Research Article

Investment risk evaluation of inland floating photovoltaic power plants in China using the HFLTS–TFN method

Yanli Xiao1, Xin Ju1, Bo Yu1, Zheng Wang1 and Chuanbo Xu2,*

1Economic and Technical Research Institute, State Grid Ningxia Electric Power Co., Ltd., Yinchuan, Ningxia, China and
2School of Economics and Management, North China Electric Power University, Beijing, China
*Corresponding author. E-mail: 90102479@ncepu.edu.cn

Abstract

Inland floating photovoltaic power plants (IFPPPs) are the key to making full use of water advantages to develop solar resources in the future. Identifying the investment risk is an important prerequisite for promoting the projects on a large scale. This paper proposes a model to assess the investment risk of IFPPPs in China. First, this paper identifies the investment risk factors and establishes an evaluation indicator system from four aspects. Second, the indicator data are collected and described by adopting hesitant fuzzy linguistic term sets and triangular fuzzy numbers to ensure soundness and completeness. Third, a weighted method combining the best–worst method and the entropy method are utilized to determine the indicator weights under the consideration of the impact of subjective preferences and objective fairness. Fourth, the results show that the overall risk level of China’s IFPPPs is ‘medium low’. Fifth, sensitivity analysis and comparative analysis are implemented to examine the stability of the evaluation results. Finally, this paper also provides some risk-response strategies for the development of China’s IFPPPs from economy, society, technology and environment.
Keywords: inland floating photovoltaic power plants; risk assessment; HFLTS–TFN; BWM

Introduction

With the rapid economic development, traditional energy consumption and CO₂ emissions continue to increase [1], so China is in a critical period of energy-structure transformation. The sustainable development strategy of ‘Reach the peak of carbon dioxide emissions before 2030 and achieve the carbon neutrality before 2060’ has been proposed. Photovoltaic generation is one of the main types of pollution-free energy with abundant reserves. Moreover, the 14th Five-Year Plan of China proposed to vigorously enhance the scale of photovoltaic generation and it is estimated that the total installed capacity of photovoltaic generation in China will exceed 1.2 billion kilowatts by 2030. Therefore, the development of photovoltaic power plants will usher in new opportunities.

At present, existing photovoltaic power plants are mainly ground-based photovoltaic power plants whose installation requires more land resources, so these projects are concentrated in the north-western provinces of China, such as Xinjiang and Gansu provinces. The power supply and demand are not balanced in these areas, so the phenomena of curtailing solar power and limiting electricity occur frequently. However, in southern China, due to the developed economic industry and variable climate change, the installed capacity of the power system has difficulty to fully meet the demand of people’s daily lives [2]. The dense population in these regions leads to a shortage of land resources for ground-based photovoltaic power plants. Fortunately, there are abundant water areas that can settle the conflict between the development of solar power projects and strains on land resources so that more and more investors are focusing on the development of inland floating photovoltaic power plants (IFPPPs). However, most of the IFPPP research is mainly from the perspectives of technology and the economy, and research on project-investment risks is still lacking. Therefore, in the context of low-carbon green development, exploring and identifying the investment risks of IFPPPs is conducive to improving the research system of floating photovoltaic power plants and promoting the development of IFPPPs.
As shown in Fig. 1, IFPPPs are usually constructed in reservoirs, ponds or lakes, and they are also new solar power projects with several significant advantages, including high power-generation efficiency, saving land resources and making full use of water resources. Currently, there are ~98,000 reservoirs and 20,000 lakes in China, most of which are located in the southern region, providing bright opportunities for the development of IFPPPs. The Chinese government has promulgated relevant policies, such as the ‘Notice of National Development and Reform Commission on Matters Concerning the Policies on the On-grid Tariff for Solar Power Generation in 2020’ and the ‘Notice on Further Promoting the Solar Power Generation Systems’, which effectively promote the orderly development of the floating solar power-generation industry and reduce the financial burden for investors. Although the natural environment and policy conditions are conducive to developing the IFPPPs, investors face many uncertainties due to the higher investment costs and longer operating period of IFPPPs. Therefore, it is of great practical significance to analyse the investment risk of IFPPPs against this background.

According to the existing research, this paper identifies the key factors that affect the benefits of IFPPPs by referring to relevant research and consulting experienced scholars, and then establishes the investment risk indicator system. On the basis of the hesitant fuzzy linguistic term set (HFLTS)–triangular fuzzy numbers (TFN) method, the best–worst method (BWM), the entropy method and fuzzy comprehensive evaluation, the model is constructed to comprehensively analyse the investment risk of IFPPPs in China, which provides related investors with theoretical support for the development and planning of IFPPPs to a certain extent. By combining the methods above, it is possible to determine the importance of indicators, screen out the key risk indicators, overcome the shortcomings of the traditional subjective weighting method and improve the accuracy of the importance of risk indicators. The IFPPPs investment risk model constructed in this article can provide decision support for governments and enterprises to build inland floating photovoltaic power plants and achieve green and low-carbon development.

1 Literature reviews

In order to better analyse the investment risks of floating photovoltaic power plants in inland China, the literature review of this paper starts with the following two aspects: research on floating photovoltaic power plants and research on risk-assessment methods.

1.1 Research on floating photovoltaic power plants

The advantages of floating photovoltaic power plants have been affirmed by many scholars. For example, Zhou et al. [2] pointed out that floating photovoltaic power plants could be integrated with the aquaculture industry and tourism development to improve space utilization. Cromratie et al. [3] put forward that water has a cooling effect on photovoltaic panels and cables, therefore increasing the power-generation efficiency of floating photovoltaic power plants. Besides, some scholars compared them with terrestrial photovoltaic panels and found that floating photovoltaic power plants have less shielding so there is higher light utilization [4]. For the above reasons, floating photovoltaic power plants have been applied earlier in foreign countries. Phoenix Solar built a 5-kW floating photovoltaic power plant in the Bishan Park, Singapore, in 2013. Kyocera TCL solar invested in a 1.7-MW floating photovoltaic power plant in Hyogo prefecture, western Japan, in 2015. The NHPC Ltd completed a 50-MW floating photovoltaic power plant in southern Kerala, India, in 2015. Although China’s floating photovoltaic power plants started late, they achieved
remarkable achievements. For example, China’s first floating photovoltaic power plant was built in Zaoyang City, Hubei Province, in 2015. China’s Three Gorges New Energy Company used the idle water of the mining sub-sidence area to build a 150-MW floating photovoltaic power plant in Huainan, Anhui Province, in 2017 [5].

