Research on Risk Assessment of Photovoltaic Building Project by Triangular Fuzzy Number Method

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***Abstract*—Conventional energy shortage and the increasing demand for energy have made energy saving a global-concerned problem. Building integrated photovoltaic project has become an important way to relieve the energy and demand contradiction. Recently, the development of photovoltaic building project in china is immature, with many kind of risk. This paper firstly builds a risk assessment model of photovoltaic building project based on triangular fuzzy number method. Then it does an example research according to a real project which risk is medium.**

Keywords- photovoltaic building; risk assessment; triangular fuzzy number

I. INTRODUCTION

Conventional energy shortage and the increasing demand for energy have made energy saving a global-concerned problem. Accelerating the development and utilization of renewable energy becomes an important way to relieve the energy and demand contradiction. Photovoltaic building has been adopted and popularized widely at home and abroad, as energy saving project combines renewable energy and building energy efficiency perfectly[1]. As a new kind of energy utilization technology which integrates solar energy and building organically, photovoltaic building project, namely building integrated photovoltaic project, is a new building form that makes it a part of the building by organically binding the solar power system(photovoltaic power generation matrix)to the building, and then providing the building or accessing grid with processed electric energy generated by generating device[2]."Medium-long Term Plan of Renewable Energy" of china clearly puts forward the acceleration of the popularization and application of building integrated photovoltaic project, integrated rooftop solar energy grid-connected photovoltaic generation device.20,000 rooftop photovoltaic generation projects will be built up in china by the year of 2020 and the total volume will be 1000,000 KW[3].

Although photovoltaic building project has advantages of nice environmental benefits, renewability, out of exhaustion, short capital construction period, flexible install capacity and so on[4],we must realize that photovoltaic building development technology in china at present is still immature and many risks will be encountered during scheme design, construction and even project management. Risk analysis and evasion will directly affect the photovoltaic building project and even the performance of the enterprise, thus, the core problem of risks analysis and evasion of photovoltaic building project is further discussing risk factors, which have an impact on photovoltaic building project[5].This paper analyzes the risks of photovoltaic building from the aspects of natural environment, technology, economic, policy in detail, establishes risks evaluation system, researches risks evaluation application research with triangular fuzzy numbers, puts forward control scheme of photovoltaic building integrated risk based on risks analysis result.

II. RISK EVALUATION INDEX SYSTEM

Because of the variety of risk influence factors of the photovoltaic building project, comprehensive analysis of photovoltaic building project risks from different dimensions and different administrative levels is needed. In this paper, we will establish the risk evaluation index system of photovoltaic building project from four dimensions of natural environment, technology, economic and policy, evaluate the whole photovoltaic building project by introducing triangular fuzzy numbers. Risk evaluation index system of photovoltaic building project is showed in Table I.

