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CASE STUDY

Selection of Best Renewable Energy Source by Using VIKOR Method

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Abstract The increasing global demand for the sustainable development of electricity sectors increased the contribution of renewable energy sources (RESs). RESs give the flexibility to install generation units at demand areas and reduce transmission and distribution losses. Selection of appropriate RES is more strategic and decisive area. This is a complex multi-criteria decision making (MCDM) problem of having uncertain and conflicting factors. In this work, we used the recently developed MCDM technique VIKOR method to choose best appropriate RES alternative for installation at Banaras Hindu University (BHU) campus, India. The advantage of VIKOR method is to have a solution closest to the ideal solution having an acceptable compromise of conflicting and non-commensurable criteria. For assigning weights to the different criteria, we used analytical hierarchy process (AHP). The importance of different criteria has been assigned by decision-makers based on their preferences. The result shows that the wind turbine option is the best choice for the case of BHU campus.

Keywords AHP · MCDM · RESs · VIKOR method · Distributed generation

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Introduction

Limitation of the conventional energy sources and their adverse environmental effect causes the increased demand of RESs in electricity generation. With small scale generating capacity of RESs, uses of distributed generation technologies with smart grid concept have exponentially increased worldwide in the recent past. The uncertainty of power generation from the RESs along with smart microgrid needs effective tools and techniques to get optimal utilization [1]. RESs planning efforts involve finding a set of sources and conversion devices in the power sector, to meet the electricity requirement or load demand in an optimal manner. RESs planning decision also involves balancing multiple aspects like technical, economical, environmental, and social aspects over a period. For maintaining the ecology and sustainable development, balancing of these factors is critically very important.

The critical task of selecting RES becomes a strenuous procedure because the decision maker would have to make a choice between an abundance of alternatives [2, 3]. Maintaining harmony between RESs and grid supply is also a big challenge [4]. Decision makers' or investors' interest about the selection of the suitable RES technology or selection of the renewable energy projects has been continuously growing. Optimal utilization of small-scale generation units of RESs helps us in multiple ways like reducing per unit generation cost, avoid carbon emissions and harness abundant available RESs. Based on past literature in this area, multiple authors agreed on a large number of criteria considered for making the selection of appropriate RESs are more complex [5, 6]. For this, the research community is doing research to develop an appropriate technique to grab preferences and to define evaluation models and algorithms for this kind of problems [7, 8].

Planning of RESs projects by using multi-criteria analysis is being attracted by the decision makers for the past many years. With increased utilization of RESs in recent time, it also increased the importance of decision-making process in the selection of best-fitted RESs technology. Earlier, dealing with the problems of RESs by single criterion approaches was aimed to identify the most efficient power generation options with minimum cost. Now a days, growing environmental awareness modified the above decision-making framework. The need for the integration of social and environmental considerations in RESs planning resulted in the increased usage of RESs technologies with multi-criteria approaches [9].

Identification of an appropriate alternative with the increased complexity of the decision-making process is a very tedious task. At the operational level, RESs projects assessments dealing with the attribute is difficult to define. An assessment may cover technical or economical areas whose boundaries may not be easily identifiable, or it may cover regions of the socio-economic, which could be an effect on various interest groups or stakeholders with their socio-economic needs or their demands [10]. Because of these difficulties, VIKOR method could be quite useful in undertaking difficult judgment procedures. The VIKOR method has been introduced in the work of Opricovic and Tzeng [11] in the year 2004, to express the conflicting and incommensurable attributes or criteria and assuming that compromise is acceptable for conflict resolution, where the decision maker wants a solution that will be closest to the ideal solution, and all the alternatives would be evaluated according to all the recognized criteria. VIKOR method ranks the alternatives and finds out the solution with compromise and closeness to the ideal solution. This shows that the VIKOR method is a multi-criteria decision-making technique which has a simple computational procedure and that allows simultaneous consideration of the closeness to the ideal and anti-ideal alternatives. As per the previous literature, there are many authors who have used VIKOR method in their work in a comparative manner [7, 11].

The present paper used this methodology for the decision support to solve the RESs selection problem. The usefulness of this methodology has been established through a case of BHU campus. For which, decision-makers want to find and select the appropriate RES at BHU campus and will provide decision support services on this basis.

