Innovations

Ratio Based MCDM Methods for Performance Evaluation and Ranking of Sites for Solar Power Plants in Fuzzy Environment

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Abstract

In this study, ratio-based MCDM methods, such as MOORA (Multi-Objective Optimization on the basis of Ratio Analysis) and MOOSRA (Multi-Objective Optimization on the basis of simple ratio analysis) and MULTIMOORA (Multiplicative Multi-Objective Optimization on the basis of a Ratio Analysis) in fuzzy environment are presented for evaluation and ranking of sites for solar power plant. By integrating ratio-based approaches with fuzzy MCDM techniques, decision-makers can effectively handle uncertainty and imprecision in evaluating sites for solar power plants. These methods provide a structured and flexible framework to make informed decisions, even when faced with subjective or fuzzy evaluations. These methods provide mechanisms to incorporate subjective judgments and preferences of decision-makers, which can be valuable when there are qualitative or subjective factors involved in the decision-making process. In the study, strong and positive correlation between the proposed methods in respect of their ranking is observed and hence aggregate rank is determined.

Key words: *Ratio Based Methods, Fuzzy Environment, Utility Function, Solar Radiation, Normalization Ranking*

1. Introduction

It's important to note that different MCDM methods, including ratio-based methods, have their own strengths. Ratio-based methods focus on the use of ratios and relative comparisons between criteria. Instead of directly comparing the absolute values or scores of criteria, ratio-based methods compute ratios based on the performance values and preference values of each criterion. These ratios provide a measure of the relative performance or preference of each alternative. Unlike some other MCDM methods that involve pairwise comparisons or utility functions, ratio-based methods focus on direct comparisons between criteria. The ratios are computed for each criterion individually and are not dependent on comparisons with other criteria. This simplifies the evaluation process but may not capture complex dependencies or trade-offs between criteria. The outcomes of the fuzzy MCDM process help in selecting the most suitable site for solar power plant that aligns with the desired criteria and preferences, taking into account the inherent fuzziness in the decision environment.

The selection of an appropriate site for solar power plants is crucial for maximizing energy production and ensuring the economic viability of the solar power plant. This literature review aims to explore the key factors that influence the site selection process for solar power plants. By examining relevant scholarly articles and reports, this review identifies and analyzes various factors. The findings of this literature review provide valuable insights for project developers, policymakers, and researchers involved in the planning and development of solar power plants. Relevant literature review on non-ratio based methods are presented in the following.

Daria KereushandIgorPerovych (2017) proposed criteria for siting solar PV farms. A multi-criteria decision analysis (MCDA) is proposed as a method of analyzing available technical information in order to support a decision making process. Using a fuzzy logic model, Yousefi*et al.,* (2018) selected a spatial site for solar power plants in the Markazi Province of Iran. The results of the research have been visualized and spatially analyzed using Geographic Information Systems (GIS). İhsan Kaya et al. (2019) made review on existing literature regarding the applications of fuzzy MCDM methods in fuzzy environment in respect of energy field
Inmaculada et al. (2019) applied GIS-based method to determine locations for solar power plants in the east Spanish region. The authors considered 3 major criteria (Social, Environmental and economic) and concluded that maps creation helps to identify viable locations with suitable PV technology. Using Geographical Information Systems (GIS) technology, Ebru.H, Colaket al., (2020) investigated the possibility of building a solar photovoltaic (PV) power plant in the Malatya Province of Turkey.The study conducted by Soydan et al., (2021) sought to determine the most suitable location for solar energy plants and provide the option of building them at the most suitable locations. Using an analytical hierarchy process (AHP) method in GIS, eleven data layers were created (sunshine duration, solar radiation, slope, aspect, road, water sources, residential areas, earthquake fault lines, mine areas, power lines and transformers).

Bandira et al. (2022) adopted GIS-based MCDM and and obtained data from NASA to identify the optimum locations for solar power plants with a case study of George Town. Wang et al. (2023) initially identified the most suitable locations using DEA for solar power plants and these areas were evaluated further using F-AHP and F-MARCOS methods to rank them. The authors opined that this study is relevant to Stake Holders (Researchers, Policymakers and industry stakeholders) in the development of renewable energy.

Ratio based MCDM methods found in the literature are presented below.