TABLE I. COMPREHENSIVE RISK EVALUATION INDEX SYSTEM

risk	*first-level factors*	*indexes*
natural environment risks(N)	geographical environment and meteorological indexes(N1)	latitude and longitude(N11)
		sunshine duration(N12
		altitude and pressure(N13)
		temperature and humidity(N14)
	extreme environment index(N2)	geological hazardindex(N21)
		comprehensive extreme climate (N22)
technology risks(T)	echnical scheme designrisk(T1)	technology design feasibility(T11)
		commission design qualification(T12)
		information and data authenticity(T13)
		design innovation(T14)
		designapplicability(T15)
	equipment selectionrisk(T2)	equipment security(T21)
		equipment stability(T22)
		equipment performance price ratio(T23)
	personnel construction safety risk(T3)	constructors' quality(T31)
		personnel safety facility(T32)
		training and supervision (T33)
		construction equipment security(T34)
	equipment installation and debugging risk(T4)	job specification soundness(T41)
		operators' relative qualification(T42)
		technology support fault(T43)
	construction period management dispatchrisk(T5)	project management team(T51)
		management dispatch scheme(T52)
		information condition(T53)
	relay protection risk(T6)	relay protection risk(T61)
	power supply reliabilityrisk(T7)	power reliability risk(T71)
	power stability risk(T8)	power stability risk(T81)
	power quality risk(T9)	power quality risk(T91)
economic risks(E)	pool purchase price(E1)	pool purchase price(E11)
	electricity to access grid(E2)	electricity to access grid(E21)
	operation cost risk(E3)	operation cost risk(E31)
	extra cost risk(E4)	extra cost risk(E41)
	efficiency risk(E5)	efficiency risk(E51)
	profit ability(E6)	operating profit ratio(E61)
		operating gross profit rate(E62)
		the profit margin of costs(E63)
	debt paying ability(E7)	cash to current liability ratio(E71)
		equity ratio(E72)
		obtained interest multiple(E73)
	development ability(E8)	income growth rate(E81)
		net profit growth rate(E82)
	operation ability(E9)	accounts receivable turnover ratio(E91)
		turnover rate of fixed assets(E92)
policy risks(P)	industrial policy(P1)	investment allowance(P11)
		offset by tax revenue(P12)
	grid policy(P2)	purchase electricity compensation(P21)
	continuity(P3)	continuity index(P31)
	operability(P4)	operability index(P41)

III. RISK EVALUATION MODEL OF PHOTOVOLTAIC BUILDING PROJECT BASED ON TRIANGULAR FUZZY NUMBER METHOD

A. Method Description

The basic principle of fuzzy comprehensive evaluation is: we start with factors which affect the decision result of evaluation objects and firstly, determine the index weight of triangular fuzzy numbers and the corresponding evaluation set of different levels from good to bad; secondly, analyze the internal relationship of each index and determine the corresponding membership function, calculate the corresponding membership degree ;thirdly, calculate the fuzzy judgment matrix and index weight of every level [6].

B. Basic Steps

1) System construction of photovoltaic building project risk evaluation indexes .Analyze the language set variables of attributes of photovoltaic building project risk evaluation indexes.

*2) Classify the photovoltaic building project risk set Y.*Let be the classification of Y,denoted by ,that is called the second-level factors set.

3) Determine index weight of various photovoltaic building project risk evaluation indexes with the method of Fuzzy-AHP. We get the judgment matrix with comparison of indexes under one criterion and the matrix is:

$$\tilde{a}=\begin{bmatrix} [1,1,1] & [a_{12}^L,a_{12}^M,a_{12}^U] & \cdots & [a_{1n}^L,a_{1n}^M,a_{1n}^U] \\ [a_{21}^L,a_{21}^M,a_{21}^U] & [1,1,1] & \cdots & [a_{2n}^L,a_{2n}^M,a_{2n}^U] \\ \cdots & \cdots & \ddots & \cdots \\ [a_{n1}^L,a_{n1}^M,a_{n1}^U] & [a_{n2}^L,a_{n2}^M,a_{n2}^U] & \cdots & [a_{nn}^L,a_{nn}^M,a_{nn}^U] \end{bmatrix} \quad (1)$$

Among them, $[a_{ij}^L, a_{ij}^M, a_{ij}^U]$ represents the importance of the ith and the jth in the proportion by means of triangular fuzzy numbers,and its value is expressed with triangular fuzzy numbers reciprocal scale showed in Table II.

TABLE II. UDGMENT MATRIX SCALE

criticality class	a_{ij} ***scale***
i and j are equally important	$\tilde{1}=[1,1,2]$
i is a little more important than j	$\tilde{3}=[2,3,4]$
i is more important than j	$\tilde{5}=[4,5,6]$
i is much more important than j	$\tilde{7}=[6,7,8]$
i is extremely more important than j	$\tilde{9}=[8,9,10]$
intermediate value of two neighboring judgments above	$\tilde{2}$ 、$\tilde{4}$ 、$\tilde{6}$ 、$\tilde{8}$

This paper draws lessons from Lambda-Max and calculates fuzzy index weight of Fuzzy-AHP.

