An Interval Type-2 Fuzzy Topsis Model for Risk Assessment of Photovoltaic Poverty Alleviation Projects in China

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Abstract: With increasing requirements of poverty alleviation and clean energy development sustainability, photovoltaic poverty alleviation (PVPA) projects have attracted much attention. To ensure the successful construction and implementation of PVPA, encouraging the active participation of PV companies is very important and necessary. Risk assessment occupies a necessary position during the whole cycle life of the PVPA project from the perspective of PV companies. Considering the potential risks of the project and ambiguity of decision makers, this paper intends to identify risk factors and proposes an interval type-2 fuzzy TOPSIS model to make a reliable and comprehensive risk assessment of the PVPA project for photovoltaic companies to minimize the loss and ensue project success.

1. Introduction

1.1 Background

With the in-depth advancement and effective implementation of the China's poverty alleviation strategy, poverty problems in rural China have been effectively resolved. According to national rural poverty survey of the National Bureau of Statistics, the amount of the rural poor families in China had been reduced to 5.51 million and the poor incidence rate had been reduced to 0.6% by the end of 2019 [1], which reflects the outstanding progress in poverty alleviation in China. Among numerous measures aiming to alleviate poverty, photovoltaic poverty alleviation (PVPA) project, which is an essential tool to increase poor families' income with a pollution-free way and promoting renewable energy utilization and environmental sustainability, has been given more attention.

The PVPA project is aiming at help the poor families to make use of generated electricity and increase income by selling the remaining part; to be more specific, this project would collect available solar power to generate electricity by installing photovoltaic panels, PV panels, on these families' roofs or roofs on the greenhouses. Generally, PVPA project has two major modes, namely the distributed mode and the centralized mode: 1) installing solar panels on the roofs of poor families' houses and providing government financial supports or loans at preferential rates, and the poor families will obtain separate income; 2) constructing large scale PV power generation plant among villages, and then poor families would get the share of the total revenue from the PV stations. PVPA projects started late in China from 2014 and have been encouraged by a series of supporting national-level policies. The total installed capacity of the first batch of PVPA project plan of 13th Five-Year Plan reached 4.186 GW, including 14 provinces (autonomous regions), 236 key poor counties, a total of 8689 village-level power stations, 710751 poverty-stricken families of 14,556 poor villages. After that, the second batch of PVPA project plan of Thirteen Five-Year Plan achieved a total amount of 1.673 GW of installed capacity, as Table 1 shows.

Table 1 Pvpa Project Plans of 13th Five-Year Plan

NO	Provinces	Countries	Villages	Families	PV stations	Construction scale (KW)
First batch	14	236	14556	710751	8689	4186237.85
Second batch	15	165	3859	301773	3961	1673017.43

In this paper, we will identify potential risk factors influencing PVPA projects, construct the index system, calculate each risk factor's index weight with Delphi method, and assess the risk level of the PVPA project from the view of PV companies. Firstly, to deal with uncertain potential risk

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factors and risk assessment in the construction and further progress of PVPA projects, interval type-2 fuzzy theory is adopted to transfer linguistic variables into manageable numeric numbers. Secondly, since it is necessary to consider uncertain construction, grid-connection and maintenance periods of the PVPA project when assessing numerous risk, we would chooses to use a Multi-Criteria Decision Making (MCDM) problem, which can group various, complicated risk factors into different categories, reaching a more sensible results and simplifying the calculation process.. Thus, a wildly-used MCDM solution which is namely Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) will be introduced. Therefore, our paper proposes an interval type-2 fuzzy TOPSIS method to effectively assess the risk level of the PVPA project from the angle of PV companies.

At length, the following part describes the entire structure of this paper. The Introduction briefly introduces the background of the research and then a literature review is presented; after that, there would be the methodology used for this research study in Section 2; then, we would demonstrate the solution procedure in section 3; Section 4 shows the Discussions; then, we would come to the Conclusions, which are shown in the last section.

