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Performance Evaluation of Hydro Power Projects in India Using Multi Criteria Decision Making Methods

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ABSTRACT

In the contemporary period of the green economy, energy planning has grown more complicated due to the inclusion of numerous standards, including technical, social, economic, and environmental. This, in turn, restricts the ability of decision-makers to make the most efficient use of energy resources. In addition, the difficulty of energy planning is exacerbated by topographical restrictions on renewable energy systems, the majority of which are found in nature. Based on factors such as total installed capacity, total reservoir capacity, total surface capacity, the height, length, number of units, and the cost of the dam were used to determine the finest hydro power project in India, according to this study. For performance evaluation, multi criteria decision making (MCDM) techniques like analytic hierarchy process (AHP) and TOPSIS (technique for order reference by similarity to ideal solution) are used in conjunction with VIKOR (vlekriterijumsko kompromisno rangiranje) for performance evaluation. AHP is used to calculate the weights of each criteria. The TOPSIS and VIKOR methods will utilise these weights to choose the optimal option. For the purpose of demonstrating the approaches' applicability, an in-depth case study of various hydropower facilities in India was carried out.

Keywords: hydro power plant selection, energy, MCDM, AHP, TOPSIS, renewable source, VIKOR.

INTRODUCTION

Energy is a critical requirement for a country to achieve both balanced growth in the economy and stability. Due to an increasing population, increased urbanisation, increased industrialisation, and other factors related to technological advancements, our daily lives have become more energy dependent. Coal, oil and other petroleum products, biomass and waste, nuclear power, natural gas, hydroelectricity, and other alternate energy sources are only a few of the many energy sources available in India. For poor countries, rising temperatures are of the utmost importance. As a result, developing nations and the rest of the globe need low-cost power generation that produces fewer emissions of greenhouse gases. The non-polluting, non-conventional, and environmentally benign energy source is hydropower. Since it produces little pollution, is quick to start up, and shuts down, it's one of the most likely alternate energy sources. By 2040, according to the International Energy Agency, India's energy demand is predicted to quadruple, with the strongest growth rates in nuclear power (3% per year) and renewable energy (2.3% per year, exclusively for hydro). Hydropower has a storage reservoir that helps meet peak demand so that the whole system can keep running.

Additionally, hydropower provides low-cost energy, water supply and flood control as well as enjoyment and farming. Hydropower, despite its many advantages, was formerly very contentious because of the social and environmental consequences it had on communities and the environment. Ecosystem destruction, greenhouse gas emissions (GHG), submersion of a significant geographical area, human migration and resettlement are among the many consequences of climate change. Sustainable hydropower development is becoming a major issue in the sector. Hydropower projects with a primary goal of generating electricity were scrutinised primarily on the basis of technical and economic factors.

Hydropower projects must thus be evaluated on the basis of environmental sustainability standards. These requirements, on the other hand, are at odds with the design of a cost-effective hydropower project with high installed capacity and minimal negative repercussions on the environment and society. So, MCDM procedures are a good way to solve hard problems, like those in the hydropower system where different criteria are important. There are a variety of parameters taken into account while evaluating hydropower plant performance, making it an MCDM process. Decision-making may be a tough and time-consuming process, especially when it comes to narrowing down the available options and assigning a ranking to each one. MCDM is a strategy used to organise, make choices, and schedule issues involving multiple criterion criteria.

These strategies are aimed at addressing these issues and making the jobs of decision-makers easier. When a decision-maker or policymaker needs to make a choice amongst a variety of options, since a perfect answer isn't readily available, they will typically turn to this method. MCDM techniques may be used to evaluate a wide range of options, rank them, and choose the best one. With the use of MCDM techniques, it's possible to accurately identify and rank the preferences of each alternative under consideration. The rank reversal paradox is a problem that often comes up in the field of MCDM-based choice. Using two new MCDM methods, VIKOR and TOPSIS, the goal of this research is to find a new way to evaluate hydropower projects in India that can be added to systems that help people make decisions.

TOPSIS uses the notion of proximity to ideal solutions and distance from ideal solutions when rating options. There is no requirement for any piece of knowledge to stand on its own in order to benefit from this strategy. Even if Euclid's distances are used, the approach does not take into account negative or positive values because of this. VIKOR aggregation function and normalising approach differ from TOPSIS. In TOPSIS, the optimal alternative is the one that is farthest from the negative solution and the closest to the positive answer. Conflicting problems, the selection of an optimal solution, and the combining of various policies may all be solved using MCDM methodologies. In the energy sector, the issues to be addressed and the aims to be achieved are usually contradictory: lower energy prices for end users; reducing energy reliance; reducing fossil fuel consumption; providing energy security, and so on. MCDM techniques can help us find a solution to these conflicting problems. Energy policymakers can use MCDM techniques to help them choose the optimal option without regard to the evaluation process. When making judgments and creating goals, officials should put this tool first in their considerations. Energy policy challenges are increasingly being addressed using MCDM approaches.

BACKGROUND

Alternatives to renewable energy were mostly analysed using MCDM methods [Shao et al., 2020]. To come up with an alternative evaluation, we turn to MCDM techniques. In a thorough investigation, the hydro plant's essential components and specifications were outlined. When attempting to obtain a wide range of PF solutions with respect to both technological and economic aspects, multi-objective optimum approaches are frequently employed [Ridha et al., 2021].

