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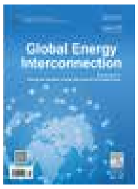

Full-length article

Benefit allocation model of distributed photovoltaic power generation vehicle shed and energy storage charging pile based on integrated weighting-Shapley method

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Abstract : In this study, to develop a benefit-allocation model, in-depth analysis of a distributed photovoltaic-power-generation carport and energy-storage charging-pile project was performed; the model was developed using Shapley integrated-empowerment benefit-distribution method. First, through literature survey and expert interview to identify the risk factors at various stages of the project, a dynamic risk-factor indicator system is developed. Second, to obtain a more meaningful risk-calculation result, the subjective and objective weights are combined, the weights of the risk factors at each stage are determined by the expert scoring method and entropy weight method, and the interest distribution model based on multi-dimensional risk factors is established. Finally, an example is used to verify the rationality of the method for the benefit distribution of the charging-pile project. The results of the example indicate that the limitations of the Shapley method can be reasonably avoided, and the applicability of the model for the benefit distribution of the charging-pile project is verified.

Keywords: Charging pile, Benefit distribution, Risk factor, Integrated weighting method, Shapley model.

1 Introduction

In the past two years, new energy vehicles (NEVs) have developed rapidly, and the NEV industry has become one of the leading industries in China and abroad. At present, the cumulative holding capacity of NEVs in China is 1.8 million, accounting for more than half of the total holding capacity of NEVs globally. At present, most of the cars sold in China are powered by oil or natural gas. In recent years, the increase in the number of cars has increased the consumption of energy. Oil and natural gas resources are also depleted as they are non-renewable resources. Power supply of NEVs is facilitated via charging piles; therefore, we need to continuously improve the charging piles to ensure the normal driving of NEVs. Therefore, to promote NEVs, first, the construction of charging piles and other associated infrastructure needs to be focused on. Charging piles are affected by various factors in the construction process, such as urban planning, residential installation conditions, and investment operation mode; with many interests and participation, and are in the initial stage globally.

In the study reported in [1], fuzzy analysis network method was used to evaluate the risk of highway public–

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private partnership (PPP) projects to overcome the interdependence and feedback between different risk ranking alternatives. The results show that the most important types of risks are political, legal, and financial. In the study reported in [2], fuzzy graph theory was used to analyze the countermeasures to mitigate these risks with hierarchical structure and its solution . In the study reported in [3], regarding cooperative games with restrictive possibilities, the average marginal tree solutions of the proposed tree structure are extended, and some new features of these solutions are obtained. In the study reported in [4] the members of the alliance were considered to have a certain degree of freedom to participate in the cooperation, and a game model was constructed wherein the participants in the alliance could subjectively determine the restrictions. In the study reported in [5], the potential function and consistency in the classical cooperative game were extended to the cooperative game with fuzzy alliance, and the Shapley value with fuzzy alliance game was studied. In the study reported in [6], in the energy-saving scheduling mode, the compensation fund was established by extracting the peak-sharing electricity fee, and the practical model of peak-shaping compensation based on the equivalent available load rate was established; however, economics of the scheduling model and fairness of the apportionment method were not discussed in detail. In the study reported in [7], through cooperative game theory, the unit start–stop optimization scheduling was regarded as the cooperation process between units, and the allocation model of cooperative surplus was established. In the study reported in [8], data on seven PPP projects in Australia were collected through questionnaires, and key risk factors for time, cost, and operational performance were obtained through analysis.

In the study reported in [9], an empirical study was conducted from the government support level of the PPP project, and the main features of PPP government support were defined based on a large number of documents, which mainly included policies, political commitments, laws, regulatory frameworks, and well-designed PPP support departments. Based on these elements, the PPP government support index was designed to explain the potential as well as practicality and limitations of the index. It is considered that government support is a necessary aspect rather than a sufficient aspect for a country's PPP activity. According to [10], subsidies should not only consider social benefits but also take into account the financial affordability. It can comprehensively adopt investment subsidies, price subsidies, transfer payments, etc., and gradually procure subsidies from source subsidies to important links, from all subsidies to choices. In addition, government guarantees or other forms of income compensation are also effective measures to overcome the risks posed by social capital investors.

