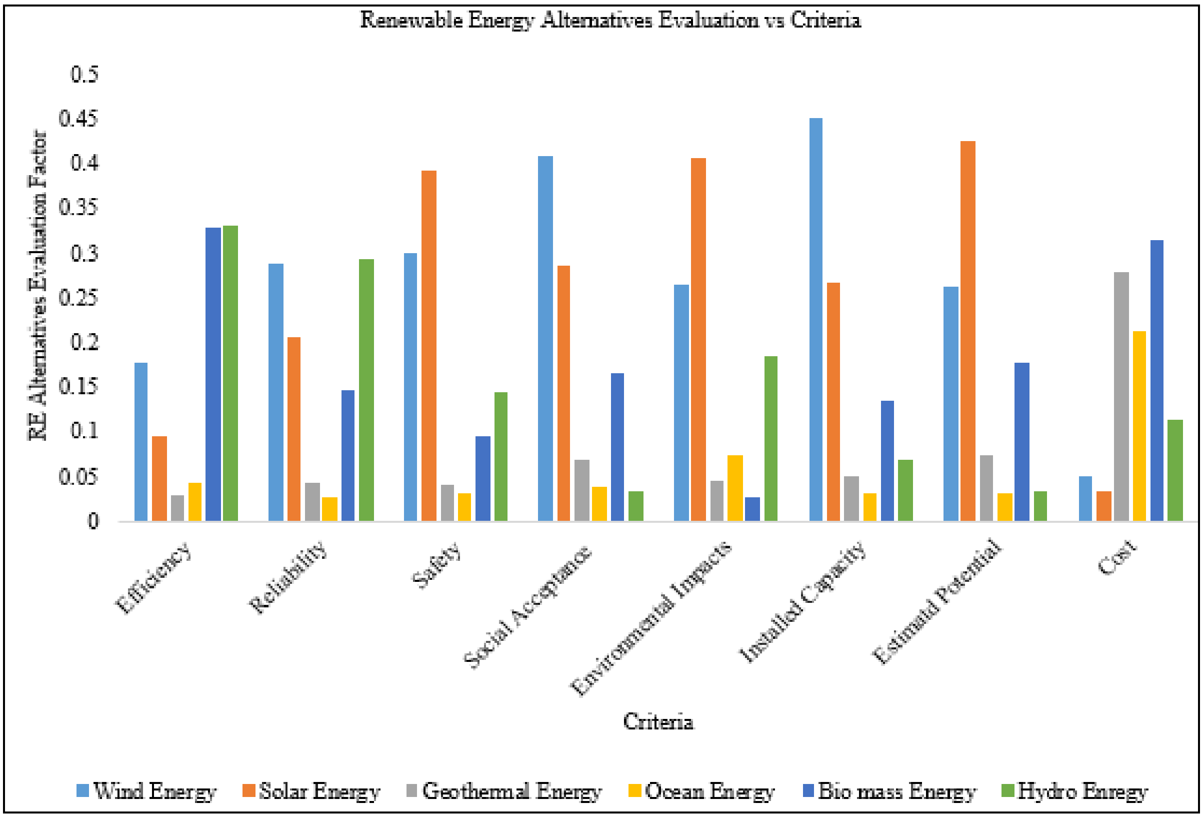

Fig. 4. The relationship between RE alternative and criteria

Solar energy also has the highest safety factor (0.391), while wind energy is ranked second with an excellent safety factor (0.299). A well-mounted solar panel poses no danger or risk to human life. A solar panel is simple to install and maintain, as well as is safe to use. By implementing preventive measures, workers are safer on the job.

Wind energy has the highest social acceptance factor (0.407), while solar energy is ranked second with a favorable evaluation factor (0.286). Because the average wind speed in Saudi Arabia is 7 m/s in most regions, KACARE has nearly ten monitoring stations and is planning a complete a wind energy monitoring network across the country. This demonstrates that social acceptance is on the rise.