Organization of the paper is in the following manner: "Literature Review" describes literature review of the RES selection process and the related work. Section "Proposed Approach" introduces the AHP method to weight criteria and use of VIKOR method for ranking the alternatives. In "A Case of BHU Campus" the proposed method is illustrated by a case of BHU campus. Section "Regional Importance" shows regional importance in the selection of best RES. Finally, "Conclusion" concludes this work.

Literature Review

The modern power sector is moving towards adoption of RESs to overcome excessive carbon emissions and limitations of fossil fuels [2, 12]. In the form of RESs system, use of small scale renewable energy based power generating units is more cost effective with multiple advantages over the other modes of power generation systems [3, 10, 13–15]. RESs gives us the flexibility for installation of generating units in remote or rural areas, where transmission and distribution of power would not be feasible [16–18]. Karki et al. [19] studied over getting environmental benefit from the rural electrification in India through RESs. Kumar and Ravikumar [20] identified hybrid RESs technology to help needs of the urban building in India. For the feasibility, increased penetration of RESs should maintain the resilience of transmission and distribution network [21]. On-site power generation from the RESs requires selection of the suitable energy sources for the installation region based on multiple criteria [5, 6, 22]. In developing countries, selection of optimal RES in the form of distributed generation technology will give us the maximum payoff with the sustainable environment [23, 24]. In a work of Kumar et al. [25] deployment of the wind and solar energy in power distribution system to achieve security of supply, cost competitiveness, and environmental responsibility have been studied. A novel intelligent energy management system (IEMS) for a DC microgrid to connect with Photovoltaic panels, utilities, and storage system, implemented from Chauhan et al. [26] for load sharing, reduce power loss and improve the system reliability. The impact of Low voltage direct current (LVDC) grid with distributed generation in power distribution has been studied by Chauhan et al. [27] to reduce power losses and improve power quality, which mainly considered photovoltaic RES for the distributed generation.

RES selection initially requires the identification and elaboration of different decision criteria that will guide in the decision-making process. Different decision-making groups may choose different decision criteria for RES selection based on some factors which affect in decision-making process like most affected factors would be the cost factors and environmental losses. San Cristóbal [22] proposed a model that considers power, investment ratio, implementation period, operating hour, useful life, operation & maintenance costs, tons of CO_2 avoided factors for selection of suitable renewable energy based generating units in Spain. In the recent work of Ahmad and Tahar [28], they divided their sub-criteria under the major criteria of technical, economical, social, and environmental. Kahraman et al. [29] divided their sub-criteria for the RESs planning into four such as technological, environmental, socio-political, and economic criteria. Based on the number of criteria, RESs planning will require the multi-criteria decision-making analysis.

Making decision is an integrated part of human life, which is coming from the history of the mankind. MCDM technique is the most famous technique for decision making in the recent world. Authors like Zimmermann [30] have divided MCDM into two categories; one is multi-objective decision making (MODM), and another one is multi-attribute decision making (MADM). However, both are used to represent the same class of MCDM models. The major difference between the two groups of methods is the selection process of the alternatives. In the MODM method, which also known as multi-objective programming problem, instead of predetermined alternatives, we have a set of optimization objective functions subject to constraints. In the MADM method, alternatives are predetermined, and a set of alternatives would be evaluated for the given set of attributes. Selection of the best alternative is based on the comparisons between each alternative on given criteria or attributes [29]. In renewable energy projects like wind farm projects, solar projects, geothermal projects or biomass projects, MCDM methods have been widely used. For deciding the optimum mix of RESs based distributed generation technology with various sectors like central power generation system, MODM methods have been used [2, 3, 9, 10]. In the work of Borges and Antunes [31], renewable energy economic planning is showing the interactions between technical and economic parts of the system. Amongst the number of decision-making techniques, Decision Support Systems, MODM, MADM (mainly AHP, PROMETHEE, ELECTRE, TOPSIS and Multi-attribute utility theory), and Fuzzy programming is the most applied MCDM technique in renewable energy projects.