Regarding the relationship between government and social capital and subject cooperation, most of the current literature reports adoption of different game models, focusing on key cooperative games and evolutionary games [11]. Analysis of specific mechanisms of certain parts of the operation of PPP projects, which focus on the access mechanism, financing mechanism, pricing mechanism, incentive mechanism, etc., have also been reported [12]. References [13-16] reported a wide variety of applications of the PPP model. Under the framework of this cooperation, countries could develop and innovate specific projects. Based on those studies, researchers have combined project practice cases to distribute energy, medical, transportation, and communication in different regions. The PPP model of projects in the fields of water treatment, ecological construction, and municipal engineering was analyzed. Some developed countries, such as the United States, Germany, and Japan, and automobile power suppliers have carried out a number of studies on electric vehicles, a nd charging infrastructure was often used as a sub-item for research on electric vehicles, and has strong dependence [17]. In [18], technical research on charging infrastructure was summarized from the perspective of physics and chemistry. According to [18], previous research pays more attention to the technology of charging infrastructure itself and ignores the impact of charging on the power grid. It should be combined with the construction of smart grid. Therefore, a more convenient, safe, and fast service for charging electric vehicles must be provided by building a solar charging station.

In the study reported in [19], genetic algorithm was applied to analyze the production and use of rechargeable batteries for electric vehicles. With the popularization and application of Internet and the advent of the era of big data, research on the networking of charging infrastructure has gradually begun. According to [20], in the construction phase of charging infrastructure, smart meters and two-way communication facilities need to be installed to enable the power supply network and users charging the electric vehicles to establish an interactive platform, which facilitates them to become an important part of the smart grid. The studies reported in [21-23] introduced the planning layout of the charging infrastructure and the model of optimizing the layout, and verified the practicability of the model through examples. The study reported in [24] first analyzed three cases in the Spanish region, namely traffic hotspots, highways, and household self-use charging piles. Subsequently, the different advantages and disadvantages of the installation position of the charging piles in the three cases were evaluated. It is believed that the home-use charging mode will greatly increase the penetration rate of electric vehicles, and the installation of a large number of fast-charging infrastructure in traffic-intensive areas can increase the revenue. Therefore, future related policies should consider improving the charging facilities in the public domain and consider strategies to deploy these facilities in the private sector. According to [25], the construction of charging infrastructure in the UK is still in the initial stage of innovation, and several types data are difficult to collect. Therefore, only the actual data such as the actual cost of expenditure in the fast-charging network project are used to empirically supply the rapid charging infrastructure. According to the analysis, establishment of a fast-charging infrastructure along the highway and progressively strengthening the fiscal incentives is considered to be more effective compared with other strategies. In addition, some scholars have specifically studied the policy support in the supply of charging infrastructure. Reference [26] reported the development of electric vehicles in Japan. The study found that from a public perspective, technological advancement and policy support have had a greater impact on the construction of charging infrastructure. Reference [27] presents the comparison and analyses of the public policies of electric vehicles and charging facilities in the United States from different perspectives.

Through literature review, it was found that the number of studies on the supply of electric vehicle charging infrastructure has increased in recent years. The development of the charging infrastructure industry is in its infancy, and most of the research on charge-supply mode is in the exploratory stage, i.e., a preliminary qualitative research stage. Literature on the benefit distribution of the charging infrastructure in PPP mode is relatively scarce, and participation in the PPP mode construction and operation in this field is involved, the research on the main body and the specific operation process is fragmented and decentralized. Although there are some studies on policy recommendations, owing to the lack of systemicity, the main relationship between the cooperation is rarely discussed, and further relevant research needs to be conducted. The quantitative exploration of the important factors affecting the supply of PPP mode to the charging infrastructure can not only improve the success rate of project implementation but also effectively satisfy the supply of charging infrastructure. It can also provide theoretical reference for the operation and control of other similar PPP projects.

Firstly, in this study, the project is analyzed from the perspectives of sustainability and practicality, and the risk factors of the charging pile project are identified through literature survey and expert interviews. Secondly, the entropy weight method and AHP are combined to objectively obtain the weights of the project benefit risk factors, and as a correction factor to construct a dynamic Shapley benefit distribution model based on each core stakeholder. Finally, the validity of the proposed benefit model of the charging pile project is verified using an example. The results of verification using the example show that the proposed model circumvents the shortcomings of the risk identification of similar projects reported in the existing research, and the distribution of interests is also idealized.

2 Construction of charging-pile benefit-distribution-impact indicator system

2.1 Introduction of the charging pile project

The project comprises a new-energy-plant charging-pile energy-storage and power-supply system. It is located in the urban comprehensive business core planning area. The government-led, distributed energy enterprise and Internet information enterprise jointly carry out the construction of charging-pile energy-storage and power-supply system. The specific capacity configuration is summarized in Table 1.