1.2 Literature Review

Photovoltaic poverty alleviation (PVPA) projects are identified as an available and effective approach to utilize clean, sustainable solar power to increase poor families' income and improve sustainability of national poverty alleviation. Government, PV companies and relative apartments have implemented some pilot PVPA projects in poverty-stricken areas since 2016 [2]. Currently, researchers at home and abroad have studied PVPA projects from different angles. Li et al. (2018) figured out that PVPA projects in China are conducive to more than two million poor households in general at the end of 2020 and reviewed the corresponding current status, challenges and policy recommendations. Shan and Yang (2019) established a tripartite evolutionary game model to discuss strategies of major participants of PVPA projects, i.e. PV companies, rural families, and local authorities, and proved that initiative supports of PV companies was the appropriate choice to promote the success implement of the project. Huiming et al. (2018) believed that PVPA projects provided a steady source of income and had the potential to extend the development of renewable energy, reduce emissions, and protect available energy, and thus it indicates the significant role that PV companies play in motivating the project development. After that, Huiming et al. (2019) also measured PVPA projects in 30 pilot counties in China with a developed index system including six dimensions and indicated that investment, social production, earnings and social security had great impacts on the poverty situations. The research results indicate that PVPA projects not only improve the income of poor families in China with a long-term income generation mode, but also increase the utilization of environment-friendly energy and reduce emissions. Meanwhile, some research has showed that PV companies played a significant role during the project implementation process.

Given that the benefits brought from PVPA project, it should be further promoted the active participation of project participants. Thus, scientifically finding out risk factors and providing a risk assessing model for PVPA project in the perspective of PV companies should be given priority to achieve these benefits. Some academic research papers have been put forward to evaluate the risk conditions of the PV project. Jakob et al. (2019) provided analysis for risk factors based on both qualitative and quantitative method for extending PV projects in the Netherlands. Steve et al. (2017) quantified the risk factors of PV and concentrated PV projects starting in 2016, 2018 and 2020. Unlike traditional PV projects, PVPA projects involve more participants, and the revenue of power operation will be shared by the PV companies and the poor families; thus the risks and risk assessments of the PVPA projects need to be further discussed. At present, several research has explored the potential risk factors and risk assessment of PVPA projects. Wu et al. (2019) classified risk factors of PVPA projects. However, as the most important participant in a PVPA project, the PV company need to be specifically aware of their own risk levels in such a project. But despite the significant role the PV companies play into this project, there are no study focusing on the angel of

PV companies specifically, identifying their risk factors, and providing a comprehensive risk assessment of PVPA project in the stand of the PV companies, which makes our research original and crucial.

Risk assessment of PVPA projects has to accurately identify risk factors during the construction, operation and maintenance processes and comprehensively consider the collaborative activities with the government, bank and poor families, which requires an index system and comprehensive risk assessment model that take into account the multi-dimensional risk factors of PVPA projects, and thus it belongs to a typical multi-criteria decision-making (MCDM) problem. Correspondingly, the MCDM method sorts or groups multiple alternatives with multiple attributes, and uses mathematical methods to evaluate conflicting multi-attribute integration alternatives, making it easy to select the better one between alternatives [9]. TOPSIS, the most common MCDM method, employs the original data to reflect the differences between each alternative projects [10]. Cengiz Toklu (2018) used TOPSIS to find the best calibration supplier with a case study. It's noteworthy that the TOPSIS method cannot effectively deal with the linguistic variables in risk assessment since linguistic variables have strong ambiguity and uncertainty. To solve this problem, we employ interval type 2 fuzzy sets to convert the qualitative factors into quantitative data in order to use TOPSIS, and builds a risk assessment model of PVPA projects from the perspective of PV companies with an interval type 2 fuzzy TOPSIS method.

2. Methodology and Materials

2.1 Risk Assessment Criteria Determination

Scientific and reasonable criteria system is one of the most important basis for obtaining disciplinary risk assessment results. For PV companies, PVPA projects have a series of potential risks than other PV power stations or infrastructure construction projects. The total risk level of a PVPA project is led by the combination of risk factors that are associated with the government, the poor families and risks arising from PV companies. On the basis of relevant references, feasibility reports and other materials, this paper sorts out and identifies possible risk factors for the PVPA projects and determines the risk assessment criteria from the angle of PV companies.