For an application of the AHP method, the structure of a multiple criteria problem is hierarchically and breaking down the problem into smaller consistent parts [32]. In this system, the objective becomes at the top of the hierarchy where as criteria and sub-criteria become at the levels, and sub-levels of the hierarchy and decision alternatives become at the bottom of the hierarchy. Selection of the suitable alternative depends on the comparison between the different alternatives on each criterion. Multiple authors used AHP method for the renewable energy planning projects [13, 28, 29, 33]. Other kinds of decision-making methods used in renewable energy investment projects are Fuzzy programming to evaluate the selection of renewable energy alternatives [29, 34], Decision Support Systems based on fuzzy decision support model for the energy-economy planning [31, 35], a methodology of Geo-spatial multi-criteria analysis used to set up the wave energy farm [36], and a linear programming optimisation methodology in the form of energy flow optimisation model (EFOM) is used for the regional energy planning with RESs and environmental constraints [37].

Taking into consideration the decision makers' preferences, MAUT (multi-attribute utility theory) is developed to help decision-makers allocate utility values to get outcomes from the evaluation of these utility values regarding multiple attributes and obtained the overall utility measures by combining these individual assignments [38]. Jones et al. [39] used this method in the planning of RESs for their respective work, and Golabi et al. [40] used this theory in the work of solar energy project portfolio selection. For the discrete nature of criteria in both quantitative and qualitative term, the ELECTRE method provides complete ordering of the alternatives. This method chooses a set of alternatives that are preferred for most of the criteria, and that will not cause an unacceptable level of discontent for any of the criteria. The ELECTRE method gives graphs for strong and weak relationships based on a concordance, discordance indices, and their threshold values. With an iterative procedure, we can have a ranking of alternatives from the graph of strong and weak relationships. Beccali et al. [10] and Georgopoulou et al. [41] used this method in their renewable energy project. Other MCDM method is PROMETHEE method, which uses the outranking principle to rank the alternatives and combined with ease of use to reduce the complexity. With PROMETHEE method we can perform a pair-wise comparison of alternatives for the ranking of the alternatives on a given number of criteria. PROMETHEE technique has been used by Goumas et al. [42], Goumas and Lygerou [43], and Haralambopoulos et al. [44] in the work of geothermal project. Pohekar and Ramachandran [45] has used PROMETHEE method for the utilisation of parabolic solar cookers in India. Mladineo et al. [46] used PROMETHEE technique to select hydro power plant installation area.

Another distance-based MCDM method is the TOPSIS method, which determines a solution of the shortest distance from the ideal solution and the farthest distance from the negative-ideal solution, but its drawback is that it does not give information of the relative importance between these two distances [47, 48]. Kaya and Kahraman [49] used modified fuzzy TOPSIS method for the selection of best energy technology, and Şengül et al. [5] used this technique for the ranking of renewable energy supply. Comparative analysis between TOPSIS and VIKOR is shown in the article by Opricovic and Tzeng [11]. Both the VIKOR and TOPSIS methods were developed as an alternative to ELECTRE method are based on an aggregating function or closeness to the ideal, and that originates in the compromise programming method. Both the VIKOR and TOPSIS methods introduce different forms of aggregating function for the ranking of alternatives and perform different kinds of normalization procedure for the elimination units of the criterion function [11]. The VIKOR method uses linear normalization technique and the normalized values, which do not depend on the assessment unit of each criterion. The TOPSIS method uses vector normalization for a particular criterion, and the value of normalization could be different for a different evaluation unit. As regards of the aggregating function, VIKOR method uses an aggregating function that will represent the distance from the ideal solution, will consider the relative importance of all the criteria, and will have a balance between total and individual satisfaction. On the other side, TOPSIS method uses an aggregating function that will include the distances from the ideal point as well as from the negative-ideal point without having their relative importance. However, the reference point could play a major role in the decision-making process, and having the reference point near to ideal is the justification of human choice [11].

This paper has shown that the use of the Compromise Ranking Method also known as the VIKOR method in the selection of the RESs. Along with VIKOR method, we used AHP technique for assigning the weights to have relative importance between each attribute. Similar approaches can be found in San Cristóbal [22], who applied the same method for the selection of renewable energy alternative in Spain, or in Kaya and Kahraman [50], who applied the VIKOR method along with AHP under fuzziness for the renewable energy planning with a case of Istanbul. In this work, authors considered a region specific problem of BHU campus for getting the better results. Multiple authors suggested that a combination of these two will allow the decision-makers to methodically allocate the values of relative importance to the attributes or criteria based on their preferences. This paper assumes that each alternative is evaluated according to all the criteria, and the compromise ranking would be performed by comparing the computation of closeness to the ideal solution F*. From the use of Lp-metric in compromise programming method, the merit of multi-criteria for compromise ranking has been developed by Yu [51] and Zeleny [52].