Zeeshan Ali Siddiqui and KirtiTyagi (2016) proposed the application of fuzzy multi-objective optimization on the basis of ratio analysis, Fuzzy-MOORA. The proposed approach is applicable to the decision making problems having wide numbers of objectives and scenarios.Amir Arabsheybani et al (2018), evaluated the overall performance of suppliers through fuzzy MOORA method. HeidaryDahooie et al (2019) developed MULTIMOORA method by determining scores based on three approaches i.e., Ratio system, Reference point, and full multiplicative form to rank the alternatives. The proposed methodology is illustrated with a real time decision making problem of selection of technological forecasting method. Arian Hafezalkotob et al (2019) presented MULTIMOORA applications in the fields of economics, industries, healthcare etc and these applications are analyzed. Narayanamoorthy et al (2020) proposed hesitant fuzzy sets MOOSRA for analysis and ranking of sites for e waste recycling plant. The authors opined that the hesitant fuzzy MOOSRA method has less sensitivity to large stability of the criteria values. Alptekin et al (2021) proposed MULTIMOOSRAL approach for evaluation and ranking of suppliers and opined that the proposed method enhanced the decision-making process. Taherdoost and Madanchian (2023) provided literature a survey on MCDM applications, categories, and different methods. The final section provides manifold information and statistics on the published works in the MCDM fields.Ramana and Deva Kumar (2023) considered empirical sites for solar power plants and analyzed their performance through Grey Relation Analysis (GRA) and Grey Relation Projection (GRP) methods in a fuzzy environment. There are limited applications of ratio based MCDM methods in specific to the sustainable energy areas. In this paper, MOORA, MOOSRA and MULTIMOORA methods are implemented for evaluation and ranking of sites for solar power plants in fuzzy environment.

2. Ratio Based MCDM Methods

Ratio-based methods such as MOORA, MOOSRA, and MULTIMOORA offer a systematic and objective approach to site selection for solar power plants. By considering multiple criteria and objectives, these methods help decision-makers identify the most suitable sites based on a balanced assessment of various factors. In the paper, twenty sub-criteria are considered for evaluation and ranking of sites for solar power plant through proposed methods in fuzzy environment.

2.1 Sub-Criteria for selection of site for solar power plant: Broadly, the criteria for site selection of a solar power plant can be classified into four main categories namely: Economical criteria (EC), Technical Criteria, Socio-Political Criteria (SP) and Environmental Criteria (EV). Criteria and the respective sub-criteria are presented below.

2.1.1Economic Criteria: Economic criteria are essential considerations in the site selection of a solar power plant. Here are some key economic factors to take into account in the study are

Market Demand and Power Purchase Agreements (EC1), Investment cost (EC2), Return on Investment (EC3), Government Incentives and subsidies (EC4), Utility fee of Electrical Energy (EC5), Operations and Maintenance Costs (EC6).

2.1.2 Technical Criteria: Technical criteria play a crucial role in the site selection process for a solar power plant. The key technical factors considered in the study are Grid Connection and Interconnection (TE1), Wind speed (TE2), Temperature (TE3), Humidity (TE4), Sun shine Hours (TE5),Solar Radiation (TE6)

2.1.3 Sociopolitical Criteria: Sociopolitical criteria are essential considerations when selecting a site for a solar power plant, as they encompass factors related to social and political aspects of the location.The following are some key sociopolitical criteria considered in the study are Skilled Manpower Availability: (SP1), Political Stability and Support (SP2), Public Acceptance (SP3), Population Density (SP4)

2.1.4 Environmental Criteria: Environmental factors are crucial considerations when selecting a site for a solar power plant. These factors encompass various aspects of the natural environment that can impact the project's feasibility, sustainability, and overall environmental impact the environmental sub-criteria namely: Ecological Impact (EV1), Landscape destruction (EV2), Noise and Visual impact (EV3), Water Availability (EV4)

The proposed methods are explained in the following sections.

2.2Fuzzy Multi-Objective Optimization on the Basis of Ratio Analysis (F-MOORA)

In this section, fuzzy-MOORA is proposed to evaluate and rank the alternative sites for solar power plant. The proposed method is described in the following steps.

Step 1: Formulate fuzzy the Decision matrix: The fuzzy decision matrix contains the pay offs of sub-criteria of sites for selection of solar power plants is considered from literature (Ramana and Deva kumar, 2023)

Step2: Normalization of the decision matrix: Normalization based on the characteristics of three types of criteria, namely larger-the-better (benefit), smaller-the-better (cost) or nominal-the-best (optimal), is used here to transform the various criteria scales into comparable scales. Normalization formulae are presented below.

As G_{ij} belongs to cost criteria, $\tilde{G}_{ij} = \left(\frac{g_j^-}{g_{ijr}}, \frac{g_j^-}{g_{ijh}}, \frac{g_j^-}{g_{ijl}} \right)$, g_j^- = $\min_i\{g_{ijl}\}$, $\forall j$.

As G_{ij} belongs to cost criteria, $\tilde{G}_{ij} = \left(\frac{g_{ijr}}{g_j^+}, \frac{g_{ijh}}{g_j^+}, \frac{g_{ijl}}{g_j^+} \right)$, g_j^+ = $\max_i\{g_{ijr}\}$, $\forall j$.