The risk assessment criteria system includes 4 primary criteria and 11 sub-criteria: (1) Economic risks include 5 sub-criteria, namely market risk (C1), financing risk (C2), long pay-back period risk (C3), subsidy variation risk (C4), and electricity price variation risk (C5); (2) Political/legal risks mainly refer to government credit risk (C6) and potential government intervention (C7); (3) Social/environmental risks might occur when facing public against (C8) from the poor families or local villagers and solar power shortage (C9); (4) Project/technical risks during project construction (C10) and electricity consumption (C11) periods. The criteria system for PVPA project risk assessment is showed in Table 2.

Table 2 Criteria System For Pvpa Project Risk Assessment

Objective	Criteria	Sub-criteria
Risk assessment of PVPA projects	Economic risks	Market (C_1)
		Financing (C_2)
		Long pay-back period (C_3)
		Subsidy variation (C_4)
		Electricity price variation (C_5)
	Political/legal risks	Government credit (C_6)
		Government intervention (C_7)
	Social/environmental risks	Public against (C_8)
		Solar power shortage (C_9)
	Project/technical risks	Construction (C_{10})
		Electricity consumption (C_{11})

2.2 An Interval Type-2 Fuzzy Topsis Approach

The risk assessment of PVPA projects involves complicated and fuzzy variables when determining criteria weights and criteria values; moreover, decision makers usually have subjective and uncertain opinions when assessing the risk level. For a reason to effectively tackle with the qualitative variables with vagueness ane uncertainty, this paper therefore introduces fuzzy theory to deal with criteria and criteria weights. Criteria and comprehensive assessment processing methods based on linguistic variables and fuzzy environments have been extensively studied by scholars at home and abroad, since fuzzy theory can not only present fuzzy or inaccurate knowledge or information but also simplify the assessment process [12]. Interval type-2 fuzzy numbers have greater advantage in solving problems with inaccurate and incomplete information in linguistic variables in practical applications [13] than do interval type-1 fuzzy numbers. According to the above analysis, this paper utilizes interval type-2 fuzzy numbers to normalize the criteria weights and the criteria values.

2.2.1 Interval Type-2 Fuzzy Theory

Definition 1: Suppose that $\tilde{A}$ is an interval type-2 fuzzy set and $\mu_{\tilde{A}}$ is the membership function of $\tilde{A}$, we can obtain Equation (1) [14]:

$$\tilde{A}=\left\{((x,u),\mu_{\tilde{A}}(x,u))\middle|\forall x\in X,\forall u\in[0,1],0\le\mu_{\tilde{A}}(x,u)\le 1\right\} \quad (1)$$

Definition 2: Use upper bound membership function $\overline{\mu}_{\tilde{A}}(x)$ and lower bound membership function $\underline{\mu}_{\tilde{A}}(x)$ to describe the uncertainty and fuzziness of $\tilde{A}$:

$$\tilde{A}==(\tilde{A}^{U},\ \tilde{A}^{L})=\begin{bmatrix}(a_1^U,a_2^U,a_3^U,a_4^U;H_1(\tilde{A}^U),H_2(\tilde{A}^U)),\\(a_1^L,a_2^L,a_3^L,a_4^L;H_1(\tilde{A}^L),H_2(\tilde{A}^L))\end{bmatrix} \quad (2)$$

Where, $a_1^U<a_2^U<a_3^U<a_4^U, a_1^L<a_2^L<a_3^L<a_4^L, a_1^U<a_1^L$ 且 $a_4^L<a_4^U$.