Table 1 Charging-pile energy-storage system equipment parameters

Component name	Device parameters
Photovoltaic module (kW)	707.84
DC charging pile power (kW)	640
AC charging pile power (kW)	144
Lithium battery energy storage (kW·h)	6000
Energy conversion system PCS capacity (kW)	800

The system is connected to the user side through the inverter and connected to the network via adopting the mode of “Spontaneous use, remaining power connected to the grid. ” The decommissioned batteries of electric vehicles are used to construct an energy storage battery system. During the trough-electricity-price period, the grid charges the energy storage battery system through the energy conversion system. During the peak-electricity-price period, the energy storage system supplies power to the vehicle charging pile or local load through the energy conversion system to maximize the electricity price difference. After the photovoltaic carport is built, the secondary configuration is employed to build a charging pile on the basis of the photovoltaic carport.

(1) Power generation via photovoltaic carport

During the daytime, the photovoltaic power generation period corresponds to the peak period of electricity price or the peak period of electricity consumption. Photovoltaic power generation is directly used for local load, and the photovoltaic power generation income is maximized by self use.

(2) Lithium-battery energy storage system

It is charged by the grid during periods of low electricity prices. During the daytime, the energy storage system outputs electrical energy to the charging pile, and during the peak period of electric-energy surplus or the period of peak price of electricity, the energy storage system releases the electric energy for local load use. By utilizing the two-way flow of energy and the peak-to-valley time-of-use electricity price of the lithium battery energy storage system, i.e., via the "low-cost storage of electricity, high-priced use" strategy, the charging-pile power supply is not only inexpensive but can also reduce the local load power consumption during the peak electricity price period, thus saving electricity costs.

2.2 Factors affecting the efficiency of charging piles

The rise of electric vehicles has brought about the popularity of charging stations, and will gradually form an electric vehicle networking model. Since electric vehicles are highly dependent on charging and replacing services, charging and replacing information services are also included in the basic services of the Internet of Vehicles to meet the rigid driving needs of electric vehicle users. As the risk factors such as market, finance and operation have different degrees of impact on the charging pile project, the construction of the charging pile interest impact risk factor index system is shown in Table 2:

Table 2 Charging pile interest influence factor index system

Primary indicator	Secondary indicators	Indicator interpretation	Indicator label
Market risk	Government credit risk	Government credit rating	C1
	Market demand risk	Market demand indicator	C2
	Tax incentive risk	Charging pile project tax	C3
	Industry standard risk	Charging pile industry development environment	C4
	Subsidy preferential policy	Charging pile project subsidy	C5
	Market competition risk	Market concentration rate	C6
Financial risk	Inflation risk	Inflation rate	C7
	currency risk	Exchange rate	C8
	Construction period loan interest rate risk	Charging pile project loan interest rate	C9
	Capital net profit margin	Charging pile project profit margin	C10
	Tax rate increase risk	Tax rate	C11
Operational risk	Project duration overdue risk	Construction time	C12
	Construction cost overrun risk	Construction cost	C13
	Operational maintenance cost overrun risk	Operation and maintenance cost	C14
	Payback period risk	Charging pile project investment recovery period	C15
	The management system is not perfect	Charging pile project schedule deviation	C16
	Project construction quality risk	Project quality control	C17
	Technical risk	Technical completion rate	C18

3 Benefit Assignment Model of Integrated Weighting: Shapley Value Method

3.1 Initial allocation of Shapley values

n investment entities are set up to form a distributed photovoltaic power generation carport and energy storage charging pile project; the formation of the alliance is recorded as N, and some of the small alliances formed by the enterprises are recorded as t, where $t \subseteq N$. The benefits obtained after the success of the dynamic alliance will be distributed among n enterprises in the alliance.

The Shapley value method was proposed by Shapley in 1953 and is a method for solving the problem of benefit distribution caused by multi-person cooperation. When n

subjects engage in an economic activity, it is assumed that each form of cooperation will receive certain benefits, and the interest activities of the n subjects have non-confrontational attributes. As the number of subjects increases, the benefits will not reduce; therefore, the biggest benefit is generated in the case of cooperation with n subjects. Shapley value method is a method of distributing the maximum benefit.

Set $I=\{1,2,\cdots,n\}$, and for any subset of the set I, there is a corresponding real value function $v(s)$, satisfying (1)–(3):

$$v(\phi)=0 \tag{1}$$

$$v\left(s_1\cup s_2\right)=v\left(s_1+s_2\right) \tag{2}$$

$$s_1\cap s_2=\phi\left(s_1,s_2\subseteq I\right) \tag{3}$$

Among them, $[I,v]$ is n subject cooperation countermeasures, and v_i is called a feature function of countermeasures. v_i is used to indicate an income that member i can get with the maximum return $v(I)$. The allocation of $x=(x_1,x_2,\cdots,x_n)$ as a cooperative countermeasure should meet the following conditions:

$$\sum_{i=1}^{n}x_i=v(I) \tag{4}$$

$$x_i\geqslant v(i),i=1,2,\cdots,n \tag{5}$$

The benefits obtained by the various entities cooperating in I through the Shapley value method are called Shapley values, which are recorded as

