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Optimal investment selection of industrial and commercial rooftop distributed PV project based on combination weights and cloud-TODIM model from SMEs' perspectives

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ABSTRACT

Photovoltaic with its main characteristics of clean and abundant reserves has been widely used. This paper investigates how to select a satisfactory industrial and commercial rooftop distributed photovoltaic (ICR-DPV) project to invest from the small and medium-sized enterprises' (SMEs) view. Flaws and inadequacies existing in the current decision-making process may cause an inaccurate investment result. Therefore, this paper establishes a cloud-TODIM framework to deal with the problems. First, criteria covering the economy, resource, risk factors and engineering feasibility are established. Second, hesitant fuzzy linguistic term set (HFLTS) and cloud model are applied to describe the indeterminate information so that the hesitation and randomness of linguistic variables can be fully expressed. Third, the analytic network process (ANP) method and entropy method are combined to gain the criteria weights, which can not only avoid too much subjectivity in weight determination but also measure the mutual influence between the various criteria simultaneously. Furthermore, the TODIM method considers the psychological behavior of investors, so it is utilized to rank alternatives to make the framework more applicable for practical evaluation. Finally, a case in Shandong province validates the applicability of the proposed framework. This paper provides a more rational and scientific decision-making framework for investors.

1. Introduction

With the explosive growth in 2017, distributed photovoltaic (DPV) has emerged as one of the most energetic and promising new energy industries in China (see Fig. 1), with its advantages of the low power loss and land saving. However, the increasingly prominent subsidy contradictions have become the bottleneck of the PV industry. And the targeted deal, which was implemented on June 1, 2018, arranges a construction scale of about 10 MW to support DPV projects. It plunges the booming PV industry into a transition period and promotes the emergence of new markets.

Under this circumstance, the industrial and commercial rooftop distributed PV (ICR-DPV) projects, with the larger and flatter rooftop area and greater power consumption than household rooftops, have received greater attention than ever (Wu et al., 2018b). More importantly, even without subsidies, the electricity bill saved by DPV generation system can also reduce the burden of business expenses.

Small and medium-sized enterprises (SMEs) play an important role in China' economy as they contribute more than 50% of China's tax revenue and more than 60% of GDP. However, the continuous escalation of Sino-US trade conflicts has brought serious and even fatal effects to a number of SMEs. In addition, China is entering a new stage of reform, but the development of SMEs is still confronted with an austere challenge. Thus, it is extremely urgent to seek a way out for the small and medium-sized PV enterprises under the double impact of the new deal and Sino-US trade war.

1.1. Literature review

Based on the recent research of ICR-DPV, most scholars focus on technical and economic feasibility (Bai, 2014; Ming et al., 2015), site selection (Liu et al., 2017; Maurovich-Horvat et al., 2016), PV module supplier selection (Li et al., 2018), distribution systems optimization (Fergani et al., 2016), negative impact (Silva et al.,

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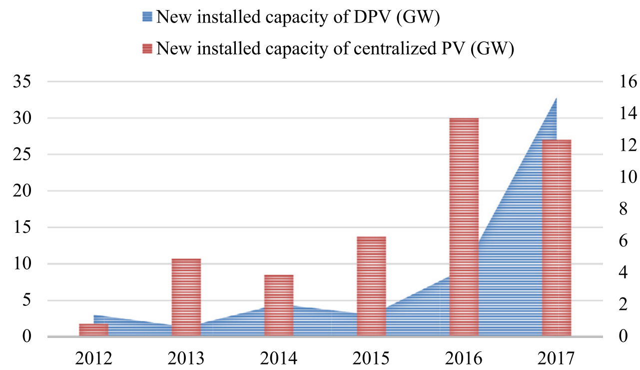

Fig. 1. New installation capacity of PV in past years. Data resources: China Industry Information Network (Network, 2018).

2016) and so on. And in the research field of ICR-DPV investment, Chen (Shujie, 2017) used value engineering method to compare investment patterns including the single player model of investor and game model among government, power supplier and investor. Li (2017) identified and analyzed multiple risks such as policy, project design and construction, operation and external environment, and then proposed relevant investment risk control strategies based on an actual case. Kwangbok et al. (Jeong et al., 2015) evaluated absolute and relative investment value of the system to help determine the optimal investment strategy based on the assessment of the life-cycle economy and environment in the rooftop PV system. Filippo (Spertino et al., 2013) provided a technical-economic analysis of investment in large scale rooftop PV systems based on incentive policies and the application of the PV market in Germany and Italy.

As noted above, though most of the current literature deals with the mode, risk, policy influence and economic evaluation of ICR-DPV investment, they have universal adaptability to all PV enterprises for the macro sense. In addition, studies on SMEs investment mostly focus on strategies (Ausloos et al., 2018), financing (Chih et al., 2018; Hasan et al., 2018) and risk evaluation (Zhu, Y. et al., 2016; Zhu et al., 2017), and researches in the energy sector still focus on energy efficiency. Thus, given the development status of SMEs, as well as the different investment characteristics between SMEs and large enterprises, conducting the specific analysis for ICR-DPV project investment can contribute to filling in the vacancy and insufficiency in present references at the current critical and sensitive period of PV policy shift.

1.2. Research gaps and aim

The investment selection of ICR-DPV project is a complex problem related to many aspects, such as favorable illumination conditions, available roof area, the amount of funding, and so forth. In this sense, the investment selection of ICR-DPV project is a complex multi-criteria decision making (MCDM) problem including an integrated description of evaluation results, a reasonable determination of weight and a proper ranking method. The problems existing in the decision-making process of may fail ICR-DPV project investment.

The first problem needed to be solved is the selection of linguistic variables. The uncertainty and ambiguity are inevitable in the practical decision-making process. Besides, it is difficult for the exact numbers to describe the preference of decision-makers due to the limitations of human understanding and indecision between multiple possible levels in the assessment (Rodriguez et al., 2012; Yuan et al., 2018). Hence, a variety of linguistic variables have been used in the decision-making process to assess alternatives, such as 2-dimension linguistic variable (Wu et al., 2018c), interval-valued triangular fuzzy numbers (Bai and Liu, 2014; Dahooie et al., 2018) and intuitionistic fuzzy sets (Devi and Yadav, 2013; Wu et al., 2016c). Though describing the uncertainty and ambiguity of evaluation indices in different ways, they lose sight of randomness and hesitation in expert grading. To handle this problem, a cloud model with hesitant fuzzy language term set (HLFTS) is introduced to reveal the uncertain state between two or more linguistic terms (Wang, H. et al., 2018). It gives the corresponding credibility and further describes the uncertain information as it considers not only the average levels of evaluation information but also fluctuation and stability. So far, few articles apply it in the investment decision-making process, as a result, this combination enriches the means and commutation of expression, as well as fills the blank in this field.

From the perspective of weight definition, subjective weighting method (Aragonés-Beltrán et al., 2014; Wu et al., 2016b) and objective weighting method (Cai et al., 2013; Wu et al., 2016c) are most commonly used at present. However, since the subjective weights are determined according to the knowledge and experience of DMs, it is ineluctable to influence the results on account of factitious factors and fuzzy randomness. In addition, objective weighting methods require high veracity of information, which limits the scope of application in some fields. This paper adopts combination weighting method to help gain a more reasonable weight as it bonds the subjective weight and objective weight organically (Väisänen et al., 2016).

With respect of ranking methods, the comparative analysis of common methods is shown in Table 1. There are multitudinous and complicated factors in ICR-DPV project investment decision process. The spontaneous risk aversion behavior and reference dependence psychology of investors are easily overlooked, while the superiority of TODIM lies in the embodiment of psychological behavior. So it is applicable for this circumstance exactly.

This paper aims to: 1) conduct identification and assessment of ICR-DPV investment factors from the perspective of SMEs and 2) establish the ICR-CPV investment decision-making framework by using a cloud—TODIM model. Compared to the previous studies, the main contributions of this paper are as follows: First, this study targets the scope of SME investment in ICR-DPV projects with minimal relevant studies involved, which has great theoretical significance and practical value for optimal investment selection of PV projects. Second, the analytic network process (ANP) method and entropy method are integrated for weight calculating so that interactional relationship between factors and objective information can be fully expressed without valid information loss. Third, by utilizing cloud-TODIM model, the ambiguity and randomness of evaluation results can be expressed simultaneously and DMs' bounded rational can be taken into account. In conclusion, the aforementioned improvements provide new perspective for establishing an effective investment decision-making framework in ICR-DPV or other renewable energy projects from the perspective of SMEs at home and abroad.

This paper is organized as follows. Section 2 elaborates the evaluation index for SME investment in ICR-DPV projects and then constructs the corresponding index system. Section 3 illustrates the fundamental conceptions of ANP method, entropy method and cloud model, and then puts forward a novel decision framework of ICR-DPV investment. Section 4 applies the framework to a case in Shandong province, China. Section 5 makes the sensitivity analysis, comparative analysis and benefit analysis to testify the robustness and superiority of the proposed framework. Section 6 draws the conclusion.

Table 1
Comparative analysis of common ranking methods.

