sustainability

MDPI

Article

Analysis on the Optimal Recycling Path of Chinese Lead-Acid Battery under the Extended Producer Responsibility System

Xin Zan [1,*] and Deyuan Zhang [2]

[1] School of Economics and Management, Beijing Jiaotong University, Beijing 100044, China
[2] Institute of Economic System and Management, National Development and Reform Commission, Beijing 100035, China; zhangdy271@gmail.com
* Correspondence: 18113021@bjtu.edu.cn; Tel.: +86-182-3570-1123

Abstract: The pollution control problem of discarded lead-acid batteries has become increasingly prominent in China. An extended producer responsibility system must be implemented to solve the problem of recycling and utilization of waste lead batteries. Suppose the producer assumes responsibility for the entire life cycle of lead batteries. In that case, it will effectively reduce environmental pollution caused by non-compliant disposal of waste lead batteries, reduce environmental pollution, and achieve the sustainable development of lead resources. Based on the operating mechanism of the extended responsibility system for lead-acid battery producers in China, this article considers three recycling channel structures: recycling only by manufacturers (mode M), recycling by the union (mode R), and third-party recycling (mode C). This article comprehensively compares the differences between the three recycling channels. The research results show that: (1) under the EPR system, the choice of production companies is affected by the recovery rate and profit rate. (2) By comparing different recycling channel models, we found that the recovery rate of independent recycling by the manufacturer is the largest. Still, the profit rate of the manufacturer that entrusts the alliance (M) to recycle is the highest. The manufacturer can entrust to alliance or independent recycling of waste lead batteries according to the different profit rates and recovery rates. (3) From the perspective of the supply chain, independent recycling (M) by production companies or recycling (R) by the commissioned union may be the best. The choice of recycling channels for producers depends on independent recycling and commissioning alliance' recycling costs and reuse costs.

Keywords: lead storage battery; extended producer responsibility system; full life cycle; recycling mode

check for updates

Citation: Zan, X.; Zhang, D. Analysis on the Optimal Recycling Path of Chinese Lead-Acid Battery under the Extended Producer Responsibility System. *Sustainability* **2022**, *14*, 4950. https://doi.org/10.3390/su14094950

Academic Editor: Elena Rada

Received: 25 March 2022
Accepted: 18 April 2022
Published: 20 April 2022

1. Introduction

Environmental issues have become a hot spot of concern in all countries. With the gradual improvement of the Chinese economy, product consumption and waste have increased rapidly. How to dispose of waste products has become the focus of social attention. It is also an inevitable requirement for China to promote green development and build an ecological civilization.

With the continuous expansion of lead-acid batteries in automobiles, electric vehicles, and communications, the demand for lead-acid batteries is also increasing. In 2020, the production of lead-acid batteries reached 227.356 million kVA, an increase of 12.28% compared with 2019 in China. The annual waste of lead-acid batteries amounted to 233.32 million KVAh, which also increased compared to 2019. It is also a heavy task to dispose of many waste lead batteries, which are growing in number year by year, especially in an environmentally friendly way to reduce the environmental pollution [1,2].

To speed up the establishment of a long-term recycling and treatment mechanism for lead-acid waste batteries, the Chinese government issued the Extended Producer Responsibility System Implementation Plan, which proposes implementing an extended producer responsibility system in the fields of lead storage batteries. The so-called comprehensive producer responsibility system (EPR) means that producers are responsible for the products they produce and the recycling, reuse, and environmental protection. Implementing the EPR system can effectively reduce the amount of municipal solid waste and increase the recycling rate of waste resources (Maitre, 2021). Compared with developed countries and regions such as the European Union and Japan that have fully implemented the EPR system, EPR implementation in developing countries differs from developed countries. Therefore, it is an essential part of the global environmental protection action to accelerate the proper implementation of EPR in developing countries [3].

For example, in developed countries such as Japan, the United States, and Germany, the recycling and reuse of waste lead batteries consumes high labor costs. In contrast, disposal and reuse benefits are low. Therefore, the government requires consumers to recycle waste lead batteries and even pay enterprises or organizations for disposal. A single waste lead storage battery treatment system was formed, including discharge, recycling, treatment, and reuse. In contrast, China still regards waste lead batteries as valuable commodities. There is a complete industrial system for the market's recovery, treatment, and reuse of waste lead batteries. Spontaneous recycling in the market is carried out by lead battery manufacturers, professional recycling companies, professional processing and recycling companies, and individual recycling personnel. Many other entities participate in the recycling of waste lead batteries. Under the competitive recycling model, there have also been non-compliant sales of waste lead batteries, "bad companies driving out good companies," unstable recovery rates, and vicious price competition [4,5].

To regulate the recycling and utilization of lead-acid batteries, the Chinese government has successively introduced a series of policies and measures to strengthen the management of industry access, and gradually formed a dual market system: the government-approved "regular" recycling and the "informal" system created by the market to spontaneously recycle and reuse.