Definition 3: The basic formulas of interval type-2 fuzzy numbers $\tilde{A}_1=(\tilde{A}_1^U,\ \tilde{A}_1^L)$ and $\tilde{A}_2=(\tilde{A}_2^U,\ \tilde{A}_2^L)$ with constant k is as follows:

$$\begin{aligned}
&\tilde{A}_1\oplus\tilde{A}_2=\begin{pmatrix}(a_{11}^U+a_{21}^U,a_{12}^U+a_{22}^U,a_{13}^U+a_{23}^U,a_{14}^U+a_{24}^U;\min(H_1(\tilde{A}_1^U),H_1(\tilde{A}_2^U)),\min(H_2(\tilde{A}_1^U),H_2(\tilde{A}_2^U))),\\(a_{11}^L+a_{21}^L,a_{12}^L+a_{22}^L,a_{13}^L+a_{23}^L,a_{14}^L+a_{24}^L;\min(H_1(\tilde{A}_1^L),H_1(\tilde{A}_2^L)),\min(H_2(\tilde{A}_1^L),H_2(\tilde{A}_2^L)))\end{pmatrix};\\
&\tilde{A}_1\otimes\tilde{A}_2=\begin{pmatrix}(a_{11}^U*a_{21}^U,a_{12}^U*a_{22}^U,a_{13}^U*a_{23}^U,a_{14}^U*a_{24}^U;\min(H_1(\tilde{A}_1^U),H_1(\tilde{A}_2^U)),\min(H_2(\tilde{A}_1^U),H_2(\tilde{A}_2^U))),\\(a_{11}^L*a_{21}^L,a_{12}^L*a_{22}^L,a_{13}^L*a_{23}^L,a_{14}^L*a_{24}^L;\min(H_1(\tilde{A}_1^L),H_1(\tilde{A}_2^L)),\min(H_2(\tilde{A}_1^L),H_2(\tilde{A}_2^L)))\end{pmatrix};\\
&k\tilde{A}_1=\left((ka_{11}^U,ka_{12}^U,ka_{13}^U,ka_{14}^U;H_1(\tilde{A}_1^U),H_2(\tilde{A}_1^U)),(ka_{11}^L,ka_{12}^L,ka_{13}^L,ka_{14}^L;H_1(\tilde{A}_1^L),H_2(\tilde{A}_1^L))\right);\\
&\sqrt[1/k]{\tilde{A}_1}=\left((\sqrt[1/k]{a_{11}^U},\sqrt[1/k]{a_{12}^U},\sqrt[1/k]{a_{13}^U},\sqrt[1/k]{a_{14}^U};H_1(\tilde{A}_1^U),H_2(\tilde{A}_1^U)),\sqrt[1/k]{a_{11}^L},\sqrt[1/k]{a_{12}^L},\sqrt[1/k]{a_{13}^L},\sqrt[1/k]{a_{14}^L};H_1(\tilde{A}_1^L),H_2(\tilde{A}_1^L)\right)
\end{aligned} \quad (3)$$

Definition 4: Rank $\tilde{A}_i=(\tilde{A}_i^U,\tilde{A}_i^L)$ with Equation (4) [11]:

$$\begin{aligned}
Rank(\tilde{\tilde{A}}_i)=&M_1(\tilde{A}_i^U)+M_1(\tilde{A}_i^L)+M_2(\tilde{A}_i^U)+M_2(\tilde{A}_i^L)+M_3(\tilde{A}_i^U)\\
&+M_3(\tilde{A}_i^L)-\frac{1}{4}(s_1(\tilde{A}_i^U)+s_1(\tilde{A}_i^L)+s_2(\tilde{A}_i^U)+s_2(\tilde{A}_i^L)\\
&+s_3(\tilde{A}_i^U)+s_3(\tilde{A}_i^L)+s_4(\tilde{A}_i^U)+s_4(\tilde{A}_i^L))\\
&+H_1(\tilde{A}_i^U)+H_1(\tilde{A}_i^L)+H_2(\tilde{A}_i^U)+H_2(\tilde{A}_i^L)
\end{aligned} \quad (4)$$

Where: $M_p(\tilde{A}_i^U)$ is the average of a_{ip}^j and $a_{i(p+1)}^j$, $M_p(\tilde{A}_i^j)=(a_{ip}^j+a_{i(p+1)}^j)/2$ and 1≤p≤3; $s_q(\tilde{A}_i^j)$ is the standard deviation of a_{ip}^j and $a_{i(p+1)}^j$; $s_4(\tilde{A}_i^j)$ is standard deviation of a_{i1}^j, a_{i2}^j, a_{i3}^j and a_{i4}^j; $H_p(\tilde{A}_i^j)$ is the membership value of $\tilde{A}_i^j$.