Among the seven factors analysed while choosing the optimum location were wind power, hub height and distance as well as cost and CO_2 emissions. An analytical hierarchy process is utilised in conjunction with an order reference method based on resemblance to an ideal solution to attain the study's goal of understanding (TOPSIS). In the first phase, we'll use an AHP to figure out how much each criterion matters. Use the TOPSIS method to determine which project is the most efficient. A case study analysed six different types of wind power installations. According to the AHP TOPSIS analysis, the wind farms near Kanyakumari and Muppandal both have excellent performance [Manoj et al., 2020].

Using Pythagorean fuzzy logic, Fei and Deng (2020) devised a new approach to multi-criteria hierarchical decision making. The decision-making process would be made more difficult if decision-makers had to supply their own weights in advance. As a result, we've come up with a new way to calculate weights based on decision matrix fuzzy data. In a study by Youssef (2020), TOPSIS was compared to AHP, the most often used MCDM approach. In terms of computational complexity and consistency, the TOPSIS technique was found to be more efficient and consistent than AHP [Fei and Deng, 2020].

Lin et al. (2020) created an evaluation criterion system for IoT platforms based on issues regarding IoT application design. For the problem of solar panel selection, Bączkiewicz et al. (2021) proposed a novel technique based on two newly established MCDM methods: characteristic objects method (COMET) combined with stable preference ordering towards ideal solution (SPOTIS) and TOPSIS. As a result of its huge ability to directly convert vast amounts of solar radiation into electrical power, solar energy is among the most attractive and environmentally benign energy sources. Photovoltaic systems are getting cheaper, making solar power more competitive with traditional energy sources, which in turn increase the interest in solar panels among businesses and homeowners. Since this is the case, a decision support system (DSS) that allows for the selection of solar panels based on a variety of factors must be created [Bączkiewicz et al., 2021].

An integrated method is developed by combining the Fuzzy Analytic Hierarchy Process and the TOPSIS in this paper. The TOPSIS technique was utilised to arrive at the final ranking, which took into consideration a range of concrete and intangible factors. The use of multi-criteria decision making approaches suggests a potential site for a renewable energy facility. There were three tools used to make a map of hybrid power plant priorities: AHP, TOPSIS and VIKOR. Aldrin Wiguna illustrated how utilising the combined Fuzzy AHP-preference ranking organization method for enrichment evaluation (PROMETEE) technique directly in ArcGIS (geographical information systems) makes the process of finding a solar farm easier and more effective [Sasikumar and Ayyappan, 2019; Asadi and PourHossein, 2019]. In an ArcGIS programme, the study's findings may be utilised to locate the best location for a solar farm. The findings of this study can help decision makers identify the best location for a solar farm faster and more efficiently. It is possible that faster assessments of a property's suitability could aid Indonesia in expanding the use of power renewables, such as solar energy, across the country [Wiguna et al., 2016].

Goh et al. (2021) was confident, that area's suitability for solar project development may be assessed using the cost-benefit analysis (CBA) framework. In the eyes of solar energy experts, a score of 100 indicates a thorough understanding of how the sun generates energy [Goh et al., 2021]. Additionally, when determining where to build a solar farm, decision makers take into account both technical and societal aspects. Using CBA to organise data in a way that makes it simpler for experts and stakeholders to select the optimum location for a solar project is demonstrated in this study. A solar power plant site-suitability evaluation has been developed by Ruiz et al. (2020), that takes into consideration sustainable development and conservation efforts in cultural, natural, and biological areas [Vishnupriyan and Manoharan, 2018]. Multi criteria decision analysis shows that the yearly optimal tilt grid-connected PV system is the best option for this site. Prioritizing renewable energy system choices and selecting the optimum electric power system using the AHP approach is evaluated using the best-worst method and stochastic multi-criteria acceptable analysis [Štreimikienė et al., 2016].

Streimikiene used qualitative and quantitative criteria to evaluate Lithuania's principal power generation technologies in terms of their institutional, economic, technical, and environmental characteristics. Other MCDMs, such as weighted sum model (WSM), stepwise weight assessment ratio analysis (SWARA), measuring attractiveness by a categorical based evaluation technique (MACBETH), promethee for sustainability assessment (PROSA), etc., are used to address sustainable energy development challenges. MCDA is widely used in combination with life cycle analysis (LCA) [Wang et al., 2021; Estévez et al., 2021; Hemming et al., 2018]. In order to address the location selection problem, Ozdemir and Sahin (2018) used AHP, which takes into consideration five key criteria: prospective energy output, safety, environmental factors, distance from existing transmission lines, and topographical characteristics. This was accomplished using the AHP method. A solar PV power facility's location may be determined using both tangible and intangible data [Ozdemir and Sahin, 2018].