Theory	Methods	Relevant researches	Distinguishing Feature(s)
Utility theory	Linear weighting method	(Alwine and Dejmek, 1993; Chen et al., 2009)	It is easy to cause information loss and distortion by aggregating operators to get global values directly.
	TOPSIS	(Bai, 2014; Kengpol et al., 2013)	The final ranking value of alternatives can be obtained, but the reasons why the alternative satisfies the criteria or dissatisfies the criteria cannot be displayed concretely, thus it is not conducive to follow-up the improvement.
	VIKOR	(Wan et al., 2013; Wu et al., 2016a)	
Outranking relation	ELECTRE	(Govindan and Jepsen, 2016; Wu et al., 2016c)	The compensation problem can be solved to some extent, but the calculation process requires more parameters and is relatively complex.
	PROMETHEE	Wu et al. (2018a)	There is no need for dimensionless and standardized processing, but the psychological behavior of DMs is not considered.
Prospect theory	TODIM	(Chen et al., 2015; Qin et al., 2017)	It assumes that DMs are bounded rational, the psychological characteristics and loss avoidance behavior of DMs are considered in particular.

2. Analysis of evaluation attributes

ICR-DPV project investment from the standpoint of SMEs is influenced by various factors which include not only the total lifecycle cost, but also energy factors and risk factors. Besides, numerous aspects of engineering feasibility factors deserve conscientious consideration1]. On the grounds of the available literature, expert suggestions from different fields and feasibility research reports, the attributes considered for the investment of ICR-DPV projects are divided into economy factors, resource factors, risk factors and engineering feasibility. Table 2 presents the evaluation index system (including 12 sub-criteria) for ICR-DPV project investment, which will be employed hereinafter. The interpretations of sub-criteria are listed in detail as below.

2.1. Economy factors

Three sub-criteria affiliated with the economy factors for ICR-DPV project investment are aggregated as follows:

(1) Construction cost (C11): It accounts for a large percentage in investment cost(Wu et al., 2018b), including land acquisition and demolition costs, site preparation and facility costs, power distribution facility costs, transportation costs, and so on.
(2) Operation and maintenance cost (C12): It consists of various fees and amortization of daily operation and maintenance. In addition, the solar panels, batteries, inverters and controllers need regular cleaning, maintenance and replacement in order to avoid performance and efficiency degradation (Wu et al., 2018b), which will certainly give rise to the cost as well.
(3) Annually average capital income (C13): It reveals the profitability of projects directly (Wu et al., 2018b). SMEs attach great importance on it because of its small scale and limited economic strength.

According to the mathematical model (Wang et al., 2017), $I = \sum_{i=1}^{n} I_S + \sum_{i=1}^{n} I_F$, $I_S = Q \times P_1$, $I_F = Q \times P_2$, where I means generating revenue, I_S means sales revenue, I_F means fiscal subsidy, n means life cycle, Q means power generation, P_1 means feed-in tariffs and P_2 means subsidy electricity price. As we can see from the model, when subsides have been completely removed, SMEs only rely on electricity selling to make profits. Particularly, China has introduced the carbon trading scheme, and pilot work has been carried out in seven places. Since PV project has almost no carbon emissions, it may be a significant benefit to small and medium-sized PV enterprises because they can trade surplus carbon emission rights in the market transactions and the extra revenue can subsidize the installation costs.

Table 2
Evaluation index system for ICR-DPV project investment.

Criteria	Sub-criteria
Economy factors	Construction cost
	Operation and maintenance cost
	Annually average capital income
Resource factors	Sunshine time
	Global horizontal irradiance
	Gross installation area
Risk factors	Extreme weather damage
	Fluctuations in policy
	Loan financing and solvency
Engineering Feasibility	Electrical transmission and distribution system
	Influence on power quality
	Electricity demand

2.2. Resource factors

Three sub-criteria related to the energy factors are summarized below:

(1) Sunshine time (C21): It intuitively measures the richness of solar energy resources (Wu et al., 2014). And it is deeply influenced by regional characteristics and represents the time that solar radiation can be effectively used in some places within one year.
(2) Global horizontal irradiance (GHI) (C22): It depends on both the latitude and the longitude, which reflects the total amount of solar radiation and has an enormous and crucial impact on the electricity generation. GHI is comprised of direct normal irradiance (DNI) (Wu et al., 2014) and diffuse horizontal irradiance (DHI), and meets $GHI = DHI + DNI \times \cos\theta$, θ stands for the solar zenith angle here.
(3) Gross installation area (C23): It refers to the rooftop area where the structure load meets the requirements and obstacles are eliminated. Furthermore, it determines the number of placeable solar panels and total installed capacity(Hu et al., 2016).

2.3. Risk factors

Three sub-criteria concerned with the risk factors are aggregated as follows:

(1) Extreme weather damage (C31): It probably stays throughout the ICR-DPV project as the photovoltaic devices

are installed in the rooftop and fully exposed to the open air (Wu and Hu, 2016). During the preparation period, construction investment against low temperature, lightning protection, anti-fog and anti-dust (Gao, 2015) should be added to resist the damage of natural disasters in different degrees. During the operation period, it is necessary to strengthen the forecast of the weather and strive to minimize the risk before the natural disaster arrives.

(2) Fluctuations in policy (C32): The feed-in tariff of ICR-DPV does not have a price advantage, it relies on national and regional subsidy policy at the present stage (Wu and Hu, 2016). Besides, the government support and encouragement for ICR-DPV vary from place to place. Thus, it is necessary to study relevant policies, make reasonable choices before investing. What's more, focusing on the sustainability and implementation of government subsidies is also of great significance. Carbon trading market system is still in its infancy in China, and carbon tax is on the way of its discussed and planned. So, SMEs need to pay attention to the impact of local policy fluctuations on profits.

(3) Loan financing and solvency: ICR-DPV investment has the characteristics of high initial investment cost and long payback period (Li, 2017). Compared with large enterprises, SMEs have relatively narrow financing channels and high borrowing costs, which further affect corporate reputation and repaying capability.

2.4. Engineering feasibility

Three sub-criteria relevant to the engineering feasibility are summarized below:

(1) Electrical transmission and distribution system (C41): It assesses whether the current power grid or its future planning accords with the power supply requirements (e.g., voltage level, grid) (Wang et al., 2015) and reflects the feasibility of grid access technology.

(2) Influence on power quality (C42): It tests the ability of adaptation to transmission loss of local power grid. As PV system connects to the electricity grid by inverter usually, it may affect voltage distribution in feeders and produce the harmonic pollution (Gao, 2015).

(3) Electricity demand (C43): It reflects the potential of the PV market and the need for ICR-DPV projects in different regions owing to its alleviation of time-based and regional power shortages (Bai, 2014). And more importantly, on-grid energy concerns the economic benefits of PV systems.

3. Methodology

The ICR-DPV project practical investment decision-making scenes involve various complex and interrelated factors. However, traditional researches tend to focus on how to evaluate and select the alternatives by using methods or models, but neglect the psychological behavior factors of DMs and practical operability.

This section constructs a framework for SMEs to make ICR-DPV investment decision-making, including the description of the linguistic information, the determination of the index weights and the ranking of the alternatives based on the interpretation of the basic theory and steps of the decision model. The three-stage decision framework for ICR-DPV investment is shown in Fig. 2.

3.1. HFLTS: the expression of linguistic information

In traditional linguistic decision frameworks, the expression of linguistic information is quite limited for the reason that the information must be expressed in a predefined terminology. However, for the description of indicator information, fuzzy language is easier to understand and accurate than quantitative information. HFLTS have been proposed to facilitate the simultaneous use of multiple consecutive terms and adopted to express vagueness and hesitations recently (Wang, H. et al., 2018).

Definition 1. (Zhang et al., 2017): Let $S = \{s_0, s_1, s_2, \ldots, s_n\}$ be a linguistic term set with odd granularity $g+1$. Generally, the linguistic term set should meet the following conditions:

(1) The set is ordered: $s_i \geq s_j \Leftrightarrow i \geq j$;
(2) Maximum operator: If $s_i \geq s_j$, then $\max(s_i, s_j) = s_i$;
(3) Minimal operator: If $s_i \geq s_j$, then $\min(s_i, s_j) = s_j$;
(4) There exists a negation operator: $neg(s_i) = s_j j = g - i$.

Definition 2. (Zhang et al., 2017): Let $S = \{s_0, s_1, s_2, \ldots, s_n\}$ be a linguistic term, H_s be an ordered finite subset of the consecutive linguistic terms of S. It can be defined as follows:

$$H_s = \{\langle x, h(x)\rangle | x \in X\} \tag{1}$$

Definition 3. (Zhu, C. et al., 2016): Let $S = \{s_0, s_1, s_2, \ldots, s_n\}$ be a linguistic term set, where n is an even number, a HFLTS in S is a set that when applied to the linguistic terms of S returns a subset of S with several values in [0, 1], denoted by $H(x) = \{(s_i, l(s_i)) | s_i \in S\}$, where $l(s_i) = \{r_1, r_2, \ldots, r_{yi}\}$ is a set with y values in $[0, 1]$ denoting the possible membership degrees of the element $s_i \in S$ to the set $H(x)$.