$$\Phi(v)=\left(\varphi_1(v),\varphi_2(v),\ldots,\varphi_n(v)\right) \tag{6}$$

where $\varphi_i(\mathrm{v})$ represents the benefit of the i-th member of the cooperation I:

$$\varphi_i(\mathrm{v})=\sum_{s\in s_i}\omega(|s|)\left[v(\mathrm{s})-\mathrm{v}(\mathrm{s}/i)\right],\quad i=1,2,\ldots,n \tag{7}$$

$$\omega(|s|)=\frac{(\mathrm{n}-|s|)!(|s|-1)!}{n!} \tag{8}$$

where s_i represents the set I containing all subsets of the member i, $|s|$ and n represent the number of elements in s and I, $\omega(|s|)$ represents the weighting factor, $v(s)$ represents the benefit of s, and $v(s/i)$ represents the benefit that can be obtained after going out of i in s.

3.2 Improving the benefit distribution strategy of Shapley value method

3.2.1 No quantitative treatment of indicators

The charging pile benefit impact index system established in this study has the characteristics of multi-level and multi-index. In order to facilitate a comparative analysis, it is necessary to eliminate the differentiation of the evaluation-index unit dimension . Simultaneously, the evaluation indicators comprise extremely large indicators, very small indicators, and intermediate indicators.

Assume that the charging-pile-project benefit-impact-evaluation object $a=\{a_1,a_2,\ldots,a_m\}$, and the comprehensive evaluation index system of each evaluation object is $u=\{u_1,u_2,\ldots,u_n\}$. When the attribute value of the evaluation object $a_i(i=1,2,\ldots,m)$ under the index $u_j(j=1,2,\ldots,n)$ is a_{ij}, the decision matrix $A=(a_{ij})_{m\times n}$, $M=(1,2,\ldots,m)$, and $N=(1,2,\ldots,n)$. Generally, the different types of indicators are profitable and cost based. Since the dimensions of different attributes may be different, we need to perform dimensionless processing on attribute indicators in the calculation process.

For benefit attributes, generally,

$$r_{ij}=\frac{a_{ij}-\min\limits_i a_{ij}}{\max\limits_i a_{ij}-\min\limits_i a_{ij}} \tag{9}$$

For cost-type attributes, let

$$r_{ij}=\frac{\max\limits_i a_{ij}-a_{ij}}{\max\limits_i a_{ij}-\min\limits_i a_{ij}} \tag{10}$$

The matrix $R=(r_{ij})_{m\times n}$ obtained by the above dimensionless processing is called a normalized decision matrix.

3.2.2 ANP-method subjective-weighting model

The ANP model uses the eigenroot method to obtain the sorting vector. If the consistency is satisfied, the eigenvector will be the network element sorting vector (weight), and all the network element sorting vectors will be combined and constructed as a matrix:

$$W_{ij}=\begin{bmatrix} w_{i1}^{j1} & w_{i1}^{j2} & \cdots & w_{i1}^{jn_j} \\ w_{i2}^{j1} & w_{i2}^{j2} & \cdots & w_{i2}^{jn_j} \\ \cdots & \cdots & \cdots & \cdots \\ w_{in_j}^{j1} & w_{in_j}^{j2} & \cdots & w_{in_j}^{jn_j} \end{bmatrix} \tag{11}$$

The column vector of W_{ij} represents the importance ranking vector of the a_i element to a_j element. The ordering vectors of the interactions of all network layer elements are combined to get a supermatrix under the control element:

$$W=\begin{array}{c} 1 \\ \cdots \\ n_1 \\ 1 \\ \cdots \\ n_2 \\ \cdots \\ 1 \\ \cdots \\ n_N \end{array}\begin{bmatrix} W_{11} & W_{12} & \cdots & W_{1N} \\ \\ \\ \\ W_{21} & W_{22} & \cdots & W_{2N} \\ \\ \\ \\ \\ W_{N1} & W_{N2} & & W_{N3} \end{bmatrix} \tag{12}$$

Each element in W is represented by a matrix, and their sum is 1, but W is not a normalized matrix . For the convenience of calculation, the supermatrix needs to be normalized, i.e., the elements of the super-matrix are weighted, and the weighted supermatrix $\overline{W}=\left(\overline{W}\right)_{n\times n}$ is obtained: $\overline{W}=\lambda_{ij}W_{ij}$; λ_{ij} represents a weighting factor, where$i,j=1,2,\cdots,N$.

(4) Calculate the limit supermatrix.