Energy production technologies and environmental implications are two of the most common applications of LCA. The AHP and TOPSIS methodologies are commonly utilised in combination with the Fuzzy set theory, according to a comprehensive evaluation of the literature [Urošević and Marinović, 2021]. AHP was used in around half of the cases to include the social consequences of renewable energy in the multiple-criteria decision analysis (MCDA) process. Increases to almost 60% if the analytic network process (ANP) variation is added. AHP offers a number of characteristics that make it ideal for participatory applications [Zlaugotne et al., 2020]. Using this method, the case studies were able to use an interactive approach because of the matched comparisons. As a result, AHP uses an additive preference function, which is an approach that may be easily understood by decision-makers [Vinchurkar and Samtani, 2019]. If AHP is being used to study group decision-making in real-world situations, it must be evaluated to see if all of the comparisons are consistent [Vassoney et al., 2021].

METHODOLOGY

Proposed methodology for optimum solution

For the best solar panel, we first need to evaluate the weights of each criterion using analytical hierarchy process (AHP) (Figure 1). After determining the weights for these criteria, we must next determine the ranks for all projects utilising MCDM, such as TOPSIS [Fei and Deng, 2020]. Finally, the projects will be ranked according to their overall performance (Figure 2).

Here are the ten factors we used to determine the finest solar panel (Table 1):

- total installation capacity (MW) – Installation capacity is a direct measure of the capability to generate electricity in this study;
- total reservoir capacity (km^3) – volume of water that can be held in the reservoir;
- total surface capacity (km^2) – we say that the dam's total capacity is equal to its total surface area;
- height (m) – the vertical distance between the natural streambed and the dam's crest at the dam's downstream toe determines the dam's height. When the height of a dam is measured by its weighted average height above the natural streambed, without taking into account spillways, there should be no spillways;
- length (m) – the horizontal measurement of the distance from one natural abutment to the next along the top of the dam;
- numbers of units – engineered structures in a diversion hydroelectric power plant for the direct conversion of water potential energy into electric power;
- cost of the dam (CR) – it's an important consideration for the project's long-term financial viability. The low capital cost of an economically effective project makes it a favourable investment opportunity.

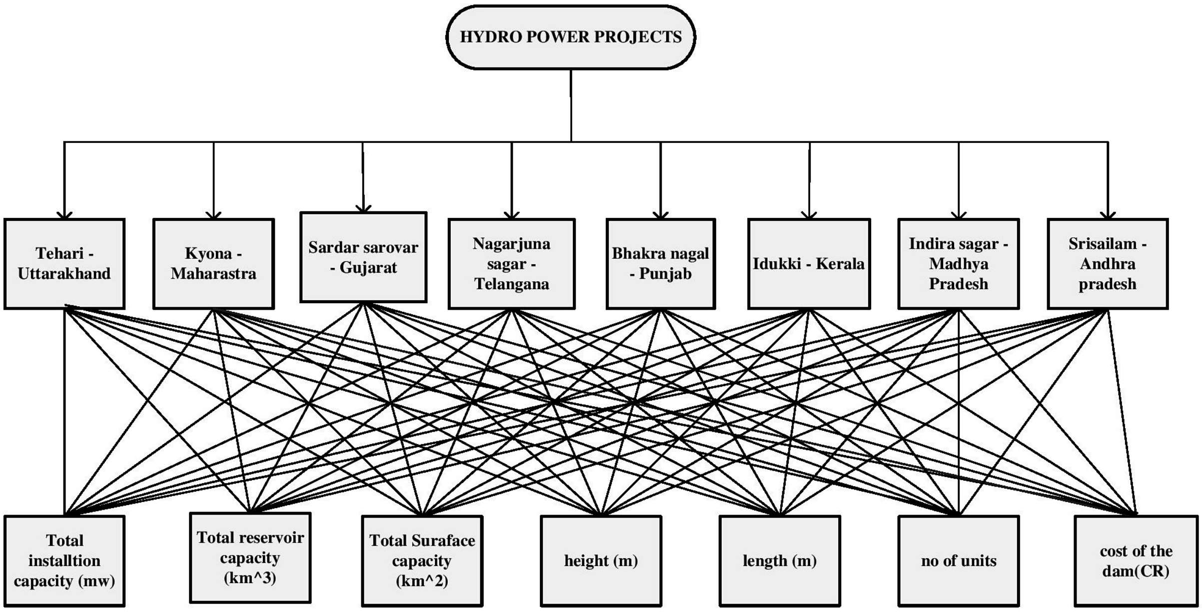

Figure 1. Decision hierarchy

Table 1. Nomenclature

Hydro plant’s	Criteria’s
P1 - Tehari-Uttarakhand P2 – Kyona - Maharashtra P3 - Sardar Sarovar - Gujarat P4 - Nagarjuna Sagar - Telangana P5 - Bhakra nagal - Punjab P6 - Idukki-Kerala P7 - Indira Sagar - Madhya Pradesh P8 - Srisailam - Andhra Pradesh	C1 - total installation capacity (MW) C2 - total reservoir capacity (km^3) C3 - total surface capacity (km^3) C4 - height (M) C5 - length (M) C6 - no of units C7 - cost of the dam (CR)

