Risk Analysis and Evaluation of Wind Electric Farm Construction

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***Abstract*—Wind energy resources are rich in China. At the end of 2012, China's wind power installed capacity has reached 75.324 GW, at the top list in the world. However in China, high-speed development of wind power industry has brought great risks. In this paper, after decomposition of identified four aspects of risk factors, there is also a risk evaluation index system in paper. According to the risk characteristics of wind electric farm and fuzziness of human thinking, utilizing the advantages of triangular fuzzy number and fuzzy complementary judgment matrix and being combined with fuzzy comprehensive evaluation. In paper there is a model based on fuzzy triangular numbers for risk analysis and evaluation. Based on the evaluation results, there are some feasible risk disposal advices.**

Keywords-wind electric farm; triangular fuzzy number; risk analysis; evaluation

I. INTRODUCTION

In China, construction of Wind electric farm developed very quickly. At the end of 1989, it is just 4200 kW but in 2010 it is up to 75,340,000 kW, ranking first in the world. [1] But from 2010, with the economy going down, electricity demand continued to decline.[2] Wind electric farm's profit is declining. Wind electric farm has become a high cost industry. Construction and investment risk of Wind electric farm is increasing.

II. RISK IDENTIFICATION OF WIND ELECTRIC FARM CONSTRUCTION

The key to reducing the risk of wind field construction is risk control in three stages such as planning, construction, and production.

A. *Process of Wind Electric Farm Construction Risk Identification*

First of all, using the SWOT analysis threat, opportunity, advantages that wind electric farm project facing and made qualitative analysis on the internal and external environment of wind electric farm project have[3]. We can sum up the potential risks of wind electric field. According to the internal rate of return IRR of wind electric farm, we can identify sensitivity analysis from a direct impact on the profitability index risk project. The profit levels determine the degree of influence of risk. Then we can get risk list as based on risk analysis and assessment[4].

Technological process of wind electric farm construction risk analysis and assessment just as Figure 1.

According to Table I, risk assessment of wind electric farm construction is just as following.

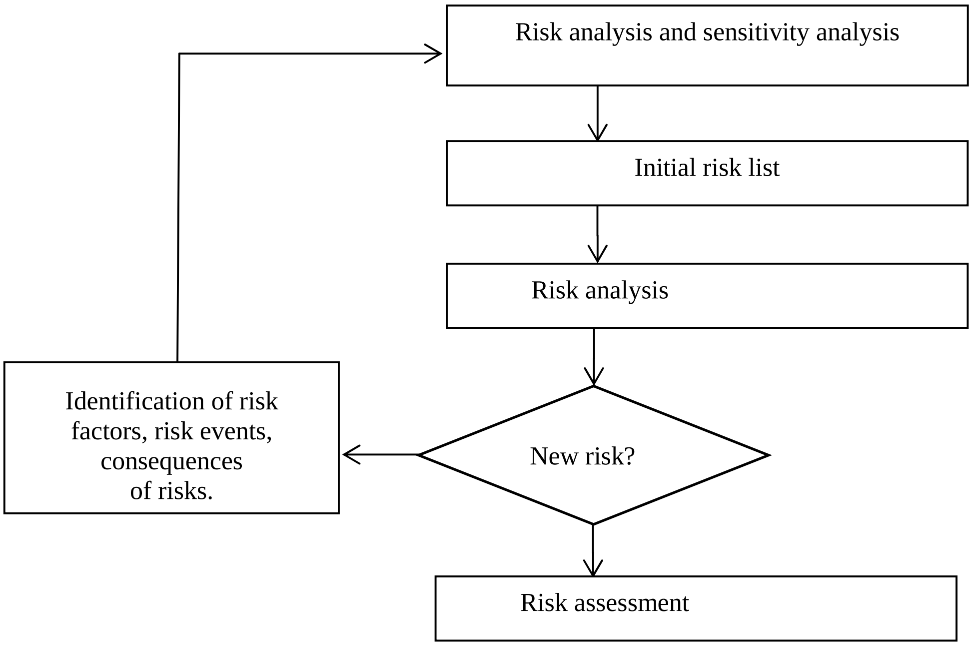

Figure 1. Technological process of wind electric farm construction risk analysis and assessment.