In order to promote the healthy development of floating photovoltaic power plants, various scholars have actively contributed their efforts. Miguel et al. [6] presented the main design features of a floating photovoltaic cover system for water-irrigation reservoirs. Liu et al. [7] proposed and assessed an integrated floating photovoltaic-pumped storage power system in electricity generation and the conservation of water and land resources. Goswami and Sadhu [8] conducted an experiment for 17 months to determine the performance of floating photovoltaic modules and their study showed that the average performance ratio and the degradation rate was 71.58% and 1.18%, respectively, for the floating photovoltaic modules. Cazzaniga et al. [9] thought that floating photovoltaic power plants represented an industry with great potential and introduced a methodology currently used in this industry to perform a mooring design. It can be seen from the above that more and more scholars have paid attention to IFFPPs, but few studies have conducted research on the investment risks of IFFPPs in a certain region.

1.2 Research on risk-assessment methods

In the risk assessment of IFFPPs, the experts’ linguistic description of indicators is mostly uncertain and fuzzy. Thus, it is extremely crucial to choose an appropriate method to collect indicator information. Although Zadeh [10] proposed the fuzzy set theory to solve this problem, it has the disadvantage that a single linguistic value cannot fully describe the ambiguity of information. Fortunately, this problem can be solved using the HFLTS method, which describes multiple variables at the same time and obtains more realistic results. In view of its good data-collection characteristics, the HFLTS has been widely used in many fields. For example, Wu et al. [11] used the HFLTS to collect the indicator information of low-speed wind-farm projects in hilly areas. Chen et al. [12] calculated the possibility distributions of the HFLTS to collect experts’ assessments and attribute levels to conduct the overall assessments.

As the evaluation environment is relatively complicated, it is difficult to describe information with precise real values. Therefore, TFN, which include the upper limit, the lower limit and the most probable value [13], are introduced into the investment risk of IFFPPs to describe the indicator information more comprehensively. Besides, this paper also performs fuzzy comprehensive evaluation based on TFN and uses mathematical logic for operations and related definitions for linguistic value conversion, and then obtains the corresponding risk-assessment level. Fuzzy comprehensive evaluation has great superiority in solving multi-criteria decision-making (MCDM) problems, so it has been widely used in risk assessment with multiple evaluation criteria, such as the risk assessment of renewable-energy island microgrids [14], the development trend of water-resources analysis [15] and customer satisfaction with online to offline food delivery [16].

MCDM methods can effectively measure the influence degree of different factors on project risk. Comparing the analytic hierarchy process (AHP) method and the BWM, which both determine the subjective weights, it can be found that the BWM has more obvious advantages. First, the BWM can greatly reduce the amount of calculation in solving practical problems [17]; for the MCDM problem with n indicators, the AHP method requires $n^2-n$ comparison data to obtain the indicator weights, while there are $2n-3$ comparison data in the calculation of the BWM. Second, the vector-based calculation of the BWM is significantly better than the matrix-based calculation of the AHP. Third, as the BWM only needs to compare the optimal or worst indicator with the other indicators [18], it can reduce the probability of judgement errors caused by the experts’ confusion and avoid the data inconsistency resulting from a large number of comparisons in order to get more reliable calculation results. Currently, the BWM has been used in various research on the selection of sustainable hydrogen-production technology [19], the corn-cultivation location selection of bioethanol production [20], decision analysis of China’s energy security [21], etc.

However, experts’ evaluation is the core of the subjective weighted methods to determine the indicator weights, so the accuracy of the process is easily affected by experts’ subjectivity. The emergence of the entropy method can solve this problem well. The entropy method is a common objective-weighted method, which determines the indicator weights by the indicators’ own information [22]. Many scholars have carried out related research work based on this method. For example, Wang et al. [23] used the entropy method to evaluate the reliability of high-voltage direct-current transmission protection systems; Yuan et al. [24] assessed the investment risk of coal-fired power plants in countries along the Belt and Road initiative based on the entropy method. Zhao et al. [25] evaluated the environmental vulnerability of mainland China based on the entropy method.

Obviously, the following conclusions can be drawn: (i) analysing the investment risk of China’s IFFPPs is needed and urgent; (ii) the HFLTS method is currently relatively mature to improve the scientific soundness of indicator selection; TFN are widely used in risk assessment with multiple evaluation criteria; (iii) determining indicator weights by combining the BWM and the entropy method further enhances the comprehensiveness of the investment risk of IFFPPs. There is currently a lack of relevant research that combines the HFLTS and TFN methods to assess the risks of floating photovoltaic power station projects and this paper fills the gap.
2 Investment risk-evaluation system of IFPPPs

Identifying risk factors is a prerequisite for implementing scientific risk management. And establishing a scientific investment risk-evaluation indicator system is necessary to obtain objective and effective risk-evaluation results. Through combing the literature and analysing the characteristics of photovoltaic power plants, this paper establishes an investment risk-evaluation indicator system for IFPPPs and divides them into four categories, including technical risk, economic risk, social risk and environmental risk, as shown in Table 1.

2.1 Technical risk (C1)

2.1.1 Unreasonable location (C11)
Site selection is a key part of the development of IFPPPs. Many aspects are involved in the site-selection process of IFPPPs, such as light intensity, effective light duration, hydrological environment, etc. The unreasonable siting of the IFPPPs will not only have a negative impact on the economic benefits of the projects, but may also cause the projects to fail to meet the requirements [26].

2.1.2 Improper structural design (C12)
The content of the structural design includes the size of the photovoltaic panels, the distance between the photovoltaic panels, the installation inclination angle [27], etc. Design flaws or unreasonable designs often lead to economic losses for project investors. For example, improper photovoltaic panel structural design will lead to insufficient utilization of solar radiation and available light, and therefore the design cannot achieve maximum production efficiency.

2.1.3 Difficulty of integrating into the grid (C13)
Most investors obtain investment income through grid-connected power transmission of the IFPPPs [28]. IFPPPs are built in areas where the power-distribution network facilities are relatively lagging, such as suburban waters. In addition, photovoltaic power generation also has the characteristics of instability, intermittency and uncontrollability. All of the above have brought certain difficulties and risks to the grid connection of IFPPPs.

2.2 Economic risk (C2)

2.2.1 High initial investment cost (C21)
The initial investment cost of IFPPPs is relatively high [5]. Compared with ground-based photovoltaic power stations, the investment cost of IFPPPs is about 12% higher [29].

2.2.2 High operation and maintenance cost (C22)
IFPPPs need to face more risks in the operation and maintenance phases. This risk includes battery-replacement costs [26], external power-supply costs, dust-removal costs, as well as high maintenance costs due to the impact of the pond environment on the floating frame [30].

