Research on the Enterprise Selection of Retired Power Battery Cascade Utilization from the Perspective of Non-Cooperative Game

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Abstract

Based on non-cooperative game theory, a fuzzy decision-making method was proposed to solve the problem of automobile production enterprises' selection of retired power battery echelon utilization enterprises from the perspective of game theory.Firstly, the evaluation index system of echelon utilization enterprises is constructed, and the objectives of three decision-making subjects, benefit, cost and environmental sustainability, and their affiliations are analyzed and explained. Secondly, decision-making experts use the Fermatean fuzzy language set to evaluate the correlation between the realization of the goal of decision-making subject according to the characteristics of different echelon utilization enterprises under the comprehensive evaluation index system.Thirdly, in order to coordinate the internal conflict relations of the three decision-making objectives, the decision objectives are regarded as the game parties based on the game theory, and the scheme characteristics of each candidate enterprise under each index are used as strategies to establish the game decision model and rank the optimal candidate enterprise. Finally, an example of echelon utilization of enterprises in the Yangtze River Delta is calculated to validate the feasibility and practicability of the proposed method.

Keywords

Retired Power Battery, Enterprise Selection of Echelon Utilization, Fermatean Fuzzy Language Set, Game Theory.

1. Introduction

With global warming and the sharp decrease of oil energy, the government and all sectors of society pay more and more attention to the future development of new energy vehicles and power batteries. The service life of the existing vehicle power battery is generally 4-6 years. When the power battery capacity attenuates to 80% of the initial capacity, it is no longer suitable for new energy vehicles and will enter the retirement stage.According to the Data of China Automotive Technology research Center,in 2025, the total amount of retired power batteries will be about 780,000 tons, of which about 550,000 tons of retired power batteries can be used in echelon.If the retired power battery is not effectively recycled, it will cause a huge waste of non-renewable resources and ecological environment pollution. The Ministry of Industry and Information Technology of China issued the "Industry standard conditions for comprehensive Utilization of new energy Vehicle Waste power battery".It is clearly pointed out that the comprehensive utilization of retired power batteries should "follow the principle of first step utilization and then recycling". Reasonable recovery and step utilization of power batteries has become a hot issue in the field of ecological chain management of electric vehicles.

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In 2018, China's seven ministries and commissions issued on the "New energy Vehicle Power battery recycling management Interim Measures", it makes clear that The recovery and utilization of power batteries in China shall implement the Extended Producer Responsibility (EPR) system, that is, automobile production enterprises shall establish power battery recycling channels and be responsible for the recovery of retired power batteries generated after the use and scrapping of new energy vehicles.At present, our country power battery recycling and comprehensive utilization is still in its pilot phase, has not formed a mature industrial chain, even though national policy advocacy cell arrangement in use, the car battery as an energy storage device to use again, but in reality under the condition of automobile production enterprises cannot reach retirement power battery testing, evaluation and dismantling of professional qualifications, and capital investment and cost requirements of general enterprises difficult to bear. For the recovery and utilization of power batteries, the existing common practice is that the automobile production enterprises will recycle the batteries, and entrust the third party comprehensive utilization enterprises with technical advantages and accumulated experience to deal with. Therefore, it is of great significance to select the appropriate power battery echelon utilization enterprises for the realization of power battery value maximization, sustainable development of the industry and commercial ecology.

At present, according to the available literature, the research on the comprehensive evaluation of power battery cascade utilization enterprises is still limited, and its comprehensive evaluation index system also needs to be improved. In addition, in the evaluation process of power battery cascade utilization enterprises, there are many unknown or uncertain factors in operation environment, policy system and other aspects, which also increases the difficulty of decision-making.Due to the complexity and fuzziness of decision-making problems, it is more reasonable to use fuzzy set theory to express the problems which are difficult to be quantitatively analyzed.Atanassov first proposed the concept of intuitionistic fuzzy sets, which used membership, non-membership and hesitation to describe the uncertainty of things, and could extract their similarity from a large amount of data for effective evaluation and prediction.On this basis, Yager proposed the Pythagorean fuzzy set and the Fermatean fuzzy set, the intuitional fuzzy set only satisfies the situation that the sum of membership and non-membership degrees is less than 1, and the sum of the square and cube of membership and non-membership degrees is less than or equal to 1 (as shown in Figure 1).The membership space is the decision information covered by the fuzzy set. The membership space of fermatean fuzzy set has been greatly expanded. The larger the membership space is, the stronger the ability to express the uncertain evaluation data and retain more information, so that the decision-maker does not have to change the decision-maker's evaluation information in order to meet the constraints of the sum of membership and non membership.At present, the Fermatean fuzzy set has been solved in the simulated real laboratory decision problem of New Coronavirus pneumonia virus medical test.