The standard deviation can be obtained with Equation (5):

$$\begin{cases} s_q(\tilde{A}_i^j)=\sqrt{\frac{1}{2}\sum_{k=q}^{q+1}(a_{ik}^j-\frac{1}{2}\sum_{k=q}^{q+1}a_{ik}^j)^2}, 1 \le q \le 3 \\ s_4(\tilde{A}_i^j)=\sqrt{\frac{1}{4}\sum_{k=1}^{4}(a_{ik}^j-\frac{1}{4}\sum_{k=1}^{4}a_{ik}^j)^2} \end{cases} \quad (5)$$

2.2.2 Comprehensive Risk Assessment with Interval Type-2 Fuzzy Topsis

TOPSIS, a commbonly used assessment method solving MCDM problems, was put forward by Hwang and Yoon in 1981, whose basic principle is determine the best alternative during various normalized judgement matrices by selecting the one with highest closeness [9]. Considering the ambiguity involved in criteria and criteria weights determination of PVPA project risk assessment, expert opinions are used and treated as linguistic variables. Based on this, integrating interval type-2 fuzzy with TOPSIS could be help us construct a comprehensive risk assessment model with interval type-2 fuzzy TOPSIS.

Suppose that p decision makers try to comprehensively assess the risk level of n PVPA projects, with respect to m assessment criteria.

Step 1: Define the risk assessment problem, including the alternative projects, criteria system, experts, and relative matrices.

Suppose that alternative projects, criteria, and decision makers are separately denoted by $A=(A_1, A_2, \cdots, A_n)$, $U=(U_1, U_2, \cdots, U_m)$, $D=(d_1, d_2, \cdots d_p)$, and the initial risk assessment values for alternative project j regard to criteria i determined by decision maker d_p are noted by $\tilde{x}_{ij}^p$. The criteria weight matrix is represented by $W=\{w_1, w_2, \cdots, w_m\}$.

Step 2: Construct the initial judgement matrix.

Suppose the initial judgement matrix and the average judgement matrix are denoted by $Y_P=[\tilde{x}_{ij}^p]_{m\times n}$ and $\overline{Y}=[\tilde{x}_{ij}]_{m\times n}$:

$$Y_P = \begin{array}{c} \\ U_1 \\ U_2 \\ \vdots \\ U_m \end{array} \begin{array}{c} \begin{array}{cccc} A_1 & A_2 & \cdots & A_n \end{array} \\ \begin{bmatrix} \tilde{x}_{11}^p & \tilde{x}_{12}^p & \cdots & \tilde{x}_{1n}^p \\ \tilde{x}_{21}^p & \tilde{x}_{22}^p & \cdots & \tilde{x}_{2n}^p \\ \vdots & \vdots & \vdots & \vdots \\ \tilde{x}_{m1}^p & \tilde{x}_{m2}^p & \cdots & \tilde{x}_{mn}^p \end{bmatrix} \end{array} \quad (6)$$

$$\overline{Y}=\frac{\tilde{x}_{ij}^1 \oplus \tilde{x}_{ij}^2 \oplus \cdots \oplus \tilde{x}_{ij}^p}{p} \quad (7)$$

Step 3: Calculate and rank the weighted average judgement matrix.