In terms of installed capacity, wind energy has the highest evaluating factor as well. Solar energy is once again falling behind wind energy. Turaif, Yanbu, and Sharurah are just a few of the locations in Saudi Arabia where there is significant airflow. These are the locations where large-scale wind turbines can be installed.

Among all the factors, efficiency is the most important. Although hydro and biomass have the highest efficiency values, their scores for the other most significant criteria are far lower. Both are harmful to the environment. Dams and storage water emit green gases and carbon dioxide, whereas biomass emits a large number of poisonous gases and elements into the environment. On the other hand, solar energy is leading in estimated potential, environmental impacts, and safety factors while wind energy lags behind solar energy and leads other RE alternatives. Wind energy advances in installed capacity, social acceptance, and reliability while solar energy lags behind wind energy and leading other RE alternatives. At the same time, both solar energy and wind energy have the least evaluating factor for the cost. However, it is not effective in the selection of the RE source as cost is the lowest area in prioritizing matrix of the criteria.

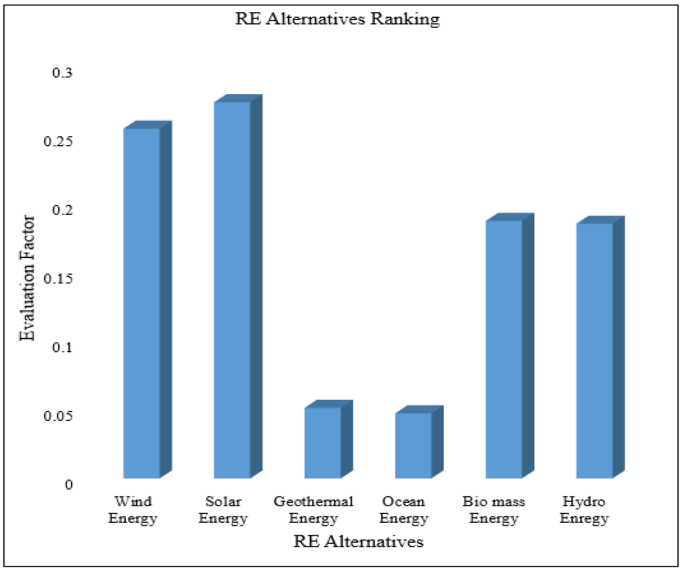

Fig. 5. Overall ranking of RE alternatives

Still, ranking is necessary to select the best RE alternatives. As such, Fig. 5 shows the ranking of different RE alternatives. The results demonstrate that solar energy is the most important RE option (27.38 percent), followed by wind energy (25.46 percent), biomass energy (18.74 percent), hydro energy (18.53 percent), geothermal energy (5.138 percent), and ocean energy (4.73 percent). As a result, solar energy is the most suiTable RE alternative for Saudi conditions, while wind energy is the second-most important RE alternative to produce electricity from renewable energy sources. Saudi Arabia is located in the "sunbelt" and also has a wide area with a high average wind speed and land availability; therefore, solar and wind energy facilities should be developed so that future energy demands can be met by renewable energy sources in accordance with the Vision 2030. Qurayyat, Rafha, and Jeddah are all possible locations for a solar power plant. Turaif, Yanbu, and Sharurah also have a high wind speed and are prime places for a wind farm.

IV. CONCLUSIONS

Renewable energy alternatives were evaluated using a multi-criteria decision analysis (MCDA). Saudi Arabia is one of the world's largest consumers of energy. Domestically, the implementation of various renewable energy projects can provide a clean and oil-free energy supply. The rise of renewable energy sources not only meets energy demand, but also ensures a long-term energy supply. AHP method was implemented to prioritize the RE alternatives in Saudi Arabia. The results of the current study are as follows.