In addition, in the selection of power battery echelon utilization enterprises, it is difficult to use a single goal to evaluate its good or bad, when the qualitative objectives affect each other or even conflict, the characteristics of each candidate enterprise evaluation value can not only meet one goal, while ignoring the constraints of other goals.Therefore, it is necessary to put forward and build a reasonable and effective comprehensive evaluation method and decision model of power battery cascade utilization enterprise on the basis of grasping and refining the relationship characteristics between alternative enterprises and decision objectives.Here, in the construction of power battery arrangement in use of enterprises on the basis of the comprehensive evaluation index system, puts forward the benefits, costs and environmental sustainable development three decision-making target, to coordinate the relationship between internal conflict subject, main decision target as a game, according to the conflicts of interest relationship between the decision goal according to the target present a conflict relationship can be considered as non-cooperative game. In pilot enterprises to select problems, combined with fuzzy decision and the thought of game theory, this paper proposes a power battery arrangement in using fuzzy game decision method of enterprises to choose, according to the benefits, costs and environmental sustainable development three goals as game interest subjects, to each enterprise performance under various index solution features as a strategy, for the aim to

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maximize their own interests to choose the right strategy, so as to realize the goal to achieve Nash equilibrium to determine the optimal candidate enterprise.

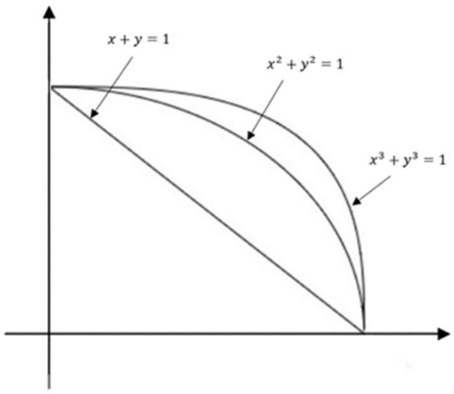

Fig. 1 Comparison of IFSs, PFSs and FFSs

2. Preliminaries

2.1 Fermatean Fuzzy Linguistic Term Set

Definition 1: Let X be the fixed set, $s_{\theta_F(X)}$ is the uncertain language variable and, $s_{\theta_F(X)} \in S$, $S=\{s_i \mid i=0,1,...,2t\}$, then an FFLTS F on X can be

$$F=\{x, s_{\theta_F(X)}, \mu_F(x), \nu_F(x) \mid x \in X\} \tag{1}$$

Where $\mu_F(x)$ and $\nu_F(x)$ are respectively the membership degree and non-membership degree. The indeterminacy degree is given by $\pi_F(x)=\sqrt[3]{1-\mu_F^3(x)-\nu_F^3(X)}$. For $\forall x \in X, \mu_F(x), \nu_F(x) \in [0,1]$,and $\mu_F^3(x)+\nu_F^3(X) \le 1$. X When the set has only one element, FFLTS $F=\{s_{\theta_F(x)}, \mu_F(x), \nu_F(x)\}$ stands for Fermatean Fuzzy Linguistic Number (FFLN).

Definition 2: Let S be a continuous linguistic term set, and let $f_1=(s_{\theta_{f_1}}, \mu_{f_1}, \nu_{f_1})$ and $f_2=(s_{\theta_{f_2}}, \mu_{f_2}, \nu_{f_2})$ be two any FFLNs, $s_{\theta_f(X)} \in S$, $\lambda > 0$, the operational laws of FFLNs are defined as follows:

$$(1)\ f_1 \oplus f_2=(s_{\theta_{f_1}+\theta_{f_2}}, \sqrt[3]{\mu_{f_1}^3+\mu_{f_2}^3-(\mu_{f_1}\mu_{f_2})^3}, \nu_{f_1}\nu_{f_2})$$

$$(2)\ f_1 \otimes f_2=(s_{\theta_{f_1}\theta_{f_2}}, \mu_{f_1}\mu_{f_2}, \sqrt[3]{\nu_{f_1}^3+\nu_{f_2}^3-(\nu_{f_1}\nu_{f_2})^3})$$

$$(3)\ \lambda f_1=(s_{\lambda\theta_{f_1}}, \sqrt[3]{1-(1-\mu_{f_1}^3)^\lambda}, \nu_{f_1}^\lambda)$$

$$(4)\ f_1^\lambda=(s_{\theta_{f_1}^\lambda}, \mu_{f_1}^\lambda, \sqrt[3]{1-(1-\nu_{f_1}^3)^\lambda})$$

$$(5)\ neg(f_1)=(s_{2t-\theta_{f_1}}, \mu_{f_1}, \nu_{f_1})$$

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Definition 3: Let $f=(s_{\theta_f},\mu_f,\nu_f)$ be an FFLN; the score function of f can be defined as:

$$S(f)=\frac{\theta_f}{2t+1}(\mu_f^3-\nu_f^3) \tag{2}$$

The acccuracy function of f can be defined as:

$$H(f)=\frac{\theta_f}{2t+1}(\mu_f^3+\nu_f^3) \tag{3}$$

Define 4 Let $f_j=(s_{\theta_{f_j}},\mu_{f_j},\nu_{f_j})(j=1,2,...,n)$ be FFLNs, and the weight γ_j of f_j satisfy $0<\gamma_j\le 1$, $\sum_{j=1}^{n}\gamma_j=1$, then the FFLWG operator can be defined as:

$$FFLWG(f_1,f_2,...,f_n)=\left(s_{\prod_{j=1}^{n}\theta_j^{\gamma_j}},\prod_{j=1}^{n}\mu_j^{\gamma_j},\prod_{j=1}^{n}\nu_j^{\gamma_j}\right) \tag{4}$$

2.2 Construction of Comprehensive Evaluation Index System of Power Battery Cascade Utilization Enterprise Selection

Table 1. Comprehensive evaluation index system of power battery cascade utilization enterprises

	Level indicators	The secondary indicators	The index type
Comprehensive evaluation index system of power battery cascade utilization enterprises	B_1Enterprise qualification	C_1Corporate reputation	Benefit type
		C_2Information System level	Benefit type
	B_2Product/service	C_3Product timely recovery of the corresponding time	Cost type
		C_4Recovery price level	Benefit type
		C_5Logistics and transportation cost	Cost type
	B_3Business operations	C_6Ability to test/classify/disassemble	Benefit type
		C_7Hazardous material handling capacity	Benefit type
	B_4Green environmental protection	C_8Residual energy conversion capacity	Environmentally sustainable
		C_9"Three waste" processing capacity	Environmentally sustainable

At present, the evaluation index system of power battery cascade utilization enterprise selection in China is not matured. First of all, the enterprise qualification and service level of power battery cascade utilization enterprises need to be considered; Secondly, from the perspective of commercial ecology, electric vehicle production enterprises also need to consider the technical difficulties of cascade utilization of enterprises of the business operation indicators. In addition, the traditional multi-objective decision is often to maximize the benefit and minimize the cost to achieve the economy of the scheme, but with people's attention to environmental protection and sustainable development issues, enterprises in the selection and evaluation of more and more consideration of green environmental protection goals. Therefore, the green environmental indicators of power battery cascade utilization enterprises should also be taken into account. In this paper, according to the research basis of these scholars on green suppliers and the research ideas of power battery cascade utilization, the evaluation indexes of power battery cascade utilization enterprises are divided into four dimensions: enterprise qualification, product and service, business operation and green environmental protection. Based on the perspective of the conflict of interests of the objectives, this paper analyzes the decision of the three main objectives, namely, benefit, cost and environmental sustainability, in the selection of retired battery echelon utilization enterprises. According to the positive correlation between the evaluation index and the realization of the decision goal, the classification and analysis were carried out, and the comprehensive evaluation index system selected by power battery cascade utilization enterprises was constructed (as shown in Table 1).

3. The Proposed Approch

The enterprise selection problem of power battery cascade utilization is a multi-objective optimization problem. Under the objective of environmental sustainable development, the decision objective of pursuing benefit maximization and cost minimization must be considered to determine the best alternative enterprise according to the different characteristics of alternative enterprises and the impact of achieving the decision objective under each attribute.

Table 2. FFLN correlation expert individual evaluation matrix

O_x	$C_i(=1,2,\dots,9)$	$\boldsymbol{A_{ij}(j=1,2,\dots n)\vert f_{ij}^x}$			
		A_1	A_2	$\cdots$	A_n
O_1	C_1	$A_{11}\vert f_{11}^1$	$A_{12}\vert f_{12}^1$	$\cdots$	$A_{1n}\vert f_{1n}^1$
	C_2	$A_{21}\vert f_{21}^1$	$A_{22}\vert f_{22}^1$	$\cdots$	$A_{2n}\vert f_{2n}^1$
	$\cdots$	$\cdots$	$\cdots$	$\cdots$	$\cdots$
	C_5	$A_{51}\vert f_{51}^1$	$A_{52}\vert f_{52}^1$	$\cdots$	$A_{5n}\vert f_{5n}^1$
O_2	C_6	$A_{61}\vert f_{61}^2$	$A_{62}\vert f_{62}^2$	$\cdots$	$A_{6n}\vert f_{6n}^2$
	C_7	$A_{71}\vert f_{71}^2$	$A_{72}\vert f_{72}^2$	$\cdots$	$A_{7n}\vert f_{7n}^2$
O_3	C_8	$A_{81}\vert f_{81}^3$	$A_{82}\vert f_{82}^3$	$\cdots$	$A_{8n}\vert f_{8n}^3$
	C_9	$A_{91}\vert f_{91}^3$	$A_{92}\vert f_{92}^3$	$\cdots$	$A_{9n}\vert f_{9n}^3$