Step3: Determine relative weights of criteria: Relative weights are also considered from the literature

Step4: Determine weighted normalized matrix of the alternative: weighted normalized matrix ofthe alternatives is determined from the following relation.

$$\tilde{v}_{ij} = x_{ij} * s_j$$

where i = 1, 2, ..., n; n – the number of alternatives;

j = 1, 2,…m; m – the number of criteria;

S_j – Relative weight of enabler 'j';

Step 5: Determine sum of the elements of weighted normalized matrix of benefit and cost criteria:sum of the elements of weighted normalized matrix of benefit and cost criteria are determined from the following relation.

$$A_{ij} = \sum_{i=1}^{i=g} x_{ij} * s_j$$

$$B_{ij} = \sum_{i=g+1}^{i=n} x_{ij} \times s_j$$

g – the number of non-beneficial enablers; (n–g) – the number of beneficial enablers;

Step 6: Obtain Crisp index of sub-criteria: Crisp assessment index is obtained through three point (Optimistic, Mean and Pessimistic) estimatesof beneficial and non-beneficial criteria.

Step 7: Determine normalized assessment Index of the alternative: Normalized assessment index of alternative is determined from the following relation.

$$y_i = A_i - B_i$$

Step 7: Ranking of Alternatives: Normalized assessment index values of the alternatives are used for ranking based on the descending order of normalized assessment index.

2.3 Fuzzy Multi-Objective Optimization on the Basis of Simple Ratio Analysis (F-MOOSRA)

Fuzzy MOOSRA is proposed to evaluate and rank the alternative sites for solar power plant. The proposed method is described in the following steps.

Step 1: Formulate fuzzy the Decision matrix: The fuzzy decision matrix contains the pay offs of sub-criteria of sites for selection of solar power plants is considered as discussed in step 1 of section 2.2

Step2: Normalization of the decision matrix: Normalized fuzzy decision matrix as discussed in step 2 of section 2.2

Step3: Determine relative weights of criteria: Relative weights are considered from literature

Step4: Determine weighted normalized decision Matrix: Normalized assessment index of alternative is determined as discussed in step 4 of section 2.2

Step 5: Determine sum of the elements of weighted normalized matrix of benefit and cost criteria:sum of the elements of weighted normalized matrix of benefit and cost criteria are determined

Step 6: Obtain Crisp index of sub-criteria: Crisp assessment index is obtained through three point (Optimistic, Mean and Pessimistic) estimatesof beneficial and non-beneficial criteria.

Step-7: Determine the performance score. The performance score of alternative material is computed as simple ratio of weighted sum of beneficial and non-beneficial criteria/attribute from the following relation.

$$y_{ij} = \sum_{i=1}^{i=g} x_{ij} \times s_j / \sum_{i=g+1}^{i=n} x_{ij} \times s_j$$

where j = 1, 2, ..., m; m – the number of alternatives;

i = 1, 2,… n; n – the number of enablers;

g – the number of non-beneficial enablers; (n–g) – the number of beneficial enablers;

Si – Relative weight of enabler ‘i’;

x_{ij}-crisp index of j^{th} criteria of i^{th} alternative

Step 7: Ranking of Alternatives: Performance score values of the alternatives are used for ranking based on their descending order.

2.4 FUZZY Multiplicative Multi-Objective Optimization on the basis of a Ratio Analysis (F-MULTIMOORA)

Full multiplicative form of MOORA (MULTIMOORA) uses multiplication of criteria for beneficial and non-beneficial attributes separately and their ratio, providing dimensionless number for comparison. MOORA method, when combined with the full multiplicative form is identified as MULTIMOORA approach. The proposed method is described in the following steps.

Step 1: **Obtain the utility of Full Multiplicative Form**: The product of weighted normalized alternatives ratings on beneficial criteria are divided by the product of weighted normalized alternatives ratings on non-beneficial criteria from the following relation (Hafezalkotob and Hafezalkotob,2016),

$$A_i = \coprod_{j=1}^{g} x_{ij} \wedge w_j ; B_i = \coprod_{j=g+1}^{n} x_{ij} \wedge w_j$$

$U_i$is the degree of for ith alternative, A-Beneficial criteria; B-Non-Beneficial criteria

Step 2: Obtain Crisp utility function value: Crisp utility value is obtained through three point (Optimistic, Mean and Pessimistic) estimates of beneficial and non-beneficial criteria using the following relation

$$U_i = \frac{A_i}{B_i}$$

Step 3: Ranking of Alternatives: utility values of the alternatives are used for ranking based on their descending order.

3 Results and Discussion

The proposed methods are implemented to the study on 50 alternative sites for solar power plant considered in the literature (Ramana and Deva Kumar,2023). Results and discussion are presented in the following sections.