In brief, we can say that VIKOR method works on ranking and selection of the alternatives from the given one in the existence of conflicting criteria. It gives a compromise solution that will be accepted by the decision makers because of its maximum group utility for the “majority”, and of the minimum individual regret for the “opponent”. By the use of linear normalization, this method representing the closeness to the ideal solution based on aggregating function. Where, in TOPSIS method, use of vector normalization and two reference points does not consider the relative importance of the distances. From the group utility measures, PROMETHEE method ranks the alternatives with a linear preference function similar to the ranking of VIKOR method. Also, ELECTRE II gives similar value like VIKOR method from the linear surrogate criterion functions.

Proposed Approach

Performance Evaluation Using AHP Method

With the help of AHP method, we can assign weights to the relative importance of the attributes [32]. Based on our objective function we can find out the relative importance of the attributes. For that, we should have to construct a pair-wise comparison matrix with a scale of the relative importance. Values entered in the pair-wise comparison matrix should be based on Saaty’s Nine Point scale. Saaty’s Nine point scale for the AHP is; comparison of an attribute with itself will always assign the value of 1, it means the main diagonal entries of the matrix will have same values 1. For the other cells the numbers 3, 5, 7, and 9 based on experts verbal judgments ”moderate importance,” ”strong importance,” ”very strong importance,” and ”absolute importance” along with 2, 4, 6, and 8 for compromise between the previous values.

Suppose we have n number of attributes, the pair-wise comparison matrix will develop between the ith attributes and jth attributes which will be a square matrix A_{nxn} and aij will denote the comparative importance of ith attribute with jth the attribute. In this pair-wise comparison matrix, $a_{ij} = 1$ when $i = j$ and $a_{ji} = 1/a_{ij}$. The eigenvector or priority weights vector w will be calculated by the summation of each column of the matrix and then divide each element of the matrix with the summation of its column. Then, averaging across the rows will give us the normalized eigen vector.

$$A = \begin{bmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & a_{nn} \end{bmatrix}$$

We have to know the vector $w = [w_1, w_2, ., w_n]$ which represents the weight of the each criterion which is given in pair-wise comparison matrix A. To recover the vector w from the pair-wise comparison matrix A, it will go for a method of two-step procedure:

For each of the A’s columns divide each entry in column i of A by the sum of the entries in column i. This yields a new matrix, called Anorm (for normalized) in which the sum of the entries in each column is 1.

Estimate Wi as the average of the entries in row i of A_{norm}.

$$w_i = \frac{\sqrt[n]{\prod_{i=1}^{n} a_{ij}}}{\prod_{j=1}^{n} \sqrt[n]{\prod_{j=1}^{n} a_{ij}}}$$

Where n = number of criteria

$$\lambda_{max} = \frac{(Aw)_i}{nw_i}$$

$CI = (\lambda_{max} - n)/(n-1)$
CR = CI / RI
For getting the value of CI, we must have the λ_{max} by multiplying each element of the matrix with the eigenvector. The smaller the CI represents the, smaller the deviation from the consistency. If CI is sufficiently small, it means the decision-makers' comparisons are probably consistent enough and give useful estimates of the weights for their objective. Perfectly consistent decision-maker will give the ith entry in $AW^T = n$ (ith entry of W^T). It shows that a perfectly consistent decision-maker has CI = 0. Then, find out the consistency ratio (CR) with dividing the consistency index (CI) from the random index (RI). Finally, if the CR<0.01, then the degree of consistency is satisfactory. Otherwise, judgment matrix needs to be readjusted until satisfactory.