*a)*Let $\alpha=1$,calculate the decision matrix $T_m=(T_{ijm})_{n\times n}$ with cut set α- ,and we get the weight with analytic hierarchy process: $W_m=(W_{im})_{n\times n}, i=1,2,\cdots n$.

*b)*Let $\alpha=0$,use cut set α and we obtain the upper and lower bounds decision matrix $T_l=(T_{ijl})_{n\times n}$, $T_n=(T_{ijn})_{n\times n}$,and we get the weight: $W_l=(W_{il})_{n\times n}, W_n=(W_{in})_{n\times n}, i=1,2,\cdots n$

c) weight adjustment

$$W_l^*=\min\left(\frac{W_{im}}{W_{ip}}\middle|1\le i\le n\right)*(W_{il})_{n\times n}$$

$$W_n^*=\max\left(\frac{W_{im}}{W_{in}}\middle|1\le i\le n\right)*(W_{il})_{n\times n} \quad (2)$$

$$W_i=\left(W_{il}^*, W_{im}, W_{in}^*\right)_{n\times n} \quad (3)$$

*d)*fuzzy up the weight.

*e)*Checking consistency.

*f)*expertise aggregation

$$W_{i-f}^*=\frac{1}{2}((1-\gamma)W_{il}^*+W_{im}+\gamma W_{in}^*)$$

and among that, γ means investment preference degree

*4) Determine the language weight decision-making matrix of risk indexes.*The experts determine the language weight of photovoltaic building project based on the importance of indexes and establish judgment matrix of photovoltaic building project indexes showed in Table III

TABLE III. JUDGMENT MATRIX

	C₁	*C₂*	...	*Cₘ*
D₁	W_{11}	W_{12}	...	W_{1m}
D₂	W_{21}	W_{22}	...	...
…	...	...	...	...
Dₖ	W_{k1}	W_{k2}	...	W_{km}
weight	W_1	W_2	...	W_m

Among that:

$$w_j=\left[w_{1j}, w_{2j}, w_{3j}\right]=\frac{1}{k}\sum_{i=1}^{k}w_{ij}, j=1,2,\cdots,m \quad (4)$$

$$w_{1j}==\frac{1}{k}\sum_{i=1}^{k}w_{1ij}, w_{2j}==\frac{1}{k}\sum_{i=1}^{k}w_{2ij}, w_{3j}==\frac{1}{k}\sum_{i=1}^{k}w_{3ij} \quad (5)$$

5) Determine indexes' triangular fuzzy numbers judgment matrix. The triangular fuzzy numbers attribute value of photovoltaic building project risk evaluation factors which is showed in Table IV.

TABLE IV. TRIANGULAR FUZZY NUMBERS JUDGMENT MATRIX

		C₁	*C₂*	...	*Cₙ*
Dₖ	**A₁**	X_{11k}	X_{12k}	...	X_{1mk}
	…	...	...	...	...
	Aₘ	X_{m1k}	X_{m2k}	...	X_{mmk}

Among them:

$$X_{ij}=\left[o_{1j}, p_{2j}, q_{3j}\right]=\frac{1}{k}\sum_{i=1}^{k}X_{ij}, i=1,2,\cdots,m, j=1,2,\cdots,m \quad (6)$$

$$o_{ij}==\frac{1}{k}\sum_{i=1}^{k}o_{ijk}, p_{ij}==\frac{1}{k}\sum_{i=1}^{k}p_{ijk}, q_{ij}==\frac{1}{k}\sum_{i=1}^{k}w_{ijk} \quad (7)$$

Total number of experts is *k*,the number of photovoltaic building project risk evaluation indexes is *m*,X_{ij} is the weight of jth photovoltaic building project risk evaluation index determined by experts of kth sequence($1\le j\le m$).