2.2.3 Financing risk (C23)
The technology of China’s IFPPPs is in its infancy and the consumer market for water-based photovoltaic power is not mature. There is great uncertainty in the future income of IFPPPs. Therefore, banks and other financial institutions are unwilling to take high risks to provide funds for their project construction, meaning that investors face difficulties in finances [31].

2.2.4 Imperfect subsidy mechanism (C24)
The integrated industry that combines inland floating photovoltaic generation and agriculture has photovoltaic power-generation subsidy standards, but it lacks incentive measures that comprehensively consider farming subsidies. Moreover, there are regional differences and differences in understanding, which invisibly increase the business risk of investors.

Table 1: The investment risk-evaluation indicator system of IFPPPs

| Target layer | First-level indicators | Second-level indicators |
|--------------|------------------------|-------------------------|
| Investment risk of IFPPPs | Technical risk (C1) | Unreasonable location (C11) |
| | Economic risk (C2) | High initial investment cost (C21) |
| | Social risk (C3) | High operation and maintenance cost (C22) |
| | Environmental risk (C4) | Financing risk (C23) |
| | | Imperfect subsidy mechanism (C24) |
| | | Complicated approval procedures (C31) |
| | | Insufficient electricity demand (C32) |
| | | Public opposition (C33) |
| | | Severe weather conditions (C41) |
| | | Risk of water corrosion to equipment (C42) |
| | | Water ecological environment destruction (C43) |
2.3 Social risk (C3)

2.3.1 Complicated approval procedures (C31)
Compared with ordinary photovoltaic projects, the administrative approval of IFPPPs also includes procedures for comprehensive land utilization and breeding. Thus, the approval process is complicated. In addition, some power-supply companies do not standardize the grid-connected service process of distributed photovoltaic power plants, which leads to the time-consuming process of grid-connected projects.

2.3.2 Insufficient electricity demand (C32)
IFPPPs are usually connected to the distribution network below 35 kV for nearby utilization. When the power-consumption capacity of the construction area of the project is low, the photovoltaic power station may run under low load for a long time or be idle, causing economic loss and a waste of resources.

2.3.3 Public opposition (C33)
The public's acceptance of the new technology is critical to its smooth implementation. If the public opposes the deployment of IFPPPs, it will cause the project to be delayed or cancelled [32].

2.4 Environmental risk (C4)

2.4.1 Severe weather conditions (C41)
IFPPPs need to face severe weather, which includes strong winds, continuous rain, little light duration, etc. These harsh climatic conditions may cause photovoltaic modules to malfunction. For example, the battery needs to run at low power during the rainy season, which will cause the battery to wear out easily [33].

2.4.2 Risk of water corrosion to equipment (C42)
The current life cycle of photovoltaic power stations is 25 years. Because the floating body frame or pile foundation can be corroded by various microorganisms, harmful chemicals, acid and alkaline water quality in the water for a long time, it leads to the risk of early scrapping [34].

2.4.3 Water ecological environment destruction (C43)
In the development process of IFPPPs, it will inevitably have a certain impact on the surrounding ecological environment [35]. For example, in the fishing and light complementary project, it will cause problems such as the inconvenience of fishing, cumbersome feed management and difficulty in dredging and disinfection, which will affect the development of the fishery.

3 Investment risk-evaluation model of IFPPPs
On the basis of combining domestic and foreign research on risk-evaluation methods, the data-analysis method of HFLTS–TFN and the BWM–entropy method are used to establish the investment risk-evaluation model of IFPPPs, as shown in Fig. 2.

3.1 Data collection based on HFLTSs
The problem of investment risk evaluation is complicated and vague. In the process of analysing indicators, experts may hesitate between multiple evaluation terms in the evaluation of a certain indicator. At this time, a single evaluation term is difficult to accurately reflect the judgement of experts. Therefore, it is necessary to introduce HFLTSs to improve the reliability of decision-making [36]. The evaluation data-collection process based on the HFLTS method is as follows:

Step 1: Set the meaning of the evaluation linguistic sets. Suppose $S = \{s_0, s_1, s_2, \ldots, s_n\}$ is a linguistic term set. According to the investment risk rating, the correspondence between linguistic variables and linguistic term sets classified in this paper is shown in Table 2.

Step 2: Based on the relevant data information and evaluation indicator system, relevant experts are invited to analyse and evaluate the investment risks of IFPPPs.

Step 3: Use the function $E_{GH}$ to express the evaluation results of the HFLTS method. The result of an expert's evaluation of a certain indicator may be between two linguistic sets, or even between multiple linguistic sets. In view of this situation, the operation of HFLTSs can be expressed by the function $E_{GH}$:

$$E_{GH}(s_i) = \{s_i/s_i \in S \} = \{s_i\} \quad (1)$$

$$E_{GH}(\text{between } s_i \text{ and } s_j) = \{s_k/s_k \in S \text{ and } s_i \leq s_k \leq s_j\} \quad (2)$$

$$E_{GH}(\text{less than } s_i) = \{s_k/s_k \in S \text{ and } s_k \leq s_i\} \quad (3)$$

$$E_{GH}(\text{more than } s_i) = \{s_k/s_k \in S \text{ and } s_i \leq s_k\} \quad (4)$$

3.2 Evaluation data processing based on TFN
The TFN method can quantitatively analyse the qualitative evaluation problem that it is difficult to describe the research object through accurate numerical values in fuzzy environmental decision-making by setting the upper and lower limits of the evaluation threshold function [31]. Since the qualitative linguistic terms based on HFLTSs cannot intuitively reflect the evaluation values and perform mathematical operations, this paper uses the method of combining HFLTSs and TFN to process evaluation data and quantitatively express them. The process is as follows:

Step 1: Set the correspondence between HFLTSs and TFN. According to the meaning represented by the linguistic sets and the actual type of investment risk, the linguistic information is converted into TFN, as shown in Table 3.