For enterprise selection problem, let $O=\{O_1,O_2,\dots,O_a\}$ be a set of decision objectives, $C=\{C_1,C_2,\dots C_m\}$ be a set of index attributes, $A=\{A_1,A_2,\dots,A_n\}$ be a set of alternative enterprises, γ_k be the weight of experts $E_k(k=1,2,\dots,l)$, satisfying $0\le\gamma_k\le1$, $\sum_{k=1}^{l}\gamma_k=1$. Let $A_{ij}(i=1,2,\dots,m;j=1,2,\dots,n)$ is the characteristic performance of the scheme under the attribute, which is called the characteristic variable of the scheme. Each experts gives his/her payoff judgment of the correlation to achieve decision objectives O_x over the characteristic variables A_{ij} by using FFLTSs, and Fermatean fuzzy linguistic payoff matrices $M^k=[f_{ij,k}^x]_{m\times n}(k=1,2,\dots,l)$,where $f_{ij,k}^x=(s_{\theta_{ij,k}^x},\mu_{ij,k}^x,v_{ij,k}^x)$, and $s_{\theta_{ij,k}^x}$ is linguistic assessment over A_j with respect to C_i given by the experts E_k based on linguistic term set $S=\{s_0,s_1,...,s_g\}$. According to Figure.1, $\{C_1,...,C_5\}\in\{O_1\}$, $\{C_6,C_7\}\in\{O_2\}$, $\{C_8,C_9\}\in\{O_3\}$. According to the evaluation of the correlation between scheme characteristic variables A_{ij} and the realization of decision objectives O_x, the FFLN correlation expert evaluation matrix is constructed, as shown in Table 2.

3.1 Method

According to the conflict of interest relationship of multiple subjects, it can be regarded as non-cooperative game relationship. In the non-cooperative game model, the players of the game make changes according to the strategies of other players in order to satisfy their own maximum interests. When strategise does not meet the maximum interest, the strategise is changed.In the non-cooperative game method, the conflicts of the game subjects are solved and the internal relations are coordinated to determine the best scheme composed of strategies.The selection problem of retired battery cascade utilization enterprise has three decision objectives: benefit, cost and environmental sustainable development. Let $O=\{O_1,O_2,O_3\}$ be a set of game players, and $S=\{S_1,S_2,S_3\}$ be a set of game strategies.The comprehensive correlation value of scheme characteristic variables A_{ij} to achieve the game decision objective O_x is r_{jx}. Each player will be affected by all other game strategies. Therefore, the profit of each player in the same scheme is in the form of relative value, that is, the relative profit is $U_{jx}(S)$.Thus,a three-parties non-cooperative game is defined as a nine-tuple:

$$G\{O_1,O_2,O_3,S_1,S_2,S_3,U_{j1}(S),U_{j2}(S),U_{j3}(S)\} \tag{5}$$

Where $S_1=\{A_{1j},...,A_{5j}\}$, $S_2=\{A_{6j},A_{7j}\}$ $S_3=\{A_{8j},A_{9j}\}$, O_1, $O_2$and O_3 are represented as the three parties of the game, and their game strategies, and the game payment matrix is defined as

$$G=[U_1(S_1,S_2,S_3),U_2(S_1,S_2,S_3),U_3(S_1,S_2,S_3)]_{5\times2\times2} \tag{6}$$

Step 1: Construct FFLN correlation group evaluation matrix $M_1=[f_{ij}^x]_{m\times n}$.

Aggregate the expert individual evaluation matrix $M^k=[f_{ij,k}^x]_{m\times n}(k=1,2,...,l)$ into a the FFLN group evaluation matrix $M_1=[f_{ij}^x]_{m\times n}$ by the $FFLWG$ operator:

$$FFLWG(f_{ij,1}^x,f_{ij,2}^x,...,f_{ij,l}^x)=(s_{\prod_{k=1}^{l}\theta_{f_{ij,k}^x}^{\gamma_k}},\prod_{k=1}^{l}\mu_{f_{ij,k}^x}^{\gamma_k},\prod_{k=1}^{l}\nu_{f_{ij,k}^x}^{\gamma_k}) \tag{7}$$

Step 2: Calculate the FFLN comprehensive correlation evaluation matrix of game decision objectives $M_2=[r_{jx}]_{n\times a}$.