Based on the criteria weights, construct the weighted average judgement matrix $\overline{Y}_W$ with following Equation (8):

$$\overline{Y}_W=\left[\tilde{v}_{ij}\right]_{m\times n}, \tilde{v}_{ij}=w_i \otimes \tilde{f}_{ij} \quad (8)$$

Step 4: Rank the weighted average judgement matrix $\overline{Y}_W$ with Equation (4) as follows:

$$\overline{Y}_{WR}=[Rank(\tilde{v}_{ij})]_{m\times n} \quad (9)$$

Step 5: Obtain the positive and negative ideal solutions: x^+ and x^- with Equation (10):

$$x^+=(v_1^+, v_2^+, \cdots, v_m^+)=\begin{cases} \max(Rank(\tilde{v}_{ij})), & \text{benefit criteria} \\ \min(Rank(\tilde{v}_{ij})), & \text{cost criteria} \end{cases} \quad (10)$$

Step 6: Calculate alternatives' distances from x^+ and x^-.

$$d^{+}(x_j)=\sqrt{\sum_{i=1}^{m}(Rank(\tilde{v}_{ij})-v_i^{+})^2};\quad d^{-}(x_j)=\sqrt{\sum_{i=1}^{m}(Rank(\tilde{v}_{ij})-v_i^{-})^2} \quad (11)$$

Step 7: Based on the distances, rank the alternative projects according to their closeness values:

$$CC(x_j)=\frac{d^{-}(x_j)}{d^{+}(x_j)+d^{-}(x_j)} \quad (12)$$

Generally, the alternative with the highest closeness value has the most outstanding performance in TOPSIS methodology. Nevertheless, the performance of alternative PVPA projects is decided by their comprehensive risk levels in descending order, namely the one with the lowest closeness value has the lowest risk level. For this reason, we will rank the alternative PVPA projects in descending closeness values [14].

3. Solution Procedure with the Interval Type-2 Fuzzy Topsis Approach

In following parts, we would discuss solution procedures of PVPA project risk assessment with proposed interval type-2 fuzzy TOPSIS method, and we would illustrate major steps of this approach in the following part[15].

Assume that the risk assessment of PVPA projects involves n alternatives, there are p experts who are attempting to comprehensively assess the risk levels with respect to m assessment criteria. The risk assessment procedure mainly includes four phases: (1) firstly, experts will determine the criteria weights depending on their professional background; (2) secondly, process the experts' determined criteria weights into corresponding IT2FNs using Table 3; (3) thirdly, launch a comprehensive risk assessment with proposed interval type-2 fuzzy TOPSIS approach; (4) finally, select the best alternative according to assessed risk levels.

3.1 Illustrative Example and Results

This section takes three PVPA projects {A1, A2, A3} as an illustrative example, and invite 3 experts {D1, D2, D3} to evaluate the risk levels. This section aims to figure out the risk factors and assess the risk level of PVPA projects.

In this basis, transform experts' qualitative variables into fuzzy type-2 fuzzy numbers and obtain the criteria weight matrix. The criteria weight matrix obtained is showed in following Table 3.

Table 3 Criteria Weights

Criteria	Criteria weights
Market (C_1)	((0.5, 0.7, 0.7, 0.87; 1, 1) (0.6, 0.7, 0.7, 0.78; 0.9, 0.9))
Financing (C_2)	((0.7, 0.9, 0.87, 0.97; 1, 1) (0.8, 0.87, 0.9, 0.92; 0.9, 0.9))
Long pay-back period (C_3)	((0.83, 1, 0.97, 1; 1, 1) (0.9, 0.97, 1, 0.98; 0.9, 0.9))
Subsidy variation (C_4)	((0.5, 0.7, 0.7, 0.83; 1, 1) (0.6, 0.7, 0.7, 0.77; 0.9, 0.9))
Electricity price variation (C_5)	((0.17, 0.3, 0.27, 0.43; 1, 1) (0.2, 0.27, 0.3, 0.35; 0.9, 0.9))
Government credit (C_6)	((0.83, 1, 0.97, 1; 1, 1) (0.9, 0.97, 1, 0.98; 0.9, 0.9))
Government intervention (C_7)	((0.23, 0.3, 0.33, 0.47; 1, 1) (0.3, 0.33, 0.3, 0.4; 0.9, 0.9))
Public against (C_8)	((0.07, 0.2, 0.23, 0.43; 1, 1) (0.2, 0.23, 0.2, 0.33; 0.9, 0.9))
Solar power shortage (C_9)	((0.83, 1, 0.97, 1; 1, 1) (0.9, 0.97, 1, 0.98; 0.9, 0.9))
Construction (C_{10})	((0.83, 1, 0.97, 1; 1, 1) (0.9, 0.97, 1, 0.98; 0.9, 0.9))
Electricity consumption (C_{11})	((0.37, 0.6, 0.57, 0.77; 1, 1) (0.5, 0.57, 0.6, 0.67; 0.9, 0.9))