3.2. Cloud model: the quantification of appraisal value

Definition 4. (Wu, Y. et al., 2016a,b,c,d). Let $U = \{A\}$ be the universe of discourse and Q a linguistic variable in U. If $x (x \in U)$ is a random instantiation of concept Q satisfying $En' \sim N(En, He^2)$, $x \sim N(Ex, En'^2)$ and the certainty degree of x belonging to variable Q meets:

$$\mu = e^{-\frac{(x-Ex)^2}{2(En')^2}} \tag{2}$$

Then the distribution of x in the universe U is called a normal cloud. The cloud model describes the overall quantitative property by three numerical characteristics, which are:

(1) Ex: Expectation, which is the mathematical expectation of the cloud drops in the qualitative linguistic universe and is the most representative sample of the concept.
(2) En: Entropy, which represents the indeterminacy of the qualitative concept and is determined by the ambiguity and randomness of the concept.
(3) He: Hyper entropy, which is the measurement of the uncertainty of En and mainly indicates the dispersion of the cloud drops.

Definition 6. (Wang, J.-J. et al., 2018). Let x_1, x_2 be two normal clouds: $x_1 = (Ex_1, En_1, He_1)$, $x_2 = (Ex_2, En_2, He_2)$. The distance between x_1 and x_2 is defined as follows:

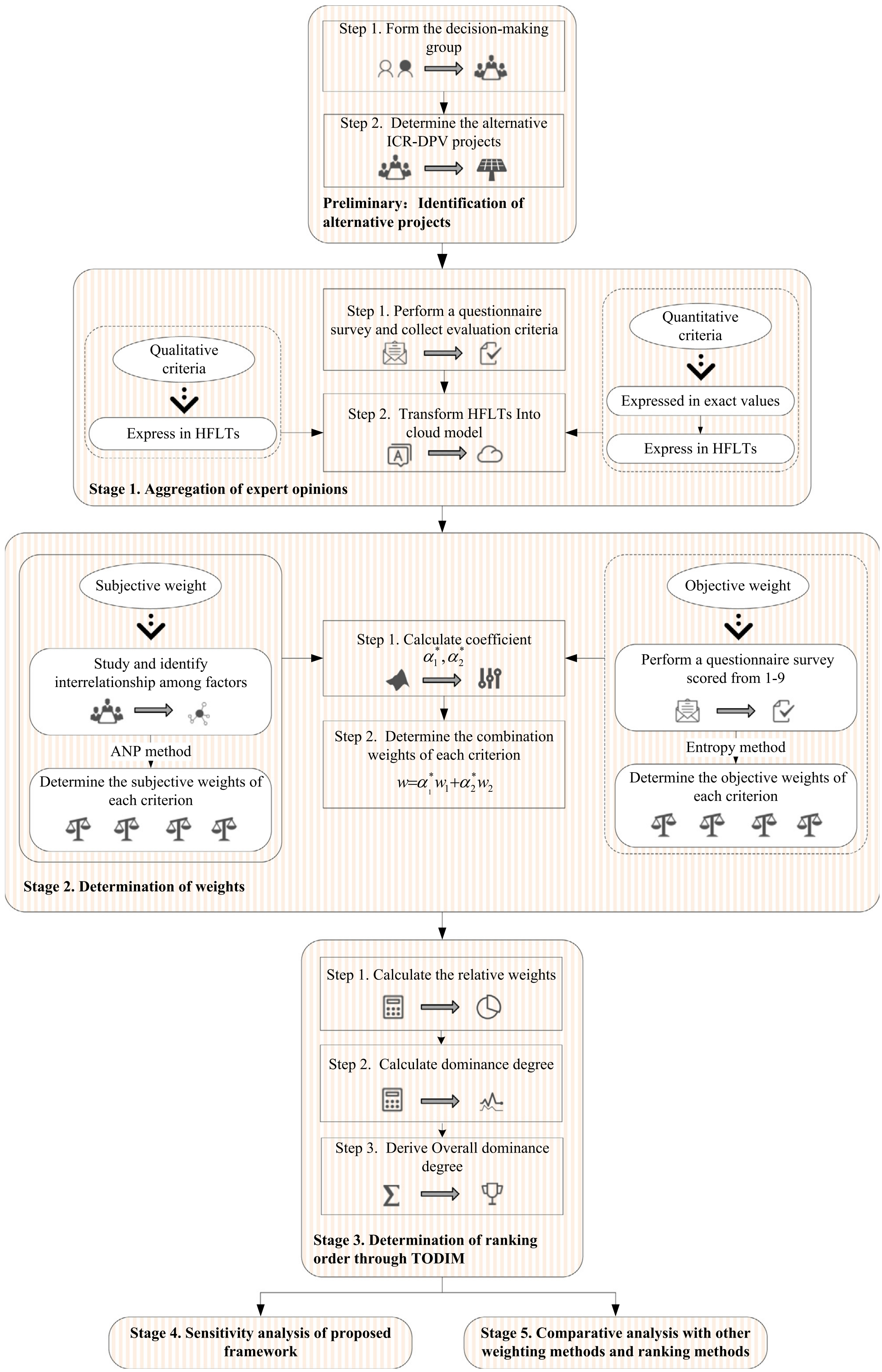

Fig. 2. The flowchart of the proposed framework for ICR-DPV investment.

$$d(x_1,x_2)=\left|\left\langle 1-\frac{(En_1)^2+(He_1)^2}{(En_1)^2+(He_1)^2+(En_2)^2+(He_2)^2}\right\rangle Ex_1-\left\langle 1-\frac{(En_2)^2+(He_2)^2}{(En_1)^2+(He_1)^2+(En_2)^2+(He_2)^2}\right\rangle Ex_2\right| \tag{3}$$

3.3. The entropy theory: the determination of objective weights

Definition 2 (Tang, 2011). Let e_j be the entropy of attribute j:

$$e_j=-\frac{1}{\ln n}\sum_{i=1}^{m}\left\langle \frac{y_{ij}}{\sum_{i=1}^{m}y_{ij}}\times\ln\left(\frac{y_{ij}}{\sum_{i=1}^{m}y_{ij}}\right)\right\rangle \tag{4}$$

where $e_j\in[0,1]$.

Definition 3 (Tang, 2011). Let g_j, ω_j be the otherness coefficient and entropy weight of attribute j respectively:

$$g_j=1-e_j \tag{5}$$

$$\omega_j=\frac{g_j}{\sum_{i=1}^{n}g_j} \tag{6}$$

where $\omega_j\in[0,1]$ and $\sum_{j=1}^{m}\omega_j=1$. The value of g_j indicates the inconsistency in the contribution of each attribute, and ω_j reflects the difference between two attributes.

3.4. Comprehensive integration weighting method based on game theory: the integration of subjective and objective weights

The basic theory of this weighting method is to minimize the deviation between the obtained combination weight and each basic weight, and establish the target model according to the optimization goal (Zeng and Liu, 2017):

$$\min\|\alpha_1W_1+\alpha_2W_2-W_j\|_2(\alpha_j>0,j=1,2) \tag{7}$$

where $\alpha_1W_1+\alpha_2W_2$ represents a linear combination of subjective and objective weights, and the final combination weight w can be obtained by adjusting the value of α_i.

The first derivative condition that satisfies the optimization can be inferred firstly:

$$\sum_{i=1}^{2}\alpha_iW_jW_i^T=W_jW_j^T(j=1,2) \tag{8}$$

and the corresponding linear equation is:

$$\begin{bmatrix}W_1W_1^T & W_1W_2^T\\ W_2W_1^T & W_2W_2^T\end{bmatrix}\begin{bmatrix}\alpha_1\\ \alpha_2\end{bmatrix}=\begin{bmatrix}W_1W_1^T\\ W_2W_2^T\end{bmatrix} \tag{9}$$

Then, normalize the value of α_1 and α_2 after it is calculated, and get the subjective weighting coefficient α_1^* and objective weighting coefficient α_2^*, meeting:

$$\begin{cases}\alpha_1^*,\alpha_2^*>0\\ \alpha_1^*+\alpha_2^*=1\end{cases} \tag{10}$$

Finally, the combination weight of each attribute can be obtained:

$$w=\alpha_1^*W_1+\alpha_2^*W_2 \tag{11}$$

3.5. Investment decision framework of the ICR-DPV project

According to the above theoretical analysis, a cloud-TODIM model is built to develop a novel framework for ICR-DPV project investment decision for SMEs. The algorithm framework is shown in Fig. 2 and the steps are described as follows.

Stage 1: Expression of evaluation information.

The procedure of how to transform HFLTS into clouds can be summarized in the following steps:

Step 1. Determine the alternatives and evaluation criteria. There are K experts to evaluate the influence factors of investment for n alternatives, and initial assessment language values are given.

Step 2. Transfer the initial language values into HFLTS by functions below (Wang, H. et al., 2018):

(1) $E_{G_H}(s_i)=\{s_i|s_i\in S\}=\{s_i\}$
(2) $E_{G_H}(between s_i and s_j)=\{s_k|s_k\in S and s_k\geq s_i and s_k\leq s_j\}=\{s_i,s_{i+1},\ldots,s_j\}$
(3) $E_{G_H}(less than s_i)=\{s_j|s_j\in S and s_j\leq s_i\}=\{s_0,s_1,\ldots,s_i\}$
(4) $E_{G_H}(greater than s_i)=\{s_j|s_j\in S and s_j\geq s_i\}=\{s_i,s_{i+1},\ldots,s_g\}$

Taking into account the uncertainty of investment environment, experts may have a preference to give language term on the basis of their own experience and corresponding statistical data during this conversion process. Based on this, after completing the conversion, we obtain HFLTS $H(x)=\{(s_i,l(s_i))|s_i\in S\}$ with the possible membership degrees of all evaluation indices.