Let e be the number of index attributes under the same game decision objective, In each alternative enterprise A_j, according to the correlation classification relationship between decision objectives and index attributes, transform the FFLN group evaluation matrix $M_1=[f_{ij}^x]_{m\times n}$ into the FFLN comprehensive absolute correlation payoff matrix $M_2=[r_{jx}]_{n\times a}$ of each player by:

$$r_{jx} = \frac{1}{e}(f_{j1}^x + f_{j2}^x + \ldots + f_{je}^x) \quad (8)$$

Step 3: Calculate the comprehensive absolute correlation accurate payoff matrix of game decision objectives $M_3 = [r_{jx}^{'}]_{n\times a}$.

Transform the comprehensive absolute correlation payoff matrix $M_2 = [r_{jx}]_{n\times a}$ into the comprehensive absolute correlation accurate payoff matrix $M_3 = [r_{jx}^{'}]_{n\times a}$ by:

$$r_{jx}^{'} = S(r_{jx}) = \frac{\theta_{r_{jx}}}{2t+1}(\mu_{r_{jx}}^3 - \upsilon_{r_{jx}}^3) \quad (9)$$

Step 4: Calculate the relative payoff matrix of game decision objectives $M_4 = [U_{jx}(S)]_{n\times a}$.

Since different strategy sets are used for each game decision objective O_x, each player will be affected by all other game strategies S_x. Transform the comprehensive absolute correlation accurate evaluation matrix $M_3 = [r_{jx}^{'}]_{n\times a}$ into the relative payoff matrix of game decision objectives $M_4 = [U_{jx}(S)]_{n\times a}$ by:

$$U_{jx}(S) = \frac{r_{jx}^{'}}{r_{j1}^{'} + \ldots + r_{j(x-1)}^{'} + r_{j(x+1)}^{'} + \ldots + r_{ja}^{'}} \quad (10)$$

Step 5: Construct the payoff matrix of the strategic portfolio for the game decision objective, and calculate the relative payoff of the portfolio E_{GM}^x.

Suppose $U_{j1}(S)$-$U_{jx}(S)$ represents the positive correlation between game objectives, and $U_{j(x+1)}(S)$ -$U_{ja}(S)$ represents the negative correlation between game objectives. Then, Equation (11) is used to calculate the profit value E_{GM}^j of each alternative enterprise A_j strategy combination. The payoff matrix of strategy combination of game decision objectives of each alternative enterprise is shown in Table 3.

$$E_{GM}^j = U_{j1}(S) \times \ldots \times U_{jx}(S) \times (1 - U_{j(x+1)}(S)) \times \ldots \times (1 - U_{ja}(S)) \quad (11)$$

Table 3. payoff matrix of strategy combination of game decision objectives

A_j	O_x / S_x			E_{GM}^j
A_1	$O_1 / \{A_{11},\ldots,A_{51})$	$O_2 / \{A_{61},A_{71})$	$O_3 / \{A_{81},A_{91})$	E_{GM}^1
A_2	$O_1 / \{A_{12},\ldots,A_{52})$	$O_2 / \{A_{62},A_{72})$	$O_3 / \{A_{82},A_{92})$	E_{GM}^2
…	…	…	…	…
A_n	$O_1 / \{A_{1n},\ldots,A_{5n})$	$O_2 / \{A_{6n},A_{7n})$	$O_3 / \{A_{8n},A_{9n})$	E_{GM}^j

 Volume 8 Issue 1, 2022
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Step 6: Sort in descending order according to the relative profit value of the combination. E_{GM}^{j}

In the decision-making process of non-cooperative game, the Nash equilibrium strategy should satisfy Equation (12).

$$\begin{aligned} U_{O_1}(S_1^*,S_2^*,S_3^*) &= \sup_{S_1} U_{O_1}(S_1^*,S_2,S_3) \\ U_{O_2}(S_1^*,S_2^*,S_3^*) &= \sup_{S_2} U_{O_2}(S_1,S_2^*,S_3) \\ U_{O_3}(S_1^*,S_2^*,S_3^*) &= \sup_{S_3} U_{O_3}(S_1,S_2,S_3^*) \end{aligned} \tag{12}$$

There is a Nash equilibrium strategy $S^*=(S_1^*,S_2^*,...,S_n^*)$ for each decision objective, which is to pursue the maximization of the benefit of each game decision objective in a non-cooperative game, compare $E_{GM}^{j}(j=1,2,...,n)$, and then arrange the alternatives in descending order.