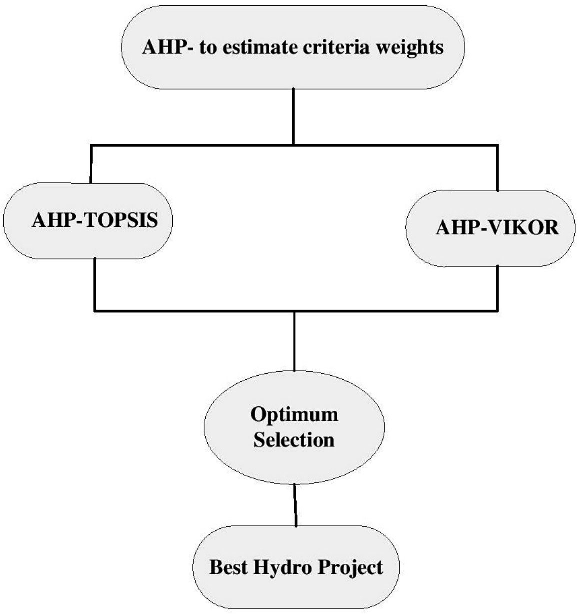

Figure 2. Step by step procedure for selection of solar panel

Analytical hierarchy process

With this method, the weights of the criteria variables can be computed. There are three steps involved in the process.

- step 1 – the first need to create a hierarchical framework with our goals, criteria, and projects all arranged in a three-tiered structure. In this 8 projects considered, i.e. hydro projects, and 7 criteria’s;
- step 2 – Table 2 shows a matrix of 7×7 with a dimension of 7×7. Table 3 illustrates the creation of a normalised pair-wise comparison matrix;
- step 3 – consistency matrix is being calculated (Table 4). Adding all of the values in a row yields a weighted total value. The λ ratio is then found by dividing the weighted total value for each row by the weight of the criterion;

Table 2. Comparison of pair-wise matrix

Criteria’s	C1	C2	C3	C4	C5	C6	C7
C1	1	2	4	2	2	7	2
C2	0.5	1	2	3	5	4	0.25
C3	0.25	0.5	1	2	2	4	0.33
C4	0.25	0.33	0.5	1	2	3	0.33
C5	0.2	0.2	0.5	0.5	1	2	0.33
C6	0.166	0.25	0.25	0.33	0.5	1	0.25
C7	0.14	4	3	3	3	4	1

Table 3. Normalised pair-wise comparison matrix

Criteria’s	C1	C2	C3	C4	C5	C6	C7
C1	0.3990	0.2415	0.3555	0.2892	0.2702	0.28	0.4454
C2	0.1995	0.1207	0.1777	0.2169	0.2702	0.16	0.0556
C3	0.0997	0.0603	0.0888	0.1446	0.1081	0.16	0.0734
C4	0.0997	0.0398	0.0444	0.0723	0.1081	0.12	0.0734
C5	0.0798	0.0241	0.0444	0.0361	0.0540	0.08	0.0734
C6	0.0662	0.0301	0.0222	0.0238	0.0270	0.04	0.0556
C7	0.0558	0.4830	0.2666	0.2169	0.1621	0.16	0.2227

Table 4. Calculating the consistency matrix

Criteria's	C1	C2	C3	C4	C5	C6	C7
C1	0.3259	0.3431	0.4201	0.3188	0.2801	0.2652	0.4478
C2	0.1629	0.1716	0.2101	0.2391	0.2801	0.1516	0.0560
C3	0.0815	0.0858	0.1050	0.1594	0.1120	0.1516	0.0739
C4	0.0815	0.0566	0.0525	0.0797	0.1120	0.1137	0.0739
C5	0.0652	0.0343	0.0525	0.0399	0.0560	0.0758	0.0739
C6	0.0541	0.0429	0.0263	0.0263	0.0280	0.0379	0.0560
C7	0.0456	0.6863	0.3151	0.2391	0.1680	0.1516	0.2239

$$\lambda = \text{W.S.V} \,/\, \text{C.W} \tag{1}$$

where: W.S.V – weighted sum value;
C.W – criteria weight.
Using the equation (1) the resulting value is shown in Table 5.

$$\text{C.I} = (\lambda\text{max}-n)/(n-1) \tag{2}$$

where: C.I – consistency index.

$$\text{C.R} = \text{C.I} \,/\, \text{R.C.I} \tag{3}$$

where: C.R – consistency ratio;
R.C.I – random consistency index (Table 6).
This is followed by calculating the consistency ratio, which needs to be smaller than 0.10. If this is case, the resulting weights for the various criterion are accurate (Table 7).

TOPSIS method

We were tasked with picking the best hydropower project from a pool of eight contenders. Hydro power, total installation capacity (MW), total reservoir capacity (km^3), total surface capacity (km^2), height (m), length (m), and cost of the dam (CR) are all factors to take into consideration.

The TOPSIS method's process is as follows:

- step 1 – decision matrix construction (Table 8). There are seven projects and eight criteria in the matrix, which is 7×8. The X-axis represents criteria, whereas the Y-axis represents projects.
- step 2 – evaluation matrix. The determination of normalized values of projects X_{kl}:

$$\overline{X_{kl}} = \frac{X_{kl}}{\sqrt{\sum_{k=1}^{n}(X_{kl})^2}}, \qquad k = 1,2,\dots,\mathrm{p};\ l = 1,2,\dots,\mathrm{q} \tag{4}$$

Table 5. Calculation of λ ratio

Criteria	Weighted sum value	Criteria weights	λ
C1	2.4011	0.3259	7.3684
C2	1.2713	0.1716	7.4102
C3	0.7692	0.1050	7.3231
C4	0.5699	0.0797	7.1497
C5	0.3975	0.0560	7.0970
C6	0.2714	0.0379	7.1637
C7	1.8296	0.2239	8.1710

Table 6. Random index

No	1	2	3	4	5	6	7	8	9	10
RCI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Table 7. Beneficial and non-beneficial criterion values calculated using AHP

Criteria	C1	C2	C3	C4	C5	C6	C7
Beneficial / Non-beneficial	Benf.	Benf.	Benf.	Benf.	Non Benf.	Non Benf.	Non Benf.
Weight	0.3259	0.1716	0.1050	0.0797	0.0560	0.0379	0.2239

Using the equation 4 normalized decision matrix is shown in Table 9.

