Risk assessment of river-type hydropower plants by using fuzzy logic approach

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Abstract: In this paper, a fuzzy rating tool has been developed for river-type hydropower plant projects risk assessment and expert judgments have been used instead of probabilistic reasoning. The methodology is a multi-criteria decision analysis which provides a flexible and easily understood way to analyze project risks. The external risks, which are partly under the control of companies, have been considered in the model. The eleven classes of risk factors were determined based on the expert interviews, field studies and literature review as follows: site geology, land use, environmental issues, grid connection, social acceptance, financial, natural hazards, political/regulatory changes, terrorism, access to infrastructure and revenue. The relative importance (impact) of risk factors was determined from the survey results. The survey was conducted with the experts that have experience in river-type hydropower projects. The survey results revealed that the site geology and environmental issues were considered as the most important risks. The new risk assessment method enabled a Risk Index (R) value to be calculated, establishing a 4-grade evaluation system: low risk having R values between 1.2 and 1.6; medium risk, between 1.6 and 2; high risk, between 2 and 2.4; extreme risk, between 2.4 and 2.8. Applicability of the proposed methodology was tested on a real case hydropower project namely Kulp IV which was constructed on Dicle River in East Anatolia in Turkey. The proposed risk analysis will give investors a more rational basis on which to make decisions and it can prevent cost and schedule overruns.

Keywords: *Hydropower, Risk Analysis, Fuzzy Logic.*

1. Introduction

Renewable energy projects life cycle is full of various risks which will cause cost and schedule overrun or project failure. The surveys conducted by Gronbrekk et al. [1] and Komendantova et al. [2] identified the highest risk as political and regulatory changes for renewable energy projects in developing countries. Similarly, Ernst and Young [3] identified the most important business risk for 2010 as regulation and compliance.

Construction of river-type hydropower plants involves uncertainties because of various external factors such as site geology, grid connection, and environmental issues. These factors increase the construction costs and duration. For example, in one of the river-type hydropower plant in Turkey, namely Kulp IV, the cost of civil works increased by a factor of two because of unpredicted geologic structure at the tunneling site. In another example, the judges have ruled against hydroelectric power plants in 33 completed cases in Turkey, issuing a stay of execution decision or canceling the construction altogether because of the environmental issues.

In the literature there are several studies considering the risk analysis in construction projects [4] but risk analysis in renewable energy projects, especially for hydropower plants is very limited. In classical project risk analysis techniques, risk rating values are calculated by multiplying impact and probability values and direct analysis of these linguistic factors is often neglected [5]. Most existing risk analysis models, such as Monte Carlo simulation and tornado chart, are based on quantitative techniques which require numerical data. Kangari and Riggs [6] note that probabilistic models suffer from detailed quantitative information which is not normally available in the real construction world. However, much of the information related to risk analysis is not numerical [7]. Rather, this information is expressed as words or sentences in a natural language. These conceptual factors can be expressed in linguistic terms that are, so called fuzzy information [8]. Uncertainty factors such as "poor geology" or "unstable policy" fall into this category. The aim of this paper is to introduce a new approach for hydropower projects risk assessment through the fuzzy set concepts.

2. Methodology

The eleven classes of risk factors were determined based on the expert interviews, field studies and literature review. The risk factors and their evaluation criteria are listed in Table 1. The risk factors are: site geology (geotechnical properties of the construction site), land use (right to use of the land for the construction of hydropower scheme), environmental issues (impact on ecosystem), grid connection (connection to the power system), social acceptance (impact on local community who use the river or the surrounding lands), financial (the status of the inflation and interest rate), natural hazards (earthquake, flooding and landslide), political/regulatory changes (level of political stability), terrorism (human-made disasters), access to infrastructure (road, electricity and water), revenue (cash flow). It should be noted that the financial, political/regulatory changes and terrorism were regarded as risks related to country conditions and their evaluation were done based on [9], [10].

In order to determine the relative importance (impact) of the risk factors, a survey was conducted with the experts from the banks and companies that have experience in the construction of river-type hydropower schemes. 14 experts were participated to the survey. The participants were asked to grade the importance of the risk factors regarding their importance and seriousness of concern. They graded the risk factors using a scale between 1-4, where 1 r epresents "low" and 4 " very high". The experts ranked site geology and environmental issues as the most important risks for river-type hydropower plants (Fig.1).