3.1 F-MOORA

Sum of the elements of weighted normalized matrix: Sum of the elements of weighted normalized matrix of benefit and cost criteria are determined from the relations as discussed in step 5 of section 5.2. The values are presented in table 2 and table3

Table 1: Sum of the elements of weighted normalized matrix of benefit sub-criteria

Alts	Fuzzy Aij			Alts	Fuzzy Aij		
A1	0.2500	0.3734	0.4967	A26	0.2467	0.3701	0.4934
A2	0.2467	0.3701	0.4934	A27	0.2110	0.3343	0.4577
A3	0.2280	0.3514	0.4747	A28	0.2277	0.3510	0.4744
A4	0.2915	0.4149	0.5382	A29	0.2467	0.3701	0.4934
A5	0.2659	0.3893	0.5126	A30	0.2715	0.3949	0.5182
A6	0.1886	0.3120	0.4353	A31	0.2225	0.3458	0.4692
A7	0.2504	0.3737	0.4971	A32	0.2247	0.3481	0.4714
A8	0.2504	0.3737	0.4971	A33	0.2467	0.3701	0.4934
A9	0.2467	0.3701	0.4934	A34	0.2993	0.4226	0.5460
A10	0.2280	0.3514	0.4747	A35	0.2527	0.3760	0.4994

A11	0.2147	0.3380	0.4614	A36	0.2435	0.3669	0.4902
A12	0.2491	0.3725	0.4958	A37	0.2272	0.3506	0.4739
A13	0.3181	0.4414	0.5648	A38	0.2393	0.3626	0.4860
A14	0.2467	0.3701	0.4934	A39	0.3061	0.4295	0.5528
A15	0.2255	0.3489	0.4722	A40	0.1234	0.2467	0.3701
A16	0.3139	0.4372	0.5606	A41	0.2370	0.3604	0.4837
A17	0.2502	0.3736	0.4969	A42	0.2616	0.3850	0.5083
A18	0.2838	0.4071	0.5305	A43	0.2467	0.3701	0.4934
A19	0.2957	0.4191	0.5424	A44	0.2449	0.3682	0.4916
A20	0.2750	0.3984	0.5217	A45	0.2846	0.4079	0.5313
A21	0.1457	0.2691	0.3924	A46	0.2622	0.3856	0.5089
A22	0.2471	0.3704	0.4938	A47	0.2279	0.3512	0.4746
A23	0.2496	0.3729	0.4963	A48	0.2467	0.3701	0.4934
A24	0.2467	0.3701	0.4934	A49	0.2769	0.4003	0.5236
A25	0.2032	0.3265	0.4499	A50	0.2467	0.3701	0.4934

Table 2: Sum of the elements of weighted normalized matrix of Cost sub-criteria

Alts	Fuzzy Bij			Alts	Fuzzy Bij		
A1	0.0936	0.1276	0.2128	A26	0.0956	0.1275	0.1913
A2	0.0956	0.1275	0.1913	A27	0.0965	0.1331	0.2274
A3	0.0973	0.1346	0.2314	A28	0.0936	0.1276	0.2128
A4	0.1150	0.1678	0.3200	A29	0.0956	0.1275	0.1913
A5	0.0907	0.1222	0.1984	A30	0.1027	0.1448	0.2587
A6	0.0965	0.1331	0.2274	A31	0.1012	0.1419	0.2510
A7	0.0973	0.1346	0.2314	A32	0.0984	0.1367	0.2371
A8	0.0980	0.1360	0.2352	A33	0.0956	0.1275	0.1913
A9	0.0956	0.1275	0.1913	A34	0.1010	0.1415	0.2499
A10	0.0980	0.1360	0.2352	A35	0.1067	0.1523	0.2786
A11	0.0948	0.1299	0.2190	A36	0.0907	0.1222	0.1984

A12	0.1027	0.1448	0.2587	A37	0.1008	0.1413	0.2492
A13	0.1166	0.1707	0.3278	A38	0.0988	0.1374	0.2388
A14	0.0956	0.1275	0.1913	A39	0.1079	0.1544	0.2843
A15	0.0889	0.1189	0.1896	A40	0.1275	0.1913	0.3825
A16	0.1150	0.1678	0.3200	A41	0.0948	0.1299	0.2190
A17	0.1017	0.1428	0.2532	A42	0.0988	0.1374	0.2388
A18	0.1079	0.1544	0.2843	A43	0.0956	0.1275	0.1913
A19	0.1166	0.1707	0.3278	A44	0.1012	0.1419	0.2510
A20	0.1067	0.1523	0.2786	A45	0.1021	0.1436	0.2554
A21	0.1275	0.1913	0.3825	A46	0.1021	0.1436	0.2554
A22	0.0984	0.1367	0.2371	A47	0.1017	0.1428	0.2532
A23	0.1008	0.1413	0.2492	A48	0.0956	0.1275	0.1913
A24	0.0956	0.1275	0.1913	A49	0.1010	0.1415	0.2499
A25	0.0889	0.1189	0.1896	A50	0.0956	0.1275	0.1913