Step 3. (Zhu, C. et al., 2016): Transform the HFLTS $H(x)=\{(s_i,l(s_i))|s_i\in S\}$ into the cloud $Y_{H(x)}$ ($Ex_{H(x)}$, $En_{H(x)}$, $He_{H(x)}$) according to the following process and aggregate into an integrated matrix:

(1) Let the linguistic term set be

$S=$ - $\{s_0:\ poor, s_1:\ medium\ poor, s_2:\ medium, s_3:\ medium\ good, s_4:\ good\}$ where the universe is $[X_{min},X_{max}]$. Five clouds can be generated with their numerical characteristics utilizing the golden ratio. After that, the relation between linguistic variables and their corresponding clouds can be obtained:

$$Ex_0=(X_{\min}+X_{\max})/2,\ Ex_{\frac{n-1}{2}}=X_{\max},\ Ex_{-\frac{n-1}{2}}=X_{\min} \tag{12}$$

$$Ex_j=\frac{Ex_0+0.382j(X_{\min}+X_{\max})/2}{n-3/2} \tag{13}$$

$$Ex_{-j}=\frac{Ex_0-0.382j(X_{\min}+X_{\max})/2}{n-3/2},\ \left(1\leq j\leq\frac{n-3}{2}\right) \tag{14}$$

$$En_{-1}=En_1=0.382(X_{\max}-X_{\min})/6 \tag{15}$$

$$En_0 = 0.618En_1,\ En_{-j} = En_j = En_{j-1}/0.618,\ \left(2 \le j \le \frac{n-1}{2}\right) \tag{16}$$

$$He_{-j} = He_j = He_{j-1}/0.618 \tag{17}$$

where He_0 is given by experts.

(2) Based on the linguistic variables and their corresponding clouds, the conversion from HFLTS to clouds can be accomplished:

$$Ex_{H(x)} = \frac{1}{|index(H(x))|}\left(\sum_{i\in index(H(x))}\frac{Ex_i}{|l(s_i)|}\left(\sum_{r\in l(s_i)} r\right)\right) \tag{18}$$

$$En_{H(x)} = \sqrt{\frac{1}{|index(H(x))|}\left(\sum_{i\in index(H(x))}(En_i)^2\right)} \tag{19}$$

$$He_{H(x)} = \sqrt{\frac{1}{|index(H(x))|}\left(\sum_{i\in index(H(x))}(He_i)^2\right)} \tag{20}$$

where $|l(s_i)|$ is the count of a real number in $l(s_i)$, and $|index(H(x))|$ is the cardinality of $index(H(x))$, $index(H(x)) = \{i|(s_i, l(s_i))\in H(x), l(s_i)\ne\{0\}\}$ with $s_i\in S$.

Stage 2: Determination of combination weights of criteria.

The subjective weights are obtained by ANP method. It not only fully reflects the knowledge and experience of DMs, but also considers the correlation between criteria. Meanwhile, the objective weights are calculated by the entropy method based on the actual data.

Step 1. Construct the ANP structure, determine the mutual influence relationship among each factor, establish the pairwise comparison matrix, and then use the Super Decision software to derive the subjective weights ω_{1j}.

Step 2. Recycle questionnaires which are scored respectively from 1 to 9 based on their importance from experts. Normalize the questionnaire data and get the objective weights ω_{2j} according to formula (4) through (6).

Step 3. Use Matlab software to calculate coefficient α_1^* and α_2^* based on formula (9) and (10), and combine the subjective weights and objective weights by using comprehensive integration weighting method based on game theory and derive the combination weights ω_j finally.

Stage 3: Selection of optimal investment projects.

TODIM is the extension of the prospect theory, which incorporates the DMs' psychological behavior into MCDM process (Wu et al., 2018a). The TODIM method takes DMs' cognitive competence, emotion and psychology into consideration, eliminates occasional inconsistencies resulting from these comparisons and implements value judgment (Chen et al., 2015). Since the classical TODIM model is inapplicable to the fuzzy environment directly, this paper expands it to fit in the cloud model better.

Step 1. Let $\omega_j = \max\{\omega_j|j = 1, 2, ..., m\}$ and ω_{jr} be the relative weight for attribute b_j relative to attribute b_r, and

$$\omega_{rj} = \frac{\omega_r}{\omega_j} \tag{21}$$

Step 2. Calculate the weight and dominance degree of the alternative A_p relative to the alternative A_q as below:

$$\delta(A_p, A_q) = \sum_{j=1}^{m}\phi_j(A_p, A_q)$$

where

$$\phi_j(A_p, A_q) = \begin{cases} \sqrt{\dfrac{d(x_{pj}, x_{qj})\omega_{jr}}{\sum_{j=1}^{m}\omega_{jr}}}, if x_{pj} - x_{qj} > 0 \\ 0, if x_{pj} - x_{qj} = 0 \\ -\dfrac{1}{\theta}\sqrt{\dfrac{d(x_{qj}, x_{pj})\sum_{j=1}^{m}\omega_{jr}}{\omega_{jr}}}, if x_{pj} - x_{qj} < 0 \end{cases} \tag{22}$$

In this definition, the parameter θ is the loss aversion coefficient. The decrease of θ means that DMs are more inclined to reduce the risk of loss occurrence than maximizing profit. In addition, $d(x_{pj}, x_{qj})$ represents the distance between clouds x_{pj} and x_{qj} which can be calculated by formula (3).

Step 3. Work out the overall dominance degree of the alternative A_p relative to other alternatives as follows:

$$T(A_p) = \sum\nolimits_{q=1}^{m}\delta(, A_q) \tag{23}$$

where $\delta(, A_q) = \sum_{j=1}^{n}\phi_j(A_p, A_q)$, $p, q\in m$.

Step 4. Standardize $T(A_p)$, get the overall dominance degree $S(A_p)$ and rank the alternatives. The project with the maximum $S(A_p)$ is the optimal project to invest finally.

$$S(A_p) = \frac{T(A_p) - \min T(A_p)}{\max T(A_p) - \min T(A_p)}, \quad p = 1, 2, \cdots, m \tag{24}$$

4. A case study

In order to verify the feasibility of the above-mentioned framework in the actual decision-making environment, this section practically applies it to real case of ICR-DPV investment selection for SMEs.

4.1. Project overview

According to the distribution of solar energy resources in Table 3 and the DNI of Shandong province given by National Renewable Energy Laboratory (NREL) shown in Fig. 3, Shandong province which belongs to II zone is one of the solar energy-rich regions in China. More than two-thirds of the regions have over 2200 h of sunshine time per year, providing a broad development prospect for ICR-DPV. Due to the limited budget, a SME plans to invest an ICR-DPV project in Shandong province after a thorough investigation. It selects 11 approved projects as alternatives from the enterprise's project library. The basic situations of the projects are shown in Table 4 and their locations are marked in Fig. 3.

Before applying the decision model constructed in this paper, the primary election should be conducted for ICR-DPV projects. Considering the small scale of SME assets and the weak ability towards external economic shocks, large-scale projects such as A_2

Table 3
Regional classification of solar energy in China.
Data resources: China Meteorological Administration Wind and Solar Energy Resources Center.

Partition	Annual total radiation (MJ/m^2)	Annual total radiation (kW·h/m^2)	Average daily radiation (kW·h/m^2)
I	≥6,300	≥1,750	≥4.8
II	5,040–6,300	1,400–1,750	3.8–4.8
III	3,780–5,040	1,050–1,400	2.9–3.8
IV	<3,780	<1,050	<2.9

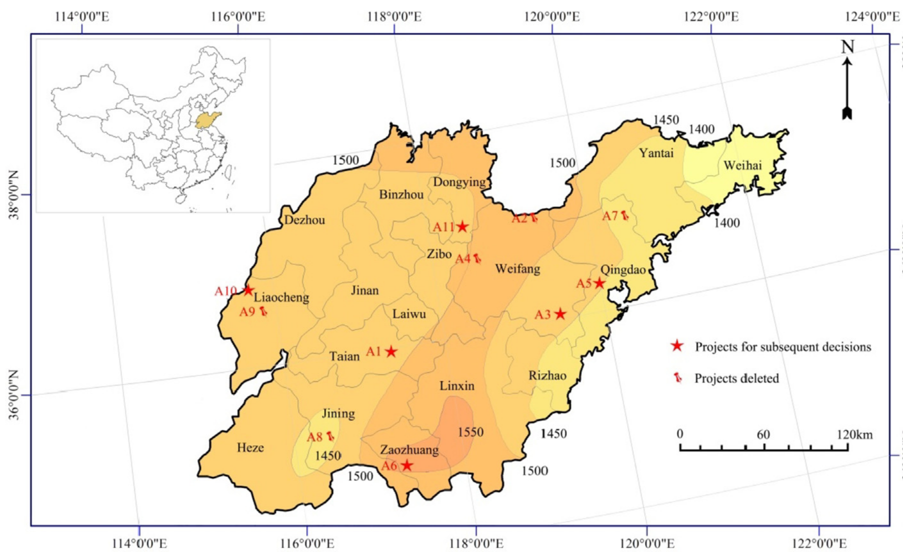

Fig. 3. DNI resource map and geographical locations of ICR-DPV project alternatives.

