A Hybrid Decision Model For Renewable Energy Source Selection In Pakistan

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Abstract

Energy needs are increasing all over the world. The current sources of energy are decreasing rapidly and their usage is causing environmental pollution including air and water pollution. Due to this reason, the need of the hour is to switch towards renewable and sustainable energy sources. The selection of a suitable renewable energy source is the most important task to meet the country's energy need, especially in a scenario where these alternatives negatively affect the surrounding environment. Involvement of multiple benchmarks such as technical, environmental, economic, land occupy, and sustainability are making energy planning more complex for decision makers. Wind, biomass, hydro-thermal, geothermal and solar are the alternative renewable energy sources in Pakistan. In such circumstances, companies need tools and techniques to find out the best solution in the contest of conflicting objectives, multiple alternatives and different criteria. Multi-Criteria Decision Making (MCDM) techniques are the decision supporting techniques which are ideal for such scenarios. After accessing the potential of energy generation from different renewable energy resources in Pakistan through literature review and discussion with experts, this research work presents a hybrid model for decision support about the selection of the renewable energy source in Pakistan. In order to develop this model, two MCDM techniques, i.e. Analytical Hierarchy Process (AHP) and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) are employed in this study. The results of the analysis suggest that solar power is the best option in Pakistan. The proposed model will help the policy makers and energy planners for the development of long run energy policies for the country.

Keywords—Analytical Hierarchy Process (AHP), Energy Planning, Renewable Energy, Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS).

1 Introduction

Energy production is essential for human development. The demand of energy is increasing rapidly due to increased population. Fossil fuels are covering almost 80% of global demand of energy. Renewable energy and nuclear energy are contributing only 13.1% and 6.5% respectively [1]. Increase in the demand of energy all over the world is forcing policy makers and planners to consider the decentralized concept of renewable energy systems which has been recognized as the solution for the current demand of energy both in the domestic and industrial environment [2]. In this modern age, it is not possible for a society to survive without continues energy production and by increasing the sources of energy. In fact, the progress and development of any nation or society can be scaled in terms of per capital energy consumption [3].

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Pakistan is facing the energy shortfall where nearly half population has no or poor access to electricity [4]. The energy demand per capital is increasing remarkably. Pakistan's energy supply mainly depends upon fossil fuels which is more than 60% of total energy production, while the renewable energy resources like solar, thermal, wind and biomass need dedicated infrastructure and special attention to exploit properly [5]. Since fossil fuels are limited and decreasing rapidly, and their usage causes significant effect on the environment, the need of the hour is the exploitation of renewable energy resources. This is necessary not only because of less dependency on fossil fuels, but also for the protection of the environment as these alternative renewable energy resources are environment-friendly [6].

Multi-Criteria Decision Making (MCDM) methods are very prevalent and well-known in efficient energy management. These tools are used for the solution of the problems involving multiple and conflicting objectives. These techniques have helped in most countries to mitigate energy poverty. In these techniques, results are dependent upon the decision-makers [7]. Many countries use these techniques for the identification of the best model solution or for the selection of the best alternative in the selection of renewable energy resource, such as Ighravwe et al. [8] made a mini-grid business model for a community in Nigeria under the criteria of economic and envi-ronment, Chia-Nan Wang et al. [9] used this technique for choosing the optimal location of solar power plant in Viet Nam and claimed that this approach is flexible and practical. Pouya et al. [10] made a hybrid model of all renewable energy sources and applied MCDM technique to rank all renewable energy sources in Iran. Yunna et al. [11] applied fuzzy MCDM technique for the selection of most efficient and appropriate renewable power source in China.

The purpose of this work is to develop a hybrid decision model for ranking the renewable energy source in Pakistan. The hybrid decision model is composed of two existing MCDM techniques: AHP and TOPSIS. For making criteria-based decision matrix, the AHP method is used and TOPSIS is used for making the decision matrix of alternatives and then to rank alternatives.

2 Methods

In this research study, "Analytical Hierarchy Process"(AHP) and "Technique for Order of Preference by Similarity to Ideal Solution"(TOPSIS) methods are employed to evaluate the alternatives of renewable energy production pathways. A questionnaire was developed to gather the data from experts. It included the criteria and alternatives. A scale of 1 to 10 is used as low to the high importance of criteria for TOPSIS and Saaty's scale is used for AHP. Weights are given to each alternative and the criteria by experts. The average of all responses of specific alternative and criteria is used for further calculation.

2.1 AHP

Analytical hierarchy Process (AHP) is a multi-criteria decision support technique developed by Thomas Saaty in 1977 [12]. In this decision aiding technique, expert's opinion is used for weighting the individual alternatives and the alternatives are compared with respect to criteria. Subsequently, a priority score is derived for each alternative. The alternative with the highest score is preferred [13]. Table 1 and Table 1 show the templates of the criteria matrix and the pairwise comparison matrix used in this analysis. In Table 1, $C_1 ..., C_n$ represents *Criteria 1* to *Criteria n.* In Table 2, C_i and $A_1 ..., A_n$ represents the i^{th} Criteria and Alternatives respectively.