- step 3 – weighted normalized decision matrix construction. X_{kl} and its related weight w_l (given in Table 8) are multiplied by the normalised evaluation matrix to arrive at the final result.

$$V_{kl} = \bar{X}_{kl} \times W_l \tag{5}$$

where: V_{kl} – normalized weighted decision matrix.

Table 10 shows a normalised weighted decision matrix, which is what the equation (5) calls for.

- step 4 – positive and negative ideal solutions determination. V_k^+ is maximum value as a best project for beneficial; V_k^- is minimum value as a worst project for beneficial; V_k^+ and V_k^- is shown in Table 11.
- step 5 – calculation of the Euclidean distance:

$$S_k^+ = \sqrt{\sum_{l=1}^{p} (v_{kl} - v_l^+)^2} \tag{6}$$

$$S_k^- = \sqrt{\sum_{l=1}^{p} (v_{kl} - v_l^-)^2} \tag{7}$$

where: S_k^+ – euclidean distance from the positive ideal;
S_k^- – euclidean distance from the negative ideal.

Table 8. Decision matrix for project

Alternatives	C1	C2	C3	C4	C5	C6	C7
P1	1000	4	52	261	575	4	18830
P2	1960	3	892	103	807	3	7777
P3	1450	9	375	139	1210	11	60603
P4	816	12	285	124	1550	8	11600
P5	1325	9	168	226	520	10	17640
P6	780	6	60	169	366	6	5200
P7	510	12	185	70	1821	8	11300
P8	1670	6	616	145	512	13	30301

Table 9. Normalized decision matrix

Alternatives	C1	C2	C3	C4	C5	C6	C7
P1	0.2771	0.1703	0.0430	0.5571	0.1935	0.1662	0.2515
P2	0.5431	0.1191	0.7367	0.2207	0.2716	0.1247	0.1039
P3	0.4018	0.4027	0.3101	0.2966	0.4072	0.4571	0.8094
P4	0.2261	0.4921	0.2354	0.2652	0.5216	0.3325	0.1549
P5	0.3672	0.3976	0.1388	0.4833	0.1750	0.4156	0.2356
P6	0.2161	0.2363	0.0496	0.3612	0.1231	0.2494	0.0694
P7	0.1413	0.5202	0.1524	0.1497	0.6128	0.3325	0.1509
P8	0.4628	0.2604	0.5089	0.3103	0.1723	0.5403	0.4047

Table 10. Weighted normalized decision matrix

Alternatives	C1	C2	C3	C4	C5	C6	C7
P1	0.0903	0.0292	0.0045	0.0444	0.0108	0.0063	0.0563
P2	0.1770	0.0204	0.0774	0.0176	0.0152	0.0047	0.0233
P3	0.1309	0.0691	0.0326	0.0236	0.0228	0.0173	0.1812
P4	0.0737	0.0844	0.0247	0.0211	0.0292	0.0126	0.0347
P5	0.1196	0.0682	0.0146	0.0385	0.0098	0.0157	0.0528
P6	0.0704	0.0405	0.0052	0.0288	0.0069	0.0094	0.0156
P7	0.0461	0.0893	0.0160	0.0119	0.0343	0.0126	0.0338
P8	0.1508	0.0447	0.0534	0.0247	0.0097	0.0205	0.0906

Table 11. Best value V_k^* and worst value V_k^-

Alternatives	C1	C2	C3	C4	C5	C6	C7
V_k^*	0.1770	0.0893	0.0774	0.0444	0.0069	0.0047	0.0156
V_k^-	0.0461	0.0204	0.0045	0.0119	0.0343	0.0205	0.1812

Table 12. Euclidean distance from ideal best *Sk+* and from ideal worst *Sk-*

S_k^+/ S_k^-	Tehari	Kyona	Sardar sarovar	Nagarjuna sagar	Bhakra nagal	Idukki	Indira sagar	Srisailam
S_k^+	0.13	0.20	0.08	0.12	0.09	0.14	0.18	0.07
S_k^-	0.20	0.27	0.16	0.12	0.15	0.09	0.15	0.17

Table 13. Performance score using TOPSIS with AHP

Alternatives	P1	P2	P3	P4	P5	P6	P7	P8
Rank	7	1	8	4	2	5	6	3
Pi	0.51	0.75	0.36	0.57	0.63	0.55	0.52	0.61