Table 4
The basic situations of alternatives.

Project	Location	Gross installation area (10^3 m^2)	Installed capacity (MWp)	Sunshine duration (h)	Date of declaration (y/m)	Electricity consumption in 2017 (billion kW·h)
A_1	Xintai	103.5	5.7	2,443	2016/8	18.128
A_2	Shouguang	490.0	40.0	2,541	2016/6	49.385
A_3	Zhucheng	94.3	3.0	2,471	2017/3	49.385
A_4	Qingzhou	50.1	4.5	2,612	2016/9	49.385
A_5	Jiaozhou	194.6	7.7	2,571	2017/10	40.106
A_6	Zaozhuang	147.0	5.0	2,700	2018/2	13.521
A_7	Laixi	27.8	3.0	2,019	2018/6	40.106
A_8	Jining	53.0	5.2	1,962	2017/12	28.112
A_9	Liaocheng	236.0	20.0	2,598	2017/5	26.226
A_{10}	Linqing	3.4	0.4	2,650	2018/4	26.226
A_{11}	Dongying	11.5	1.1	2,341	2017/9	27.756

Data resources: Shandong Development and Reform Commission and Shandong Provincial Bureau of Statistics.

and A_9 which may increase their financial risks and greatly test their solvency are excluded. Meanwhile, according to "Notice on Matters Related to Distributed Photovoltaic Grid-connected" issued by State Grid Shandong Electric Power Company (News, 2018) in June 2018, the newly applied distributed photovoltaic project will be suspended acceptance in addition to the poverty alleviation project. As a result, it is unavailable to invest project A_7. Besides, there are numbers of coal mining groups around A_8, which may exhaust a lot of soot and affect the efficiency of solar panels, taking on great safety and operational risks. Moreover, while the lifetime of PV power generation is about 25 years, the rooftop service life of A_4 is less than 17 years. From this perspective, it not only influences the continuous and stable consumption of PV, but also shuts down the project due to factors such as relocation. Based on the above analysis, before the decision on the ICR-DPV projects, projects A_2, A_4, A_7, A_8 and A_9 are deleted. And finally six ICR-DPV projects for subsequent decisions are determined, respectively A_1, A_3, A_5, A_6, A_{10} and A_{11}.

4.2. Decision model application

In order to carry out a comprehensive assessment of all alternatives, the enterprise invited 50 experienced experts to form an expert committee to ensure the professionalism, effectiveness and rationality. After discussion, the expert committee finalized a set of project investment indicator systems applicable to SMEs, including economy factors, resource factors, risk factors and engineering feasibility, which is shown in Table 2. The pilot projects of carbon trading approved by the National Development and Reform Commission in October 2011 were Beijing city, Shanghai city, Tianjin city, Chongqing city, Hubei province, Guangdong province and Shenzhen city, while Shandong province had not been included in the scope. For this reason, this case does not take the impact of carbon trading on SMEs investment into consideration.

4.2.1. Stage 1

Based on the determined decision index system, the expert groups give the initial assessment language value of ICR-DPV project evaluation criteria by the Delphi method according to their professional background and experience. The qualitative criteria are expressed in language values, and the quantitative criteria are expressed in exact values. Since direct weighting of exact values may increase the gap between projects, experts use language to evaluate the collected quantitative criteria. Appraisal values of six projects in HFLTS are shown in Table 5.

On the basis of the conversion algorithm with the determined domain $[X_{\min}, X_{\max}] = [0, 100]$ in Table 6 and Fig. 4, corresponding clouds of each attribute can be transformed from HFLTS, as shown in Table 7.

4.2.2. Stage 2

Step 1: Brainstorming is held in expert group members to finalize the interdependencies and pair-wise comparisons among the criteria and the network layer model is shown in Table 8 based on the consensus. The symbol "$\surd$" means that the index in the row may have an impact on the index in the column. Then work out the values of the attribute subjective weights by Super-Decision software: $\omega_{1j}=$ (0.1200, 0.0843, 0.1319, 0.0897, 0.0966, 0.1118, 0.0678, 0.0697, 0.0626, 0.0554, 0.0595, 0.0507).

Step 2: 60 questionnaires are distributed to administrators of SMEs, experts and scholars in the fields of energy, economy, electrical power system and environment. The questionnaire is designed as Table A1 in Appendix A, and respondents need to rate the importance of indicators by marking 1 to 9. By validating the recovery questionnaire, 47 valid questionnaires are finally retained. Based on these data, objective weights of 12 criteria can be calculated as $\omega_{2j}=$ (0.1038, 0.0910, 0.1334, 0.0843, 0.0756, 0.0538, 0.0426, 0.0908, 0.1074, 0.0791, 0.0718, 0.0665).

Step 3: Coefficient $\alpha_1^* = 0.5896$, $\alpha_2^* = 0.4327$ can be calculated by Matlab software and the final combination weights are obtained ω_j=(0.1156, 0.0891, 0.1355, 0.0893, 0.0897, 0.0892, 0.0584, 0.0804, 0.0833, 0.0669, 0.0662, 0.0587) based on formula (11). Three kinds of weights are summarized in Table 9.

4.2.3. Stage 3

Calculate the distance between the clouds based on the formula (3) and the results are shown in Table 10.

Then, the dominance of alternative A_p overreach alternative A_q under 12 criteria can be worked out by formula (22). To be in accordance with the real situations, we suppose the parameter θ is 0.5. The dominance matrix under C11 here in Table 11, and the overall dominance degree of alternative A_p overreach alternative A_q is shown in Table 12.

Based on formula (24), overall dominance can be standardized and all the alternatives $A_p (p = 1, 3, 5, 6, 10, 11)$ can be ranked in accordance with the value $S(A_p)$ in Table 13.

In summary, on the ground of the above calculation process, the final result is $A_3 > A_{10} > A_6 > A_5 > A_{11} > A_1$. Therefore, A_3, the ICR-DPV project located in Zhucheng is the best to invest in.

Table 6
Linguistic variables and their corresponding clouds.

Linguistic scales	Clouds
Poor (P)	$s_0(0,\ 10.31,\ 0.262)$
Medium Poor (MP)	$s_1(30.9,\ 6.37,\ 0.162)$
Medium (M)	$s_2(50,\ 3.93,\ 0.1)$
Medium Good (MG)	$s_3(69.1,\ 6.37,\ 0.162)$
Good (G)	$s_4(100,\ 10.31,\ 0.262)$

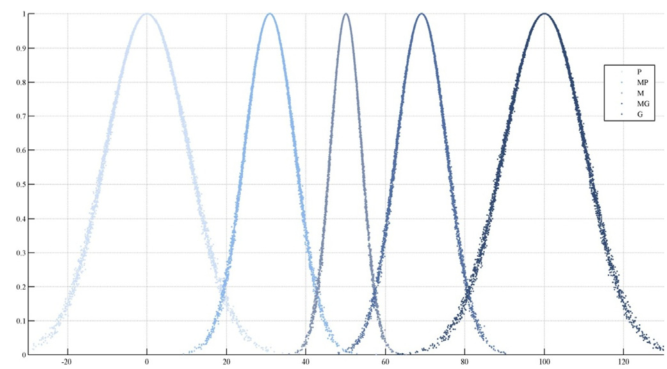

Fig. 4. Five clouds of scoring levels.

5. Results and discussion

According to the aforementioned judgment standards and rules, it is found that the ranking of all the ICR-DPV investment projects in descending order is $A_3, A_{10}, A_6., A_5, A_{11}, A_1$, where A_3 is the optimal investment choice. Sensitivity analysis and comparative analysis are conducted in this section.

5.1. Sensitivity analysis

As the different attitudes of DMs may lead to different ranking results, this paper uses different values of parameter θ to simulate

Table 5
Appraisal values of six projects in HFLTS.