1) Solar energy is a potent alternative for Saudi Arabia. It is ideal for solar parks because of its location. Solar energy can be utilized to generate power as well as heat.
2) The Kingdom of Saudi Arabia (KSA) should take the initiative to install multiple wind turbines in strategic locations as part of pilot projects to assess the viability of wind energy generation. As a result, the country will be able to reach the Saudi Vision 2030's aim of 20 percent renewable energy generation.
3) Although solar and wind energy have become progressively cost competitive with traditional fuels, it is crucial to consider these sources to reduce energy production uncertainty and increase green energy sources.
4) Solar and wind energies not only create more jobs, but also reduce undesired environmental impacts, reduce fossil fuel depletion, stimulate economic growth, and mitigate climate change.
5) This study's results encourage the country's successful transition to renewable energy from fossil fuels.

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APPENDIX

Saaty's Scale of importance for rating the criteria

Numerical Rating	Saaty's Scale of Importance	Reciprocal Rating
9	Extremely Important	1/9
8	Very Strong to Extremely	1/8
7	Very Strong Importance	1/7
6	Strongly to very Strong	1/6
5	Strong Important	1/5
4	Moderately to Strong	1/4
3	Moderate Importance	1/3
2	Equally to Moderate	1/2
1	Equal Importance	1

The random consistency index with respect to size of the original pairwise matrix

Size of the original Pairwise matrix (n)	1	2	3	4	5	6	7	8	9	10
Random Consistency Index (RI)	0	0	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.49

Symbolical representation of the criteria

Symbol	Criteria
C_1	Efficiency
C_2	Reliability
C_3	Safety
C_4	Social Acceptance
C_5	Environmental Impacts
C_6	Installed Capacity
C_7	Estimated Potential
C_8	Cost

Symbolical representation of the RE Alternatives

Symbol	RE Alternatives
A_1	Wind Energy
A_2	Solar Energy
A_3	Geothermal Energy
A_4	Ocean Energy
A_5	Biomass Energy
A_6	Hydro Energy

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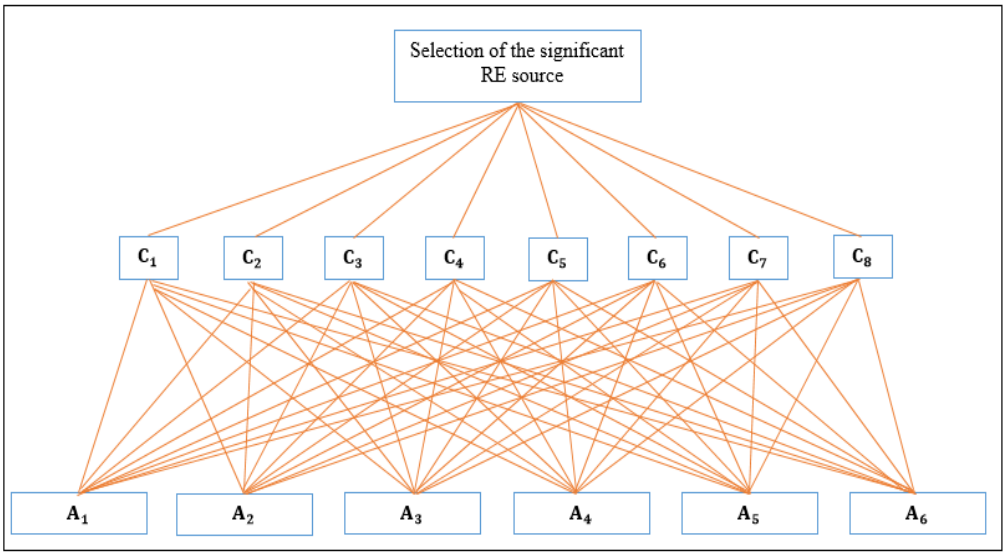
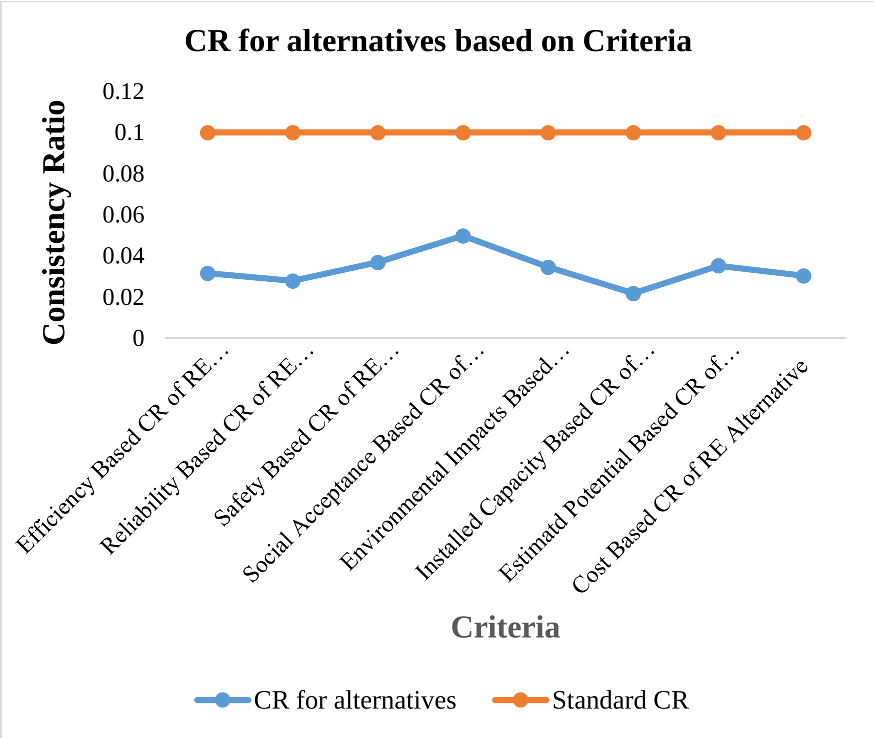
A pairwise comparison of criteria to criteria