The elements of W are interdependent. In order to reflect this relationship, the obtained supermatrix needs to be processed with stable weights, i.e., each of the supermatrices is calculated for their relative ordering vector:

$$\lim_{k\to\infty}\left(1/N\right)\sum_{k=1}^{N}\overline{W}^{k} \tag{13}$$

If the limit of (13) uniquely converges, the weight of each evaluation index is the value of the row corresponding to the metamatrix.

3.2.3 Entropy weight method objective weighting model

Entropy was originally proposed as a probability in thermodynamics and is used in various fields of research. The entropy weight method mainly analyzes the variability of each index, uses the information entropy to calculate the entropy weight of each index according to their degree of variation, and then corrects the weight of each index through the calculated entropy weight. The final objective is more objective.

Entropy value E_j of the index j is expressed as follows:

$$E_j=-k\sum_{i=1}^{n}r_{ij}\ln\left(r_{ij}\right),j=1,2,\ldots,m \tag{14}$$

where $j=1,2,\ldots,m$, and $k=1/\ln\left(n\right)$ is a constant related to the number of samples; the purpose is to make $E_j\in\left[0,1\right]$; r_{ij}satisfies $0<r_{ij}<1$and$\sum_{i=1}^{n}r_{ij}=1$. When$r_{ij}=0\frac{n!}{r!(n-r)!}$, $r_{ij}\ln\left(r_{ij}\right)=0$.

2) Information deviation is expressed as follows

$$d_j=1-E_j \tag{15}$$

3) Index weight calculation is expressed as follows:

$$w''=\frac{d_j}{\sum_{j=1}^{m}d_j}=\frac{1-E_j}{m-\sum_{j=1}^{m}E_j},\left(j=1,2,\ldots,m\right) \tag{16}$$

where w'' represents the objective weight value of the indicator, d_j and E_j represent the information deviation degree and entropy value of the j index, respectively.

3.2.4 subjective and objective integrated weighting model

The above subjective and objective weighting methods all have certain deficiencies. In order to overcome the above shortcomings and make the final index weights take into account both subjective and objective factors, in this section, we develop a new integration with the subjective and objective weight deviations as the objective function s. The weighting model is used to determine the weight of the evaluation indicators.

It is assumed that the subjective weight vector of the charging-pile benefit-impact index calculated by ANP method is $w'=\left(w_1',w_2',\ldots,w_n'\right)^T$ and satisfies $w_j'\in\left[0,1\right]$, $\sum_{j=1}w_j'=1$; the entropy weight method is used to calculate the objective weight vector $w''=\left(w_1'',w_2'',\ldots,w_n''\right)^T$ of the charging-pile benefit-impact index, and this vector satisfies $w_j''\in\left[0,1\right]$ and$\sum_{j=1}w_j''=1$; subjective weight weighting with objective weights gives the final weight vector:

$$w=\alpha w'+\beta w'' \tag{17}$$

where α,β satisfy $\alpha,\beta>0,\alpha+\beta=1$. For the benefit distributions of the m stakeholders, the membership score is recorded for the actual contribution to the influencing factors, and the membership matrix is R.

$$R=\left(r_{ij}\right)_{m\times n}=\begin{vmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ r_{m1} & r_{m2} & \cdots & r_{mn} \end{vmatrix} \tag{18}$$

Then the actual contribution of each member in the alliance is $Q=w*R$, and Q is consistently processed to obtain

$$Q=\left(Q_1,Q_2,\cdots,Q_n\right) \tag{19}$$

It is standardized to obtain the benefit distribution adjustment coefficient of each participant:

$$p_i=\frac{Q_i}{\sum_{i=n}^{n}Q_i} \tag{20}$$

In the initial allocation scheme of the project, the default members are equal in terms of the correction factor, and all correction factors have the value $\frac{1}{n}$. The evaluation criteria after introducing the correction factor are summarized in Table 3:

Table 3 Correction factor evaluation criteria

Correction factor	Indicator description
$\frac{Q_i}{\sum_{i=n}^{n}Q_i}\geqslant\frac{1}{n}$	After the enterprise$i$ has passed the benefit revision, the profit of this enterprise is accordingly larger.
$\frac{Q_i}{\sum_{i=n}^{n}Q_i}=\frac{1}{n}$	The enterprise$i$benefit distribution is the same as the original distribution.
$\frac{Q_i}{\sum_{i=n}^{n}Q_i}\leqslant\frac{1}{n}$	After the enterprise$i$has passed the benefit correction, the profit of this enterprise is correspondingly smaller.