Step 2: Set the membership function. Suppose a mapping $\mu_A$ from $U$ to $[0,1]$ is defined on the universe $U$, and $\mu_A : U \rightarrow \{0,1\}$, $u \rightarrow A(u) \in [0,1]$ is called a fuzzy set on $U$. And $A(u)$ is called the membership function. The TFN can...
be expressed as $\tilde{A} = (a, b, c)$ and the membership function is shown in Equation (5):

$$\mu_{\tilde{A}}(u) = \begin{cases} \frac{b - u}{b - a}, & a \leq u \leq b \\ \frac{u - c}{b - c}, & b \leq u \leq c \\ 0, & \text{others} \end{cases}$$  \hspace{1cm} (5)$$

Besides, the related operation rules of TFN are as follows, where $\tilde{A}_1 = (a_1, b_1, c_1)$ and $\tilde{A}_2 = (a_2, b_2, c_2)$ represent TFN:

$$\tilde{A}_1 + \tilde{A}_2 = (a_1 + a_2, b_1 + b_2, c_1 + c_2)$$  \hspace{1cm} (6)

$$\tilde{A}_1 \times \tilde{A}_2 = (a_1 a_2, b_1 b_2, c_1 c_2)$$  \hspace{1cm} (7)

$$\lambda \tilde{A}_1 = (\lambda a_1, \lambda b_1, \lambda c_1)$$  \hspace{1cm} (8)

$$\left(\tilde{A}_1\right)^{-1} = \left(\frac{1}{a_1}, \frac{1}{b_1}, \frac{1}{c_1}\right)$$  \hspace{1cm} (9)

Step 3: Calculate the TFN value evaluated by experts. Quantitative analysis of expert evaluation results is based on membership functions. For example, some experts’ assessment of ‘unreasonable location’ is between ‘very low’ (VL) and ‘low’ (L). Among them, the probabilities of VL, L and ‘medium low’ (ML) are 40%, 50% and 10% respectively. Then the HFLTS can be expressed as $H_{21}(C_{11}) = \{0.4, 0.5, 0.1\}$ and the calculation steps are as follows:
3.3 Determination of evaluation indicator weights

Determining weights of the evaluation indicators is a key segment of risk analysis, so this paper starts scientifically in sequence from the three stages for determining subjective weights, objective weights and comprehensive weights.

3.3.1 Subjective weight determination based on the BWM

The BWM is used to calculate the weights of investment risk-assessment indicators for IFPPPs. The BWM was proposed by Rezaei in 2015 [37]. Experts first identify the best (most important) and worst (least important) indicators from the n indicators. Then they use the two indicators as the reference standard and compare them with other indicators. The comparison results need to be expressed in integers from 1 to 9 [38]. The specific steps of the BWM are as follows:

Step 1: There are m experts to select n indicators and uniformly determine the best indicators and the worst indicators. The best indicator is represented by $C_B$, and the worst indicator is represented by $C_w$.

Step 2: Determine the priority of the optimal indicator over other indicators. Each expert evaluates and scores with an integer ranging from 1 to 9, where 1 means ‘equally important’ and 9 means ‘extremely important’, so a comparison vector $A_B = (a_{B1}, a_{B2}, \ldots, a_{Bn})$, and the $a_{Bi}(a_{Bi} = 1)$ is the degree to which ith expert thinks the optimal indicator $C_B$ is better than the indicator $C_i$.

Step 3: Determine the priority of other indicators over the worst indicators. Similarly, each expert evaluates and scores with an integer from 1 to 9, and thus constructs a comparison vector $A_w = (a_{w1}, a_{w2}, \ldots, a_{wn})^T$, and the $a_{wi}(a_{wi} = 1)$ is the degree to which expert i believes that other indicators $C_j$ are better than the worst indicator $C_w$.

Step 4: According to the solution idea obtained by minimizing the maximum deviation, the following mathematical programming model can be constructed to solve the subjective indicator weights using Equation (10):

$$\begin{align*}
\min & \max_j \{ |w_B - a_{Bj}w_B|, |w_j - a_{wj}w_w| \} \\
\text{s.t.} & \quad \sum_j w_{oj} = 1 \\
& \quad w_{oj} \geq 0, \text{ for all } j
\end{align*}$$

Calculate the optimal weights of all indicators determined by experts according to Equation (11), where $\xi$ is the consistency index. And the closer its value is to 0, the higher the consistency [14]:

$$\begin{align*}
\min & \xi \\
\text{s.t.} & \quad |w_B - a_{Bj}w_B| \leq \xi, \text{ for all } j \\
& \quad |w_j - a_{wj}w_w| \leq \xi, \text{ for all } j \\
& \quad \sum_j w_{oj} = 1 \\
& \quad w_{oj} \geq 0, \text{ for all } j
\end{align*}$$

3.3.2 Determining the objective weights through the entropy method

The entropy method determines the indicator weights by the data themselves, so it can avoid the influence of subjective factors. The relevant steps are shown below:

Step 1: Set the quantification standard for HFLTS evaluation results. According to the corresponding relationship between the risk size and the linguistic set, set $S_i$ equal to i. And the quantitative value of the evaluation standard of the calculation experts on the indicator is shown in Equation (12). Among them, $x_{ij}$ represents the evaluation value of each expert indicator:

$$e_j = -\frac{1}{\ln m} \sum_{i=1}^{m} \left( \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}} \ln \left( \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}} \right) \right) p_{ij} e_j \in [0, 1]$$

Step 2: Calculate the entropy weight $w_{oj}$:

$$g_j = 1 - e_j \quad (13)$$

$$w_{oj} = \frac{g_j}{\sum_{j=1}^{n} g_j} \quad (14)$$

3.3.3 Determining the comprehensive weights

According to the subjective and objective indicator weights, the comprehensive indicator weights are obtained based on the multiplication normalization method as follows:

$$w = \frac{\sqrt{w_{oj} \times w_{oj}}}{\sum_{j=1}^{n} \sqrt{w_{oj} \times w_{oj}}}$$

3.4 Investment risk assessment

The influence degree of different risk factors is usually relative and uncertain, and it cannot be quantified. Fuzzy comprehensive evaluation provides a method for evaluating fuzzy variables. In this paper, the fuzzy comprehensive evaluation based on HFLTS-TFN is used to aggregate the uncertain fuzzy numbers of experts’ judgements to realize the overall evaluation of the investment risk of IFPPPs. The investment risk assessment is divided into the following three steps:

Step 1: Establish a first-level indicator evaluation vector. The TFN of all the second-level indicators under each first-level indicator constitute the first-level indicator evaluation vector, which is expressed as $V_{C_i} = (H_{c_{i1}}, H_{c_{i2}}, \ldots, H_{c_{in}})^T$. 

$$V_{C_i} = \begin{pmatrix} 0.4 & 0.5 & 0.1 \\ \forall t \in \{1, 2, \ldots, M \} \end{pmatrix}$$

$$= 0.4s_0 + 0.5s_1 + 0.1s_2$$

$$= (0.4(0.00, 0.00, 0.17), 0.5(0.00, 0.17, 0.34), 0.1(0.17, 0.34, 0.51))$$

$$= (0.02, 0.12, 0.29)$$

$$\min \xi$$

$$\text{s.t.}$$

$$|w_B - a_{Bj}w_B| \leq \xi, \text{ for all } j$$

$$|w_j - a_{wj}w_w| \leq \xi, \text{ for all } j$$

$\sum_j w_{oj} = 1$

$w_{oj} \geq 0, \text{ for all } j$
. The HFLTS $Hc$ is an ordered finite subset of the continuous linguistic set, expressed as $Hc = \{< s_i, h(s_i) > | s_i \in S \}$. The variable $h(s)$ represents the possible membership degrees of $s$ belonging to the set $Hc$.

