
Power Battery Recycling Mode and Decision-making Model for New Energy Vehicles Under the Background of Dual Carbon

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Abstract

Recycling and cascade utilization of waste power batteries for new energy vehicles is an effective measure to manage carbon emissions in the power battery industry chain and achieve the dual carbon target. In view of the current confusion of recycling channels and the unclear benefits and costs of the recycling market, the article constructs three recycling modes: self-operated recycling mode, industry alliance recycling mode and third-party enterprise recycling mode. With profit maximization as the decision-making goal, a recycling profit function model is established, and through the comparative analysis of profits of different recycling modes, the relationship and influencing factors between them are obtained, which can provide reference for enterprises to make recycling decisions.

Keywords: New energy vehicles, power batteries, recycling modes, carbon peak, carbon neutrality.

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1 Introduction

Under the dual pressure of the increasing shortage of fossil energy such as oil and the response to global climate change, it has become an irreversible development trend for new energy vehicles to replace traditional fuel vehicles. From 2015, the production and sales of new energy vehicle in China started a breakthrough growth, which has also brought about an explosive growth in the demand for power batteries. The application of power batteries provides key support for carbon peaking and carbon neutrality. Meanwhile, low carbonization or even zero carbonization is also a new requirement for power batteries and related enterprises. In addition to reducing carbon emissions in power battery production, recycling and cascade utilization of waste power batteries is also an effective measure to achieve carbon emission management in the power battery industry chain and achieve the dual carbon goal. According to the Research Report on the Circular Economy Potential of New Energy Vehicle Batteries in 2030 released by Greenpeace, a global environmental protection organization, China's waste power batteries will reach 708 GWh by 2030 (starting from 2021), and these batteries will be recycled and effectively used in cascade, which will reduce carbon emissions by nearly 33.42 million tons compared to manufacturing the same quantity of new batte [1].

The recycling and utilization of waste power batteries has already attracted attention from all walks of life. China has promoted the development of the power battery recycling industry chain through the implementation of relevant encouragement and guidance policies. In 2018, the Ministry of Industry and Information Technology issued the Interim Measures for the Administration of Recycling Traction Batteries of New Energy Vehicles, requiring manufacturers to take the initiative to take responsibility for battery recycling. The Key Points of Industrial Energy Conservation and Comprehensive Utilization in 2020 released in 2020 emphasizes promoting the construction of a power battery recycling system for new energy vehicles, accelerating the exploration and promotion of a market-oriented recycling mode that is technically economical and environmentally friendly, and fostering a number of power battery recycling backbone enterprises. In January 2022, the Implementation Plan for Accelerating the Comprehensive Utilization of Industrial Resources printed and issued by eight departments including the Ministry of Industry and Information Technology, proposed to improve the management system, and strengthen the traceability management of the whole life cycle of power batteries for new energy vehicles; promote

the cooperation between the upstream and downstream of the industrial chain to build recycling channels and a cross-regional recycling system. However, since the recycling of power batteries is still in the early stage of commercialization, and the industry regulatory policies and recycling standards are not perfect in addition to other reasons, resulting in a series of problems like confusion in recycling channels, unclear benefits and costs in the recycling market, which affect the enthusiasm of formal recycling enterprises and the benign development of the industry. Therefore, how to further standardize the power battery recycling system, design a scientific and reasonable recycling mode, and stimulate the enthusiasm of the main recycling body to participate in recycling is becoming a hot issue for research.

At present, scholars at home and abroad have conducted research on the recycling of new energy power batteries. For example, foreign scholars Thierry [2] and Javaraman [3] analyzed the product recycling strategy in the reverse logistics process, and proposed the specific process of product recycling in the recycling process, and gave the recycling method; Spicer et al. [4] constructed and analyzed the OEM recycling mode, the combined recycling mode and the third-party recycling mode under the premise of the EPR producer responsibility extension system, discussed the third-party recycling mode, recycling-related costs and recycling operation methods, etc. by taking them as the analysis objects, and described the recycling rules of third parties; Zou and Liu [5] analyzed the current situation of the power battery recycling industry and the necessity of recycling and related recycling policies, and discussed and put forward relevant suggestions. Domestic scholars Jiang Chuanyu et al. [6] analyzed the waste of resources and environmental pollution caused by waste power batteries, and put forward corresponding countermeasures and suggestions for researching the recycling mode of waste power batteries with the new energy vehicle industry in Ganzhou as an example; Jin Qihao [7] studied the characteristics of power battery recycling based on the life cycle, constructed a corresponding recycling mode by combining the characteristics of 4 different stages, and gave the optimal choice; Ni Fei [8] analyzed the current characteristics of domestic power battery recycling. Based on this background, he analyzed the recycling and reuse of scrapped products in the domestic new energy vehicle industry, and finally put forward suggestions and countermeasures; Fang Yi [9] studied the existing problems in the current recycling process of waste power batteries in China from three aspects, and summarized the supply chain of recycling; Yao Yan et al. [10] proposed that in order to achieve the maximum resource recycling of battery materials in Sanyuanli, it is necessary to build a power