TABLE I. RISK ASSESSMENT OF WIND ELECTRIC FARM CONSTRUCTION.

	Fist Level	Second Level	Risk Scenario Description
External Risk	Political and economic risk U_1	Government support U_{11}	State subsidies
		Price policy U_{12}	State price
		Laws and regulations U_{13}	Legal adjustment
		Financing rate U_{14}	Loan program
	Social and legal risk U_4	Public Security U_{21}	Damaged equipment
		Climate U_{22}	Influence of extreme temperature for air density
		Natural disaster U_{23}	Earthquake, fire, flood, lightning
		Geological conditions U_{24}	Improper location
	Technical and management U_3	Waste electrical U_{31}	Too much electricity
		Construction organization U_{32}	Construction schedule delay, Construction equipment is not complete, The construction quality is not reliable
		Operation and maintenance U_{33}	Repair and maintenance is not seasonable, Lack of repair materials and equipment, Inadequate safety regulations
		Wind energy resources U_{34}	Wind data is not accurate, The location is not correct, The actual use of time is low
Internal risk U_4		Development obstacles U_{41}	Not through the registration
		Fan selection U_{42}	Single machine reliability is lower than 98%, The reliability of less than 95%
		Contract management U_{43}	Contract terms omission, The terms of the contract the expression is wrong, The claim is ineffective, Contract disputes
		Project team U_{44}	Project management mode selection is improper, low quality of personnel, Occupation moral hazard

B. *Process of Wind Electric Farm Construction Risk Analysis and Assessment*

1) Set Risk List

According to wind electric farm construction risk analysis and assessment, risk index element set will be divided into two stages[5].

a) First Level of Risk Index Element Set

$$P = \{U_1, U_2, \ldots, U_i\} \tag{1}$$

b) Second Level of Risk Index Element Set

$$u_1 = \{u_{11}, u_{12}, \ldots, u_{1j}\}$$

$$u_2 = \{u_{21}, u_{22}, \ldots, u_{2j}\}$$

$$\ldots$$

$$u_i = \{u_{i1}, u_{i2}, \ldots, u_{ij}\} \qquad i = 4, j = 4$$

c) Establishment of Risk Evaluation Set

According to influence of risks to wind electric farm construction, we can get evaluation sets:

$$\mathbf{V} = \{\boldsymbol{v_1}, \boldsymbol{v_2}, \boldsymbol{v_3}, \boldsymbol{v_4}, \boldsymbol{v_5}\}$$

= {very high risk, high risk, medium risk, low risk, very low risk} (2)

2) Set fuzzy Evaluation Matrix of Single Factor

There are two characteristics of risks—Probability of occurrence P and loss of risk L. Using these two features as target to evaluate all risk elements we can get fuzzy relation R_L and R_P of risk factors set U_1 and Risk evaluation set V according to the condition of P and L risk factors set. We find five Experts. They gave evaluation value.

$$R_L = \begin{bmatrix} r_{L11} & r_{L12} & \cdots & r_{L15} \\ r_{l21} & r_{l22} & \cdots & r_{L25} \\ r_{Lm1} & r_{Lm2} & \cdots & r_{Lm5} \end{bmatrix} \tag{3}$$

$$R_p = \begin{bmatrix} r_{p11} & r_{p12} & \cdots & r_{p15} \\ r_{p21} & r_{p22} & \cdots & r_{p25} \\ r_{pm1} & r_{pm2} & \cdots & r_{pm5} \end{bmatrix} \tag{4}$$

Suppose m is the number of two level index elements. No prior relationship exists between P and L. According to the parallel relationship between R_L and R_P we can put R_L and R_P into a fuzzy single factor risk judgment matrix.