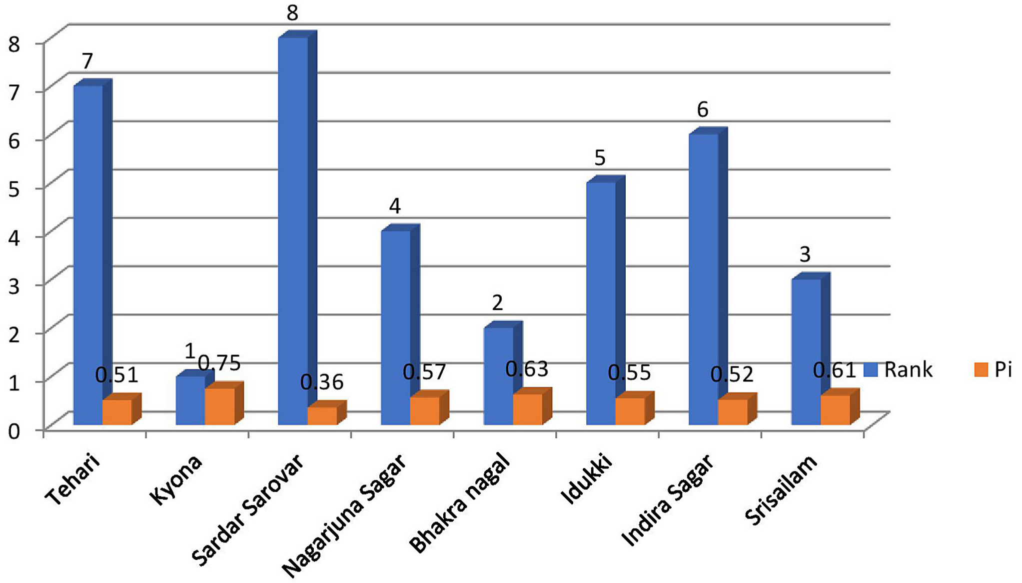

Figure 3. Histogram of various hydro power projects using TOPSIS

Using equations 6 and 7, S_k^+ & S_k^- is shown in Table 12.

- step 6 – calculating performance score:

$$P_k = \frac{S_k^-}{S_k^+ + S_k^-} \tag{8}$$

where*:* P_k – performance score.

Using the equation 8 P_k is as shown in Table 13.

- step 7 – ranking the priority. *Pi* is ranked in decreasing order from highest to lowest.

The higher the score, the higher the project's position in the rankings will be (Fig. 3).

CALCULATION RESULTS

AHP calculations

It's based on established criteria and the variety of combinations that can be selected for the chain of significance chart. Specifically, the issue, criterion, and other possibilities are all located on three levels: the major level, the second level, and the basic level. Prior to creating an AHP system graph, it is necessary to perform pair-wise criterion analysis in order to assign weights to each pair. During the pairwise assessment phase, we compare and contrast each scenario using Saaty's nine-point scale [Manoj et al., 2020].

The first step is to create a seven-by-seven comparison matrix utilising seven criteria. Everything in this matrix was based on a scale from 1 to 9. It's going to be different for everyone.

$$\lambda_{max} = 7.383288779$$

From the equation (2),

$$C.I = 0.063881463$$

where: n – no. of criteria = 7.

From the equation (3),

$$C.R = 0.048395048 < 0.100$$

Analytical hierarchy process (AHP) criterion weights were evaluated since we found 0.086101, or 8.61 percent inaccuracy, which is less than 10 percent. If the mistake is greater than 10%, then the AHP stages should be repeated until the error is less than 10%. The TOPSIS approach will be used to rank the wind power projects once the weights for each criterion have been determined.

TOPSIS calculations

The AHP technique allowed us to assign relative importance to each criterion, as seen in the Table 14.

VIKOR method

There are many options, and the VIKOR approach is to choose the best one. A decision matrix may be used to determine which criteria are useful (Table 15) (the greater the value, the better). That particular criterion f_k^*, w_l, is weighted according to the best value for those criteria (Table 16). To figure out an individual's regret (R_k), you add up all of the criteria for that person and then multiply that number by the formula.

The following steps are encompassed by the Algorithm of VIKOR:

- step 1 – The goal of normalising the performance matrix is to standardise the matrix entries' unit of measurement and evaluation. The process of calculating alternate normalised values Alternative $k's$ score on criteria l is known as F_{kl}.

Table 14. Decision matrix for alternative blends using AHP

Parameter	Benf.	Benf.	Benf.	Benf.	Non Benf.	Non Benf.	Non Benf.
Weightage	0.3258	0.1715	0.1050	0.0797	0.0560	0.03788	0.2239
Fuel	Total installation capacity (mw)	Total reservoir capacity (km^3)	Total Suraface capacity (km^2)	Height (m)	Length (m)	No of units	Cost of the dam (CR)
P1	1000	4	52	261	575	4	18830
P2	1960	3	892	103	807	3	7777
P3	1450	9	375	139	1210	11	20365
P4	816	12	285	124	1550	8	11600
P5	1325	9	168	226	520	10	17640
P6	780	6	60	169	366	6	5200
P7	510	12	185	70	1821	8	11300
P8	1670	6	616	145	512	13	30301