To improve the contribution rate of distributed photovoltaic power generation sheds and energy storage charging piles by comprehensively considering the alliance benefit distribution factor under the initial Shapley value method, the alliance contribution factor under the integrated weighting method, and the average distribution of alliance members, the benefit distribution factor before improvement is set to v_i, and the improved benefit distribution factor is set to K_i; then,

$$K_i = v_i + p_i - \frac{1}{n} \tag{21}$$

The final benefit allocation ϕ_i' of participant i is

$$\phi_i' = \phi_i + \left(p_i - \frac{1}{n}\right)v\left(s\right) \tag{22}$$

4 Case analysis

4.1 Shapley value method initial allocation

The charging-pile project adopts the PPP model, and the investor consists of three members: government agency A, private investor B, and Internet enterprise C. After evaluation, the overall project income was 3.452 million yuan. Based on past investment and operation experience, the interests of the individual members A, B, and C were solely managed at 1,035,600 yuan, 813,600 yuan, and 616,400 yuan, respectively. The benefits from the AB, AC, and BC cooperations were 2,219,100 yuan, 1,849,200 yuan, and 1,479,400 yuan, respectively. The initial allocation of Shapley values for each participant calculated by (1)–(8) is summarized in Table 4:

Table 4 Initial allocation of Shapley values by each participant

Participant *i*	**A**				**B**				**C**			
S	A	AB	AC	ABC	B	BA	BC	ABC	C	CA	CB	ABC
V(S)	103.56	221.91	184.92	345.2	81.36	221.91	147.94	345.2	61.64	184.92	147.94	345.2
V(S/i)	0	81.36	61.64	147.94	0	103.56	61.64	221.91	0	103.56	81.36	221.91
[S]	1	2	2	3	1	2	2	3	1	2	2	3
W[S]	1/3	1/6	1/6	1/3	1/3	1/6	1/6	1/3	1/3	1/6	1/6	1/3
V(S)- V(S/i)	103.56	140.55	123.28	197.26	81.36	118.35	86.3	123.29	61.64	81.36	66.58	123.29
ϕ_i	188.21				136.43				110.95			

Through the initial allocation of Shapley value method, the initial benefit distribution amount of A is 1,882,100 yuan, the initial benefit distribution of B is 1,364,300 yuan, and the initial benefit distribution of C is 1,009,500 yuan.

4.2 Integrated Empowered Charging-Pile-Benefit-Distribution Correction

In this study, the risk is divided into five levels using common risk classification methods: low, Lower, medium, high, and Higher. The risk ranges from 0 to 10, where 0 indicates no risk, and 10 indicates Higher risk . Moreover, the pattern of a questionnaire survey is selected to interview the participants of the charging-pile PPP project and related experts; different experts are selected to evaluate each risk indicator. The evaluation system standards are listed in Table 5:

Table 5 Risk indicator evaluation criteria

Evaluation index	low	Lower	medium	high	Higher
C1	0-2	2-4	4-6	6-8	8-10
C2	0-2	2-4	4-6	6-8	8-10
…	…	…	…	…	…
C18	0-2	2-4	4-6	6-8	8-10

Through the actual contribution of government agencies A, private investors B, and Internet companies C to the abovementioned influencing factors, the membership degree is recorded, and the membership degree matrix is defined as R. The impact of membership degree is summarized in Table 6:

Table 6 Impact of participant membership

Secondary indicators	A	B	C
Government credit risk	6	9	7
Market demand risk	7	5	6
Tax incentive risk	5	6	4
Industry standard risk	6	6	7
Subsidy preferential policy	5	8	8
Market competition risk	3	4	5
Inflation risk	4	6	5
currency risk	6	8	6
Loan interest rate risk	4	5	6
Capital net profit margin	7	7	5
Tax rate increase risk	7	4	6
Project duration overdue risk	8	9	8
Construction cost overrun risk	6	7	8

continue

Secondary indicators	A	B	C
Operational maintenance cost risk	3	6	5
Payback period risk	1	4	2
The management system is not perfect	7	8	9
Project construction quality risk	2	3	4
Technical risk	3	6	5

The initial matrix is normalized to the matrix according to (1) and (2). In order to avoid the subjectivity of expert scoring, the method of entropy weight is used to quantitatively empower the risk factors affecting the benefit of the charging-pile project. The weights of the core stakeholders of the charging pile project are obtained using (11)–(18). See Table 7 for details.