Step 2: Calculate the investment risk level of each first-level indicator. The expression $W_C$ is the total weight of the second-level indicator under the first-level indicator, and the expression $w_{ci}$ is the weight of the $j$th second-level indicator under the $i$th first-level indicator. The calculation steps are shown in Equations (16) and (17); then sort out the investment evaluation risk value $R_C$ of each first-level indicator:

$$R_C = W_C \circ V_C = (w_{c1}, w_{c2}, \ldots, w_{c_h}) \times (H_{c1}, H_{c2}, \ldots, H_{c_h})^T \tag{16}$$

$$R_C = (R_{c1}, R_{c2}, \ldots, R_{c_h})^T \tag{17}$$

Step 3: Calculate the overall investment risk level, where the expression $W_i$ is the weight of the first-level indicator and the expression $w_{ci}$ is the weight of the $i$th first-level indicator. The calculation is as follows:

$$R = W_i \circ R_C = (w_{c1}, w_{c2}, \ldots, w_{c_h}) \times (R_{c1}, R_{c2}, \ldots, R_{c_h})^T \tag{18}$$

Step 4: Calculate the TFN result of the investment risk level of IFPPPs according to Equation (19), and judge the closest level of investment risk of IFPPPs. The higher the similarity between the judgement result and a certain level of investment risk, the closer the project is to that level. Among them, the variables $A_1 = (a_1, b_1, c_1)$ and $A_2 = (a_2, b_2, c_2)$ are any two TFN:

$$S_d(A_1, A_2) = 1 - \frac{|a_1-a_2| + |b_1-b_2| + |c_1-c_2|}{3} \tag{19}$$

4 A case study

In the international context of low-carbon development, it has become a worldwide consensus to actively develop renewable energy to promote the sustainable development of society. IFPPPs are widely used in countries all over the world because of their clean and pollution-free complementarity with agriculture and fisheries, and higher power-generation efficiency. China is also actively promoting the development of IFPPPs. In order to better promote the development of IFPPPs in China, the key risk factors and overall risk levels of IFPPPs are analysed by the above investment risk-evaluation model.

4.1 Collection of investment risk data

To ensure the accuracy of data acquisition, this article refers to the data-acquisition methods of existing research literature [39]. Four experts in related fields are invited to form an expert committee. These experts have the following characteristics: (i) they have engaged in or studied the management of photovoltaic power plants and (ii) they have a certain understanding of the field of risk assessment. According to the knowledge level and work experience, the evaluation weights of the four experts accounted for 0.3, 0.3, 0.2 and 0.2, respectively. Each expert uses the linguistic sets in the HFLTS to evaluate the 13 second-level indicators in Section 2. The investment risk-assessment results of IFPPPs are shown in Table 4.

According to the language sets in Table 1 and the TFN algorithm in Section 3.2, the evaluation results of each expert for each secondary indicator and each mean value of the expert committee are calculated, as shown in Table 5.

4.2 Determination of indicator weights

According to repeated discussions of the expert committee, the high initial investment cost is determined as the best (most important) indicator and insufficient electricity demand is the worst (least important) indicator. Each expert scores the remaining indicators according to the relevant steps of Section 3.3. The subjective indicator weights are shown in Table 6 and the consistency index values of the experts are all <1, which implies a very good consistency. Then the entropy method is applied to get objective weights. Finally, the comprehensive weight of

| Indicators | Expert 1 | Expert 2 | Expert 3 | Expert 4 |
|------------|----------|----------|----------|----------|
| C11        | 0.4s, 0.6s | 0.4s, 0.6s | 0.4s, 0.5s, 0.1s | 0.4s, 0.5s, 0.1s |
| C12        | 0.4s, 0.5s, 0.1s | 0.4s, 0.6s | 0.5s, 0.5s | 0.4s, 0.5s, 0.1s |
| C13        | 0.4s, 0.3s, 0.3s | 0.3s, 0.3s, 0.4s | 0.2s, 0.5s, 0.3s | 0.4s, 0.3s, 0.3s |
| C21        | 0.5s, 0.5s | 0.2s, 0.2s, 0.6s | 0.4s, 0.6s | 0.4s, 0.6s |
| C22        | 0.2s, 0.6s, 0.2s | 0.7s, 0.3s | 0.6s, 0.4s | 0.5s, 0.5s |
| C23        | 0.5s, 0.5s | 0.3s, 0.6s, 0.1s | 0.4s, 0.4s, 0.2s | 0.7s, 0.3s |
| C24        | 0.1s, 0.5s, 0.4s | 0.4s, 0.6s | 0.4s, 0.3s, 0.3s | 0.6s, 0.4s |
| C31        | 0.7s, 0.3s | 0.5s, 0.5s | 0.4s, 0.4s, 0.2s | 0.4s, 0.6s |
| C32        | 0.5s, 0.5s | 0.4s, 0.6s | 0.3s, 0.5s, 0.2s | 0.4s, 0.4s, 0.2s |
| C33        | 0.2s, 0.8s | 0.5s, 0.5s | 0.7s, 0.3s | 0.3s, 0.5s, 0.2s |
| C41        | 0.2s, 0.6s, 0.2s | 0.4s, 0.6s | 0.4s, 0.6s | 0.4s, 0.5s, 0.1s |
| C42        | 0.4s, 0.4s, 0.2s | 0.7s, 0.3s | 0.5s, 0.5s | 0.4s, 0.6s |
| C43        | 0.3s, 0.6s, 0.1s | 0.1s, 0.7s, 0.2s | 0.4s, 0.6s | 0.8s, 0.2s |
4.3 Investment risk evaluation of IFPPPs

According to Equation (16), the investment risk level of the first-level indicators of IFPPPs are calculated and the calculation process is as follows:

\[ R_{C1} = (0.62 \ 0.15 \ 0.23) \times \begin{pmatrix} 0.06 & 0.20 & 0.37 \\ 0.19 & 0.36 & 0.53 \\ 0.31 & 0.48 & 0.65 \end{pmatrix} = (0.14 \ 0.29 \ 0.46) \]

\[ R_{C2} = (0.04 \ 0.14 \ 0.50 \ 0.32) \times \begin{pmatrix} 0.60 & 0.77 & 0.93 \\ 0.56 & 0.73 & 0.89 \\ 0.46 & 0.63 & 0.80 \\ 0.31 & 0.48 & 0.65 \end{pmatrix} = (0.43 \ 0.60 \ 0.77) \]

\[ R_{C3} = (0.39 \ 0.27 \ 0.34) \times \begin{pmatrix} 0.31 & 0.48 & 0.65 \\ 0.25 & 0.42 & 0.59 \\ 0.19 & 0.36 & 0.53 \end{pmatrix} = (0.25 \ 0.42 \ 0.59) \]