3.2 Overall Risk Levels of Pvpa Projects

According to the performance of each project, invited experts evaluate the risk situation of each alternative project (see Table 4). In this basis, construct the initial judgement matrix and calculate the average judgement matrix $\bar{Y}$.

Table 4 Evaluation Results Of the Alternatives

Criteria	Alternatives	Experts		
		d_1	d_2	d_3

Market (C1)	A_1	EHRL	RHRL	RHRL
	A_2	RHRL	MHRL	MRL
	A_3	RLRL	MRL	MRL
Financing (C2)	A_1	RHRL	MHRL	RHRL
	A_2	RHRL	MRL	MHRL
	A_3	MRL	MRL	MLRL
Long pay-back period (C3)	A_1	MRL	RLRL	MLRL
	A_2	MHRL	EHRL	EHRL
	A_3	MLRL	MRL	MLRL
Subsidy variation (C4)	A_1	MRL	MLRL	MRL
	A_2	RHRL	MHRL	RHRL
	A_3	RHRL	MRL	MRL
Electricity price variation (C5)	A_1	MRL	MRL	MRL
	A_2	MRL	MRL	MRL
	A_3	MRL	MRL	MRL
Government credit (C6)	A_1	MRL	MLRL	MLRL
	A_2	MRL	MLRL	MLRL
	A_3	MRL	MLRL	MLRL
Government intervention (C7)	A_1	MLRL	MRL	MLRL
	A_2	MLRL	MRL	MLRL
	A_3	MLRL	MRL	MLRL
Public against (C8)	A_1	MLRL	RHRL	MHRL
	A_2	RLRL	MHRL	MRL
	A_3	RLRL	RLRL	MLRL
Solar power shortage (C9)	A_1	EHRL	RHRL	MHRL
	A_2	RHRL	EHRL	MHRL
	A_3	ELRL	MLRL	MRL
Construction (C10)	A_1	MHRL	MHRL	MLRL
	A_2	MLRL	RLRL	RLRL
	A_3	RLRL	RLRL	RLRL
Electricity consumption (C11)	A_1	MRL	RHRL	MRL
	A_2	MLRL	RHRL	MHRL
	A_3	MLRL	RLRL	MLRL

Table 5 Ranking Results

Alternatives	Positive solution	Negative solution	Closeness	Rank
A_1	3.74	5.87	0.62	2
A_2	2.48	6.04	0.71	3
A_3	6.65	0.87	0.12	1

According to the ranking results, alternative A3 has the lowest closeness value, namely A3 has the lowest risk level among all the alternatives. The ranking sequence of PVPA projects is A3 > A1> A2.

4. Conclusions

Photovoltaic poverty alleviation (PVPA) project brings opportunities both for clean power development and poverty reduction in China, but it has various aspects of potential risks, especially for the PV enterprises. Therefore, it is important to launch a study on comprehensive risk assessment of PVPA in China given the current situation.

To address this problem, the work established a criteria system and a risk assessment framework by proposing an interval type-2 fuzzy TOPSIS model, which offer PV companies another way to assess the project. We identified 4 primary criteria and 11 sub-criteria influencing the risk level of the PVPA projects, used IT2FNs to handle uncertain and ambiguous linguistic variables, and then adopted TOPSIS method to determine the overall risk degrees and calculate the rankings for the alternative projects as well. According to the results, alternative A3 had the lowest risk level among all the alternatives.

However, there are some limitations in our work. On the one hand, China's PVPA development and its business mode are still immature, and thus more potential risk factors, such as PV enterprise' reputation, could be taken into consideration. On the other hand, more assessment models can be applied to validate the practical use and effectiveness of the above-mentioned method.

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