Table 7 Charging pile interest impact factor indicator weight

Secondary indicators	Indicator label	AHP weight	Entropy weight method weight	Combination weight
Government credit risk	C1	0.0123	0.033501	0.022901
Market demand risk	C2	0.0096	0.021871	0.015736
Tax incentive risk	C3	0.0136	0.03156	0.02258
Industry standard risk	C4	0.0213	0.006407	0.013854
Subsidy preferential policy	C5	0.013	0.050843	0.031922
Market competition risk	C6	0.0422	0.049504	0.045852
Inflation risk	C7	0.0252	0.03156	0.02838
currency risk	C8	0.1155	0.022834	0.069167
Loan interest rate risk	C9	0.0627	0.03156	0.04713
Capital net profit margin	C10	0.1351	0.027127	0.081114
Tax rate increase risk	C11	0.1948	0.059314	0.127057
Project duration overdue risk	C12	0.0139	0.003714	0.008807
Construction cost overrun risk	C13	0.1258	0.016048	0.070924
Operational maintenance cost risk	C14	0.0638	0.08856	0.07618
Payback period risk	C15	0.0446	0.335995	0.190298
The management system is not perfect	C16	0.0217	0.012277	0.016989
Project construction quality risk	C17	0.0521	0.088765	0.070433
Technical risk	C18	0.0328	0.08856	0.06068

The actual contribution of each participant in the charging pile PPP project calculated using (19)–(22) is listed in Table 8.

Table 8 Correction values of contribution values of each participant in the charging pile PPP project

	A	B	C
*Q*value	4.271634	5.482738	5.071604
Q-value normalization	0.288118208	0.369806223	0.342075569

Through the normalization of Q, the contribution rate of each participant of the charging pile PPP project is q_i= (0.342831, 0.353718, 0.303451), i.e., the actual contribution factors of government agencies A, private investors B, and Internet companies C in the operation of distributed photovoltaic power generation sheds and energy storage charging piles are 0.342831, 0.353718, and 0.303451, respectively. It can be known from the initial conditions that the value created by the three alliances is 3.452 million yuan, and the benefit distribution amount of each participating entity is corrected using (20)–(21).

$$\phi_A^{'} = \phi_A + \left(p_A - \frac{1}{n}\right)v(s) = 188.21 + \left(0.288118208 - \frac{1}{3}\right) * 345.2 = 172.6017$$

$$\phi_B^{'} = \phi_B + \left(p_B - \frac{1}{n}\right)v(s) = 136.43 + \left(0.369806223 - \frac{1}{3}\right) * 345.2 = 149.0204$$

$$\phi_C^{'} = \phi_C + \left(p_C - \frac{1}{n}\right)v(s) = 110.95 + \left(0.342075569 - \frac{1}{3}\right) * 345.2 = 113.9678$$

It was verified that this revised plan meets the necessary conditions for successful cooperation. The Shapley integrated-empowerment benefit-distribution model is used to more objectively and rationally distribute the benefits of the charging-pile PPP project, so that the benefits deserved by each participant are indeed received by them; therefore, the overall interests of the project are consistently achieved, and the ideal case of full utilization of resources is realized.

5 Conclusion

In this study, we comprehensively considered the three factors of "market, finance, and operation," regarding the implementation of charging-pile projects, and calculated the benefit distribution value based on weighted Shapley-value comprehensive evaluation; this method overcame the limitation of the Shapley-value method, which considered only a single factor. Finally, the fairness and rationality of the benefit distribution model proposed in this paper were evaluated through a case study. Based on the study of Shapley benefit-distribution model of charging pile, the following conclusions are drawn:

(1) Dynamic risk factor indicator system. Through literature survey and expert interview, in this study, a dynamic risk factor index system that combines the various PPP project risk characteristics was established, which can be used as a reference for identifying similar project risk factors.

(2) Benefit correction allocation model. To avoid the shortcomings of interest distribution by neglecting the actual contribution of each core stakeholder, firstly, the multi-dimensional benefit risk factor index system of charging pile was constructed. Then, based on the weighting factor of the risk index, the Shapley model was used to correct the risk factors. Finally, a dynamic benefit distribution model of PPP distributed photovoltaic-power-generation carport and energy-storage charging pile based on multi-dimensional risk factors was established. Moreover, from the practicality perspective, the revised model was integrated into the project; this model can be used as a reference model for the rational benefit allocation of different core stakeholders for similar projects, and an interest distribution plan that satisfies the core stakeholders of the project can be established. This model fully reflects the principle of "benefit sharing and risk sharing" of PPP projects and encourages all parties to work together to improve project performance.