Use of VIKOR Method

When the decision maker is unable to take a decision or doesn't know to express their preferences at the beginning stage of the system design, the VIKOR method would be an effective tool for the multi-criteria decision-making process. For the value of a maximum group utility of the "majority" (min S, given by Eq. 2), and a minimum individual regret of the "opponent" (min R, given by Eq. 3), obtained compromise solution would be accepted by the decision makers. Based on the involvement of the decision-makers' preferences by weights of criteria, the compromise solutions would be the basis for negotiations. The result of the VIKOR ranking depends on the ideal solution Q with values of v, which will be only for a given set of alternatives. Any changes to a given set of alternatives will lead to the result of modified VIKOR ranking for the new set of alternatives. The fixed ideal solution would be defined by the decision maker based on the best f_i and the worst f_i values, but it could be avoided.

Here each alternative would be evaluated with each criterion function and, the compromise ranking would be performed with the comparison of the measure of closeness to ideal solution F*. Compromise solution F^C will be a feasible solution that will be the closest to the ideal solution and will have a compromise established by mutual concessions [8]. With multi-criteria measure for the compromise ranking of alternatives is developed from the Lp-metric by using an aggregating function from the compromise programming method Yu [51], Zeleny [52]:

$$L_{pj} = \left[\sum_{i=1}^{n} \left\{w_i \left(f_i^* - f_{ij}\right) / \left(f_i^* - f_i^-\right)\right\}^p\right]^{1/p} \quad (1)$$

$1 \le p \le \infty$, j=1,2,.....,J
where $L_{1,j}$ denoted as S_j in Eq. 2 and $L_{\infty,j}$ denoted as Rj in Eq. 3, are used to formulate the ranking measure.

For the VIKOR method, the number of j alternatives is denoted as a_1, a_2,..., a_j. For any alternative a_j the rating of the i_{th} facet is denoted by f_{ij}, and this is the value of the i_{th} criterion for the alternative a_j; where j=1,2,....,m and i=1,2,.....,n. The compromise ranking algorithm of the VIKOR method is divided into the following four steps which are given below [11]:

Step I: For all the criterion functions, find out the best f_i^* and the worst f_i values, i = 1,2,...,n. If the i_{th} function represents a benefit then $f_i^* = f_{ij}$ and $f_i^- = f_{ij}$, whereas if the i_{th} function represents a cost $f_i^* = f_{ij}$ and $f_i^- = f_{ij}$.

Step II. Compute the values of S_j and R_j, j = 1,2,...,m from the relations of

$$S_j = \sum_{i=1}^{n} w_i \left(f_i^* - f_{ij}\right) / \left(f_i^* - f_i^-\right) \quad (2)$$

$$R_j = \left[w_i \left(f_i^* - f_{ij}\right) / \left(f_i^* - f_i^-\right)\right] \quad (3)$$

Where w_i denotes the weights of criteria, which expresses the decision maker's preference for the relative importance of the criteria.

Step III: compute the values of Q_j, from the given relation

$$Q_j = v\left(S_j - S^*\right) / \left(S^- - S^*\right) + (1-v)\left(R_j - R^*\right) / \left(R^- - R^*\right) \quad (4)$$

Where $S^* = S_j$; $S^- = S_j$; $R^* = R_j$; $R^- = R_j$ and as a weight v has been introduced for the strategy of maximum group utility, while (1 - v) is for the weight of the individual regret. The solution will be obtained by S_j with a maximum group utility based on "majority" rule, where the solution will be obtained by R_j with a minimum individual regret of the "opponent." In general, the value of the v is taken as 0.5, but we can take any value of v in the range of 0 to 1.

Step IV: Now rank the alternatives with the sorting of the results of S, R, and Q in increasing order. From this we will have three ranking lists for S, R, and Q. Suppose we have a compromise solution of the alternative A^1 best ranked by the minimum value of the measure Q, then it should satisfy the given conditions. Propose as a compromise solution the alternative A^1, which is the best ranked by the measure Q(minimum), if the following two conditions are satisfied:

a. First one is the acceptable advantage. $Q\left(A^2\right) - Q\left(A^1\right) \geq DQ$, where DQ = 1/ (J - 1) and A^2 is the alternative with the second position on the ranking list by Q;
b. The second one is the acceptable stability in decision-making. The alternative A^1 should also be the best ranked by S or/and R. This compromise solution should be stable for a decision-making process, that could be the strategy of maximum group utility (when v >0.5 is needed), or by consensus (v ≈ 0.5), or with veto (v <0.5).