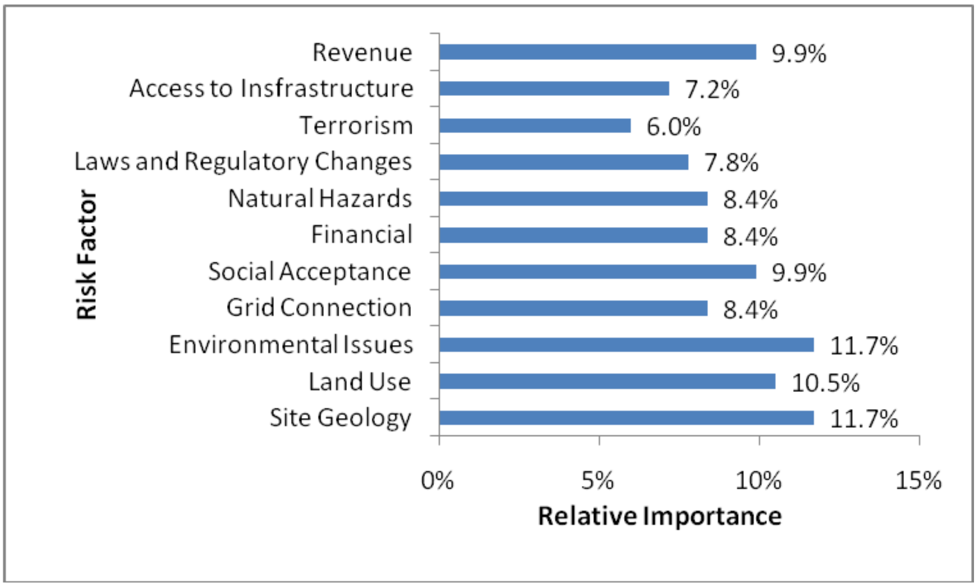

Fig.1 The importance of risk factors of river-type hydropower plants based on the survey results

Table 1. Evaluation criteria of risk factors in river type hydropower plants

Risk Factor	Score (1)	Score (2)	Score (3)	Score (4)
Site Geology	Rock mass quality is very good-good: RQD=%60-100	Rock mass quality is fair: RQD=%40-60	Rock mass quality is poor-very poor: RQD=%0-50	Soil with high ground water level
Land use	Property of Treasury	Forest	Private property: Agricultural land	Private property: Residential area
Environmental Issues	Project has detailed Environmental Impact Report	Project has Environmental Impact Report	Project has no Environmental Impact Report	Project is in an ecological sensitive area.
Grid Connection	Close to power system	Near to power system	Far to power system	Connection to the power system has some limitations
Social Acceptance	Project has detailed Social Impact Report	Project has Social Impact Report	Project has no Social Impact Report	Local community benefit from the river or the surrounding lands
Financial[a]	Economic performance of country is very high	Economic performance of country is high	Economic performance of country is medium	Economic performance of country is low
Natural Hazards	Low risk	Medium risk	High risk	Very high risk
Change in Laws and Regulations[a]	Political risk of country is low	Political risk of country is medium	Political risk of country is high	Political risk of country is very high
Terrorism[b]	Terror risk index of country is low	Terror risk index of country is medium	Terror risk index of country is high	Terror risk index of country is extreme
Access to Infrastructure	Very easy	Easy	Difficult	Very difficult
Revenue	Design discharge is high reliable	Design discharge is medium reliable	Design discharge is low reliable	Design discharge is unreliable

[a] country related risk and its evaluation is based on [9], [b] terrorism risk index is based on [10]

For each 11 parameter, an 1x4 input matrix was developed, each column corresponding scores 1- 4. If the score for a parameter is 3 and the input matrix (I) for the parameter is:

$$I = \begin{bmatrix} 0 & 0 & 1 & 0 \end{bmatrix} \quad (1)$$

Each parameter has an identical membership grading matrix. The fuzzy grading matrices were developed considering the degree of error a scoring observer may cause due to subjectivity and bias in the assessment process [11], [12]. Eq. (2) shows the fuzzy grading matrix (*FG*) used in this study:

$$FG = Score \begin{matrix} 1 \\ 2 \\ 3 \\ 4 \end{matrix} \begin{bmatrix} 1 & 0.4 & 0 & 0 \\ 0.2 & 1 & 0.2 & 0 \\ 0 & 0.2 & 1 & 0.2 \\ 0 & 0 & 0.4 & 1 \end{bmatrix} \qquad (2)$$