Table 15. Normalized decision matrix of VIKOR method with AHP

Alternatives	Total installtion capacity (mw)	Total reservoir capacity (km^3)	Total Suraface capacity (km^2)	Height (m)	Length (m)	No of units	Cost of the dam (CR)
P1	0.28	0.17	0.04	0.56	0.19	0.17	0.39
P2	0.54	0.12	0.74	0.22	0.27	0.12	0.16
P3	0.40	0.40	0.31	0.30	0.41	0.46	0.42
P4	0.23	0.49	0.24	0.27	0.52	0.33	0.24
P5	0.37	0.40	0.14	0.48	0.17	0.42	0.36
P6	0.22	0.24	0.05	0.36	0.12	0.25	0.11
P7	0.14	0.52	0.15	0.15	0.61	0.33	0.23
P8	0.46	0.26	0.51	0.31	0.17	0.54	0.63

Table 16. Best (f_k*) and worst value (f_k-) using AHP

Criterias	f_k^*	f_k^-
C1	0.54	0.14
C2	0.52	0.12
C3	0.74	0.04
C4	0.56	0.15
C5	0.61	0.120
C6	0.54	0.120
C7	0.63	0.11

$$\overline{F_{kl}} = \frac{F_{kl}}{\sqrt{\sum_{k=1}^{q}(F_{kl})^2}}, \tag{9}$$

$$k = 1,2,\ldots,\text{p};\ l = 1,2,\ldots,\text{q}$$

- step 2 – Determine the best f_k^* and the worst f_k^- values for each criterion functions, $k = 1,2,\ldots,\text{n}$.

$$fk^* = \max fkl, \qquad fk^- = \min fkl \tag{10}$$

- step 3 – The utility measure and the regret measure for each maintenance alternative is given as

$$S_k = \sum_{k=0}^{q}(w_k * \frac{f_k^* - f_{kl}}{f_k^* - f_k^-}) \rightarrow \text{Beneficial} \tag{11}$$

$$S_k = \sum_{k=0}^{q}(w_k * \frac{f_{kl} - f_k^-}{f_k^* - f_k^-}) \rightarrow \text{Non - beneficial} \tag{12}$$

$$R_k = max_k(w_k * \frac{f_k^* - f_{kl}}{f_k^* - f_k^-}) \rightarrow \text{Beneficial} \tag{13}$$

$$R_k = min_k(w_k * \frac{f_{kl} - f_k^-}{f_k^* - f_k^-}) \rightarrow \text{Non - beneficial} \tag{14}$$

The utility and regret measures are represented by S_k and R_k, respectively, while the weight of the k^{th} criteria is represented by w_k. Using the equations from 11 to 14 S_k and R_k values are shown in Table 17.

- step 4 – calculate the VIKOR index:

$$Q_l = v * \left(\frac{S_k - S^*}{S^- - S^*}\right) + (1 - v) * \left(\frac{R_k - R^*}{R^- - R^*}\right) \tag{15}$$

Using equation (15) VIKOR index values are shown in Table 18.

Table 17. Utility measure S_k and regret measure R_k using AHP

Alternatives	S_k	R_k
P1	0.60	0.22
P2	0.28	0.17
P3	0.48	0.14
P4	0.52	0.26
P5	0.44	0.14
P6	0.54	0.27
P7	0.62	0.33
P8	0.53	0.22

Table 18. VIKOR index values and its ranking using AHP

Alternatives	VIKOR index values and its ranking	
P1	0.68	6
P2	0.10	1
P3	0.29	3
P4	0.68	5
P5	0.26	2
P6	0.72	7
P7	1.00	8
P8	0.59	4

Table 19. Ranking of hydropower projects from TOPSIS and VIKOR

Ranking	TOPSIS	VIKOR
1	P2	P2
2	P5	P5
3	P8	P3
4	P4	P8
5	P6	P4
6	P7	P1
7	P1	P6
8	P3	P7

The best and worst values of S_k and R_k must then be determined, with S^* equaling the minimum value of Si and R^* equaling the minimum value of R_k, and Q_l must then be calculated using S^- and R^- as the maximum and minimum values, respectively.

Weighed according to the Q_l value, the alternatives are assigned ranks 1 through 5 with rank 1 being the lowest value of Q_l and this order is as follows. Based on these rankings, the decisions made in VIKOR can choose the best option (Table 19). A compromise solution is provided.

- step 5 – rank the order of preference.

The alternative with the smallest VIKOR value is determined to be the best value (Fig. 4).