4. Numerical Example

4.1 Problem Description

B enterprise is one of the earliest automobile manufacturers in China to produce new energy vehicles. From 2015 to the end of 2016, the nation's cumulative sales volume has exceeded 260,000 new energy vehicles. The power batteries of this batch of new energy vehicles have entered the battery decommissioning stage. With the arrival of the decommissioning peak, new energy vehicle manufacturers as the main body of recycling responsibility must not only consider the safety risks and cost issues of transporting batteries from different regions to the processing center in the actual recycling process, but also consider the recycling of decommissioned batteries. How to use it later to maximize its effectiveness. However, the new energy vehicle manufacturer lacks the qualifications and expertise for the echelon utilization of retired power batteries in practice, and is often handed over to a third-party company for recycling. Therefore, in the selection of alternative enterprises, the main consideration is the outstanding enterprises in the use of retired batteries in the Yangtze River Delta, so as to promote the large-scale use of waste power batteries in the Yangtze River Delta region to build capacity for the industrialization of automated equipment in the use of waste power batteries, so as to achieve an exemplary role to help solve the problems in other regions. Recycling and disposal of decommissioned batteries.

Table 4. FFLN correlation expert individual evaluation matrix

O_x	C_i	Relevant value of the alternative enterprise$A_{ij}(j=1,2,\dots n)$|			
		A_1	A_2	A_3	A_4
O_1	C_1	$\langle s_2,(0.7,0.3)\rangle$	$\langle s_1,(0.6,0.4)\rangle$	$\langle s_2,(0.7,0.3)\rangle$	$\langle s_1,(0.6,0.4)\rangle$
	C_2	$\langle s_2,(0.8,0.3)\rangle$	$\langle s_1,(0.7,0.3)\rangle$	$\langle s_3,(0.8,0.2)\rangle$	$\langle s_1,(0.5,0.5)\rangle$
	C_3	$\langle s_4,(0.7,0.3)\rangle$	$\langle s_4,(0.7,0.3)\rangle$	$\langle s_5,(0.9,0.1)\rangle$	$\langle s_3,(0.7,0.3)\rangle$
	C_4	$\langle s_4,(0.9,0.2)\rangle$	$\langle s_2,(0.8,0.2)\rangle$	$\langle s_2,(0.8,0.3)\rangle$	$\langle s_1,(0.7,0.3)\rangle$
	C_5	$\langle s_3,(0.7,0.4)\rangle$	$\langle s_2,(0.7,0.3)\rangle$	$\langle s_4,(0.7,0.2)\rangle$	$\langle s_2,(0.8,0.2)\rangle$
O_2	C_6	$\langle s_2,(0.8,0.3)\rangle$	$\langle s_3,(0.7,0.3)\rangle$	$\langle s_4,(0.7,0.3)\rangle$	$\langle s_2,(0.7,0.4)\rangle$
	C_7	$\langle s_3,(0.7,0.3)\rangle$	$\langle s_3,(0.8,0.2)\rangle$	$\langle s_2,(0.8,0.3)\rangle$	$\langle s_5,(0.7,0.3)\rangle$
O_3	C_8	$\langle s_3,(0.7,0.4)\rangle$	$\langle s_3,(0.6,0.4)\rangle$	$\langle s_4,(0.9,0.2)\rangle$	$\langle s_2,(0.7,0.2)\rangle$
	C_9	$\langle s_4,(0.8,0.2)\rangle$	$\langle s_3,(0.7,0.3)\rangle$	$\langle s_2,(0.7,0.4)\rangle$	$\langle s_2,(0.5,0.5)\rangle$

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In this paper, the retired battery recycling and utilization team of B enterprise is taken as the research object. The meaning of indicators is explained in the volume survey, and the relevant information of the respondents is collected as necessary. Members of the respondents include personnel from relevant departments of battery recycling and processing, external experts, environmental personnel, r&d personnel and sales personnel, etc.The method of questionnaire survey was adopted to conduct a questionnaire survey among 32 members of the team. There were 29 valid questionnaires with a recovery rate of 90.63%.By summarizing the identity information of the participants in the questionnaire, five decision groups were finally determined, and the collected data were summarized to obtain the Fermatean fuzzy language evaluation matrix.After preliminary screening of alternative enterprises, there are 4 comprehensive recycling enterprises that need further evaluation, that is, the set of alternative enterprises is $A=\{A_1,A_2,A_3,A_4\}$.Affect the choice of the enterprises to carry out A pilot use enterprise main influence index attributes separately for the enterprise prestige (C_1), information system level (C_2), recycling price level (C_3), the ability to test/classification/dismantling (C_4), ability to handle danger (C_5), product recycling in time response time (C_6), logistics transportation costs (C_7), the remaining energy capacity (C_8), "three wastes" treatment capacity (C_9), the index attribute set is $C=\{C_1,C_2,...,C_9\}$.In the selection and decision problem of echelon utilization enterprises, the decision objectives are benefit objective (O_1), cost objective (O_2) and environmental objective (O_3), namely, the target set is $O=\{O_1,O_2,O_3\}$.The five expert groups $E=\{E_1,E_2,...,E_5\}$ have equal decision-making rights during the evaluation, and the expert weight $\gamma_k(k=1,2,...,5)$ satisfies $0\le\gamma_k\le1$, $\sum_{k=1}^{5}\gamma_k=1$, that is, the expert weight is $\gamma_k=0.2(k=1,2,...,5)$.The expert initial decision evaluation matrix is $M^k=[f_{ij,k}^x]_{m\times n}$, and the language term set is . $S=\{s_0=\text{Irrelevant},s_1=\text{slightly correlated},s_2=\text{moderately correlated},s_3=\text{strongly correlated},s_4=\text{very stron}$ $\text{-gly correlated}\}$, where $f_{ij,k}^x$ is the evaluation value of FFLN correlation between the alternative enterprise characteristics A_j and the objectives O_x realization under the attribute C_i of the expert $E_k(k=1,2,...,5)$.Experts need to evaluate the four candidates and select the best partner.Limited by space, only the expert E_1 evaluation matrix is given here (see Table 4).