battery recycling mode with the new energy vehicle enterprises as the main body. On this basis, they analyzed the relevant costs and profits under the new energy vehicle enterprise recycling mode; Zhang Guofang et al. [11] proposed five power battery recycling modes based on factors such as power battery recycling cost and recycling efficiency, and gave the optimal selection of recycling mode.

According to the review of domestic and foreign literature, the current research mainly focuses on several aspects such as national policies and regulations, construction of recycling network, recycling processing technology, etc., while there is less research on recycling mode design and selection. Especially considering the current dual carbon background, the research on the decisions of recycling modes for power batteries of new energy vehicles is hardly involved. To this end, based on the research of scholars at home and abroad, this article constructs three recycling modes and analyzes and compares these recycling modes, and then builds a mathematical model for each recycling mode with the profit maximization as the goal. Besides, and the profits under different recycling modes are also analyzed, to obtain the optimal solution belonging to the respective parameters of the recycling modes, thereby providing decision-making reference for enterprises while selecting the recycling mode, which has certain research value and significance.

2 Establishment of Recycling Modes for Waste Power Batteries

As an emerging industry, the power battery recycling and utilization has a number of participants including suppliers, manufacturers, retailers, consumers, and professional third-party enterprises in the industry chain. However, the division of labor among them is still unclear. In November 2019, the Ministry of Industry and Information Technology issued the *Guidelines for the Construction and Operation of Service Networks for Recycling of Power Batteries in New Energy Vehicles*, proposing that the new energy vehicle production and cascade utilization enterprises should establish recycling service outlets through self-construction, joint-construction, authorization, etc. in accordance with relevant national management requirements. Based on the existing organizational mode for recycling of power batteries of new energy vehicles and the national policy direction, with reference to the research results of relevant scholars at home and abroad, the self-operated recycling model, the industry alliance recycling model and the third-party recycling

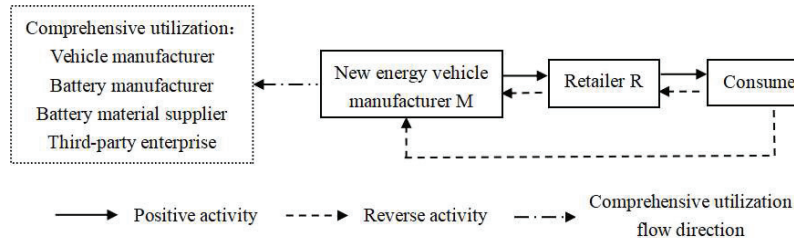


Figure 1 Self-operated recycling mode.

model are constructed, with the new energy vehicle manufacturers as the main recycling body.

2.1 Self-operated Recycling Mode (CRM-CM)

This model means that the new energy vehicle manufacturers should recycle waste power batteries from consumers through retailers or self-built recycling service outlets. After preliminary sorting and processing, they should be delivered or sold to comprehensive utilization enterprises or used for their own relevant exploration and research (such as cascade utilization). In this mode, the new energy vehicle manufacturers use two ways to recycle such batteries: one is to complete the recycling through retailers which are mainly offline 4S stores; the other is to recycle directly from consumers through self-built recycling outlets. The retailer channel is relatively mature and direct-to-consumer, so the first way is more advantageous and is currently most widely used. The comprehensive utilization enterprises here refer to new energy vehicle manufacturers, battery manufacturers, battery material suppliers and third-party enterprises with power battery processing capabilities and qualifications. The recycled power batteries are entrusted to comprehensive utilization enterprises for processing, which also saves the relevant investment in processing. The structure of the self-operated recycling mode is as shown in Figure 1.