The steps of AHP are given below [14-17].

1) State the problem and its objective.
2) Make a hierarchy, keeping objective at the top, the criteria at intermediate level, and alternatives at the bottom level.
3) Develop pairwise comparison matrices $(n \times n)$ of alternatives based on each of criteria by using the Saaty's scale to weight the alternative. The dominant alternative gets the higher weight. Similarly construct a pairwise criteria matrix.
4) Normalize the pair wise comparison matrices and obtain individual priorities for all matrices.
5) Synthesize the model by multiplying the priority matrix of all alternatives with priority of criteria matrix.
6) Check the consistency of all matrices by computing the value of $(\lambda \max)$. First calculate the consistency index given by $C.I = \lambda \max - \frac{n}{(n-1)}$. Compute consistency ratio (C.R) as $R = \frac{C.I}{R.I}$, where $R.I$ is a random index and is given in the Table 3 [16, 17].

2.2 TOPSIS

TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) is a multi-criteria decision-making tool designed by Huang and Yoon in 1981 [18]. In this technique, the +ve and -ve ideal solutions are identified and the separation from both are calculated. The alternative at the smallest distance from +ve ideal solution and the largest distance from -ve ideal solution is selected as most preferable alternative [19]. The calculation steps of TOPSIS are given below.

1) Development of decision matrix

$$A = \begin{pmatrix} x_{11} & x_{12} & \dots & x_{1n} \\ x_{21} & x_{22} & \dots & x_{2n} \\ \vdots & & \vdots & \vdots \\ x_{1m} & x_{2m} & \dots & x_{nm} \end{pmatrix} \qquad (1)$$

Where x_{nm} is the average weight of an alternative.

2) Normalization of decision matrix
3) Weighted normalization of matrix $D.C$, where D is the matrix of average weights for all

Criteria Matrix	**Expert 1**			**Expert 2**			**...**	**Expert n**			**Average**		
C1	C1	...	C	C1		Cn		C1	...	Cn	C1	...	Cn
C2													
⋮													
C n													

TABLE 1: Criteria matrix

Ci	**Expert 1**			**Expert 2**			**...**	**Expert n**			**Average**		
A1	A1	...	An	A1	...	An		A1	...	An	A1	...	An
A2													
⋮													
An													

TABLE 2: Pariwise comparison matrix

n	1	2	3	4	5	6	7	8	9	10
R.I	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

TABLE 3: Random index

criteria, $C = matrix(c_1, c_2, ..., c_n)$, where $c_1, c_2, ..., c_n$ are criteria.

4) Calculate Positive Ideal Solution (PIS) and Negative Ideal solutions (NIS).
5) Calculation of Separation from Positive Ideal Solution (SPIS) and Separation from Negative Ideal solutions (SNIS).
6) Calculate closeness to coefficient (CC) ideal solution.

Table 4 shows the weight matrix of criteria. Table 5 shows decision matrix for alternative i.

3 An Application: Renewable Energy Source Selection for Pakistan

The proposed model (Figure 1) is a combination of two different MCDM techniques: AHP method and TOPSIS method. In AHP method, we identify criteria weights and from TOPSIS method selection of alternate renewable energy source is done. Decision makers or opinion of experts are used for making pairwise comparison of criteria. The criteria chosen for the proposed model are most commonly used globally and locally (shown in Table 6) and from opinion of decision makers.

4 Model Development

A hybrid model (Figure 1) is created to evaluate the overall rank of renewable energy pathway. AHP is used to derive the weights of criteria and TOPSIS is used to evaluate the overall rank of alternatives. Hybrid model enhances the reliability of overall results as two techniques are incorporated due to which limitations of techniques are minimized.

5 Results and Discussion

A hybrid model of two MCDM techniques, i.e. AHP and TOPSIS, has been developed. Local weights of criteria are calculated by using AHP as shown in Table 7. These local priorities are index to the importance of each criteria. All weights are based on the subjective judgments made by experts. It is evident from the results that the efficiency has the highest priority value of 53%, the second highest value of 21% for environmental impacts, 11% for overall cost, 8% for the sustainability, and least value of 5% for land use. Environmental impacts are important in deciding the pathway of the energy generation due to the increasing burden of CO2 emission and Ozone depletion. Therefore, it can be inferred that a renewable energy pathway having a high efficiency and lower environmental impacts is desirable based on the local priorities derived from the criteria matrix.

Table 8 shows the weighted decision matrix obtained by multiplying the local priority of criteria by decision matrix. This table shows the integrated result of criteria and alternatives which is further normalized to evaluate the +ve and -ve ideal solutions.