It can be seen from the above evaluation results that the risk level of the first-level indicator \( R_{C2} \) is the highest and the risk level of the first-level indicator \( R_{C4} \) is the lowest. Then, according to Equations (17) and (18), the overall investment risk value of IFPPPs is calculated and the result is as follows:

\[ R_C = (0.30 \ 0.25 \ 0.18 \ 0.27) \times \begin{pmatrix} 0.16 & 0.32 & 0.49 \\ 0.47 & 0.64 & 0.81 \\ 0.25 & 0.42 & 0.59 \\ 0.10 & 0.26 & 0.43 \end{pmatrix} = (0.23 \ 0.39 \ 0.56) \]

According to Equation (19), the similarity of each investment risk level value is calculated and the result is shown in Fig. 3. It can be seen that the overall investment risk evaluation calculation result of IFPPPs has the highest similarity with ML, i.e. the overall investment risk of IFPPPs is at a relatively low level in China.
4.4 Sensitivity analysis

The results of risk evaluation are easily affected by indicator weights and the number of experts. Thus, it is necessary to conduct a sensitivity analysis of the above calculation results in two different ways to test the stability of this framework.

4.4.1 Fluctuation of indicator weights

To examine the stability of the evaluation results, the sensitivity analysis of the influences for the first-level indicator weights of the IFPPs site selection will be implemented. Four criteria, namely technical risk, economic risk, social risk and environmental risk, all take 10%, 20% and 30% less and more weight than the initial weights. The variation results of each investment risk level similarity are displayed in Fig. 4.

When the C1 or C4 weight fluctuation is from small to large, the similarity values of ML gradually increase. On the contrary, the similarity values of ML decrease as C2 or C3 increases. The similarity values of VL and medium high (MH) are equal when the C1 weight increases by 10% of the original value or the C2 weight decreases by 10% of the original value; regardless of how the weights of C3 fluctuate in Fig. 4, the similarity values of VL and MH are nearly equal.

Taking a closer look at these results, the similarity values of ML are always the highest; the similarity values of very high (VH) are always the lowest. It can be seen that the variations in the first-level indicator weights within a

Fig. 3: Investment risk similarity value of IFPPs

Fig. 4: Sensitivity analysis results of indicator weights
certain extent have no significant impact on the final results. Therefore, the results obtained by using this model are correct and scientific.

4.4.2 Fluctuation in the number of experts
As the number of experts may have an impact on the results, we invited more experts in risk management or photovoltaic power plants. In this part, we sent out questionnaires to these experts and collected their answers. Considering that too many experts are likely to cause internal confusion among the decision committee, increase the difficulty of data collection, increase the error rate and other issues, too few experts may cause inaccurate evaluation results due to insufficient consideration or large deviations, so the sample sizes are 4, 5, 6, 7, 8, 9 and 10, respectively. And the detailed results are shown in Table 7.

It can be seen from the results that the evaluation results will also change when the total number of experts changes within a certain range. This means that the results vary depending on the attitudes of different experts. But no matter how the total number of experts changes, the risk-evaluation level is consistent, which illustrates the robustness of the framework.

4.5 Comparative analysis
To verify the reliability of the risk-evaluation results, we use the matter-element extension method [40] to conduct the comparative analysis. We divide the effectiveness into seven levels: VL, L, ML, M, MH, H and VH. The classic domain and segment domain of each indictor are shown in Table 8.

First, the indicator information is collected to get the score of each expert. Second, according to the relevant definition of the matter-element extension method, the evaluation level of each indicator is calculated, as shown in Table 9. Next, we can get the comprehensive correlation degree of each evaluation level, as shown in Table 9. Then, according to the principle of maximum correlation, we can get that the investment risk level of IFFPPs is ML. We can find that the above results are consistent with the results in Section 4.3, so the evaluation result is scientific.

5 Suggestions for the development of IFFPPs
The construction of IFFPPs is conducive to alleviating the contradiction between the increase in energy demand and sustainable development. Compared with the construction of traditional photovoltaic power stations, areas with high energy demand and abundant waters such as southern China are more suitable for the development of IFFPPs. In order to effectively avoid investment losses, the relevant risk-response measures are proposed as follows.

5.1 Economic aspect
Economic risk is the highest risk for the development of IFFPPs. High initial investment costs, operation costs and maintenance costs are key factors hindering the development of IFFPPs. In terms of investment costs, investors can increase their efforts to develop new technologies to improve the level of floating photovoltaic technology; at the same time, investors should quantify production based on the actual conditions of IFFPPs, improve management levels and reduce the marginal cost of project investment. From the perspective of operation and maintenance costs, the operation and maintenance of IFFPPs are much more complicated than those of traditional photovoltaic power plants. Investors can adopt intelligent operation and maintenance methods as much as possible to reduce the high labour costs caused by traditional operation and maintenance methods, such as establishing an operation and maintenance platform, using visualization technology based on the combination of building information management and geographic information system, and utilizing robot-inspection technology.

5.2 Social aspect
Factors such as complex approval procedures at the social level, insufficient power demand and public opposition have a greater impact on the investment and operation of IFFPPs projects. Complicated approval procedures have the greatest impact on the investment risk of IFFPPs. In order to further promote the development of IFFPPs, the

| Number of experts | Comprehensive evaluation values | Evaluation level |
|-------------------|---------------------------------|------------------|
| 4                 | (0.228, 0.387, 0.557)           | 0.666           |
| 5                 | (0.229, 0.390, 0.559)           | 0.666           |
| 6                 | (0.233, 0.395, 0.563)           | 0.660           |
| 7                 | (0.234, 0.394, 0.563)           | 0.660           |
| 8                 | (0.229, 0.388, 0.557)           | 0.665           |
| 9                 | (0.231, 0.390, 0.559)           | 0.665           |
| 10                | (0.242, 0.410, 0.588)           | 0.643           |
government functional departments should optimize the work process, improve the efficiency of approval and release relevant information in a timely way; besides, investors should reserve enough time for approval and can also hire professionals to carry out project applications to reduce errors in the application process that are due to insufficient professional knowledge reserves.