2.2 Industry Alliance Recycling Mode (CA-CRA)

The industry alliance recycling mode means that new energy vehicle manufacturers combine with other manufacturers and upstream and downstream enterprises in the supply chain to form a recycling alliance to build a recycling network through joint ventures or contracts, through which waste power batteries are recycled and then sold to comprehensive utilization enterprises

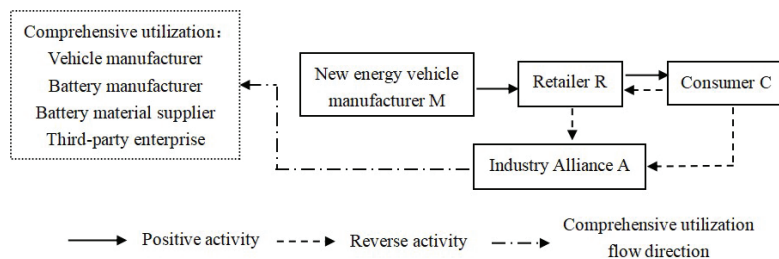


Figure 2 Industry alliance recycling mode.

for processing. In this mode, the industry alliance can directly recycle waste power batteries from consumers, or use the retailer platform for recycling. Member companies can share recycling and processing costs and obtain benefits according to the cooperation agreement.

The industry alliance recycling mode can solve the problem of substandard recycling and “breaking the pale” caused by the self-operated recycling mode of a single enterprise to a large extent. The members of the industry alliance are mainly composed of relevant member companies involved in the recycling and processing of power batteries, including power battery manufacturers, new energy vehicle enterprises, and electric vehicle rental companies. The cooperation method in this mode is mainly that each member company performs its own duties and jointly builds a power battery recycling network after discussion. This mode can also be understood as the working mode for the member companies of all parties in the supply chain in the reverse logistics process. In addition, in the era of rapid development of Internet of Things and big data technology, a system or cloud platform can be developed, which is similar to the management system in the logistics industry. Through related technologies, the relevant information and data in the power battery recycling process are transmitted to the system platform in real time for monitoring, forecasting, and recoverable value analysis. Multiple members can log in to their corresponding functional sections for recycling management. As a result, the industry alliance recycling mode can achieve higher efficiency and wider applicability. The structure of the industry alliance recycling mode is as shown in Figure 2.

2.3 Third-party Recycling Mode (CT)

The third-party recycling model means that the new energy vehicle manufacturer entrusts a professional third-party recycling enterprise to recycle

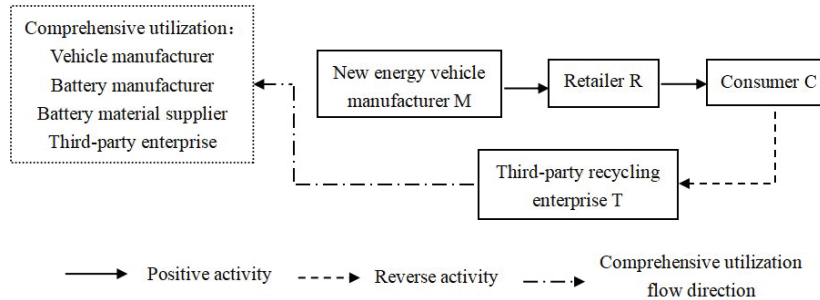


Figure 3 Third-party recycling mode.

waste power batteries, and does not directly participate in the recycling work. Under this model, new energy vehicle manufacturers contract the recycling and processing business to a third-party by signing an agreement, in which they agree upon their respective rights and obligations, and undertake recycling and processing costs and obtain benefits. Enterprises of different scales and types have different development strategies. Some enterprises, such as smaller enterprises, are unable to independently establish their own power battery recycling network due to technical or cost limits, and some large enterprises do not plan to participate in the industry alliance recycling mode due to their own reasons. In this case, the third-party recycling mode is applicable. The advantages of this mode are that firstly, there is no need to invest a lot of manpower, material resources and financial resources in the early stage, and secondly, a professional third-party enterprise for recycling can realize the recycling and reuse of batteries to a greater extent. The structure of the third-party recycling mode is as shown in Figure 3.

