Multi-Criteria Decision Making for Risk Management of Feasibility Phase of Solar Park in India

N Ranganath, Debasis Sarkar, Dhaval Dhaneshwar and Yashdeep Purohit

Abstract— This paper aims at application of Multi-Criteria Decision Making (MCDM) tool like fuzzy VIKOR for decision making process amongst available alternatives for a solar power plant project in India. Here the available three alternatives are “application of both preventive and corrective mitigation measures” which would involve more additional project cost but reduces the project risks in terms of time and cost overrun, “application of preventive mitigation measure”, which involves less additional project cost but increases the project risks and “application of corrective mitigation measure”, which also involves less additional project cost and increases the project risks. The decision makers considered for this study are client and main contractor respectively. It has been observed from the analysis of this study that after application of fuzzy VIKOR the alternative application of both preventive and corrective mitigation measures would be recommended to the project authorities. The decision makers client and the main contractor need to provide and arrange for the additional funding for implementation of both preventive and corrective mitigation measure so the successful completion of the project within stipulated time and cost frame is enhanced.

Keywords— Multi-Criteria Decision Making, Risk management, Feasibility, Solar park.

I. Introduction

Feasibility phase is a vital phase for a solar power plant. The risks faced during the feasibility phase makes may solar plants non-viable. Thereby a detailed risk management is very much required for increasing the viability of the solar power projects. India being an emerging economy, the energy demand is ever increasing. To meet the energy demand India has adopted a policy to boost and promote the renewable energy sector. Solar energy sector is one of the major areas which is receiving utmost attention and priority to meet the energy demand in India. Efforts are also being made in India in a huge extent to make the solar power more competitive than the fossil–fuel based energy (Purohit and Purohit, 2010), Purohit et al. (2013). Zarza et al. (2006) presented a conceptual design of the first solar power plant using Direct Steam Generation (DSG) in a parabolic-trough solar field. Aragones-Beltran et al. (2010) made attempt to apply Analytic Network Process (ANP) which is a very popular Multi-Criteria Decision Making (MCDM) tool for selection of solar photovoltaic power plant projects. Jacobson and Delucchi (2011) carried out their research in all renewable energy forms like solar, wind and water. Nithyanandam and Pitchumani (2014) and Dominguez et al. (2012) worked on the cost effectiveness of the solar power plants. MCDM tools applicable to infrastructure projects may also prove quite effective for solar power plant projects. Sarkar and Dutta (2011) applied Expected Value Method (EVM) which proved to be quite effective risk management tool for infrastructure projects like metro rail construction. Sarkar and Singh (2019) applied MCDM tool like Fuzzy Analytical Hierarchy Process (FAHP) for risk analysis of elevated corridor metro rail projects. Sarkar and Singh (2019) compared three MCDM tools to develop risk index for infrastructure projects. Furthermore, Ranganath et al. (2020) applied MCDM tool like Fuzzy TOPSIS to carry out risk analysis of solar power plants. This paper aims at carrying out risk analysis for the feasibility phase of a solar power plant in India by application of MCDM tool like fuzzy VIKOR.

II. Case Study

The Case Study considered for this research is a solar power plant in Karnataka. This plant is planned by four companies viz. KEPL, MEPL, SEPL&SAPL at Gaddikere Village near Hagaribommanahalli, Bellary Dist, Karnataka. The capacity of Power Generation of this project is about 12.1 MW (11.0 MW on AC side and 12.1 MW on DC side). The total extent of area comprising all the three survey number works out to be 57.21 Acres. The project was commissioned in the year 2016-17.