$$R = \begin{bmatrix} r_{11} & r_{12} & \ldots r_{15} \\ r_{21} & r_{22} & \ldots r_{25} \\ r_{m1} & r_{m2} & \ldots r_{m5} \end{bmatrix} \tag{5}$$

$$R = \begin{bmatrix} 0.3 & 0.5 & 0.2 & 0.1 & 0.2 \\ 0.5 & 0.5 & 0.3 & 0.3 & 0.2 \\ 0.1 & 0 & 0.3 & 0.5 & 0.2 \\ 0.2 & 0 & 0.1 & 0.3 & 0.6 \\ 0.2 & 0.2 & 0.6 & 0.1 & 0.2 \\ 0 & 0.2 & 0.4 & 0.2 & 0.2 \\ 0.2 & 0.4 & 0.4 & 0.2 & 0.1 \\ 0.2 & 0.4 & 0.4 & 0.2 & 0.3 \\ 0.3 & 0.4 & 0.3 & 0.3 & 0.5 \\ 0.6 & 0.4 & 0.5 & 0.1 & 0.5 \\ 0.1 & 0.5 & 0.4 & 0.4 & 0.6 \\ 0.2 & 0.4 & 0.4 & 0.2 & 0.1 \\ 0.2 & 0.3 & 0.5 & 0.3 & 0.2 \\ 0.3 & 0.4 & 0.3 & 0.4 & 0.5 \\ 0.7 & 0.1 & 0.2 & 0.2 & 0.5 \\ 0.6 & 0.1 & 0.5 & 0.2 & 0.2 \end{bmatrix}$$

TABLE II. 0.1 TO 0.9 SCALE.

Scale	The Meaning of Two Elements Compared to
0.5	Two elements are equally important
0.6	The former was slightly more important than the latter
0.7	The former is important than the latter
0.8	The former is more important than the latter
0.9	The former is very important than the latter
0.1, 0.2, 0.3, 0.4	If the importance of U_i and U_j is a_{ij}, U_j and U ratio is $a_{ji} = 1 - a_{ij}$

TABLE III. AN IMPORTANT ELEMENT OF RISK EVALUATION TABLE ($i = 4, j = 4$).

Standards of U_i	u_{i1}	u_{i2}	. . .	u_{ij}
u_{i1}	The expert scaling with triangular fuzzy numbers according to Table 3.1.as (l_{ij}, m_{ij}, s_{ij}). l_{ij} is the most pessimistic value. m_{ij} is the most probable value. s_{ij} is the most optimistic value. $l_{ii}=m_{ii}=s_{ii}=0.5, l_{ij}+s_{ji}=m_{ij}+m_{ji}=s_{ij}+I_{ji}=1$			
u_{i2}				
. . .				
u_{ij}				

According to F-AHP, we should Structure two stage judgment matrix and the consistency check.

K is the number of experts who marks elements of U_i. According to standards in Table II, such as the importance of quantitative comparison of two scoring, expert can mark elements of U_i as Table III.

Construction of kXn two level index layers we can get comparison judgment matrixes.

$$B_i^{(q)} = \left(b_{ij}^{(q)}\right)_{nXn} = \begin{bmatrix} b_{11}^{(q)} b_{12}^{(q)} & \ldots & b_{1j}^{(q)} \\ b_{21}^{(q)} b_{22}^{(q)} & \ldots & b_{2j}^{(q)} \\ b_{i1}^{(q)} b_{i2}^{(q)} & \ldots & b_{ij}^{(q)} \end{bmatrix} \tag{6}$$

$(q = 1,2,\ldots,k)$ q is the number of experts? value of $b_{ij}^{(q)}$ is based on Table 2.

3) Consistency Check of $B_i^{(q)}$ as Following:

Fuzzy probability of (l_{ij}, m_{ij}, s_{ij}) is

$$P_{(l)} = \frac{1}{2(1+N)} \tag{7}$$

$$P_{(m)} = \frac{N+2NM+M}{2(1+N)(1+M)} \quad (8)$$

$$P_{(s)} = \frac{1}{2(1+M)} \quad (9)$$

We can assuming (l_{ij}, m_{ij}, s_{ij}) has the same probability of occurrence, such as $M = N = 1$.