2.4 Comparative Analysis of Three Recycling Modes

According to the analysis of the above three power battery recycling models of new energy vehicles, it can be seen that there are three main factors affecting the recycling decision: The first is strategic factors, which mainly include corporate strength, corporate goals, etc.; the second is operational factors, which mainly include investment, cost, profitability, etc.; the third is management factors, which include personnel management, information system construction and so on. Based on these influencing factors, a contrastive analysis was conducted on the three recycling models from 7 aspects like recycling business positioning and recycling logistics cost, and the analysis results are shown in Table 1.

Table 1 Comparative analysis of power battery recovery mode

	Self-operated Recycling	Industry Alliance Recycling	Third-party Enterprise Recycling
Recycling business positioning	Important	Moderately important	Non-core business
Recycling logistics cost	Moderately high	Low	High
Recycling scale	Small	Big	Moderately big
Scaled economy	Low	High	Moderate
Operation risk	By self	Share	By the third party
Information communication	Timely	Slow	Inconvenient
Applicable enterprise	Large enterprises	Both large and small enterprises	Both large and small enterprises

It can be seen from Table 1 that each recycling mode has its own advantages and disadvantages, and there is no recycling mode applicable to all enterprises. For large enterprises with a variety of products and sufficient funds, manpower and technology, they can choose to establish a self-operated recycling model; for enterprises whose expansion of the recycling model will seriously affect their own development and slow down their core business, they can choose to join the industry alliance. Or choose a third-party recycling mode. In real business operations, companies need to choose a low-cost, high-yield recycling model according to their own circumstances.

3 Decision Model for the Recycling Mode

3.1 Basic Assumptions

Assumption 1: Assume that the recycling enterprise will recycle waste batteries in the forms like trade-in, a price P will be generated at this time. Assume that the known quantity of recycled batteries S is positively correlated with the recycling price P , and the quantity of recycled power batteries for new energy vehicles is affected by the recycling enterprise's recycling effort (η). In real life, without any recycling benefits, the recycling body can also receive a small number of waste batteries S_0 . According to the above, the waste battery supply function is:

$$S(P, \eta) = S_0 + aP + b\eta (a > 0, b > 0)$$

$$S(P, \eta) = S_0 + aP + b\eta (a > 0, b > 0)$$

Assumption 2: In the recycling process, the main recycling body determines the recycling mode, and when cooperating with other enterprises, its behavioral decision determines its recycling effort (η) and the recycling price (P) of waste batteries.

Assumption 3: In the recycling process of power batteries for new energy vehicles, there is a fixed recycling cost C_F , and a variable cost including the recycling cost P, the unit processing cost C_U and various discounts of waste batteries.

Assumption 4: Assume that the power batteries for new energy vehicle can bring unit income ω after recycled, and it includes various benefits from recycling waste batteries.

Assumption 5: In the assumed model, the communication among enterprises is timely and the information is symmetrical, and there is no need to consider the internal and external competition relationship, only the simple relationship under this model is considered.

Notes:

P – price of recycled waste batteries, i.e. the price after the "trade-in" strategy is applied.

η – recycling enterprise' effort

S – quantity of recycled power batteries

S_0 – quantity of recycled waste power batteries without recycling price and recycling effort

C_F – fixed recycling cost

C_U – unit recycling and use cost

ω – Unit recycling income

Π_i^j, C_i^j – profit function, and cost function, where $i = M, R, A$ and T denote the new energy vehicle manufacturer, the retailer, the industry alliance and the third-party recycling enterprise, respectively; $j = 1, 2,$ and $3,$ denote the self-operated recycling mode, the industry alliance recycling mode and the third-party enterprise recycling mode of waste power batteries.