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References

[1] Alireza Valipour, Nordin Yahaya, Norhazilan Md Noor, Simona Kildiene, Hadi Sarvari (2015), Abbas Mardani. A fuzzy analytic network process method for risk prioritization in freeway PPP projects: an Iranian case study. Journal of Civil Engineering and Management, 21(7), 933-947

[2] Jimenez Losada A, Fernande JR, Ordonez M (2013) Myerson values for games with fuzzy communication structures. Fuzzy Sets and Systems, 213(16): 74-90

[3] Beal S, Remila E, Solal P (2010)Rooted tree solutions fortree games. European Journal of Operational Research, 203(2): 404-408

[4] Gallardo J M, Jimenez N, Jimenez Losada A, et al (2015) Games with fuzzy authorization structure: A Shapley value. Fuzzy Sets and Systems, 272:115-125

[5] Hongxia Sun, Qiang Zhang (2010) Characterization of Shapley value in games with fuzzy coalitions. systems Engineering-Theory &Practice, 30(8): 1457- 1464

[6] Hu Jianjun, Hu Feixiong (2009) A novel compensation mechanism of remunerative peak load regulation under energy saving dispatch framework. Automation of Electric Power Systems, 33(10):16-18

[7] Xie Jun, Zhang Xiaohua, Wu Fuxia, et al (2012) Peaking cost allocation using cooperative game theory and engineering concept. Power System Protection and Control, 40 (11):16-23

[8] Hemanta Doloi (2012) Understanding impacts of time and cost related construction risks on operational performance of PPP projects. International Journal of Strategic Property Management, 16(3), 316-337

[9] Verhoest K, Petersen O H, Schemer W, et al (2015) How Do Governments Support the Development of Public Private Partnerships? Measuring and Comparing PPP Governmental Support in 20 European Countries. Transport Reviews, 35(2):118-139

[10] Yang T, Long R, Cui X, et al (2016) Application of the public-private partnership model to urban sewage treatment. Journal of Cleaner Production, 142:1065-1074

[11] Ouenniche J, Boukouras A, Rajabi M (2016) An Ordinal Game Theory Approach to the Analysis and Selection of Partners in Public-Private Partnership Projects. Journal of Optimization Theory and Applications, 169(1):314-343

[12] Liu J, Gao R, Cheah C Y J (2016) et al. Incentive mechanism for inhibiting investors' opportunistic behavior in PPP projects]. International Journal of Project Management, 34(7):1102-1111

[13] Mouraviev N, Kakabadse N (2014) Impact of externalities on sustainable development: evidence from public-private partnerships in Kazakhstan and Russia. Corporate Governance, 14(5):653-669

[14] Vian T, Mcintosh N, Grabowski A, et al (2015) Hospital Public-Private Partnerships in Low Resource Settings: Perceptions of

How the Lesotho PPP Transformed Management Systems and Performance. Health Systems &Reform, 1(2):155-166

[15] Singh L B, Kalidindi S N (2006) Traffic revenue risk management through Annuity Model of PPP road projects in India. International Journal of Project Management, 24(7):605-613

[16] Valipour A, Yahaya N, Noor N M, et al (2015) A fuzzy analytic network process method for risk prioritization in freeway PPP projects: an Iranian case study. Journal of Civil Engineering& Management, 21(7):933-947

[17] Al-Alawi B M, Bradley T H (2013) Total cost of ownership, payback, and consumer preference modeling of plug-in hybrid electric vehicles. Applied Energy, 103(1):488-506

[18] Rahman I, Vasant P M, Singh S M, et al (2016) Review of recent trends in optimization techniques for plug-in hybrid, and electric vehicle charging infrastructures. Renewable &Sustainable Energy Reviews, 58:1039-1047

[19] Han X, Ouyang M, Lu L, et al (2014) A comparative study of commercial fithiumion battery cycle life in electrical vehicle: Aging mechanism identification.Journal of Power Sources, 251(2):38-54

[20] Qiang Sun, Xubo Ge, et al (2011) Review of Smart Grid Comprehensive Assessment Systems. Proceedings of the CSU-EPSA, 23(6):105-110

[21] Rahman I, Vasant P M, Singh S M, et al (2016) Review of recent trends in optimization techniques for plug-in hybrid, and electric vehicle charging infrastructures. Renewable &Sustainable Energy Reviews, 58:1039-1047

[22] Dumortier J, Kent M W, Payton S B (2016) Plug-in vehicles and the future of road infrastructure funding in the United States. Energy Policy, 95:187-195

[23] Han W, Zhang G, Xiao J, et al (2014) Demonstrations and marketing strategies of hydrogen fuel cell vehicles in China. International Journal of Hydrogen Energy, 39(25):13859-13872

[24] Madina C, Zamora I, Zabala E (2016) Methodology for assessing electric vehicle charging in frastructure business models. Energy Policy, 89:284-293

[25] Serradilla J, Wardle J, Blythe P, et al (2017) An evidence-based approach for investment in rapid-charging infrastructure. Energy Policy, 106: 514-524

[26] Ahman M (2006) Government policy and the development of electric vehicles in Japan. Energy Policy, 34(4):433-443

[27] Skerlos S J, Winebrake J J (2010) Targeting plug-in hybrid electric vehicle policies to increase social benefits. Energy Policy, 38(2):705-708

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