3.1.1 Crisp index of sub-criteria: Crisp assessment index is obtained through three point (Optimistic, Mean and Pessimistic) estimates of beneficial and non-beneficial criteria and presented in table 3

Table 3: Crisp assessment index

Alt	Beneficial sub-Criteria	Non Beneficial sub-criteria	Alt	Beneficial sub-Criteria	Non Beneficial sub-criteria
A1	0.3734	0.1361	A26	0.3701	0.1328
A2	0.3701	0.1328	A27	0.3343	0.1427
A3	0.3514	0.1445	A28	0.3510	0.1361
A4	0.4149	0.1844	A29	0.3701	0.1328
A5	0.3893	0.1297	A30	0.3949	0.1568
A6	0.3120	0.1427	A31	0.3458	0.1533
A7	0.3737	0.1445	A32	0.3481	0.1471
A8	0.3737	0.1462	A33	0.3701	0.1328
A9	0.3701	0.1328	A34	0.4226	0.1528
A10	0.3514	0.1462	A35	0.3760	0.1658
A11	0.3380	0.1389	A36	0.3669	0.1297
A12	0.3725	0.1568	A37	0.3506	0.1525
A13	0.4414	0.1879	A38	0.3626	0.1478
A14	0.3701	0.1328	A39	0.4295	0.1683
A15	0.3489	0.1257	A40	0.2467	0.2125
A16	0.4372	0.1844	A41	0.3604	0.1389

A17	0.3736	0.1543	A42	0.3850	0.1478
A18	0.4071	0.1683	A43	0.3701	0.1328
A19	0.4191	0.1879	A44	0.3682	0.1533
A20	0.3984	0.1658	A45	0.4079	0.1553
A21	0.2691	0.2125	A46	0.3856	0.1553
A22	0.3704	0.1471	A47	0.3512	0.1543
A23	0.3729	0.1525	A48	0.3701	0.1328
A24	0.3701	0.1328	A49	0.4003	0.1528
A25	0.3265	0.1257	A50	0.3701	0.1328

3.1.2 Normalized assessment Index of the alternative: Normalized assessment index of alternative with corresponding ranks of the sites for solar power plant are presented in table 4

Table 4: Rankings of Alternative Sites for Solar Power Plants (F-MOORA)

Alts	Normalized assessment Index	Rank	Alts	Normalized assessment Index	Rank
A1	0.2372	10	A26	0.2372	11
A2	0.2372	11	A27	0.1916	47
A3	0.2069	39	A28	0.2149	36
A4	0.2305	25	A29	0.2372	11
A5	0.2596	3	A30	0.2381	9
A6	0.1692	48	A31	0.1925	46
A7	0.2292	27	A32	0.2010	41
A8	0.2275	28	A33	0.2372	11
A9	0.2372	11	A34	0.2698	1
A10	0.2051	40	A35	0.2103	38
A11	0.1991	43	A36	0.2372	21
A12	0.2157	34	A37	0.1981	44

A13	0.2535	4	A38	0.2148	37
A14	0.2372	11	A39	0.2612	2
A15	0.2232	30	A40	0.0342	50
A16	0.2528	5	A41	0.2214	31
A17	0.2192	33	A42	0.2371	22
A18	0.2388	8	A43	0.2372	11
A19	0.2312	24	A44	0.2149	35
A20	0.2326	23	A45	0.2526	6
A21	0.0566	49	A46	0.2303	26
A22	0.2234	29	A47	0.1969	45
A23	0.2204	32	A48	0.2372	11
A24	0.2372	11	A49	0.2475	7
A25	0.2008	42	A50	0.2372	11

The results obtained through the MOORA method indicate that Site 34 is the most suitable location for establishing a solar power plant with assessment index of 0.2698. Site 34 exhibits the favorable beneficial criteria of Return on investment (EC3), Government Incentives and subsidies (EC4), Utility fee of Electrical Energy (EC5), Wind speed (TE2), Temperature (TE3), Solar Radiation (TE6), Ecological Impact (EV1), Noise and Visual impact (EV3) and Water Availability (EV4). In respect of non-beneficial criteria of Market Demand and Power Purchase Agreements (EC1), Operations and Maintenance Costs (EC6)Grid Connection and Interconnection (TE1), Humidity (TE4), Landscape destruction (EV2) and all the sociopolitical sub-criteria are preferred

3.2 F-MOOSRA

Multiple- Objective Optimization on the Basis of Simple Ratio Analysis (MOOSRA) method was employed to assess and rank empirical sites for deployment of solar power plants. Results are presented in the following sections.

3.2.1 Performance score and Ranking of alternatives. The performance score of alternative material is computed as simple ratio of weighted sum of beneficial and non-beneficial criteria/attribute and the performance scores of the alternatives and their ranking are presented in the following table.