So triangular fuzzy number expected value is

$$e_{ij}^{(q)} = P_{(l)} \times l_{ij}^{q} + P_{(m)} \times m_{ij}^{q} + P_{(s)} \times s_{ij}^{q} \quad (10)$$

Expected value judgment matrix:

$$E_i^{(q)} = \left(e_{ij}^{(q)}\right)_{nXn} = \begin{bmatrix} e_{11}^{(q)} e_{12}^{(q)} & \cdots & e_{1j}^{(q)} \\ e_{21}^{(q)} e_{22}^{(q)} & \cdots & e_{2j}^{(q)} \\ e_{i1}^{(q)} e_{i2}^{(q)} & \cdots & e_{ij}^{(q)} \end{bmatrix} \quad (11)$$

$(q = 1,2,\ldots,k)$ q is the number of experts?

To calculate the weight vector $w_i^{(q)}$

$$w_i = \frac{1}{n} - \frac{1}{2a} + \frac{1}{an}\sum_{k=1}^{n} b_{ik} \quad (12)$$

$$i \in N, a \geq (n-1)/2$$

Construction of characteristic matrix

$$C_i^{(q)} = \left(c_{ij}^{(q)}\right)_{n\times n} = \begin{bmatrix} c_{11}^{(q)} c_{12}^{(q)} & \cdots & c_{1j}^{(q)} \\ c_{21}^{(q)} c_{22}^{(q)} & \cdots & c_{2j}^{(q)} \\ c_{i1}^{(q)} c_{i2}^{(q)} & \cdots & c_{ij}^{(q)} \end{bmatrix} \quad (13)$$

$$C_{ij}^{(q)} = \mathrm{a}\left(w_i^{(q)} - w_j^{(q)}\right) + 0.5 \quad (14)$$

$(q = 1,2,\ldots,k)$ q is the number of experts?

Calculated for each comparison, we can get judgment matrix compatibility index $\mathrm{I}\left(B_i^{(q)}, C_i^{(q)}\right)$. If $\mathrm{I}\left(B_i^{(q)}, C_i^{(q)}\right) < 0.1$, then we can get the second level comparison matrix from exporter q is consistency. If $\mathrm{I}\left(B_i^{(q)}, C_i^{(q)}\right) \geq 0.1$, then second level comparison matrix should be charged.

If second level comparison matrixes $B_i^{(q)}$ from K experts are consistent with each other, we can get second level index layer fuzzy comprehensive evaluation matrix B_i.

$$B_j = \left(b_{ij}\right)_{n\times n} = \begin{bmatrix} b_{11} b_{12} & \cdots & b_{1j} \\ b_{21} b_{22} & \cdots & b_{2j} \\ b_{i1}\, b_{i1} & \cdots & b_{ij} \end{bmatrix} \quad (15)$$

$$b_{ij} = (b_{ij}^{(1)} \oplus b_{ij}^{(2)} \oplus b_{ij}^{(3)} \oplus \ldots.\oplus b_{ij}^{(k)})/k$$

According to Eq. (12), we can get weight vector of second level index layer:

$$W_{ii} = (w^{i1}, w^{i2}, \ldots., w^{ij})^T$$

So

$$W_{11} = (0.38,0.22,0.92,0.11)^T$$

$$W_{22} = (0.27,0.43,0.25,0.222)^T$$

$$W_{33} = (0.36,0.27,0.22,0.65)^T$$

$$W_{44} = (0.61,0.31,0.24,0.68)^T$$

Using the same method, we can get weight vector of first level index:

$$W_{LP} = (w_1^{LP}, w_2^{LP}, \ldots, w_n^{LP}) \quad (16)$$

P is probability of risk. L is the risk consequence. Assume that P and L are parallel.

$$W_{LP} = (0.28,0.58,0.27,0.39)$$

Assume that there are m two level index. The element weight vector of first and second level indicators can be synthesis for the total weight vector.

$$w = W_{LP}.\begin{bmatrix} W_{11} & & \\ & \ddots & \\ & & W_{nn} \end{bmatrix} = (w_1, w_2, \ldots, w_m)^T$$

w = (0.08, 0.05, 0.07, 0.04, 0.07, 0.06, 0.07, 0.06, 0.08, 0.06, 0.06, 0.07, 0.05, 0.07, 0.05, 0.07)^T