The risks identified during the feasibility phase of the solar power project are tabulated in Table

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TABLE: RISKS ASSOCIATED WITH THE FEASIBILITY PHASE OF THE SOLAR POWER PROJECT

RISKS IDENTIFIED UNDER PHASE-1(FEASIBILITY STUDIES)

No	Activity Risks	No	Sub- Activity Risks
(i)	Problems in Letter of Intent (LOI)	1	Delay in Issue of LOI
		2	Wrong Details of Contract
		3	Delay in responding to Wrong details by Client
(ii)	Problems in Acceptance and Kick of Meeting & Finalization of the Scope and Deliverables.	4	Delay in Acceptance of LOI
		5	Delay in conducting Kick of Meeting
		6	Gaps in scope of work
		7	Improper objectives Scope & Deliverables finalisation
(iii)	Risks in Site location	8	Proximity to International border
		9	Proximity to wild life sanctuary
		10	Presence of forest land
		11	Proximity to eco sensitive zone
		12	Proximity to Historical monuments, Place of worship etc.
		13	Presence of sensitive lands within the project boundary
		14	Highly undulating and rocky terrain.
		15	Presence of Built-up Close to Project
		16	Access to Site
		17	Ground Water Table
		18	Impact on Environment
		19	Social Impact
		20	Availability of Land
		21	Permission from Government
		22	Presence of low laying area.
(iv)	Problems in Reconnaissance Survey of Site	23	Identification of Different Site for Reconnaissance
		24	Wrongly Identification of Site Boundary & Orientation
		25	Missing of Key Data during Reconnaissance survey
(v)	Risks in Collection of Data	26	Improper Data Collection
		27	Inadequate Data Collection
(vi)	Problems in Inception Report Preparation (IR) & Submission	28	Misinterpretation the Scope of Work
		29	Defining of Unrealistic Approach & Methodology
		30	Insufficient Time Allocation for Investigation & Design
		31	Delay in Submission of IR
(vii)	Problems in Review and Approval IR	32	Review by non-technical professional
		33	Delay in review & forwarding the observations
		34	Delay in approval of IR
(viii)	Risks in Preparation & Submission of Draft Feasibility Report (DFR)	35	Improper Approach & Methodology for Feasibility Report
		36	Insufficient Survey & Investigation
		37	Mistakes in Conducting Survey & investigations
		38	Hydraulic and hydrological Investigations
		39	Recommendation of Foundation Type
		40	Poor Interpretation of Data
		41	Wrong Planning of Master Plan
		42	Presence of Utilities
		43	Raw Material Sources
		44	Preliminary Design
		45	Drawings & Documentation
		46	Mistake in Quantity Calculations
		47	Adopting Wrong Schedule of Rates for Estimation
		48	Delay in Preparation of Draft Feasibility Report
		49	Delay in Submission of Draft Feasibility Report
(ix)	Problems in Presentation and Discussion	50	Presenting Wrong Details about Project
		51	Discussions of un-related points during presentation
		52	Authenticity of Clients Observations & Incorporation in Report
(x)	Problems in Approval of DFR	53	Review by non-technical professional
		54	Delay in review & forwarding the observations
		55	Delay in approval of DFR
(xi)	Problems in Submission of Final DFR	56	Delay in Receiving Comments/Observation of Draft DFR
		57	Delay in Attending the Comments/Observation of Draft DFR
		58	Delay in Submission of Final Feasibility Report

III. Conceptual Framework for MCDM Tool Fuzzy VIKOR and Case Analysis

VIKOR method was developed for multi-criteria optimization of complex systems. It determines the compromise ranking list, the compromise solution and the weight stability intervals for preference stability of the compromise solution obtained with the initial (given) weights. VIKOR focuses on ranking and selecting from a set of alternatives in the presence of conflicting criteria.

VIKOR method introduces the ranking index based on the particular measure of "closeness" to the ideal solution by using linear normalization.

A. Steps of this method:

Step 1:

Identification of objectives of the decision-making process and definition of the problem. Decision making is the process of gathering information and selecting the optimal alternative so as to meet the decision goals. Hence, the primary step is defining the decision goal that in our case is to evaluate and select a favorable agile concept design for implementation. After preliminary screening, three alternatives A1, A2 and A3 are considered for further evaluation.