3.2 Recycling Profit Maximization-based Recycling Decision Model

(1) Self-operated Recycling Mode

In this mode, the new energy vehicle manufacturer is responsible for recycling waste batteries. It needs to recycle the waste batteries through the

network platform for sales of new energy vehicles. In this case, the recycling cost is quite low, and it is only a very low fixed cost, which is only λ times that of a well-established recycling network ($0 < \lambda < 1$), and the fixed recycling cost is related to the main body's recycling effort, so in this case, the fixed recycling cost is $\lambda C_F \eta^2$; the retailer recycles waste batteries at price P through promotional discounts and other means, and then the recycle new energy vehicle manufacturer then buys it at a price of P_0 . From this, the profit function of the main recycling enterprise is:

$$\max \pi_M^1 = (\omega - P_0 - C_u)(S_0 + aP + b\eta) \tag{1}$$

$$s.t. \max \pi_R^1 = (P_0 - P)(s_0 + aP + b\eta) - \lambda C_F \eta^2 \tag{2}$$

After the P, η in Formula (2) is subject to solution of differential coefficient, and an equation set is established:

$$\begin{cases} P = \frac{2P_0 a \lambda C_F - P_0 b^2 - 2\lambda C_F S_0}{4a\lambda C_F - b^2} \\ \eta = \frac{b(S_0 + aP_0)}{4aC_F - b^2} \end{cases} \tag{3}$$

Substitute Formula (3) into Formula (1) and a function of P_0 is obtained:

$$\max \pi_M^1 = \frac{2a\lambda C_F(\omega - C_U - P_0)(S_0 + aP_0)}{4a\lambda C_F - b^2} \tag{4}$$

After P_0 in Formula (4) is subject to solution of first derivative, we obtain:

$$P_0 = \frac{a\omega - aC_U - S_0}{2a} \tag{5}$$

After the result is substituted into Formula (3), the optimal recycling price and the optimal recycling effort coefficient under the self-operated recycling mode are calculated:

$$\begin{cases} P^* = \frac{(a\omega - aC_U - S_0)(2a\lambda C_F - b^2) / 2a - 2\lambda C_F S_0}{4a\lambda C_F - b^2} \\ \eta^* = \frac{b(S_0 + a? - aC_U)}{2(4a\lambda C_F - b^2)} \end{cases} \tag{6}$$

After P_0 and Formula (6) are substituted into Formulas (1) and (2) as well as $S(P,\eta)=S_0+aP+b\eta$, we obtain:

$$\begin{cases} \pi_M^1 = \frac{\lambda C_F(S_0 + a\omega - aC_U)^2}{2(4a\lambda C_F - b^2)} \\ \pi_R^1 = \frac{\lambda C_F(S_0 + a\omega - aC_U)^2}{4(4a\lambda C_F - b^2)} \\ S^1 = \frac{a\lambda C_F(S_0 + a\omega - aC_U)}{4a\lambda C_F - b^2} \end{cases} \quad (7)$$

(2) Industry Alliance Recycling Mode

In this mode, the new energy vehicle manufacturer join the industry alliance, and jointly establish a recycling platform with many other members of the alliance to uniformly recycle waste batteries, process and screen the same, and finally achieve recycling. However, with this mode, it is necessary to hand over the battery unit processing fee C_U and the entrusted processing fee m , so the decision model obtained is:

$$\max \pi_M^2 = (\omega - C_U - m)(S_0 + aP + b\eta) \quad (8)$$

$$s.t \begin{cases} \max \pi_A^2 = (m - P_0)(S_0 + aP + b\eta) \\ \max \pi_R^2 = (P_0 - P)(S_0 + aP + b\eta) - \lambda C_F \eta^2 \end{cases} \quad (9)$$

Similarly, we obtain:

$$\begin{cases} \pi_M^2 = \frac{\lambda C_F(a\omega + am - aC_U)(S_0 + am)}{4a\lambda C_F - b^2} \\ \pi_A^2 = \frac{\lambda C_F(S_0 + am)^2}{2(4a\lambda C_F - b^2)} \\ \pi_R^2 = \frac{\lambda C_F(S_0 + am)^2}{4(4a\lambda C_F - b^2)} \\ S = \frac{a\lambda C_F(S_0 + am)}{4a\lambda C_F - b^2} \end{cases} \quad (10)$$