Table 9 is derived from Table 8. It shows the separations from positive (SPIS), negative ideal solutions (SNIS), closeness coefficient (CC) and rank of renewable energy (R.E) alternatives. A desirable alternative should have minimum separation from the positive ideal solution, maximum separation from negative ideal solution, and a highest value of closeness coefficient. The solar energy alternative has 0.041 unit separations from positive ideal solution and 0.285 unit separation from negative ideal solution with the highest

Criteria	Expert 1	Expert 2	Expert 3	...	Expert n	Average
Criteria 1						
Criteria 2						
Criteria 3						
⋮						
Criteria n						

TABLE 4: Weight matrix of the criteria

Criteria	Expert 1	Expert 2	Expert 3	...	Expert n	Average
Criteria 1						
Criteria 2						
Criteria 3						
⋮						
Criteria n						

TABLE 5: Decision matrix for the alternatives

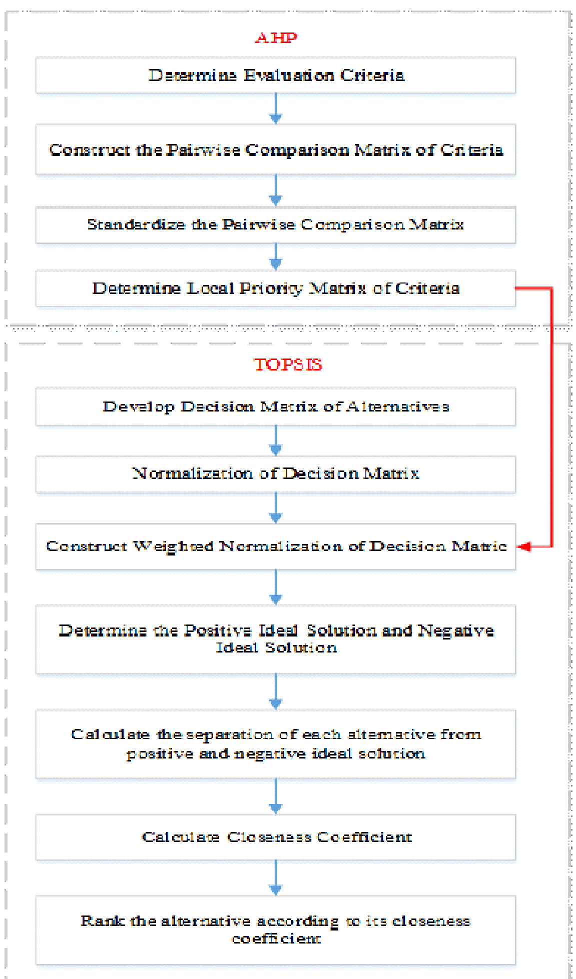

Fig. 1: The proposed model

Criteria	Reference
Technical Efficiency	[20] [21] [22] [23] [24] [25]
Overall Cost	[26] [22] [21] [27] [28]
Environmental	[21] [27] [29] [20]
Land Use	[21] [29] [30] [25]
Sustainability	[29] [27] [31] [32] [33] [34]

TABLE 6: Decision table for the alternatives

Criteria matrix	Priority
Land use	0.053
Sustainability	0.080
Overall installation cost	0.116
Environmental impact	0.213
Efficiency	0.538
Sum	1.000

TABLE 7: Local priority of criteria matrix

value of closeness coefficient. Hence, the solar energy alternative has been ranked number 1 among other alternatives. In the same way, hydro-thermal, wind, geothermal and biomass energy alternatives have been ranked as 2,3,4,5, respectively.

6 Conclusion

The purpose of this study was to select a suitable renewable energy resource using proposed hybrid decision model. The result of this research study shows that solar energy is the most suitable renewable energy source for Pakistan. Solar Energy capacity in Pakistan is estimated to be 2,900,000 MW, but only 200 MW of solar energy power plants were installed till 2018 [35]. Hence, the proposed research study and the resulted ranks in Table 8 will help the policy makers and energy planners for making long-term energy policies for Pakistan. However, changing the criteria or alternatives

Decision Matrix	Wind	Solar	Biomass	Geothermal	Hydro-thermal
Land Use	8.00	8.67	4.33	4.33	9.33
Sustainability	6.00	8.33	5.33	6.67	6.67
Overall Cost to install	5.33	8.67	6.00	5.00	7.67
Environmental Impacts	3.67	4.67	5.67	3.33	5.00

TABLE 8: Decision matrix of the alternatives

Alternatives	SPIS	SNIS	CC	Rank
Wind	0.184	0.119	0.392	3.000
Solar	0.041	0.285	0.874	1.000
Biomass	0.277	0.097	0.259	5.000
Geothermal	0.209	0.098	0.319	4.000
Hydrothermal	0.085	0.211	0.713	2.000

TABLE 9: Computation of SPIS, SNIS & CC

using this model may change the ranking. Alternatives can also be assessed with the simulation model.

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