	A_1	A_3	A_5	A_6	A_{10}	A_{11}
C11		$\{(s_4, 0.6)\}$	s_2	s_3	s_3	s_2
C12		$\{(s_3, 0.8)\}$	$\{(s_1, 0.8)\}$	$\{(s_2, 0.8)\}$	s_4	$\{(s_1, 0.9)\}$
C13		$\{(s_3, 0.8)\}$	s_3	s_3	s_1	$\{(s_1, 0.9), (s_2, 0.6)\}$
C21		$\{(s_3, 0.8)\}$	s_1	s_4	s_3	$\{(s_2, 0.7)\}$
C22		$\{(s_4, 0.7)\}$	s_2	$\{(s_4, 0.9)\}$	$\{(s_4, 0.9)\}$	$\{(s_3, 0.7)\}$
C23		$\{(s_2, 0.9)\}$	s_4	$\{(s_2, 0.5), (s_3, 0.8), (s_4, 0.5)\}$	$\{(s_1, 0.6)\}$	$\{(s_1, 0.6)\}$
C31		$\{(s_3, 0.6)\}$	$\{(s_1, 0.6), (s_2, 0.9)\}$	$\{(s_2, 0.6)\}$	$\{(s_3, 0.7)\}$	$\{(s_3, 0.8)\}$
C32		s_3	s_2	$\{(s_4, 0.9)\}$	$\{(s_2, 0.8)\}$	s_4
C33		$\{(s_3, 0.8)\}$	$\{(s_1, 0.8)\}$	$\{(s_3, 0.8)\}$	$\{(s_3, 0.9)\}$	$\{(s_2, 0.8)\}$
C41		s_4	s_3	$\{(s_3, 0.8)\}$	$\{(s_3, 0.8)\}$	$\{(s_3, 0.7)\}$
C42		$\{(s_3, 0.7)\}$	s_2	$\{(s_2, 0.7)\}$	s_3	$\{(s_3, 0.7)\}$
C43		s_4	s_3	$\{(s_1, 0.8)\}$	$\{(s_3, 0.9)\}$	$\{(s_3, 0.8)\}$

Table 7
Appraisal values of six projects in clouds.

	A_1	A_3	A_5	A_6	A_{10}	A_{11}
C11	(37.3, 5.29, 0.190)	(60, 10.31, 0.262)	(50, 3.93, 0.1)	(69.1, 6.37, 0.162)	(69.1, 6.37, 0.162)	(50, 3.93, 0.1)
C12	(41.5, 6.37, 0.162)	(55.3, 6.37, 0.162)	(24.7, 6.37, 0.162)	(40, 3.93, 0.1)	(100, 10.31, 0.262)	(27.8, 6.37, 0.162)
C13	(35, 3.93, 0.1)	(55.3, 6.37, 0.162)	(69.1, 6.37, 0.162)	(69.1, 6.37, 0.162)	(30.9, 6.37, 0.162)	(28.9, 5.29, 0.190)
C21	(50, 3.93, 0.1)	(55.3, 6.37, 0.162)	(30.9, 6.37, 0.162)	(100, 10.31, 0.262)	(69.1, 6.37, 0.162)	(35, 3.93, 0.1)
C22	(55.3, 6.37, 0.162)	(70, 10.31, 0.262)	(50, 3.93, 0.1)	(90, 10.31, 0.262)	(90, 10.31, 0.262)	(48.4, 6.37, 0.162)
C23	(69.1, 6.37, 0.162)	(45, 3.93, 0.1)	(100, 10.31, 0.262)	(43.4, 7.36, 0.324)	(18.5, 6.37, 0.162)	(18.5, 6.37, 0.162)
C31	(30, 3.93, 0.1)	(41.5, 6.37, 0.162)	(31.8, 5.29, 0.190)	(30, 3.93, 0.1)	(48.4, 6.37, 0.162)	(55.3, 6.37, 0.162)
C32	(100, 10.31, 0.262)	(69.1, 6.37, 0.162)	(50, 3.93, 0.1)	(90, 10.31, 0.262)	(70, 7.8, 0.280)	(100, 10.31, 0.262)
C33	(40, 3.93, 0.1)	(55.3, 6.37, 0.162)	(24.7, 6.37, 0.162)	(55.3, 6.37, 0.162)	(62.2, 6.37, 0.162)	(40, 3.93, 0.1)
C41	(25.2, 5.29, 0.190)	(100, 10.31, 0.262)	(69.1, 6.37, 0.162)	(55.3, 6.37, 0.162)	(55.3, 6.37, 0.162)	(48.4, 6.37, 0.162)
C42	(21.6, 6.37, 0.162)	(48.4, 6.37, 0.162)	(50, 3.93, 0.1)	(35,3.93, 0.1)	(69.1, 6.37, 0.162)	(48.4, 6.37, 0.162)
C43	(15.5, 6.37, 0.162)	(100, 10.31, 0.262)	(69.1, 6.37, 0.162)	(24.7, 6.37, 0.162)	(62.2, 6.37, 0.162)	(55.3, 6.37, 0.162)

Table 8
ANP network layer model.

	C11	C12	C13	C21	C22	C23	C31	C32	C33	C41	C42	C43
C11						✓	✓		✓			
C12						✓	✓		✓			
C13									✓			
C21	✓		✓		✓						✓	
C22	✓		✓						✓		✓	
C23	✓	✓	✓						✓			
C31	✓	✓	✓	✓	✓				✓			✓
C32	✓	✓	✓			✓			✓	✓		✓
C33												
C41	✓					✓					✓	
C42												
C43								✓		✓		

Table 9
Calculation results of weights.

	Subjective weights	Objective weights	Combination weights
C11	0.1200	0.1038	0.1156
C12	0.0843	0.0910	0.0891
C13	0.1319	0.1334	0.1355
C21	0.0897	0.0843	0.0893
C22	0.0966	0.0756	0.0897
C23	0.1118	0.0538	0.0892
C31	0.0678	0.0426	0.0584
C32	0.0697	0.0908	0.0804
C33	0.0626	0.1074	0.0833
C41	0.0554	0.0791	0.0669
C42	0.0595	0.0718	0.0662
C43	0.0507	0.0665	0.0587

Table 11
The dominance matrix under C11.

Alternative	A_1	A_3	A_5	A_6	A_{10}	A_{11}
A_1	0	−100.96	−112.96	−36.78	−36.78	−112.96
A_3	5.71	0	12.12	−198.83	−198.83	12.12
A_5	6.39	−214.36	0	−102.08	−102.08	0
A_6	2.08	11.24	5.77	0	0	1.77
A_{10}	2.08	11.24	5.77	0	0	5.77
A_{11}	6.39	−214.36	0	−31.32	−102.08	0

Table 12
The overall dominance degree of alternative A_p overreach alternative A_q.

Alternative	A_1	A_3	A_5	A_6	A_{10}	A_{11}
A_1	0	−913.3	−886.26	−707.28	−872.32	−450.03
A_3	−213.39	0	−312.64	−504.76	−685.57	−172.46
A_5	−599.81	−1109.85	0	−671.5	−478.08	−504.15
A_6	−266.85	−620.26	−371.82	0	0	−371.19
A_{10}	−442.4	−595.49	−472.44	−574.45	0	−169.28
A_{11}	−555.35	−999.16	−579.36	−448.16	−607.34	0

Table 13
Final ranking of alternatives.

Alternative	A_1	A_3	A_5	A_6	A_{10}	A_{11}
$S(A_p)$	0	1	0.1965	0.6217	0.6886	0.0559
Ranking	6	1	4	3	2	5

Table 10
The distance between all alternatives.

	C11	C12	C13	C21	C22	C23	C31	C32	C33	C41	C42	C43
$d(A_1,A_3)$	16.977	6.910	10.110	20.975	20.669	13.543	10.299	22.382	13.732	1.797	13.370	16.446
$d(A_1,A_5)$	18.994	8.370	3.525	27.696	1.967	22.382	7.506	30.970	22.157	13.312	30.252	26.825
$d(A_1,A_6)$	6.185	17.542	4.413	30.970	15.143	20.912	0.000	5.000	13.732	7.665	19.387	4.635
$d(A_1,A_{10})$	6.185	2.379	26.506	17.165	9.773	40.121	8.394	8.072	21.305	7.665	23.735	23.370
$d(A_1,A_{11})$	18.994	6.825	11.408	19.852	9.114	39.571	6.489	0.000	0.000	4.842	13.370	19.915
$d(A_3,A_5)$	36.045	15.280	9.114	12.190	12.979	26.604	2.766	17.165	15.280	18.676	22.880	22.382
$d(A_3,A_6)$	33.433	13.732	7.635	12.380	10.000	25.383	10.299	25.145	0.000	9.773	12.015	9.737
$d(A_3,A_{10})$	33.433	12.380	30.668	6.910	14.337	35.038	3.455	13.484	11.551	9.773	10.365	17.381
$d(A_3,A_{11})$	36.045	13.735	4.010	1.967	27.805	34.770	6.910	22.382	13.732	5.321	0.000	12.380
$d(A_5,A_6)$	17.165	22.157	1.250	5.264	8.806	4.995	7.506	32.239	15.280	6.910	7.500	22.190
$d(A_5,A_{10})$	17.165	9.737	34.957	19.100	5.178	33.566	0.057	25.727	8.137	6.910	17.165	3.455
$d(A_5,A_{11})$	0.000	1.545	11.095	7.994	9.368	32.653	2.881	30.970	22.157	10.365	22.880	6.910
$d(A_6,A_{10})$	0.000	22.239	33.148	22.382	6.162	19.752	8.394	11.715	11.551	0.000	6.300	18.735
$d(A_6,A_{11})$	5.266	8.829	9.845	13.592	7.596	16.993	18.310	5.000	4.213	3.455	9.684	15.280
$d(A_{10},A_{11})$	17.165	7.500	18.894	7.613	18.740	0.773	3.455	8.072	21.305	3.455	10.365	3.455

the attitudes of DMs in actual situation. It can investigate how these changes affect the final results and evaluate the robustness of evaluation model.