After the profit function of the recycling body in Formula (10) is subject to solution of the first derivative about m , and the optimal value is obtained as below:

$$m^* = \frac{a\omega - aC_U - S_0}{2a} \quad (11)$$

After Formula (11) is substituted into Formula (10) and simplified, we obtain:

$$\begin{cases} P^* = \frac{\lambda C_F (a\omega - am - aC_U) (S_0 + am)}{4a\lambda C_F - b^2} \\ \eta^* = \frac{b(S_0 + a\omega - aC_U)}{4(4a\lambda C_F - b^2)} \end{cases} \quad (12)$$

$$\begin{cases} \pi_M^2 = \frac{\lambda C_F (S_0 + a\omega - aC_U)^2}{4(4a\lambda C_F - b^2)} \\ \pi_A^2 = \frac{\lambda C_F (S_0 + a\omega - aC_U)^2}{8(4a\lambda C_F - b^2)} \\ \pi_R^2 = \frac{\lambda C_F (S_0 + a\omega - aC_U)^2}{16(4a\lambda C_F - b^2)} \\ S^2 = \frac{a\lambda C_F (S_0 + a\omega - aC_U)}{2(4a\lambda C_F - b^2)} \end{cases} \quad (13)$$

(3) Third-party Recycling Mode

In this mode, it is necessary to sign a contract with a third-party enterprise and pay the fee F. In addition to the cost for processing of the waste batteries, the third-party enterprise also needs a large amount of funds to purchase and maintain various items of processing equipment. Therefore, the profit functions of the two are as below:

$$\begin{cases} \max \pi_M^3 = (\omega - f)(S_0 + aP + b\eta) \\ s.t \max \pi_T^3 = (f - C_U - P)(S_0 + aP + b\eta) - C_F\eta^2 \end{cases} \quad (14)$$

After simplified in the same way, we obtain:

$$\begin{cases} P^* = \frac{(a\omega - aC_U - S_0) (2aC_F - b^2)/2a - 2C_F S_0}{4aC_F - b^2} \\ \eta^* = \frac{b(S_0 + a\omega - aC_U)}{2(4aC_F - b^2)} \end{cases} \quad (15)$$

$$\begin{cases} \pi_M^3 = \frac{C_F (S_0 + a\omega - aC_U)^2}{2(4aC_F - b^2)} \\ \pi_T^3 = \frac{C_F (S_0 + a\omega - aC_U)^2}{4(4aC_F - b^2)} \\ S^3 = \frac{aC_F (S_0 + a\omega - aC_U)^2}{4aC_F - b^2} \end{cases} \quad (16)$$

Table 2 Calculated profits of recycling participants under three recycling models

	Self-operated Recycling Mode	Industry Alliance Recycling Mode	Third-party Recycling Mode
	$\frac{bM}{2(4a\lambda C_F - b^2)}$	$\frac{bM}{4(4a\lambda C_F - b^2)}$	$\frac{bM}{2(4aC_F - b^2)}$
Recycling effort coefficient	$\frac{2(4a\lambda C_F - b^2)}{2(4a\lambda C_F - b^2)}$	$\frac{4(4a\lambda C_F - b^2)}{4(4a\lambda C_F - b^2)}$	$\frac{2(4aC_F - b^2)}{2(4aC_F - b^2)}$
Quantity of recycled batteries	$\frac{a\lambda C_F M}{4a\lambda C_F - b^2}$	$\frac{a\lambda C_F M}{2(4a\lambda C_F - b^2)}$	$\frac{aC_F M}{4aC_F - b^2}$
Profit of the new energy vehicle manufacturer	$\frac{\lambda C_F M^2}{2(4a\lambda C_F - b^2)}$	$\frac{\lambda C_F M^2}{4(4a\lambda C_F - b^2)}$	$\frac{C_F M^2}{2(4aC_F - b^2)}$
Profit of the retailer	$\frac{\lambda C_F M^2}{4(4a\lambda C_F - b^2)}$	$\frac{\lambda C_F M^2}{16(4a\lambda C_F - b^2)}$	/
Profit of the industry alliance	/	$\frac{\lambda C_F M^2}{8(4a\lambda C_F - b^2)}$	/
Profit of the third party	/	/	$\frac{C_F M^2}{4(4aC_F - b^2)}$

Let $S_0 + a\omega - aC_U = M$, then the calculation results are as shown in the Table 2.