The fuzzy assessment matrix (*FA*) was obtained by multiplying input matrices (*I*) with fuzzy grading matrix (*FG*) of the parameter,

$$FA_j = I_j \times FG_j \quad (j = 1 \; to \; 11) \qquad (3)$$

where, j is the row number of the fuzzy assessment matrices. The membership degree matrix (*MD*) was obtained by multiplying weight of parameters (*w*) with fuzzy assessment matrix (*FA*) and summing the columns resulting in a one row matrix;

$$MD = w \times FA \qquad (4)$$

A decision parameter computation was agreed upon f rom several scenarios considering membership degree versus attributes curves and formulation of Risk Index (R) was given as

$$R = \frac{1 \times A_{12} + 2 \times A_{23} + 3 \times A_{34}}{A_T} \qquad (5)$$

where the area under the curve between the attributes i and j is named A_{ij} with: i =1,2, 3, and j = 2, 3, 4, . The total area under the curve is A_T. This enabled a Risk Index (*R*) value to be calculated, establishing a 4-grade evaluation system: Low risk having R values between 1.2 and 1.6; medium risk, between 1.6 and 2; high risk, between 2 and 2.4; extreme risk, between 2.4 and 2.8. The risk scale index represents the minimum and maximum values calculated by Eq.(5).

3. Investment Costs of Hydropower Schemes

Hydro power is the backbone of carbon dioxide free energy generation, about 22% of the world's electricity production comes from hydropower installations [13]. Hydropower plants can be classified into two categories: storage and river-type. In storage type hydropower plants, dams are used to retain river flow in a reservoir. A river-type hydropower plant diverts a portion of river through a channel or tunnel (Fig.2). River-type hydro power plants are dependent on the prevailing flow rate and can present problems of reliability if the flow varies greatly with time of the year or the weather [14]. Small hydropower (SHP) plants are mostly included in this category.

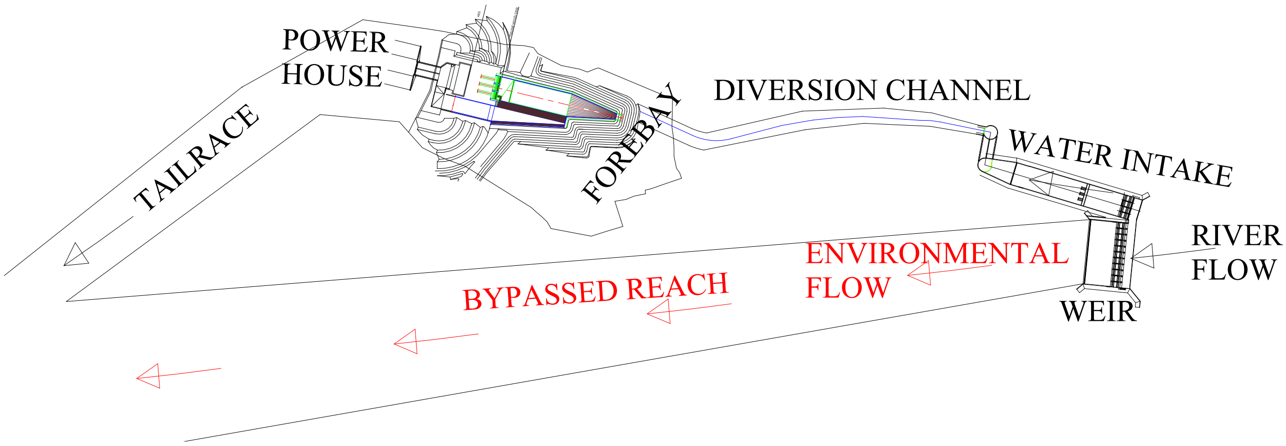

Fig.2 Site plan and components of a river-type hydropower plant

Hall et al. [15] determined the specific investment cost (total investment cost of the project divided by the installed capacity) of river-type hydropower plant in USA in the range of 2000-4000 \$/kW. Also, they reported that the civil works account for 65-75% of capital cost. Each hydropower project is site specific that can explain the wide range of investment costs. Gordon [16] identified the main factors which can lead to cost overrun as the rate of inflation and site geology. The specific investment cost (SC) of a hydro power plant is the function of the net head (H) and installed capacity (P). It is well known from the literature that the SC increases as the head and installed capacity decreases [17], [18]. The investment cost a hydropower plant can be classified as follows: project design, land use and permits, financial, civil works, electro and hydro mechanical equipment, and grid connection (Table 3).

4. An Application of the Proposed Methodology

The developed risk assessment technique was applied to a real-time hydropower project namely Kulp IV which was constructed on Dicle River in Diyarbakır in East Anatolia. The characteristics of the project are as follows: Gross head=77 m, discharge=20 m^3/s, output=12.68 MW, energy=36.64 GWh/year, tunnel length=1885 m. Table 3 presents the investment cost analysis of Kulp IV hydropower plant. Actual cost of civil works and grid connection increased by a factor of two because of the poor geology and the technical demands by TEIAS, respectively. Table 4 shows the application of the risk assessment to the hydropower project. In the assessment fuzzy grading matrix provides more room for the justification of relationships between variables on the basis of fuzzy words. The project risk evaluation was done based on the criteria presented in Table 1. For example, Turkey has been ranked as extreme for Terrorism Risk Index by Maplecroft [9]. Therefore the risk factor of terrorism has a score of 4 for the project. Yet, project has no Environmental impact report, which yields the score of environmental issues as 4. By applying this method to other risk factors, the Kulp IV hydropower project Risk index was calculated as 2.26 which means project involves high risk.