Table 5: Performance scores and Ranking (F MOOSRA)

Alts	Performance score	Rank	Alts	Performance score	Rank
A1	2.7429	15	A26	2.7861	3
A2	2.7861	3	A27	2.3425	41
A3	2.4313	31	A28	2.5786	22
A4	2.2499	46	A29	2.7861	3
A5	3.0018	1	A30	2.5184	26
A6	2.1859	48	A31	2.2559	45
A7	2.5860	21	A32	2.3669	39
A8	2.5558	23	A33	2.7861	3
A9	2.7861	3	A34	2.7656	14
A10	2.4028	35	A35	2.2686	44
A11	2.4329	30	A36	2.8294	2
A12	2.3758	37	A37	2.2988	42
A13	2.3493	40	A38	2.4528	28
A14	2.7861	3	A39	2.5515	24
A15	2.7760	13	A40	1.1609	50
A16	2.3712	38	A41	2.5939	20
A17	2.4206	32	A42	2.6041	18
A18	2.4186	33	A43	2.7861	3
A19	2.2303	47	A44	2.4017	36
A20	2.4035	34	A45	2.6267	16
A21	1.2661	49	A46	2.4827	27
A22	2.5189	25	A47	2.2757	43
A23	2.4454	29	A48	2.7861	3
A24	2.7861	3	A49	2.6193	17
A25	2.5981	19	A50	2.7861	3

The results obtained through the MOORA method indicate that Site 5 is the most suitable location for establishing a solar power plant with performance score of 3.0018 followed by Site 36. Site 5 is showing favorable beneficial criteria of Return on Investment (EC3), Government Incentives and subsidies (EC4), Solar Radiation (TE6), Political Stability and Support (SP2) , and in respect of all the Environmental sub-criteria.In respect of non-beneficial criteria of Investment cost (EC2), Wind speed (TE2) and Humidity (TE4) are preferred.

3.3 F-Multi MOORA

F-Multi MOORA method was employed to assess and rank empirical sites for deployment of solar power plants. Results are presented in the following sections.

3.3.1 Fuzzy Utility function: The triangular number of utility function values is determined for both beneficial and non-beneficial sub criteria and fuzzy utility function values are presented in the following table 6 and table 7 respectively.

Table 6: Fuzzy Utility Value of Beneficial Sub-criteria

Alts	Fuzzy Utility Value			Alts	Fuzzy Utility Value		
A1	0.5248	0.7078	0.8579	A26	0.5683	0.73	0.8714
A2	0.5683	0.7297	0.8714	A27	0.4714	0.661	0.8161
A3	0.494	0.6813	0.8341	A28	0.4935	0.681	0.8337
A4	0.5881	0.7605	0.9046	A29	0.5683	0.73	0.8714
A5	0.5482	0.7275	0.8754	A30	0.5567	0.735	0.8817
A6	0.4433	0.6363	0.7932	A31	0.4866	0.675	0.8282
A7	0.5253	0.7082	0.8583	A32	0.4896	0.677	0.8306
A8	0.5253	0.7082	0.8583	A33	0.5683	0.73	0.8714
A9	0.5683	0.7297	0.8714	A34	0.6008	0.771	0.9136
A10	0.494	0.6813	0.8341	A35	0.5286	0.711	0.8608
A11	0.4762	0.6657	0.82	A36	0.5155	0.7	0.8508
A12	0.5235	0.7067	0.8569	A37	0.4929	0.68	0.8332
A13	0.6326	0.7963	0.9357	A38	0.5095	0.695	0.8462
A14	0.5683	0.7297	0.8714	A39	0.6122	0.78	0.9216
A15	0.4907	0.6784	0.8315	A40	0.3706	0.568	0.7297
A16	0.6254	0.7906	0.9308	A41	0.5064	0.692	0.8437
A17	0.5251	0.708	0.8581	A42	0.5418	0.722	0.8707
A18	0.5758	0.7504	0.8957	A43	0.5683	0.73	0.8714
A19	0.5949	0.7661	0.9094	A44	0.5174	0.701	0.8522
A20	0.5621	0.7391	0.8857	A45	0.5771	0.751	0.8966
A21	0.3941	0.5907	0.7509	A46	0.5427	0.723	0.8714
A22	0.5206	0.7042	0.8547	A47	0.4938	0.681	0.8339
A23	0.5241	0.7072	0.8574	A48	0.5683	0.73	0.8714
A24	0.5683	0.7297	0.8714	A49	0.565	0.742	0.8878
A25	0.4614	0.6526	0.8081	A50	0.5683	0.73	0.8714