Criteria Name	Efficiency	Reliability	Safety	Social Acceptance	Environmental Impacts	Installed Capacity	Estimated Potential	Cost
Efficiency	1	7	2	4	3	9	3	9
Reliability	1/7	1	1/5	1/3	1/4	1	1/5	3
Safety	1/2	5	1	1	1/2	6	1/2	6
Social Acceptance	1/4	3	1	1	1/3	4	1/2	5
Environmental Impacts	1/3	4	2	3	1	7	1	8
Installed Capacity	1/9	1	1/6	1/4	1/7	1	1/7	1
Estimated Potential	1/3	5	2	2	1	7	1	7
Cost	1/9	1/3	1/6	1/5	1/8	1	1/7	1

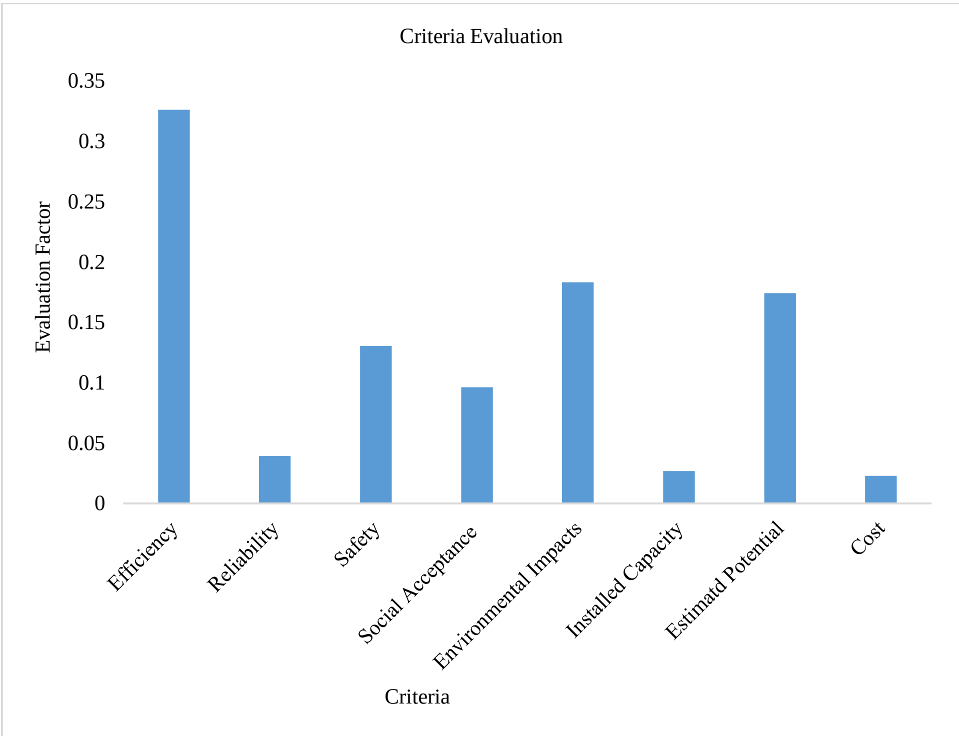
Hierarchical network for the selection and prioritization of significant RE sources



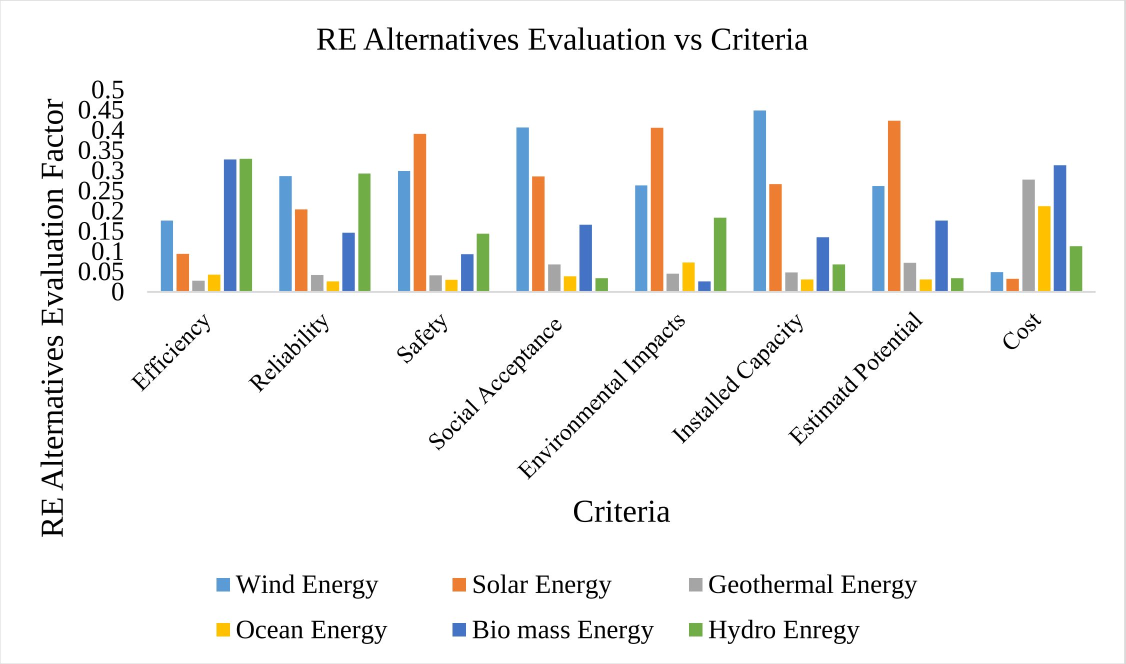
Consistency Ratio for 8 evaluating matrix for the alternatives based on each criteria



Evaluation of criteria with respect to each other



The relationship between RE alternative and criteria



Overall ranking of RE alternatives