5.3 Technical aspect

With the continuous development and improvement of photovoltaic power-generation-related technologies, the possibility of technical risks such as unreasonable site selection, improper structural design and difficulty in grid connection is relatively low, and the impact on the investment and operation of IFPPPs is relatively small. According to the analysis of the fuzzy comprehensive evaluation results of sub-indicators at the technical level, the main technical obstacle hindering the development of IFPPPs is the difficulty of grid connection. Therefore, on the one hand, investors should give priority to choose areas with a relatively good power infrastructure to reduce the risk of project connection to the grid; on the other hand, investors should conduct research on the power market and choose a suitable installation for the local power-market demand. In addition, it is recommended to build corresponding energy-storage equipment to improve the utilization rate of photovoltaic power generation.

5.4 Environmental aspect

According to the results of the case study, environmental risks such as severe weather conditions, corrosion risks and damage to the aquatic environment have the least impact on investment in IFPPPs at this stage. Therefore, investors can identify environmental risks at the end of the project-development stage based on the selected IFPPPs, including meteorological conditions, hydrological environment, etc. Investors also should actively use new anti-corrosion technologies to reduce the corrosion risk and

### Table 8: Classical domain and segment field of each indicator

| Indicators | Classical domain | Segment field |
|------------|------------------|---------------|
| C11        | [0, 0.14]        | [0.14, 0.28]  |
| C12        | [0, 0.14]        | [0.14, 0.28]  |
| C13        | [0, 0.14]        | [0.14, 0.28]  |
| C21        | [0, 0.14]        | [0.14, 0.28]  |
| C22        | [0, 0.14]        | [0.14, 0.28]  |
| C23        | [0, 0.14]        | [0.14, 0.28]  |
| C24        | [0, 0.14]        | [0.14, 0.28]  |
| C31        | [0, 0.14]        | [0.14, 0.28]  |
| C32        | [0, 0.14]        | [0.14, 0.28]  |
| C33        | [0, 0.14]        | [0.14, 0.28]  |
| C41        | [0, 0.14]        | [0.14, 0.28]  |
| C42        | [0, 0.14]        | [0.14, 0.28]  |
| C43        | [0, 0.14]        | [0.14, 0.28]  |

### Table 9: Indicator evaluation results and comprehensive evaluation level

| Indicator | Correlation coefficient | Evaluation level |
|-----------|-------------------------|------------------|
| C11       | -0.068                  | -0.103           | -0.289           | ML               |
| C12       | -0.015                  | -0.045           | -0.081           | -0.103           | -0.289           | ML               |
| C13       | -0.015                  | -0.045           | -0.081           | -0.103           | -0.289           | ML               |
| C14       | -0.015                  | -0.045           | -0.081           | -0.103           | -0.289           | ML               |
| C21       | -0.028                  | -0.045           | -0.081           | -0.103           | -0.289           | ML               |
| C22       | -0.079                  | -0.045           | -0.081           | -0.103           | -0.289           | ML               |
| C23       | -0.035                  | -0.045           | -0.081           | -0.103           | -0.289           | ML               |
| C24       | -0.029                  | -0.045           | -0.081           | -0.103           | -0.289           | ML               |
| C25       | -0.020                  | -0.045           | -0.081           | -0.103           | -0.289           | ML               |
| C31       | -0.023                  | -0.045           | -0.081           | -0.103           | -0.289           | ML               |
| C32       | -0.025                  | -0.045           | -0.081           | -0.103           | -0.289           | ML               |
| C33       | -0.030                  | -0.045           | -0.081           | -0.103           | -0.289           | ML               |
| C34       | -0.028                  | -0.045           | -0.081           | -0.103           | -0.289           | ML               |
| Comprehensive index relevance | 0.577 | 0.891 | 1.000 | 0.832 | 0.690 | 0.574 | 0.000 | ML |
extend the operating life; for example, the new patented pontoon floating system can be considered in IFFFPs. Besides, after IFFFPs are completed, it is necessary to monitor their impact on aquatic plants, animals and water quality; the government should put forward investment norms and operating mechanisms about ‘the integration of fishing and photovoltaic projects’, such as suspending the operation of distributed photovoltaic projects during the harvest season of fishery products and establishing a reasonable fishery compensation mechanism to improve the overall efficiency of investment returns.

6 Conclusions
Taking IFFPPs as the research object, this paper constructs a systematic investment risk-evaluation indicator system for floating photovoltaic power stations from four aspects, including technology, economy, society and environment. Based on the improved HFLTS–TFN method and the BWM–entropy method, an investment risk-assessment model for IFFPPs is constructed and empirically analysed. The result shows that the current investment and financing costs, operation and maintenance costs and other economic risks of China’s IFFPPs are relatively high, the environmental risks are low and the overall project-investment risks are at an ML level. It is recommended that the relevant government departments should improve the supporting policies and declaration procedures for IFFPPs. And investors should take measures such as conducting water environmental investigations and power-market research in advance, adopting advanced technologies such as new anti-corrosion technologies, improving project-management levels and reducing construction costs to reduce investment risk. In summary, the investment risk-assessment model for IFFPPs constructed in this paper identifies important investment risk factors and proposes specific measures to support investors’ investment decisions. At the same time, it has certain theoretical and practical significance for the development of IFFPPs and the realization of low-carbon development.

Funding
This research is supported by the Chinese Postdoctoral Science Foundation (2020M680488).

Conflict of interest statement
None declared.