4 Analysis of Models

From the above profit analysis of different recycling modes, the optimal solution of the parameters belonging to them can be obtained, and then through the comparative analysis, the following inferences are drawn:

Inference 1: Under the premise of each mode, there is an optimal profit distribution ratio of 2:1 when the new energy vehicle manufacturer cooperates with the retailer, the industry alliance or the third-party company, namely:

$$\pi_M^1 = 2\pi_R^1, \pi_M^2 = 2\pi_A^2 = 4\pi_R^2, \pi_M^3 = 2\pi_T^3$$

This inference indicates that, in different recycling modes, the enterprise as the main body of recycling responsibility can obtain the profits much higher than that for the cooperative enterprises, and such profit distribution follows a certain percentage. For example, in the industry alliance recycling mode, the profit of the new energy vehicle manufacturer is the highest, which is 2 times and 4 times that of the alliance organization and the retailer, respectively.

Inference 2: The quantity of recycled waste batteries is related to the recycling enterprise's recycling effort. In the third-party recycling mode, the quantity of recycled waste batteries is $(2a\lambda C_F)/b$ times the main body's recycling effort, and $(2a\lambda C_F)/b$ times for the other two systems. Under the same conditions, the formula below is always established for the three modes.

$$S^1 = 2S^2, \pi_M^1 = 2\pi_M^2$$

The inference indicates that: in an ideal state, the quantity of recycled waste batteries are affected by the recycling enterprise's effort, which means that in order to obtain high recycling profits, the company as the main recycling body needs to increase its input in recycling.

Inference 3: On the basis of the same conditions for all parameters, the formula below is always established.

$$\pi_M^1 + \pi_R^1 > \pi_M^3 + \pi_T^3 > \pi_M^2 + \pi_R^2 + \pi_A^2$$

The inference indicates that: among the three modes, the self-operated recycling mode has the highest profit, followed by the third-party recycling mode, and the industry alliance recycling mode has the lowest profit. At the same time, it also indicates that the more members there are in the supply chain, the more the transaction costs between them are, the lower the profit of the manufacturer will be, and the higher the profit loss in the whole operation process will be.

5 Conclusion and Prospect

Whether the waste power batteries can be effectively recycled or not will not only directly affect the sustainable development of the new energy vehicle industry, but also affect the realization of the dual carbon strategic goal of China. Aiming at the industrial development bottlenecks such as chaotic recycling channels, low recycling rate and low rate of return, three recycling mode were constructed based on the research of relevant scholars at home and abroad, and a recycling decision model was built on the basis of maximizing profits in this research. With the model, the profit analysis was conducted for the three recycling modes. The research work and main conclusions are as follows:

- (1) The self-operated recycling mode, alliance recycling mode and third-party recycling mode were established. A qualitative comparative analysis on the three recycling modes was conducted from 7 aspects including

recycling business positioning and recycling logistics costs, and the results show that each recycling mode has its own advantages and disadvantages, and there is no recycling mode applicable to all enterprises. Therefore, an enterprise can choose a high-profit optimal mode with a low cost.

- (2) A profit maximization-based recycling mode decision model was constructed, the profit functions of the three modes were given respectively, and the profit of the three recycling modes was calculated.
- (3) Through the analysis on the profits of different recycling modes, relevant inferences were obtained. The results show that: firstly, as the main body responsible for the recycling of waste power batteries, new energy vehicle manufacturers can obtain the highest profit from the self-operated recycling mode, followed by the third-party recycling mode, and the profit from the industry alliance recycling mode was the lowest; secondly, the recycling profit is related to the recycling enterprise's effort. If an enterprise is strong, it will attach importance to the recycling of waste power batteries and regard it as an important strategic development direction of the company. It may choose the self-operated recycling mode, otherwise, choose the third-party recycling mode or the industry alliance recycling mode.

The research on the recycling modes and decisions of waste power batteries for new energy vehicles in this article can provide a certain reference value for the member companies in the power battery recycling industry chain and the entire recycling industry when they are making recycling decisions. The research methods and ideas can be further applied to the decision research of reverse logistics in other industries. The recycling of waste power batteries for new energy vehicles is a complex process, and there are still many problems, such as the effective operation mechanism of the recycling modes, integration of the recycling link and the comprehensive utilization link, optimization of the recycling decision model and the empirical analysis, etc., which need to be further studied.

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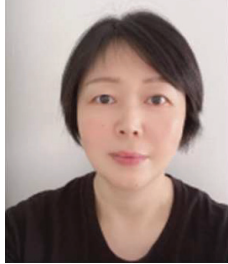
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