Table 3. Analysis of the investment cost of Kulp IV hydropower plant (P=12.7 MW)

Description	Estimated Cost ($)	Actual Cost ($)	Rate of Increase	Share of Total Cost	Reason
Project design	1,090,000	1,180,000	8.3%	2.2%	Additional project designs
Civil works	12,500,000	25,700,000	105.6%	48.6%	Poor geology (serpentine) at the tunneling site
EME[a]	6,790,000	7,490,000	10.3%	14.2%	Under estimated costs of Technical equipment demand
HME[b]	8,900,000	4,800,000	-46.1%	9.1%	The prices of DSI are very high compared to the market.
Grid connection	2,600,000	5,400,000	107.7%	10.2%	Technical demands by TEIAS and length of the power supply line was increased
Land Use and Permits	2,200,000	2,600,000	18.2%	4.9%	The cost of the forest usage permit was not taken into account
Financial	3,100,000	5,700,000	83.9%	10.8%	Increase in interest rates because of the financial crisis

[a] Electro mechanical equipment, [b] Hydro mechanical equipment

Table 4. Fuzzy risk assessment rating tool application for Kulp IV Hydropower Plant

Risk Assessment																		
								Fuzzy Logic Evaluation										
No	Risk Factor	Score	Relative Importance (W)	Input Matrix (*I*)					Fuzzy Grading Matrix (*FG*)					Fuzzy Assessment Matrix (*FA*) Membership Degree			
														1	2	3	4
1	Geology	3	0.117	0	0	1	0	*FG=f(I)*	0.00	**0.20**	**1.00**	**0.20**	*FA=FG*W*	0.000	**0.023**	**0.117**	**0.023**
2	Land Rent	3	0.105	0	0	1	0		0.00	**0.20**	**1.00**	**0.20**		0.000	**0.021**	**0.105**	**0.021**
3	Environment	3	0.117	0	0	1	0		0.00	**0.20**	**1.00**	**0.20**		0.000	**0.023**	**0.117**	**0.023**
4	Grid Connection	3	0.084	0	0	1	0		0.00	**0.20**	**1.00**	**0.20**		0.000	**0.017**	**0.084**	**0.017**
5	Social Acceptance	2	0.099	0	1	0	0		**0.20**	**1.00**	**0.20**	0.00		**0.020**	**0.099**	**0.020**	0.000
6	Financial	3	0.084	0	0	1	0		0.00	**0.20**	**1.00**	**0.20**		0.000	**0.017**	**0.084**	**0.017**
7	Natural Hazard	2	0.084	0	1	0	0		**0.20**	**1.00**	**0.20**	0.00		**0.017**	**0.084**	**0.017**	0.000
8	Political Changes	3	0.078	0	0	1	0		0.00	**0.20**	**1.00**	**0.20**		0.000	**0.016**	**0.078**	**0.016**
9	Terorism	4	0.060	0	0	0	1		0.00	0.00	**0.40**	**1.00**		0.000	0.000	**0.024**	**0.060**
10	Access to Insfrastructure	3	0.072	0	0	1	0		0.00	**0.20**	**1.00**	**0.20**		0.000	**0.014**	**0.072**	**0.014**
11	Revenue	3	0.099	0	0	1	0		0.00	**0.20**	**1.00**	**0.20**		0.000	**0.020**	**0.099**	**0.020**
Membership Degree Matrix (MD)														**0.037**	**0.335**	**0.817**	**0.211**
														0.19	**0.58**	**0.51**	**1.28**
														A_{12}	**A_{23}**	**A_{34}**	**A_T**
Decision Parameter (R)														**R =**	**2.26**	**High Risk**	

5. Conclusions

In this research, a new methodology is proposed for risk rating of river-type hydropower plant projects. The relative importance of the risk factors was determined from the expert judgments. The survey results showed that the most concerned risks are site geology and environmental issues. These results are in agreement with the Gordon [16].

Applicability of the proposed methodology has been tested on a real case. Findings of the case study demonstrate that the proposed methodology can be easily applied by the professionals to quantify risk ratings. The advantage of the proposed methodology is it will give investors a more rational basis on which to make decisions and it can prevent cost and schedule overruns. Forecasting the measure of risk of a river-type hydropower plant can be made by any decision maker with the help of the fuzzy rating tool described in this paper.

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