Let θ equals to 8, 7, 6, 5, 4, 3, 2, 1, 0.9, 0.8, 0.7, 0.6, 0.5, 0.4, 0.3, 0.2, 0.1 respectively, and corresponding results are shown in Table 14 and Fig. 5. As we can see from Table 14, A_3 always occupies the first place. That is to say, no matter how the DM's psychological behavior changes, the comprehensive performance of A_3 is prominent among alternatives and it always can meet the investment demand. Thus the robustness and stability of the proposed framework in the paper can be testified. However, it is obvious that the second, third, fifth and sixth places are changing with the increasing of θ. It can be explained that the priority of investment alternatives may alter on account of the DMs' different attitudes toward risk. When DMs are more inclined to reduce the risk of loss, the ranking results stabilize at $A_3 > A_{10} > A_6 > A_5 > A_{11} > A_1$.

5.2. Comparative analysis

5.2.1. Comparative analysis of different weighting method

To verify the advantage of combination weights, this part will discuss the difference of ranking results brought by different weighting methods. The comparisons of calculation results are shown in Table 15.

The ranking order adopting the subjective weight calculation is consistent with the result calculated by combination weights. However, as we can see from Table 9, there are obvious differences between subjective weight and comprehensive weight for some qualitative indices such as C32, C33 and C41. With regard to $S(A_p)$, the gap between A_5 and A_3 is getting smaller, while the gaps between A_6, A_{10}, A_{11} and A_3 are getting bigger in the case of similar expert assessments. Therefore, it can be seen that the change of qualitative index weight has an impact on the overall situation.

From the standpoint of calculation results derived by objective weights, the difference from the calculated result of the combination weights is changing in the order of A_1 and A_{11}. According to Table 5, the appraisal values of A_1 and A_{11} differ greatly in quantitative indices such as C11, C12, C21, C23 and C43. In addition, the objective weights of C11,C22, C23 are obviously different from their combination weights, which leads to changes in their rankings jointly.

Due to the usage of comprehensive integration weighting method based on game theory, the combination weights minimize deviations from each basic weight as much as possible. At the same time, combination weight balances the subjective weight and objective weight to avoid over-amplification of the impact of some qualitative or quantitative indicators, ensuring the relative accuracy of the results.

5.2.2. Comparative analysis of different ranking methods

In order to demonstrate the rationality and feasibility of the proposed framework, a comparison has been analyzed with classical ranking methods. According to the classification in Table 1, we select TOPSIS and PROMETHEE-II method as the representative of each category to compare with the TODIM method based on the same illustrative example.

The ranking result derived through TOPSIS is based on the calculation of the Hamming distance between the assessment index value C_i and the ideal cloud $C_0(0,0,0)$. And the net flow $\varphi(A_i)$ is used to rank the alternatives in PROMETHEE-II method. The calculation results are shown in Table 16.

From the ranking result, it can be seen that the best investment choice is A_3, which is consistent with the one gained by the cloud-TODIM decision framework. The validity and accuracy of the proposed framework can be testified.

For TOPSIS, the main difference of two ranking orders is that the sequences of A_6 and A_{10}, A_1 and A_{11}. The reasons can be interpreted as follow. On one hand, it has strong complementarity. The TOPSIS method determines y_i^+ and y_i^-, which represent the distance between evaluation value of ideal solution and negative-ideal solution respectively, while neglecting the relative importance of them. For example, according to the calculation results, A_1 is better than A_{11} with a smaller value of y_i^+ and a bigger value of y_i^-. However, if we assume $y_i^+(A_1) = y_i^-(A_1)$, the final ranking order is still $A_1 \succ A_{11}$ while A_1 has a bigger y_i^+ and smaller y_i^- than A_1. On the other hand, according to the calculation in the sensitivity analysis, the result derived by TOPSIS method is the same as the results when $\theta = 6, 7, 8$, that is, the result list of the TODIM method with the different psychological behavior of DMs contains the ranking order of TOPSIS method. In summary, TOPSIS is suitable for exploring the comprehensive performance of alternatives when DMs are not sensitive to the risk of loss.

For PROMETHEE-II, it ranks alternatives based on their net flow. The main difference between two results is the priority of A_1 and A_{11}. PROMETHEE-II eliminates compensation problem, but almost neglects the DMs' psychological behavior, and the results are calculated by directly processing of appraisal values. The ranking order of A_1 and A_{11} are changed with DMs' behavior in Table 14, while failing to reflect in PROMETHEE-II decision-making process. Similarly, results of the TODIM method also contain the computation result of

Table 14
Ranking orders of alternatives with different θ.

Different values of θ	A_1	A_3	A_5	A_6	A_{10}	A_{11}	Ranking of alternatives
8	0.0181	1	0.1570	0.6649	0.6282	0	$A_3 > A_6 > A_{10} > A_5 > A_1 > A_{11}$
7	0.0250	1	0.1680	0.6640	0.6510	0	$A_3 > A_6 > A_{10} > A_5 > A_1 > A_{11}$
6	0.0041	1	0.1556	0.6530	0.6358	0	$A_3 > A_6 > A_{10} > A_5 > A_1 > A_{11}$
5	0	1	0.1582	0.6475	0.6418	0.0041	$A_3 > A_6 > A_{10} > A_5 > A_1 > A_{11}$
4	0	1	0.1650	0.6429	0.6501	0.0133	$A_3 > A_{10} > A_6 > A_5 > A_{11} > A_1$
3	0	1	0.1726	0.6378	0.6594	0.0237	$A_3 > A_{10} > A_6 > A_5 > A_{11} > A_1$
2	0	1	0.1813	0.6319	0.6700	0.0353	$A_3 > A_{10} > A_6 > A_5 > A_{11} > A_1$
1	0	1	0.1911	0.6254	0.6819	0.0486	$A_3 > A_{10} > A_6 > A_5 > A_{11} > A_1$
0.9	0	1	0.1921	0.6246	0.6832	0.0500	$A_3 > A_{10} > A_6 > A_5 > A_{11} > A_1$
0.8	0	1	0.1932	0.6239	0.6845	0.0514	$A_3 > A_{10} > A_6 > A_5 > A_{11} > A_1$
0.7	0	1	0.1943	0.6232	0.6859	0.0529	$A_3 > A_{10} > A_6 > A_5 > A_{11} > A_1$
0.6	0	1	0.1954	0.6224	0.6872	0.0544	$A_3 > A_{10} > A_6 > A_5 > A_{11} > A_1$
0.5	0	1	0.1965	0.6217	0.6886	0.0559	$A_3 > A_{10} > A_6 > A_5 > A_{11} > A_1$
0.4	0	1	0.1976	0.6209	0.6899	0.0574	$A_3 > A_{10} > A_6 > A_5 > A_{11} > A_1$
0.3	0	1	0.1988	0.6202	0.6913	0.0590	$A_3 > A_{10} > A_6 > A_5 > A_{11} > A_1$
0.2	0	1	0.1999	0.6194	0.6928	0.0605	$A_3 > A_{10} > A_6 > A_5 > A_{11} > A_1$
0.1	0	1	0.2011	0.6186	0.6942	0.0621	$A_3 > A_{10} > A_6 > A_5 > A_{11} > A_1$

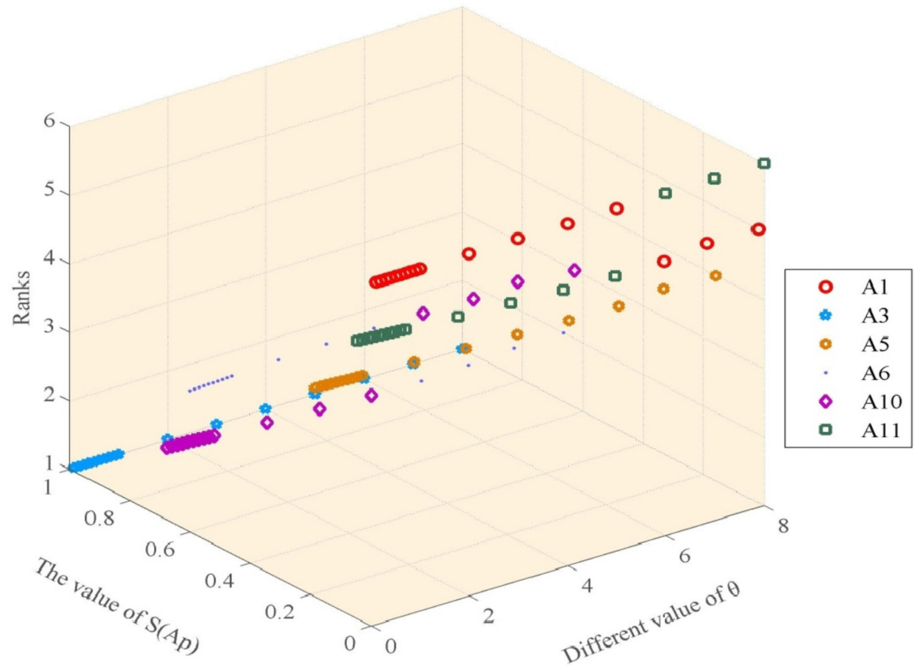

Fig. 5. The sensitivity analysis results.

Table 15
The comparison of ranking results calculated by different weights.