Table 7: Fuzzy Utility Value of Non Beneficial Sub-criteria

Alts	Fuzzy Utility Value			Alts	Fuzzy Utility Value		
A1	0.5768	0.6430	0.7560	A26	0.5884	0.6569	0.7671
A2	0.5884	0.6569	0.7671	A27	0.5833	0.6529	0.7745
A3	0.5851	0.6556	0.7796	A28	0.5768	0.6430	0.7560
A4	0.6262	0.7188	0.9021	A29	0.5884	0.6569	0.7671
A5	0.5705	0.6335	0.7383	A30	0.5974	0.6744	0.8154
A6	0.5833	0.6529	0.7745	A31	0.5939	0.6690	0.8051
A7	0.5851	0.6556	0.7796	A32	0.5876	0.6594	0.7869
A8	0.5868	0.6582	0.7845	A33	0.5884	0.6569	0.7671
A9	0.5884	0.6569	0.7671	A34	0.5934	0.6683	0.8036
A10	0.5868	0.6582	0.7845	A35	0.6066	0.6885	0.8426
A11	0.5795	0.6472	0.7638	A36	0.5705	0.6335	0.7383
A12	0.5974	0.6744	0.8154	A37	0.5931	0.6678	0.8027
A13	0.6299	0.7247	0.9138	A38	0.5884	0.6606	0.7891
A14	0.5884	0.6569	0.7671	A39	0.6093	0.6926	0.8506
A15	0.5666	0.6276	0.7276	A40	0.6569	0.7671	1.0000
A16	0.6262	0.7188	0.9021	A41	0.5795	0.6472	0.7638
A17	0.5949	0.6706	0.8081	A42	0.5884	0.6606	0.7891
A18	0.6093	0.6926	0.8506	A43	0.5884	0.6569	0.7671
A19	0.6299	0.7247	0.9138	A44	0.5939	0.6690	0.8051
A20	0.6066	0.6885	0.8426	A45	0.5959	0.6721	0.8110
A21	0.6569	0.7671	1.0000	A46	0.5959	0.6721	0.8110
A22	0.5876	0.6594	0.7869	A47	0.5949	0.6706	0.8081
A23	0.5931	0.6678	0.8027	A48	0.5884	0.6569	0.7671
A24	0.5884	0.6569	0.7671	A49	0.5934	0.6683	0.8036
A25	0.5666	0.6276	0.7276	A50	0.5884	0.6569	0.7671

3.3.4 Ranking of Alternatives: Crisp utility value is obtained through three point (Optimistic, Mean and Pessimistic) estimates of beneficial and non-beneficial criteria and the alternatives are ranked based on the utility values of the alternatives on their descending order. Ranking of alternatives are presented in the following table 8

Table 8: Ranking of Alternatives –F-Multi MOORA

Alts	Utility Function Value	Rank	Alts	Utility Function Value	Rank
A1	1.0792	17	A26	1.0943	4
A2	1.0943	4	A27	0.9910	46
A3	1.0166	39	A28	1.0374	30
A4	1.0298	33	A29	1.0943	4
A5	1.1278	2	A30	1.0648	21
A6	0.9528	48	A31	0.9850	47
A7	1.0576	23	A32	1.0044	43
A8	1.0531	25	A33	1.0943	4
A9	1.0943	4	A34	1.1296	1
A10	1.0123	40	A35	1.0072	41
A11	1.0069	42	A36	1.0841	16
A12	1.0235	37	A37	0.9952	44
A13	1.0701	19	A38	1.0285	34
A14	1.0943	4	A39	1.1001	3
A15	1.0607	22	A40	0.7139	50
A16	1.0715	18	A41	1.0473	28
A17	1.0318	32	A42	1.0699	20
A18	1.0573	24	A43	1.0943	4
A19	1.0284	35	A44	1.0246	36
A20	1.0478	27	A45	1.0938	14
A21	0.7424	49	A46	1.0513	26
A22	1.0448	29	A47	0.9918	45
A23	1.0353	31	A48	1.0943	4
A24	1.0943	4	A49	1.0857	15
A25	1.0197	38	A50	1.0943	4

The results obtained through the MultiMOORA method in fuzzy environment indicate that Site 34 is the most suitable location for establishing a solar power plant with utility value of 1.1296 followed by Site 5 and site 39 with 1.1278 and1.001 respectively. Site 34 is showing favorable sub-criteria of Market Demand and Power Purchase Agreements (EC1), Government Incentives and subsidies (EC4), Utility fee of Electrical Energy (EC5), Operations and Maintenance Costs (EC6)Humidity (TE4), Solar Radiation (TE6), Political Stability and Support (SP2), Public Acceptance (SP3), Landscape destruction (EV2), Noise and Visual impact (EV3)

3.4 Comparison of Ratio Based Methods

For the evaluation and ranking of alternative sites for solar power plants in a fuzzy environment is studied through ratio based methods F-MOORA, F-MOOSRA and F-Multi MOORA. Table 9shows rankings by the proposed ratio based methods.