4.2 Decision Process and Result

Table 5. FFLN correlation group Evaluation matrix M_1

O_x	C_i	$A_{ij}(j=1,2,...n)\|f_{ij}^x$			
		A_1	A_2	A_3	A_4
O_1	C_1	$\langle s_{1.74},(0.68,0.32)\rangle$	$\langle s_{2.22},(0.64,0.33)\rangle$	$\langle s_{2.17},(0.57,0.39)\rangle$	$\langle s_{1.43},(0.62,0.37)\rangle$
	C_2	$\langle s_{2.55},(0.78,0.27)\rangle$	$\langle s_{2.00},(0.70,0.33)\rangle$	$\langle s_{3.00},(0.76,0.28)\rangle$	$\langle s_{1.78},(0.62,0.39)\rangle$
	C_3	$\langle s_{2.30},(0.60,0.35)\rangle$	$\langle s_{2.70},(0.69,0.32)\rangle$	$\langle s_{3.90},(0.71,0.26)\rangle$	$\langle s_{1.89},(0.66,0.30)\rangle$
	C_4	$\langle s_{2.70},(0.71,0.26)\rangle$	$\langle s_{2.00},(0.61,0.42)\rangle$	$\langle s_{2.00},(0.76,0.26)\rangle$	$\langle s_{2.70},(0.71,0.26)\rangle$
	C_5	$\langle s_{2,35},(0.71,0.31)\rangle$	$\langle s_{2.17},(0.75,0.25)\rangle$	$\langle s_{2.35},(0.72,0.28)\rangle$	$\langle s_{2.70},(0.78,0.26)\rangle$
O_2	C_6	$\langle s_{2.17},(0.68,0.34)\rangle$	$\langle s_{2.17},(0.61,0.42)\rangle$	$\langle s_{2.49},(0.59,0.39)\rangle$	$\langle s_{2.30},(0.72,0.34)\rangle$
	C_7	$\langle s_{2.55},(0.72,0.28)\rangle$	$\langle s_{3.57},(0.75,0.25)\rangle$	$\langle s_{3.64},(0.59,0.35)\rangle$	$\langle s_{3.68},(0.65,0.43)\rangle$
O_3	C_8	$\langle s_{2.93},(0.74,0.40)\rangle$	$\langle s_{2.35},(0.70,0.36)\rangle$	$\langle s_{2.99},(0.76,0.30)\rangle$	$\langle s_{3.29},(0.72,0.31)\rangle$
	C_9	$\langle s_{3.18},(0.56,0.41)\rangle$	$\langle s_{3.00},(0.59,0.40)\rangle$	$\langle s_{2.17},(0.65,0.35)\rangle$	$\langle s_{3.03},(0.57,0.46)\rangle$

The proposed method is used to make a decision on the choice of partners for the power battery cascade utilization enterprise of B enterprise.The specific steps are as follows:

Step 1: According to equation (7), aggregate the expert individual evaluation matrix and construct the FFLN correlation group evaluation matrix M_1 (as shown in Table 5).

Step 2: Calculate the FFLN comprehensive correlation evaluation matrix of game decision objectives M_2.

According to Equation (8), the comprehensive absolute correlation matrix $M_2 = [r_{jx}]_{n \times a}$ of game decision objectives is calculated, and the results are shown in Table 6.