If one of the above conditions is not satisfied, then we will have to propose a set of compromise solutions, which will consist of:

c. Alternative A^1 and A^2 when the condition b is not satisfied, or
d. Alternatives A^1, A^2,..., A^M when the condition a is not satisfied and, A^M is determined by the relation $Q\left(A^M\right) - Q\left(A^1\right) < DQ$ for maximum value n means the positions of these alternatives are "in closeness."

A Case of BHU Campus

One of the characteristics of the BHU power consumption system is its high degree of dependence on fossil fuel based central power generation system. Limitations of conventional energy sources and their economic impact with environmental concern are the motivation towards the adoption of RESs. With small scale generating capacity and flexibility of onsite power generation increased the demand for RESs based distributed generation technology and helps to reduce the load of grid supply. In our case, we are proposing a set of alternatives which could be geographically feasible for onsite power generation at BHU campus.

With the overall aim of making it possible and having ten-megawatt capacity installation limitation, we have to select the best RES alternative and prioritize them for distributed generation at BHU campus. To do so, we have set more ambitious goals in renewable energy area that is developing rapidly and has established new measures to support energy sector that has not yet been managed to take off. From the different areas covered by the overall renewable energy Project, we have selected as an example for multi-criteria decision-making, only the feasible alternatives for the electric generation at BHU campus. These are shown in Table 1, which are photovoltaic (PV), concentrated solar power (CSP), wind turbine (WT), biomass (BM) and geothermal (GT).

Table 1 List of renewable energy alternatives proposed in a case of BHU campus, India

Alternatives	
A1	PV
A2	CSP
A3	WT
A4	BM
A5	GT

We have to prioritize alternatives based on selected criteria, which affect in decision making. We considered region specific criteria for BHU campus to have better simulation and managerial decision. The designed model evaluated with these criteria are shown in Table 2. Consultation with experts and department of Electric and Water Supply Service (EWSS) BHU, we considered the criteria specific for case of BHU: Investment Cost (Crores), Operation and Maintenance Cost (INR/KWh), Implementation Period (Year), Power Generation (MW), Annual Operating Hours, Environmental Loss (gCO2eq/kWh), Useful Life (Year), Area Acquisition (square meter). Consideration of the regional factors of BHU region is helpful in selection of the best alternative. Values of each criterion for different alternatives have been given in Table 3. Investment Cost criterion shows individual investment cost of different alternatives in BHU campus. Expected future Operation and Maintenance Cost, and Implementation Period data for different technologies are given by the EWSS, BHU. A Power Generation criterion is derived with geographical data like hourly wind speed and solar irradiation of BHU region. Hourly wind speed and solar irradiation data have been taken from the National Renewable Energy Laboratory website for BHU region with 25.16°N to 25.26°N and 82.89°E to 82.99°E [53]. Annual Operating Hours criterion is showing a number of hours for power generation in a year.

Table 2 List of criteria for the selection of suitable RES

Criteria	
C1	Investment Cost
C2	Operation and Maintenance Cost
C3	Implementation Period
C4	Power Generation
C5	Annual Operating Hours
C6	Environmental Loss
C7	Useful Life
C8	Area Acquisition

Table 3 Numerical values of each criterion for each alternative

Criteria	PV	CSP	WT	BM	GT
Investment Cost (min)	5	200	45	5	130
Operation and Maintenance Cost (min)	0.05	2	0.67	4	1.33
Implementation Period (min)	1	1.5	1	1.5	2
Power Generation (max)	1.3	1.1	1.4	2.1	2.5
Annual Operating Hours (max)	3800	3800	3850	7000	7500
Environmental Loss (min)	41	27	11	230	38
Useful Life (max)	25	30	25	20	30
Area Acquisition (min)	369	153	721	5434	75

Environmental Loss is considered as gram equivalent of carbon emitted from different technologies per kWh of power generation. Life span of the different alternatives is considered as Useful Life criterion. Area required for installation of different technologies is considered as Area Acquisition.