Table : Identification of the alternatives and decision makers (Step 1)

		A1		A2		A3		Criteria weightage		
	Activities with Risks	**DM1**	**DM2**	**DM1**	**DM2**	**DM1**	**DM2**	**A1**	**A2**	**A3**
1	Problems in Letter of Intent (LOI)	3	2	5	6	5	6	3	4	5
2	Problems in Acceptance and Kick of Meeting & Finalization of the Scope and Deliverables.	4	3	7	5	9	7	4	5	5

Here, A1, A2, A3 are alternatives 1,2 and 3 respectively. Alternative A1 is "application of both preventive and corrective mitigation measures" which would involve more additional project cost but reduces the project risks in terms of time and cost overrun. Alternative A2 is "application of preventive mitigation measure", which involves less additional project cost but increases the project risks. Alternative A3 is "application of corrective mitigation measure", which also involves less additional project cost and increases the project risks. DM1 and DM2 are decision makers 1 and 2 who are client and main contractor respectively. So, in the above table, Decision makers 1 and 2 will give weightage to risks associated in alternatives 1, 2 and 3. Also, Decision makers also give criteria weightage.

Step 2:

Arranging the decision-making group and describing a set of relevant attributes.

Step 3:

We define the appropriate linguistic variables for the importance weight of criteria, and the fuzzy rating for alternatives with regard to each criterion and then these linguistic variables can be expressed as positive trapezoidal fuzzy numbers.

Table : Fuzzy ratings of alternatives (Step 3)

	Alternative A1		Alternative A2		Alternative A3		Criteria Weightage		
Activities with Risks	**DM1**	**DM2**	**DM1**	**DM2**	**DM1**	**DM2**	**A1**	**A2**	**A3**
Problems in Letter of Intent (LOI)	(0.1, 0.2, 0.2, 0.3)	(0.1, 0.2, 0.2, 0.3)	(0.4, 0.5, 0.5, 0.6)	(0.5, 0.6, 0.7, 0.8)	(0.4, 0.5, 0.5, 0.6)	(0.5, 0.6, 0.7, 0.8)	(0.1, 0.2, 0.2, 0.3)	(0.2, 0.3, 0.4, 0.5)	(0.4, 0.5, 0.5, 0.6)
Problems in Acceptance and Kick of Meeting & Finalization of the Scope and Deliverables.	(0.2, 0.3, 0.4, 0.5)	(0.1, 0.2, 0.2, 0.3)	(0.7, 0.8, 0.8, 0.9)	(0.4, 0.5, 0.5, 0.6)	(0.8, 0.9, 1.0, 1.0)	(0.7, 0.8, 0.8, 0.9)	(0.2, 0.3, 0.4, 0.5)	(0.4, 0.5, 0.5, 0.6)	(0.4, 0.5, 0.5, 0.6)

Table : Linguistic variables for trapezoidal fuzzy number (Step 3)

Risk description	Acronym	Risk rating	Corresponding Fuzzy Number
Very poor (VP)	VP	1	(0.0, 0.0, 0.1,0.2)
Poor (P)	P	2	(0.1, 0.2, 0.2, 0.3)
Poor (P)	P	3	(0.1, 0.2, 0.2, 0.3)
Medium poor (MP)	MP	4	(0.2, 0.3, 0.4, 0.5)
Fair (F)	F	5	(0.4, 0.5, 0.5, 0.6)
Medium good (MG)	MG	6	(0.5, 0.6, 0.7, 0.8)
Good (G)	G	7	(0.7, 0.8, 0.8, 0.9)

Risk description	Acronym	Risk rating	Corresponding Fuzzy Number
Good (G)	G	8	(0.7, 0.8, 0.8, 0.9)
Very good (VG)	VG	9	(0.8, 0.9, 1.0, 1.0)

Step 4:

The decision makers' judgments are analyzed to get the aggregated fuzzy weight of criteria, and aggregated fuzzy rating of alternatives and a fuzzy decision matrix is constructed. Let the fuzzy rating and importance weight of the kth decision maker be xijk{xijk1, xijk2, xijk3, xijk4} and wjk{wjk1, wjk2,wjk3, wjk4} where i = {1,2, . . ., m} and j ={1, 2, . . . , n} respectively. Hence, the aggregated fuzzy ratings xij of alternatives with respect to each criterion can be calculated as:

$x_{ij} = \{x_{ij}1, x_{ij}2, x_{ij}3, x_{ij}4\}$ (1)

where

$x_{ij1} = \min\{x_{ijk1}\}$

$x_{ij2} = \frac{1}{k}\sum xijk2$

$x_{ij3} = \frac{1}{k}\sum xijk3$

$x_{ij4} = \max\{x_{ijk4}\}$

The aggregated fuzzy weight w_j of each criterion can be calculated as:

$w_j = \{w_j1, w_j2, w_j3, w_j4\}$ (2)

where

$w_{j1} = \min\{w_{jk1}\}$

$w_{j2} = \frac{1}{k}\sum wjk2$

$w_{j3} = \frac{1}{k}\sum wjk3$

$w_{j4} = \max\{w_{jk4}\}$

TABLE : INDIVIDUAL FUZZY SCORES OF THE DECISION MAKERS AND AGGREGATED SCORES OF ALTERNATIVE A1 (STEP 4)

		Individual scores				Individual scores				Aggregated scores			
No	Activities with Risks	DM1				DM2				A1			
1	Problems in Letter of Intent (LOI)	0.1	0.2	0.2	0.3	0.1	0.2	0.2	0.3	0.1	0.2	0.2	0.3
2	Problems in Acceptance and Kick of Meeting & Finalization of the Scope and Deliverables.	0.2	0.3	0.4	0.5	0.1	0.2	0.2	0.3	0.15	0.25	0.3	0.4

Aggregated scores are averages of corresponding fuzzy scores.

Average of 1st activity is

((0.1+0.1)/2) = 0.1

((0.2+0.2)/2) = 0.2

((0.2+0.2)/2) = 0.2

((0.3+0.3)/2) = 0.3

Thus, aggregated fuzzy number for 1st activity for Alternative 1 is (0.1, 0.2, 0.2, 0.3).

Average of 2nd activity is

((0.2+0.1)/2) = 0.15

((0.3+0.2)/2) = 0.25

((0.4+0.2)/2) = 0.3

((0.5+0.3)/2) = 0.4

Thus, aggregated fuzzy number for 2nd activity for Alternative 1 is (0.15, 0.25, 0.3, 0.4).

Similar steps are repeated for Alternative 2, 3 and criteria weightage.

TABLE : AGGREGATED SCORES OF ALTERNATIVE A1, A2, A3 AND THEIR CRITERIA WEIGHTAGE (STEP 4)

Weightage	A1	A2	A3	Criteria weightage
Problems in Letter of Intent (LOI)	(0.1, 0.2, 0.2, 0.3)	(0.45, 0.55, 0.6, 0.7)	(0.45, 0.55, 0.6, 0.7)	(0.23, 0.33, 0.37, 0.47)
Problems in Acceptance and Kick of Meeting & Finalization of the Scope and Deliverables.	(0.15, 0.25, 0.3, 0.4)	(0.55, 0.65, 0.65, 0.75)	(0.75, 0.85, 0.9, 0.95)	(0.33, 0.43, 0.47, 0.57)

Step 5:

The fuzzy decision matrix is defuzzified and fuzzy weight of each criterion is converted into crisp values using COA defuzzification relation. The crisp values for decision matrix and weight of each criterion are computed.

Defuzzification is done by weighted average of fuzzy numbers.

Fuzzy Number * Corresponding Criteria weight

((0.1*0.23) + (0.2 * 0.33) + (0.2*0.37) + (0.3*0.47))/(0.23+0.33+0.37+0.47) = 0.22

TABLE DEFUZZIFIED VALUES FOR ALTERNATIVE A1, A2, A3

		A1	A2	A3	Weightage
1	Problems in Letter of Intent (LOI)	0.22	0.6 0	0.6 0	0.37
2	Problems in Acceptance and Kick of Meeting & Finalization of the Scope and Deliverables.	0.29	0.6 6	0.8 8	0.47

Step 6:

Determine the best $f*_j$ and the worst $f–_j$ values of all criterion ratings, j – {1, 2, . . . , n}. The best and the worst values of all criterion ratings are determined in this step.