6) Standardization of fuzzy judgment matrix the standardized fuzzy matrix of photovoltaic building project risk evaluation is:

$$R=(r_{ij})_{m\times n}, i=1,2,\cdots,m, j=1,2,\cdots,n \quad (8)$$

Classify photovoltaic building project risk evaluation indexes into indexes of aggressive type and indexes of conservative type.let B be the index of aggressive type and let C be the index of conservative type,so calculation method of $r_{ij}$is:

$$\begin{cases} r_{ij}=(\frac{a_{1ij}}{a_{3j}^*}, \frac{a_{2ij}}{a_{3j}^*}, \frac{a_{3ij}}{a_{3j}^*}), j\in B \\ r_{ij}=(\frac{a_{3j}^-}{a_{3ij}}, \frac{a_{3j}^-}{a_{2ij}}, \frac{a_{3j}^-}{a_{1ij}}), j\in C \end{cases} \quad (9)$$

Among that, $\begin{cases} a_{3j}^*=\max_i a_{3ij}, j\in B \\ a_{3j}^-=\min_i a_{1ij}, j\in C \end{cases}$ (10)

7) Standardized weight decision-making matrix of photovoltaic building project risk evaluation:

$$V=(v_{ij})_{m\times n} \quad (11)$$

$$v_{ij}=r_{ij}\otimes w_{ij}, i=1,2,\cdots,m, j=1,2,\cdots,n \quad (12)$$

8) Fuzzy up triangular fuzzy numbers

Ambiguity resolution process of photovoltaic building project risk evaluation is:

a) triangular fuzzy numbers is as follows:

$$f_{ij}=(l_{ij}, m_{ij}, r_{ij}), i=1,2,\cdots,m, j=1,2,\cdots,n \quad (13)$$

b) Standardization is:

$$r_i^{\max}=\max_j r_{ij}, l_i^{\min}=\min_j l_{ij}$$

$$\Delta_{\min}^{\max}=\max_j r_{ij}-\min_j l_{ij} \quad (14)$$

c) Then

$$x_{lj}=(l_{ij}-l_i^{\min})/\Delta_{\min}^{\max} \quad (15)$$

$$x_{mj} = (m_{ij} - l_i^{\min}) / \Delta_{\min}^{\max} \quad (16)$$

$$x_{rj} = (r_{ij} - l_i^{\min}) / \Delta_{\min}^{\max} \quad (17)$$

d) Calculate the left and right sides normalized values is :

$$x_j^{ls} = x_{mj} / (1 + x_{mj} - x_{rj}) \quad (18)$$

$$x_j^{rs} = x_{rj} / (1 + x_{rj} - x_{mj}) \quad (19)$$

e) Calculating the total normalized crisp value is :

$$x_j^{crisp} = [x_j^{ls}(1 - x_j^{ls}) + x_j^{rs} x_j^{rs}] / [1 - x_j^{ls} + x_j^{rs}]$$

f) the crisp value is:

$$f_{ij} = l_i^{\min} + x_j^{crisp} \Delta_{\min}^{\max} . \quad (20)$$

g) Calculate the total evaluation result

The ranking matrix $B = (B_1, B_2, B_3, \ldots, B_m)$ and the comprehensive evaluation result is $Q = B \circ V$.

IV. ANALYSIS OF AN EXAMPLE

At first, according to evaluation indexes, decision-making experts establish linguistic assessment sets and evaluate the importance of various photovoltaic building project evaluation indexes which is showed in Table V. According to the results ,we determine the index weight showed in Table VI.

TABLE V. FUZZY EVALUATION VARIABLES OF RISK INDEX

risk evaluation indexes of photovoltaic building project C	*fuzzy values*
poorer	(0,1,3)
poor	(1,3,5)
general	(3,5,7)
good	(5,7,9)
better	(7,9,10)