Table 6. Correlation matrix of comprehensive indexes of game decision objectives M_2

Enterprises	The third-parties game		
	O_1	O_2	O_3
A_1	$\langle s_{2.329}, (0.705, 0.299)\rangle$	$\langle s_{2.360}, (0.701, 0.312)\rangle$	$\langle s_{3.054}, (0.667, 0.404)\rangle$
A_2	$\langle s_{2.218}, (0699, 0.318)\rangle$	$\langle s_{2.867}, (0690, 0.322)\rangle$	$\langle s_{2.676}, (0.652, 0.376)\rangle$
A_3	$\langle s_{2.684}, (0.715, 0.288)\rangle$	$\langle s_{2.565}, (0.590, 0.370)\rangle$	$\langle s_{2.581}, (0.712, 0.327)\rangle$
A_4	$\langle s_{2.101}, (0.685, 0.309)\rangle$	$\langle s_{2.989}, (0.688, 0.380)\rangle$	$\langle s_{3.159}, (0.658, 0.377)\rangle$

Step 3: Calculate the comprehensive absolute correlation matrix M_3 of game decision objectives.

According to Equation (9), the precise matrix $M_3 = [r'_{jx}]_{n \times a}$ of comprehensive absolute correlation of game decision objectives is calculated, and the results are shown in Table 7.

Table 7. Precise matrix of comprehensive absolute correlation of game decision objectives M_3

Enterprises	The third-parties game		
	O_1	O_2	O_3
A_1	0.1508	0.1484	0.1412
A_2	0.1371	0.1689	0.1197
A_3	0.1830	0.0791	0.1682
A_4	0.1226	0.1616	0.1459

Table 8. Comprehensive relative return matrix of game decision objectives M_4

Enterprises	The third-parties game		
	$U_1(S)$	$U_2(S)$	$U_3(S)$
A_1	0.5205	0.5084	0.4719
A_2	0.4750	0.6577	0.3912
A_3	0.7401	0.2253	0.6415
A_4	0.3987	0.6020	0.5133

Step 4: Calculate the relative return matrix M_4 of game decision objectives.

According to Equation (10), the relative profit value $U_{jx}(S)$ of game decision target is calculated (see Table 8).

Step 5: Calculate the combined relative returns E_{GM}^{j} .

According to Equations (11) - (12), the profit value of the strategy combination is calculated. The profit value E_{GM}^{j} of the strategy combination of the game decision objective of the alternative enterprise is shown in Table 9.

Table 9. Payoff matrix of strategy combination of game decision objectives

A_j	O_X / S_x			E_{GM}^{j}
A_1	$O_1/\{S_{11},S_{21},S_{31},S_{41},S_{51}\}$	$O_2/\{S_{61},S_{71}\}$	$O_3/\{S_{81},S_{91}\}$	0.1208
A_2	$O_1/\{S_{12},S_{22},S_{32},S_{42},S_{52}\}$	$O_2/\{S_{62},S_{72}\}$	$O_3/\{S_{82},S_{92}\}$	0.0636
A_3	$O_1/\{S_{13},S_{23},S_{33},S_{43},S_{53}\}$	$O_2/\{S_{63},S_{73}\}$	$O_3/\{S_{83},S_{93}\}$	0.3678
A_4	$O_1/\{S_{14},S_{24},S_{34},S_{44},S_{54}\}$	$O_2/\{S_{64},S_{74}\}$	$O_3/\{S_{84},S_{94}\}$	0.0815

Step6: Sort in descending order according to the relative profit value E_{GM}^{j} of combination.

According to Equation (12), there is a Nash equilibrium strategy $S^* = (S_1^*, S_2^*, \ldots, S_n^*)$ for each decision target, which seeks to maximize the benefits of each decision target in the non-cooperative game, calculates the size $E_{GM}^{j}(j=1,2,3,4)$, and then ranks the schemes in descending order to determine the optimal solution. $E_{GM}^{1}=0.1208$, $E_{GM}^{2}=0.0636$, $E_{GM}^{3}=0.3678$ and $E_{GM}^{4}=0.0815$, therefore, the ranking result of the scheme is$A_3 > A_1 > A_4 > A_2$, A_3 is the optimal cooperative enterprise.

5. Conclusion

This article proposes a fuzzy game decision-making method for the selection of power battery echelon utilization enterprises based on non-coopertive game theory. First, a comprehensive evaluation index system for the cascade utilization of decommissioned power battery enterprises was constructed, and the three major decision-making objectives of benefit, cost and environmental sustainability and their affiliations were put forward; Different retired power battery cascades use the characteristics of the enterprise to evaluate the correlation between the realization of the three decision-making objectives; again, according to the discrete evaluation data of the attribute characteristics of each scheme and the realization of the decision-making objectives, improve the conflict of interest between the objectives, and propose a game-based method The equilibrium solution model of the three major decision-making objectives of theoretical benefit, cost and environmental sustainability. The alternative enterprises are ranked and the optimal cooperative enterprise is determined. Finally, the calculation is carried out based on the example of the power automobile production enterprise in the Yangtze River Deltato to validate the feasibility and practicability of the proposed method.

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