For the two activities, Si for activity 2 is

$f*_j$ is the highest in activity 2, i.e. 0.88

f_j- is the lowest in activity 2, i.e. 0.29.

So,

S_i = Weightage * $(f*_j – f_{ij})/(f*_j – f_j-)$

	Problems in Letter of Intent (LOI)	Problems in Acceptance and Kick of Meeting & Finalization of the Scope and Deliverables.
A1	0.22	0.29
A2	0.60	0.66
A3	0.60	0.88
Weightage	0.37	0.47

f*j	**0.6**	**0.88**	**Maximum**
f-j	0.22	0.29	Minimum

A1	**0. 37**	**0.46**
A2	0	0.17
A3	0	0

Here A1 in activity 1, i.e. “Problems in Letter of Intent (LOI)” is calculated below

= 0.37 * ((0.6 – 0.22)/(0.6-0.22)) = 0. 37

Similarly, A2 in activity 2, i.e. “Problems in Acceptance and Kick of Meeting & Finalization of the Scope and Deliverables” is

= 0.47 * ((0.88-0.66)/(0.47-0.29))

= 0.17.

Now Ri for A1 is Maximum value in 0.37 and 0.46, i.e. 0.46.

Thus, Ri = 0.46

S- = 0.46 + 0.37 = 0.83, which is maximum Si.

Step 7:

Compute the values Si and Ri by the following relations:

$$S_i = \sum \frac{w_j (f*_j - f_{ij})}{f*_j - f_j^-}$$

$$R_i = \max \frac{w_j (f*_j - f_{ij})}{f*_j - f_j^-} \quad (3)$$

Compute the value Qi by the relations

$$Q_j = \frac{v_j(S_i - S^*)}{S^- - S^*} + \frac{v_j(R_i - R^*)}{R^- - R^*} \quad (4)$$

where S* = min S_i; S−= max Si; R*0min R_i; R – 0 max R_i and vis introduced as a weight for the strategy of maximum group utility, whereas 1− v is the weight of the individual target.

The values of S, R and Q are calculated for all concept designs.

Now v_j is 0.6 and 0.4.

S_i for Alternative 1 is S_1 = 0.83

S_i for Alternative 2 is S_2 = 0.17

S_i for Alternative 3 is S_3 = 0

S* is the least amongst S_1, S_2 and S_3, i.e. 0.83

S- is the highest amongst S_1, S_2 and S_3. i.e. 0.17

R_i for alternative 1 is R_1 = 0.46

R_i for alternative 2 is R_2 = 0.17

R_i for alternative 1 is R_1 = 0

R* is the least amongst R_1, R_2 and R_3, i.e. 0

R- is the highest amongst R_1, R_2 and R_3. i.e. 0.46

Q_1 = (0.6(0.83-0)/0.83-0) + (0.4 (0.46-0)/0.46-0)
= 1

Q_2 = (0.6(0.17-0)/0.83-0) + (0.4 (0.17-0)/0.46-0)
= 0.271

Q_3 = (0.6(0-0)/0.83-0) + (0.4 (0-0)/0.46-0)
= 0

Q value for alternative 1 is maximum, hence, alternative 1 should be selected amongst given alternatives.

IV. Conclusion

From the analysis it has been observed that for the feasibility phase of the solar power plant under study it has been observed that amongst the alternatives in which A1 is "application of both preventive and corrective mitigation measures" which would involve more additional project cost but reduces the project risks in terms of time and cost overrun. Alternative A2 is "application of preventive mitigation measure", which involves less additional project cost but increases the project risks. Alternative A3 is "application of corrective mitigation measure", which also involves less additional project cost and increases the project risks. DM1 and DM2 are decision makers 1 and 2 who are client and main contractor respectively. The value of "Q" for alternative A1 is maximum through the fuzzy VIKOR analysis. Thereby though some additional project cost need to be incurred by the project authorities, it would be advisable to incorporate both preventive and corrective mitigation measures. This would reduce the project risks and would enhance the probability of successful completion of the project within stipulated time and cost frame.

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