TABLE VI. COMPREHENSIVE RISK EVALUATION INDEX SYSTEM

risk	***indexes***	***evaluation sets***
natural environment risks(N)	latitude and longitude(N11)	(3.5,5.5,7.5)
	sunshine duration(N12)	(0.5,2,4)
	altitude and pressure(N13)	(0.75,2.5,4.5)
	air ground temperature and humidity(N14)	(0.75,2.5,4.5)
	geological hazard index(N21)	(0.25,0.75,2)
	comprehensive extreme climate index(N22)	(0.25,0.75,2)
technology risks(T)	technology scheme design feasibility(T11)	(6,7.75,9)
	commission design unit and designers qualification(T12)	(7,8.75,9.75)
	Information and data authenticity(T13)	(3,5,7)
	design innovation(T14)	(6,7.75,9)
	design applicability(T15)	(7,8.75,9.75)
	equipment security(T21)	(3,5,7)
	equipment stability(T22)	(2,4,6)
	equipment performance price ratio(T23)	(6,7.75,9)
	constructors' quality(T31)	(5.5,7.5,9.25)
	personnel safety facility(T32)	(5,6.75,8.25)
	construction training and supervision mechanism(T33)	(7,8.75,9.75)
	construction equipment security(T34)	(4.5,6.5,8.5)
	job specification soundness(T41)	(0.25,1.25,3)
	operators'relative qualification(T42)	(0.5,2,4)
	technology support fault(T43)	(0.5,2,4)
	project management team(T51)	(4.5,6.5,8.5)
	management dispatch scheme(T52)	(0.25,1.25,3)
	information condition(T53)	(6,7.75,9)
	relay protection risk(T61)	(0.25,1.25,3)
	power reliability risk(T71)	(7.5,9,9.75)
	power stability risk(T81)	(4.5,6.5,8.5)
	power quality risk(T91)	(7.5,9,9.75)
economic risks(E)	pool purchase price(E11)	(7.5,9,9.75)
	electricity to access grid(E21)	(7,8.75,9.75)
	operation cost risk(E31)	(6.5,8.25,9.5)
	extra cost risk(E41)	(6.5,8.5,9.75)
	efficiency risk(E51)	(3,5,7)
	operating profit ratio(E61)	(6,7.75,9)
	operating gross profit rate(E62)	(7.5,9,9.75)
	the profit margin of costs(E63)	(7,8.75,9.75)
	cash to current liability ratio(E71)	(4.5,6.5,8.5)
	equity ratio(E72)	(3,5,7)
	obtained interest multiple(E73)	(7,8.75,9.75)
	income growth rate(E81)	(5.5,7.5,9.25)
	net profit growth rate(E82)	(7,8.75,9.75)
	accounts receivable turnover ratio(E91)	(0.5,2,4)
	turnover rate of fixed assets(E92)	(0.75,2.5,4.5)
policy risks(P)	investment allowance(P11)	(3,5,7)
	offset by tax revenue(P12)	(0.25,1.25,3)
	purchasing electricity compensation(P21)	(7,8.75,9.75)
	continuity index(P31)	(8,9.25,9.75)
	operability index(P41)	(7.5,9,9.75)

We obtain the final fuzzy evaluating matrix as showed in Table VII

TABLE VII. COMPREHENSIVE RISK RESULTS

risk dimensions	**fuzzy evaluation sets**
Natural environment risk(N)	[(0,0,0),(0.2,0.6,1),(1.5,2.5,3.5),(1.5,2.1,2.7),(0,0,0)]
Technology risk(T)	[(0,0,0),(0.2,0.6,1),(1.8,3,4.2),(1,1.4,1.8),(0,0,0)]
Economic risk(E)	[(0,0,0),(0.2,0.6,1),(1.5,2.5,3.5),(1.5,2.1,2.7),(0,0,0)]
Policy risk(P)	[(0,0,0),(0.5,1.1,2.9),(1.8,2.8,3.5),(1,1.5,1.9),(0,0,0)]

Evaluation result are as follows:

Fuzzification result:D=(0.7,2.46,7.51,6.19,0.67).

Fuzzy evaluation attributecan be written as follows:

C=(lower,low,medium,high,higher)=(50,60,70,80,90),so Q=72.09 belongs to medium risk.

V. CONCLUSION

By triangular fuzzy Number method, evaluation results are more scientific and reliable since some useful information is not wasted in the process of the evaluation. Risk factors of photovoltaic building project includes natural environment risks, technology risks, economic risks and policy risks. By triangular fuzzy Number method we can integrate all the index and sub index information, which makes the conclusion more credible.

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