$$A = \begin{bmatrix} 1 & 2 & 9 & 8 & 9 & 5 & 7 & 3 \\ 1/2 & 1 & 5 & 4 & 7 & 1 & 5 & 3 \\ 1/9 & 1/5 & 1 & 2 & 2 & 1/4 & 1/2 & 1/3 \\ 1/8 & 1/4 & 1/2 & 1 & 3 & 1/5 & 1/3 & 1/5 \\ 1/9 & 1/7 & 1/2 & 1/3 & 1 & 1/7 & 1 & 1/5 \\ 1/5 & 1 & 4 & 5 & 7 & 1 & 3 & 5 \\ 1/7 & 1/5 & 2 & 3 & 1 & 1/3 & 1 & 1/2 \\ 1/3 & 1/3 & 3 & 5 & 5 & 1/5 & 2 & 1 \end{bmatrix}$$

W1=0.36, W2=0.19, W3=0.04, W4=0.04, W5=0.03, W6=0.18, W7=0.05, W8=0.10
$\lambda_{max} = 8.88$
CI = 0.1258
CR = 0.089
CR<0.1

Table 4 is having the benefit and cost values of each criterion. It represents the maximum values for the benefit and minimum values for cost criteria. Table 5 represent the ranking of given alternatives with their S and R values. Values of Q from the value of S and R for each alternative with different values of v in between 0 and 1 have been shown in Table 6.

Table 4 Benefit and cost values of each criterion

Criteria	f_i^*	f_i^-
Investment Cost (min)	45	200
Operation and Maintenance Cost (min)	0.05	4
Implementation Period (min)	1	2
Power Generation (max)	2.5	1.1
Annual Operating Hours (max)	7500	3800
Environmental Loss (min)	11	230
Useful Life (max)	30	20
Area Acquisition (min)	75	5434

Table 5 Ranking of alternatives based on their majority "S" and opponent "R" values

	PV	CSP	WT	BM	GT
S_j	0.131	0.558	0.128	0.567	0.321
R_j	0.034	0.360	0.031	0.190	0.197

Ranking the proposed alternatives by the VIKOR method that we have proposed as a compromise solution and for all the considered values of v, the alternative wind turbine is the best one. The alternative of a wind turbine with the capacity of ten megawatts is the best ranked from the values of Q. As this alternative is also the best ranked by S and R, conditions IV-a and IV-b are satisfied.

Regional Importance

As a developing country, with its fast-growing population and economy, India is facing increasing demand for energy due to technological penetration in human life. Limited availability of conventional energy sources and its negative environmental effects restricts India to fulfill its energy demand. India is a major energy-importing country and trying to reduce the country's dependence on imported conventional energy sources. An insufficient quantity of domestic conventional energy resources, commitment to reduce carbon emission levels, has forced the country to change its energy supply to renewable and sustainable resources. India has abundant reserves of RESs that can be used as a major part of the decentralized power generation system to meet the total energy demand. The government of India has set

Table 6 Values of ideal solution "Q" for different values of v

v	PV	CSP	WT	BM	GT
0	0.009	1	0	0.483	0.505
0.1	0.009	0.998	0	0.535	0.498
0.2	0.009	0.996	0	0.587	0.492
0.3	0.008	0.994	0	0.638	0.485
0.4	0.008	0.992	0	0.690	0.479
0.5	0.008	0.990	0	0.742	0.472
0.6	0.008	0.988	0	0.793	0.466
0.7	0.008	0.986	0	0.845	0.459
0.8	0.007	0.984	0	0.897	0.453
0.9	0.007	0.982	0	0.948	0.446
1.0	0.007	0.979	0	1	0.440

an ambitious target of 175,000 MW of renewable power by 2022. In the first quarter of the year 2017, the percentage contribution of RESs has reached to 15.9 percent of total power capacity in India [54]. Current installed capacity and the capacity under construction would be able to meet India's power demand till about 2026, and no new investments are likely to be made in coal-based power generation, said a report released by The Energy and Resources Institute (TERI). The report also estimates that beyond 2023-24, new power generation capacity could be all renewable, based on cost competitiveness of renewable as well as the ability of the grid to absorb large amounts of renewable energy together with battery-based balancing power [55].

Regional distributions of the RESs vary with geographical changes. The harnessing of RESs needs case-specific analysis to get the suitable mode of RES for the installation. In this work, we considered a case of BHU campus for installation of suitable RES based distributed generation units to help in reducing carbon emission levels and a load of grid supply. This will also help to achieve the vision of government of India to develop sustainable power generation system. BHU is located in the north India between 25.26° N latitude and 82.99° E longitude. It is one of the largest universities regarding land mass in India; BHU campus is a miniature representation of residential regions in the country spread over 1300 acres with approximate 35000 residents.