4) Synthetic Evaluation Results

We get fuzzy evaluation set from synthetic W and R with fuzzy operators

$$B = w \times R = \begin{bmatrix} 0.08 \\ 0.05 \\ 0.07 \\ 0.04 \\ 0.07 \\ 0.06 \\ 0.07 \\ 0.06 \\ 0.08 \\ 0.06 \\ 0.06 \\ 0.07 \\ 0.05 \\ 0.07 \\ 0.05 \\ 0.07 \end{bmatrix} \times \begin{bmatrix} 0.3 & 0.5 & 0.2 & 0.1 & 0.2 \\ 0.5 & 0.5 & 0.3 & 0.3 & 0.2 \\ 0.1 & 0 & 0.3 & 0.5 & 0.2 \\ 0.2 & 0 & 0.1 & 0.3 & 0.6 \\ 0.2 & 0.2 & 0.6 & 0.1 & 0.2 \\ 0 & 0.2 & 0.4 & 0.2 & 0.2 \\ 0.2 & 0.4 & 0.4 & 0.2 & 0.1 \\ 0.2 & 0.4 & 0.4 & 0.2 & 0.3 \\ 0.3 & 0.4 & 0.3 & 0.3 & 0.5 \\ 0.6 & 0.4 & 0.5 & 0.1 & 0.5 \\ 0.1 & 0.5 & 0.4 & 0.4 & 0.6 \\ 0.2 & 0.4 & 0.4 & 0.2 & 0.1 \\ 0.2 & 0.3 & 0.5 & 0.3 & 0.2 \\ 0.3 & 0.4 & 0.3 & 0.4 & 0.5 \\ 0.7 & 0.1 & 0.2 & 0.2 & 0.5 \\ 0.6 & 0.1 & 0.5 & 0.2 & 0.2 \end{bmatrix}$$

= (0.15, 0.34, 0.36, 0.091, and 0.089)

The maximum value is 0.36. It seems the project has Medium risk.

III. Risk Management Plan

C. Risk Factors

According to the weight sequence we can get second level of risk factors.

TABLE IV. WEIGHT SEQUENCE OF SECOND LEVEL RISK.

Second level of risk factors	Sequence
Waste electrical U_{31}	1
Government support U_{11}	2
Wind energy resources U_{34}	3
Public Security U_{21}	4
Fan selection U_{42}	5
Laws and regulations U_{13}	6
Natural disaster U_{23}	7
Climate U_{22}	8
Operation and maintenance U_{33}	9
Project team U_{44}	10
Geological conditions U_{24}	11
Construction organization U_{32}	12
Development obstacles U_{41}	13
Price policy U_{12}	14
Contract management U_{43}	15
Financing rate U_{14}	16

D. Risk Management Plan

Risk retention, risk mitigation, risk transfer, risk aversion is commonly used risk management plan.

Top 5 in Table 4 such as Waste electrical U_{31}, Government support U_{11}. Wind energy resources U_{34}, Public Security U_{21}, Fan selection U_{42} should be treated as risk aversion and risk mitigation.

Bottom 5 in Table 4 such as Construction organization U_{32}, Development obstacles U_{41}, Price policy U_{12}, Contract management U_{43}, financing rate U_{14} could be treated as risk retention.

IV. CONCLUSIONS

According to the risk characteristics of wind electric farm, utilizing the advantages of triangular fuzzy number and fuzzy complementary judgment matrix and being combined with fuzzy comprehensive evaluation. There is an F-AHP model based on fuzzy triangular numbers for risk analysis and evaluation. Risk retention, risk mitigation, risk transfer, risk aversion is commonly used risk management plan. To the case in paper, Waste electrical U_{31}, Government support U_{11}. Wind energy resources U_{34}, Public Security U_{21}, Fan selection U_{42} should be treated as risk aversion and risk mitigation. Construction organization U_{32}, Development obstacles U_{41}, Price policy U_{12}, Contract management U_{43}, financing rate U_{14} could be treated as risk retention.

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