Alternative	Subjective weights		Objective weights		Combination weights	
	$S(A_p)$	Ranking	$S(A_p)$	Ranking	$S(A_p)$	Ranking
A_1	0	6	0.0417	5	0	6
A_3	1	1	1	1	1	1
A_5	0.1812	4	0.2556	4	0.1965	4
A_6	0.6342	3	0.6025	3	0.6217	3
A_{10}	0.7362	2	0.6098	2	0.6886	2
A_{11}	0.1046	5	0	6	0.0559	5

Table 16
The computation results of TOPSIS, PROMETHEE-II and TODIM.

Method	Calculation results						Ranking orders
TOPSIS	$D(C_0, C_1)$ 1.894	$D(C_0, C_3)$ 3.546	$D(C_0, C_5)$ 2.474	$D(C_0, C_6)$ 3.080	$D(C_0, C_{10})$ 2.873	$D(C_0, C_{11})$ 1.484	$A_3 > A_6 > A_{10} > A_5 > A_1 > A_{11}$
PROMETHEE-II	$\varphi(A_1)$ −0.2702	$\varphi(A_3)$ 0.4180	$\varphi(A_5)$ −0.1811	$\varphi(A_6)$ 0.1989	$\varphi(A_{10})$ 0.2080	$\varphi(A_{11})$ −0.3735	$A_3 > A_{10} > A_6 > A_5 > A_1 > A_{11}$
TODIM	$S(A_1)$ 0	$S(A_3)$ 1	$S(A_5)$ 0.1965	$S(A_6)$ 0.6217	$S(A_{10})$ 0.6886	$S(A_{11})$ 0.0559	$A_3 > A_{10} > A_6 > A_5 > A_{11} > A_1$

PROMETHEE-II method.

Through the above discussion, ranking methods work based on different criteria and get various results. Given the characteristics of SMEs, TODIM method is more suitable for ranking in this work and the results obtained are more credible and comprehensive.

5.3. Benefit analysis

5.3.1. Economic benefit analysis

Given that economic feasibility is one of the most crucial factors for SME investment decision, it is imperative to evaluate the alternatives purely from the perspective of economic benefits.

The current electricity price standard in Shandong province is shown in Table 17. Based on the feasibility analysis reports and field researches, investment profits under different grid-connected modes can be calculated, as presented in Table 18.

As we can see from the results in Table 18, cost recovery is the fastest in the case that power is all self-consumed, neglecting the two factors: operation and maintenance cost, depreciation. However, due to the limited power consumption of enterprises, mode 1 is the optimal choice. So the economic benefit analysis is conducted on the basis of mode 1 and the results are shown in Table 19.

According to the computations, the priority of alternatives is $A_3 \succ A_{10} \succ A_6 \succ A_5 \succ A_{11} \succ A_1$, that is, A_3, with the shortest payback period and highest ROI and IRR, possesses favorable economic benefits and merits investment under the premise that the national PV power subsidy policy remains unchanged.

5.3.2. Social benefit analysis

Take A_3 as an example, calculation is based on the estimated power generation in future 20 years, and the energy savings and pollutant reductions can be derived (see Table 20). It can be seen that the popularization of ICR-DPV projects is of great practical significance for promoting the improvement of the local ecological environment and the sustainable development of social economy.

In addition, ICR-DPV projects make full use of industrial and commercial rooftop areas, which will increase the comprehensive utilization rate of urban land significantly. Moreover, the ICR-DPV

Table 17
Various electricity prices in Shandong province.

No.	Grid-connected mode	Item	Price (CNY/kW·h)
1	The produced power is self-consumed first and the remaining power connects into the grid	State subsidy	0.32
		Electricity price in Shandong province	0.9438
		Subsidy in Shandong province	0.32
		Feed-in tariff in coal-fired units in Shandong province	0.3949
2	The produced power all connects into the grid	Regional feed-in tariff in Shandong province	0.7

Data resources: National Development and Reform Commission and Shandong Price Bureau.

Table 18
Estimated total investment profits under different modes.

	A_1	A_3	A_5	A_6	A_{10}	A_{11}
Initial investment cost (10^4·CNY)	5,496	2,210	7,296	4,685	334	785
Annual power generation (10^4 kW h)	654.42	328.07	879.2	603.9	41	96.26
Annual capital income brought by the case that power is all self-consumed (10^4·CNY)	20,729.41	10,391.95	27,849.54	19,129.14	1,298.72	3,049.13
Estimated total investment profits (10^4·CNY)	15,233.41	8,181.95	20,553.54	14,444.14	964.72	2,264.13
Annual capital income brought by mode 1 (10^4·CNY)	20,010.99	10,031.79	26,884.35	18,466.17	1,253.71	2,943.46
Estimated total investment profits (10^4·CNY)	14,514.99	7,821.79	19,588.35	13,781.17	919.71	2,158.46
Annual capital income brought by mode 2 (10^4·CNY)	9,161.88	4,592.98	12,308.8	8,454.6	574	1,347.64
Estimated total investment profits (10^4·CNY)	3,665.88	2,382.98	5,012.8	3,769.6	240	562.64

Note: The service life of the ICR-DPV system is assumed as 20 years, and the proportion of the self-consumed power in the total power generation is assumed as 90%.

Table 19
The calculation results of economic benefit.

Alternative	Payback period (year)	Return on investment (ROI)	Internal rate of return (IRR)
A_1	6.36	15.73%	14.73%
A_3	4.96	20.18%	19.63%
A_5	6.13	16.32%	15.40%
A_6	5.88	17.0%	16.15%
A_{10}	5.22	19.14%	18.51%
A_{11}	6.26	15.98%	15.01%

Table 20
The calculation results of social benefit.

Estimated power generation (10^4 kW h)	Energy saving and pollutant reduction (t)			
	Standard coal	CO_2	SO_2	NO_x
6561.40	22,964.90	59,708.74	551.16	160.75

projects help give impetus to the optimization of energy structure and reduce the land resources occupied by thermal power plants. Therefore, it is conducive to excavating greater economic value.

6. Conclusion

This study aims to deal with the ICR-DPV project investment selection based on the cloud-TODIM model under the circumstance of HFLTS from SMEs' standpoint. The contributions of this framework are as follows: Firstly, the evaluation index system focuses on ICR-DPV project investment from the perspective of SMEs, which contributes to a systematic guide specifically for them. Secondly, HFLTS and cloud model are applied to describe appraisal values, so that the indeterminacy and randomness of decision information have got thorough expression. Thirdly, ANP and entropy method are aggregated to determine combination weights. The aim is to give full consideration to the rationality in the process of weight determination. Fourthly, the TODIM method is adopted so that DMs' psychological behavior in the investment decision process can be paid attention to. Finally, a case in Shandong province testifies the suitability of the established decision framework through a sensitivity analysis, a comparative analysis and a benefit analysis. According to theoretical modeling and empirical research in this paper, the proposed decision framework can provide reference for SMEs to make more reasonable investment decisions in ICR-DPV project.

As SMEs tend to be more sensitive to the fluctuation of relevant policies and expendable funds, investors can be intuitive to obtain the optimal project under different psychological states founded on the sequences derived by the algorithm. As far as the case in Section 4 is concerned, the SME is suggested to select A_3 for further investigation and implementation owing to its best comprehensive performance under different psychology. This advantage makes the proposed framework applicable to other similar fields such as site selection of low speed wind power projects and supplier selection, in which the psychological behavior of DMs is uncertain. The results show that the ICR-DPV projects have multiple significances in economic returns, social influence and environmental benefits. So SMEs investing in these projects will promote the development of this renewable energy industry, help reduce carbon emissions and alleviate the pressure of fossil energy.

In brief, the cloud-TODIM model constructed in this paper is conducive for SMEs to make investment selection meeting with their risk preference and loss aversion expectation more precisely.

However, there are some limitations in this paper. First, more researches and adjustments are required for practical ICR-DPV investment on account of constantly changing international and domestic policy situations and limited available information. Second, the index system should be slightly modified for specific SMEs in order to be applicable to the complicated requirement of the practical decision-making. Third, this paper intends to validate the feasibility through one case and select one single project as the final decision, so future works could focus on the supplement of more supporting cases and consideration of portfolio optimization.

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Appendix A

Thank you for completing the questionnaire about the optimal investment selection of ICR-DPV project from SMEs' perspectives, all of your information will be confidential and anonymity, which will only be used for scientific research instead of commercial purposes. The purpose of this questionnaire is to measure the importance of each criterion. Please evaluate the indices according to the importance and tick a "√" on the corresponding space. If you have any questions or suggestions during the process of filling in the question papers, please do not hesitate to contact us. Thanks again for your help.

Table A1
Questionnaire on the importance of indices.

Criteria	Sub-criteria	1 Extremely unimportant	2 Strongly unimportant	3 Unimportant	4 Slightly unimportant	5 Medium	6 Slightly important	7 Important	8 Strongly important	9 Extremely important
Economy factors	Construction cost									
	Operation and maintenance cost									
	Annually average capital income									
Resource factors	Sunshine time									
	Global horizontal irradiance(GHI)									
	Gross installation area									
Risk factors	Extreme weather damage									
	Fluctuations in policy									
	Loan financing and solvency									
Engineering Feasibility	Electrical transmission and distribution system									
	Influence on power quality									
	Electricity demand									

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