In this work, the five RESs that could be feasible to generate electricity at BHU campus have been taken into consideration. These RESs are photovoltaic, concentrated solar power, wind turbine, biomass and geothermal. Determination of the most appropriate RES is carried out using the steps described in the methodology section. Following steps are given in methodology section, first, determines a score via a pair-wise comparison for the region specific criteria to weight them. The listed criteria in preference ranking of RESs at BHU campus is the Investment Cost, followed by the Operation and Maintenance Cost, Implementation Period, Power Generation, Annual Operating Hours, Environmental Loss, Useful Life, and Area Acquisition. According to these results, the primary necessary conditions for the selection of RES at BHU campus is the cost factors and environmental loss.

In recent years some authors have made important contributions in the area of selection of RESs in their research works. In multiple studies by different authors, major works have been done in a generalized way to planning renewable energy for the national level. Generalization of renewable energy planning deviates from its regional factors and limitations to get best suitable region specific alternatives in distributed generation system. Availability of RESs is high dependent on geographical diversions and climatic conditions. Kabak and Dağdeviren [56] considered factors affecting in the selection of RESs for the planning of renewable energy in Turkey. Tasri and Susilawati [57] identified that hydro power source is rich source for the nation Indonesia, which may give different results for different location of the country. Diakoulaki and Karangelis [58] studied for the country Greece to identify the best alternative of RES. Şengül et al. [5] identified that hydro power source is the best source for the country Turkey, depending on regional potential and importance hydro power efficiency may vary with locations or some other alternative can be perfect in different location. Ahmad and Tahar [28] considered a list of alternatives of RESs to select the best alternative of RES for the country Malaysia. Kahraman et al. [29] identified that wind energy source is a perfect source of energy in Turkey which will differ in installation regions and their local managerial challenges. Work of Kaya and Kahraman [9] shows regional importance in their work and identified best-fitted alternative in a specific region, which gives wind energy is the most appropriate renewable energy option, and Çatalca district is the best area among the alternatives for establishing wind turbines in Istanbul.

The present study supports the decision taken by the planner to utilize optimum available RESs for the BHU campus. Thus the multi-criteria decision making analysis showed that the wind turbine is determined to be the most appropriate renewable energy supply system for BHU campus. Additionally, the photovoltaic is determined to be the second one. The planner of this project should invest, in order of priority in these systems. The planner should also evaluate the projects which are related to these RESs. Thus, investment priorities can be planned according to the ranking.

The benefits of expanding these energy sources would be enormous; RESs would reduce BHU's dependency on grid supply and elevate the environmental hazards by depending almost completely on indigenous resources. The cost of electricity, which is dropping rapidly, when drawn from RESs, opens up the competition to many conventional technologies. Renewable technologies have minimal fuel costs, and they cannot be exhausted easily. In this context, this study proposes a scientific model to prioritize alternative RESs for a region specific with their geographical factors. Evolution of smart grid technology promotes decentralized power generation with optimal utilization of regional RESs.

Conclusion

Selecting the best RES from a set of renewable energy investment projects requires different groups of decision-makers involvement in the decision-making process. It is well known that the number of factors considered in the decision-making process makes this more complex. In this work, we have taken eight factors for ranking of the five alternatives in the decision-making process for the selection of suitable RES at BHU campus. For this kind of problem, traditional single-criterion decision-making process is unable to handle anymore. The policy formulation for the use of RESs under rapidly growing renewable energy markets should be addressed in a multi-criteria context. For getting the solution, we have used the VIKOR method in this work, which gives the multi-criteria ranking index with the particular measure of closeness to the ideal solution. Weighting the importance of the different criteria for ranking of the given alternatives, we used AHP technique with VIKOR method that allows the decision-maker for assigning the values of relative importance to the attributes with their preferences. The results have shown that the wind turbine alternative is the best choice, followed by the photovoltaic alternative. In this case, greater weight has been given by the decision-makers to the criteria of investment cost, operation and maintenance cost, and environmental loss. We also discussed over regional importance in the decision-making process to select the best alternative of RES for a region specific area.

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