Table 9: Comparison of Rankings by the proposed methods

Alts	F-MOORA	F-MOOSRA	F-Multi MOORA	Alts	F-MOORA	F-MOOSRA	F-Multi MOORA
A1	10	15	17	A26	11	3	4
A2	11	3	4	A27	47	41	46
A3	39	31	39	A28	36	22	30
A4	25	46	33	A29	11	3	4
A5	3	1	2	A30	9	26	21
A6	48	48	48	A31	46	45	47
A7	27	21	23	A32	41	39	43
A8	28	23	25	A33	11	3	4
A9	11	3	4	A34	1	14	1
A10	40	35	40	A35	38	44	41
A11	43	30	42	A36	21	2	16
A12	34	37	37	A37	44	42	44
A13	4	40	19	A38	37	28	34
A14	11	3	4	A39	2	24	3
A15	30	13	22	A40	50	50	50
A16	5	38	18	A41	31	20	28
A17	33	32	32	A42	22	18	20
A18	8	33	24	A43	11	3	4
A19	24	47	35	A44	35	36	36
A20	23	34	27	A45	6	16	14
A21	49	49	49	A46	26	27	26
A22	29	25	29	A47	45	43	45
A23	32	29	31	A48	11	3	4
A24	11	3	4	A49	7	17	15
A25	42	19	38	A50	11	3	4

3.5 Correlation of the Methods

Correlation between the proposed methods in respect of their ranking is computed usingMinitab-16 and the results are presented in table 10. It is observed that there is high significant positive correlation (0.662) is existed between the MOORA and MOOSRA. Also there exists strong positive correlationbetween MultiMOORA with MOOSRA and MOORA by 0.873 and 0.920 respectively. Since the p-value is equal to 0.00, there is sufficient evidence at α = 0.00 that there exists significant correlation between the methods proposed for evaluation and ranking of proposed ratio based methods.

Table 10: Correlation of Rankings

Method	F-MOORA	F-MOOSRA	F-Multi MOORA
F-MOORA	1.000	0.662	0.920
F-MOOSRA	0.662	1.000	0.873
F-MultiMOORA	0.920	0.873	1.000

3.6 Aggregation of Ranks by Proposed Ratio Based Methods

Aggregating ranks obtained through MOORA, MOOSRA AND MultiMOORA in fuzzy environment to obtain more comprehensive and robust evaluation of alternatives. The algorithm proposed by Mohammadi and JafarRezaei (2020), is adopted to obtain aggregate ranking. Final ranking obtained through aggregation of ranks of the alternatives sites for solar power plants is presented in table 11.

Table 11: Aggregation of Ranks by Proposed ratio based Methods

Alts	Aggregate Rank	Alts	Aggregate Rank	Alts	Aggregate Rank	Alts	Aggregate Rank	Alts	Aggregate Rank
1	***17***	11	***41***	21	***49***	31	***47***	41	***27***
2	***3***	12	***38***	22	***28***	32	***43***	42	***19***
3	***39***	13	***21***	23	***31***	33	***3***	43	***3***
4	***35***	14	***3***	24	***3***	34	***2***	44	***37***
5	***1***	15	***23***	25	***34***	35	***42***	45	***14***
6	***48***	16	***20***	26	***3***	36	***16***	46	***26***
7	***24***	17	***32***	27	***46***	37	***44***	47	***45***
8	***25***	18	***22***	28	***30***	38	***33***	48	***3***
9	***3***	19	***36***	29	***3***	39	***13***	49	***15***
10	***40***	20	***29***	30	***18***	40	***50***	50	***3***

Based on the aggregate ranks, Site 5 seems to be the most favorable location for the solar power plant, followed by Site 34.

Non-ratio based methods offer flexibility in modelling complex decision problems. These methods often employ techniques such as utility functions, or preference relations to capture the interrelationships and trade-offs between criteria. Non-ratio based methods are better suited for complex decision structures where there are intricate relationships between criteria and alternatives. These methods provide mechanisms to incorporate subjective judgments and preferences of decision-makers, which can be valuable when there are qualitative or subjective factors involved in the decision-making process.

4. Concluding Remarks

Application of ratio-based MCDM methods, such as MOOSRA and MultiMOORA are proposed for evaluation and ranking of sites for solar power plants in fuzzy environment. These methods allow for the consideration of multiple factors for suitability of a site for a solar power plant. Ratio-based methods facilitate the aggregation of individual criteria rankings into an overall ranking for each site. This enables decision-makers to obtain a comprehensive view of the site's suitability by incorporating multiple perspectives and criteria simultaneously. Overall, ratio-based MCDM methods have demonstrated their usefulness in supporting the selection of sites for solar power plants. By incorporating multiple criteria and enabling comprehensive evaluations, these methods offer valuable insights to decision-makers, aiding them in making well-informed choices that align with their project goals and priorities. Evaluation and ranking techniques such as data envelopment analysis (DEA), Stochastic frontier analysis, machine learning algorithms etc., may be explored to further enhance the accuracy and efficiency of the site selection process. Additionally, investigating the impact of changing weights of the criteria can contribute to more robust decision-making frameworks.

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