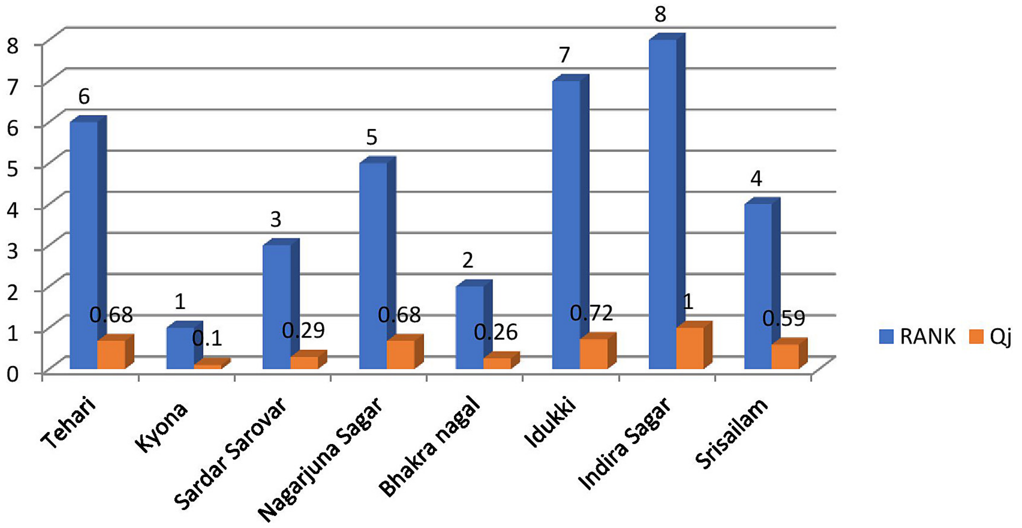

Figure 4. Histogram of various hydro power projects using VIKOR

Figure 5 shows comparison of TOPSIS and VIKOR, two cutting-edge ranking MCDM approaches, as part of a decision support system for hydropower project performance analysis. An example of how the suggested technique may be used is the selection of the most advantageous choice from a set of six possibilities while taking into account 10 factors that are critical to decision-makers. The findings support the generally held view that if various MCDM approaches are applied, the same decision issue may be evaluated differently.

Because of the wide range of algorithms and objectives that each technique may scale, it is difficult to determine which method is best for a given situation. This calls for a comparison of the approaches to see whether there are any potential applications for each. When choosing an MCDM strategy, it's important to think about whether or not it gives rankings that are similar to those of the other strategies.

Using the TOPSIS and VIKOR methodologies, the hydroelectric projects have been ranked (Table 19).

It is clear from the TOPSIS and VIKOR rankings of hydropower projects that alternative P2 (Kyona hydropower project) is the best option for hydropower generation. Because of this, it can be determined that the Kyona hydropower project (P2) is the most sustainable project based on the weights allocated to seven criteria. The two hydropower projects, Kyona (P2) and Bhakra Nagar (P5), occupy the top two spots in the total list of all eight hydroelectric projects (Fig. 5). Even using the identical input data, the two approaches yielded slightly different rankings of 3–8 choices. The different ways of calculating and the effect of the threshold settings can explain why these two methods don't agree with each other.

Ranking hydropower projects takes into account both quantitative and qualitative elements

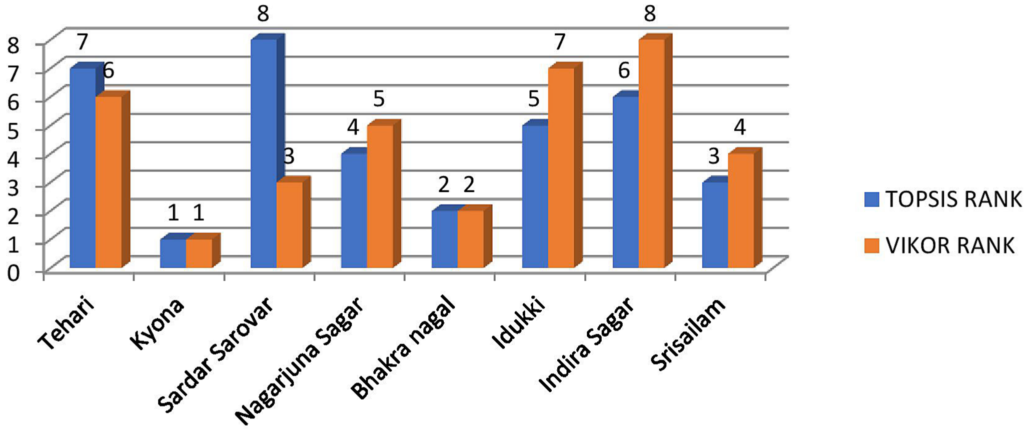

Figure 5. Comparison of rankings between TOPSIS and VIKOR

of criteria with both MCDM approaches. The complexity of the decision-making process for hydropower project sustainability rankings is due to the necessity to examine elements such as social, environmental, economic, and technological. As a result, MCDM approaches have been shown to be quite useful when it is difficult to choose the optimal choice while taking into account competing criteria and dissimilar units.

CONCLUSIONS

The TOPSIS and VIKOR methodologies are shown to be successful in ranking the main hydropower projects in India based on the seven sustainability criteria in this study. The criterion weights are calculated using the AHP approach. Hydropower projects may be evaluated and ranked based on a variety of sustainability factors using either of these two methodologies. Using the provided techniques and given weights for certain criteria, the hydropower projects at Kyona (P2) and Bhakra Nagal (P5) are evaluated as the most environmentally friendly options among the available options. Even if the same issue and the same data are used, the two strategies provide different rankings. Differences in the calculating methods and the influence of threshold values are to blame for this. As a result, there is no one approach that can be characterised as either the greatest or the worst. Some techniques are more suited to a specific use than others. Vikor is recommended for ranking because of the decision maker's ability to express their preferences accurately while looking for a better choice. Hydraulic projects with similar geographic characteristics can benefit from this research. MCDM techniques have been proved to be an accurate and realistic approach to evaluating various renewable energy technologies and projects while simultaneously taking into account multiple criteria and objectives. MCDM techniques have been shown in the research to be capable of doing a multi criteria analysis of any power project with a stochastic nature.

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