References
[1] Lee RP, Meyer B, Huang Q, et al. Sustainable waste management for zero waste cities in China: potential, challenges and opportunities. Clean Energy, 2020, 4:169–201.
[2] Zhou Y, Chang FJ, Chang LC, et al. An advanced complementary scheme of floating photovoltaic and hydropower generation flourishing water-food-energy nexus synergies. Applied Energy, 2020, 275:115389.
[3] Cromatie Clemons SK, Salloum CR, Herdegen KG, et al. Life cycle assessment of a floating photovoltaic system and feasibility for application in Thailand. Renewable Energy, 2021, 168:448–462.
[4] Dai J, Zhang C, Lim HV, et al. Design and construction of floating modular photovoltaic system for water reservoirs. Energy, 2020, 191:116549.
[5] Sahu A, Yadav N, Sudhakar K. Floating photovoltaic power plant: a review. Renewable and Sustainable Energy Reviews, 2016, 66:815–824.
[6] Redón Santafé M, Torregrosa Soler JB, Sánchez Romero FJ, et al. Theoretical and experimental analysis of a floating photovoltaic cover for water irrigation reservoirs. Energy, 2014, 67:246–255.
[7] Liu L, Sun Q, Li H, et al. Evaluating the benefits of integrating floating photovoltaic and pumped storage power system. Energy Conversion and Management, 2019, 194:173–185.
[8] Goswami A, Sadhu PK. Degradation analysis and the impacts on feasibility study of floating solar photovoltaic systems. Sustainable Energy, Grids and Networks, 2021, 26:100425.
[9] Cazzaniga R, Cicu M, Rosa-Clot M, et al. Floating photovoltaic plants: performance analysis and design solutions. Renewable and Sustainable Energy Reviews, 2018, 81:1730–1741.
[10] Zadeh LA. Fuzzy sets as a basis for a theory of possibility. Fuzzy Sets and Systems, 1978, 1:3–28.
[11] Wu Y, Liao M, Hu M, et al. A decision framework of low-speed wind farm projects in hilly areas based on DEMATEL-entropy-TODIM method from the sustainability perspective: a case in China. Energy, 2020, 213:119014.
[12] Chen ZS, Zhang X, Govindan K, et al. Third-party reverse logistics provider selection: a computational semantic analysis-based multi-perspective multi-attribute decision-making approach. Expert Systems with Applications, 2021, 166:114051.
[13] Lyu HM, Zhou WH, Shen SL, et al. Inundation risk assessment of metro system using AHP and TFN-AHP in Shenzhen. Sustainable Cities and Society, 2020, 56:102103.
[14] Wu Y, Hu M, Liao M, et al. Risk assessment of renewable energy-based island microgrid using the HFLTS-cloud model method. Journal of Cleaner Production, 2021, 284:125362.
[15] Wang G, Xiao C, Qi Z, et al. Development tendency analysis for the water resource carrying capacity based on system dynamics model and the improved fuzzy comprehensive evaluation method in the Changchun city, China. Ecological Indicators, 2021, 122:107232.
[16] Liang D, Dai Z, Wang M. Assessing customer satisfaction of O2O takeaway based on online reviews by integrating fuzzy comprehensive evaluation with AHP and probabilistic linguistic term sets. Applied Soft Computing, 2021, 98:106847.
[17] Liu P, Zhu B, Wang P. A weighting model based on best–worst method and its application for environmental performance evaluation. Applied Soft Computing, 2021, 103:107168.
[18] Gupta H, Barua MK. A framework to overcome barriers to green innovation in SMEs using BWM and Fuzzy TOPSIS. Science of the Total Environment, 2018, 633:122–139.
[19] Mei M, Chen Z. Evaluation and selection of sustainable hydrogen production technology with hybrid uncertain sustainability indicators based on rough-fuzzy BWM-DEA. Renewable Energy, 2021, 165:716–730.
[20] Kheybari S, Jawdanmehr M, Rezaie FM, et al. Corn cultivation location selection for bioethanol production: an application of BWM and extended PROMETHEE II. Energy, 2021, 228:120593.
[21] Huang B, Zhang L, Ma L, et al. Multi-criteria decision analysis of China’s energy security from 2008 to 2017 based on Fuzzy BWM-DEA-AR model and Malmquist Productivity Index. Energy, 2021, 228:120481.

[22] Feng J, Gong Z. Integrated linguistic entropy weight method and multi-objective programming model for supplier selection and order allocation in a circular economy: a case study. Journal of Cleaner Production, 2020, 277:122597.

[23] Wang T, Du ZA, Zhang K, et al. Reliability evaluation of high voltage direct current transmission protection system based on interval analytic hierarchy process and interval entropy method mixed weighting. Energy Reports, 2021, 7:90–99.

[24] Yuan J, Li X, Xu C, et al. Investment risk assessment of coal-fired power plants in countries along the Belt and Road initiative based on ANP-Entropy-TODIM method. Energy, 2019, 176:623–640.

[25] Zhao J, Ji G, Tian Y, et al. Environmental vulnerability assessment for mainland China based on entropy method. Ecological Indicators, 2018, 91:410–422.

[26] Nazir CP. Coastal power plant: a hybrid solar-hydro renewable energy technology. Clean Energy, 2018, 2:102–111.

[27] Dhimish M, Silvestre S. Estimating the impact of azimuth-angle variations on photovoltaic annual energy production. Clean Energy, 2019, 3:47–58.

[28] Vaishak S, Bhale PV. Investigation on the effect of different backsheet materials on performance characteristics of a photovoltaic/thermal (PV/T) system. Renewable Energy, 2021, 168:160–169.

[29] Bey M, Hamidat A, Nacer T. Eco-energetic feasibility study of using grid-connected photovoltaic system in wastewater treatment plant. Energy, 2021, 216:119217.

[30] Sun G, Tu X, Wang R. Research on the potential-induced degradation (PID) of PV modules running in two typical climate regions. Clean Energy, 2019, 3:222–226.

[31] Geng S, Lin L, Zhang L, et al. Site selection framework of fishing photovoltaic hybrid project under interval-valued intuitionistic fuzzy environment. Journal of Cleaner Production, 2020, 252:119774.

[32] Kui C, Zhang L, Solangi YA. Assessing the renewable energy investment risk factors for sustainable development in Turkey. Journal of Cleaner Production, 2020, 276:124164.

[33] Cazzaniga R, Rosa-Clot M. The booming of floating PV. Solar Energy, 2021, 219:3–10.

[34] Zhang H, Xu Z, Zhou Y, et al. Optimal subsidy reduction strategies for photovoltaic poverty alleviation in China: a cost-benefit analysis. Resources, Conservation and Recycling, 2021, 166:105352.

[35] Wu Y, Tao Y, Zhang B, et al. A decision framework of offshore wind power station site selection using a PROMETHEE method under intuitionistic fuzzy environment: a case in China. Ocean & Coastal Management, 2020, 184:105016.

[36] Trapani K, Millar DL, Smith HCM. Novel offshore application of photovoltaics in comparison to conventional marine renewable energy technologies. Renewable Energy, 2013, 50:879–888.

[37] Rezaei J. Best-worst multi-criteria decision-making method. Omega, 2015, 53:49–57.

[38] Yu W, Zhang Z, Zhong Q, et al. Extended TODIM for multicriteria group decision making based on unbalanced hesitant fuzzy linguistic term sets. Computers & Industrial Engineering, 2017, 114:316–328.

[39] Wu Y, Chu H, Xu C. Risk assessment of wind-photovoltaic-hydrogen storage projects using an improved fuzzy synthetic evaluation approach based on cloud model: a case study in China. Journal of Energy Storage, 2021, 38:102580.

[40] Ng DK, Cai W. Treating non-compatibility problem from matter element analysis to extenics. ACM Sigice Bulletin, 1997, 22:2–9.