Although previous studies have explored various EPR implementation plans related to waste treatment and put forward policy recommendations for the effective implementation of EPR, there is still a lack of in-depth analysis based on Chinese EPR in the recycling and reusing of waste lead batteries [6].

A large number of studies have shown that if production companies can be motivated to take the initiative to assume EPR responsibility, and lead battery manufacturers and recycled lead manufacturers are encouraged to cooperate in establishing a cross-administrative waste lead battery recycling system, it will effectively promote the reasonable collection and treatment rate of waste lead batteries [7–9]. Under different lead-acid battery recycling modes, the main factors that affect the behavioral choices of each participant have been analyzed. The behavioral game strategy characteristics of producers, unions, and third-party recyclers has been scientifically explained. Based on considering the expected benefits and recovery efficiency of all parties, the optimal realization path of the extended responsibility system of lead battery producers has been explored. Producers should be enabled to use or dispose of waste lead batteries in the most conducive way to environmental protection to promote the healthy and sustainable development of the waste lead battery recycling industry.

Therefore, this article mainly conducts the following research. First, the Stackelberg model outlines the three recycling modes producers can choose in EPR responsibilities. Secondly, a recycling model was constructed: a producer-led reverse closed-loop supply chain model commissioned by union and third parties. Under different recycling modes, this article analyzes the differences in recycling rates, prices, and profits. Finally, based on the actual survey data of the manufacturing enterprises, we conduct empirical tests and propose relevant suggestions to provide references for the government to promote the implementation of EPR reasonably.

2. Materials and Methods

2.1. Comparative Analysis of Typical Recycling Modes

2.1.1. Reverse Recycling Mode of Production Enterprises

The producer's reverse recycling model means that lead battery producers need to independently establish a recycling network and be responsible for tasks such as centralized recycling, transportation, classification, and dismantling of waste lead batteries [10]. As shown in Figure 1, lead-acid batteries are purchased by sellers, users of lead-acid batteries, or consumers. After consumption and disposal, following relevant government requirements, manufacturers will recycle lead-acid waste batteries from consumers, dealers, repairers, recycling companies, etc., and process and reuse them. Under the existing forward logistics system, lead-acid battery manufacturers need to build a reverse recycling system and set up recycling outlets by themselves. Specifically, they are responsible for a series of work processes from recycling and dismantling to reusing and extending the industrial chain.

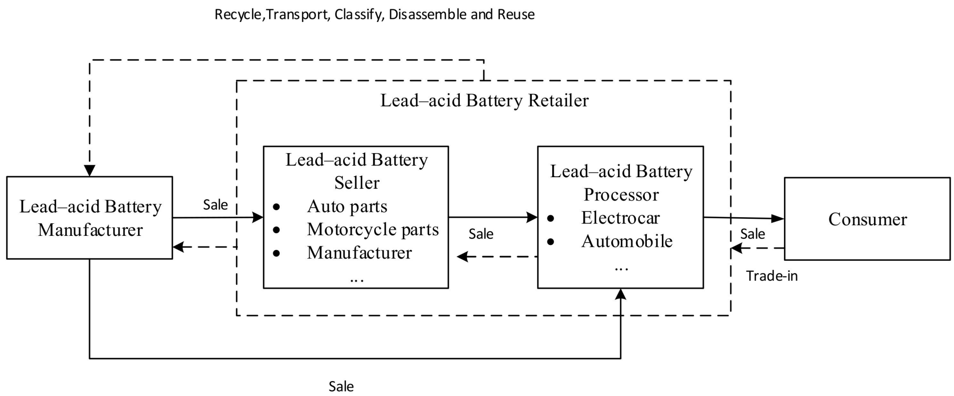

Figure 1. Reverse recycling diagram of lead-acid battery manufacturers.

Producers of lead-acid batteries are responsible for recycling and reuse, which will bring many advantages to enterprises. Producers can rely on the original sales channels to reverse the recycling of waste lead batteries. On this basis, producers rely on self-built production systems to run the follow-up links of waste lead battery recycling to obtain the corresponding economic and social benefits by maximizing the full use-value of lead storage batteries [11]. In this mode, lead-acid battery producers can better grasp the flow of resources and reduce the cost of raw materials. Companies are forced to comprehensively consider how to improve recycling efficiency, from raw material selection, production process flow, product design, resource reuse, etc. This is conducive to saving resources, protecting the environment, and shaping a sound social image of the company. However, in choosing this method they will also face many unfavorable factors. For lead battery producers, adding a recycling system to the original production system will increase the system's complexity.

In addition, producers can form a union for recycling. The alliance recycling model recycles waste directly on behalf of producers, and it is composed of manufacturers who produce the same or similar products, or of sellers. As shown in Figures 2 and 3, each manufacturer in the alliance co-funds the establishment of a specialized recycling and processing center. The waste can be transported to the nearest recycling and processing center for disposal. The alliance model is a strategic partnership of producers forming mutual trust, risk-sharing, and revenue sharing among enterprises using a standard contract. It is a planned and lasting mechanism of producer cooperation. The consortium can also recycle and reuse waste from enterprises outside the alliance when it is profitable after the regular operation.

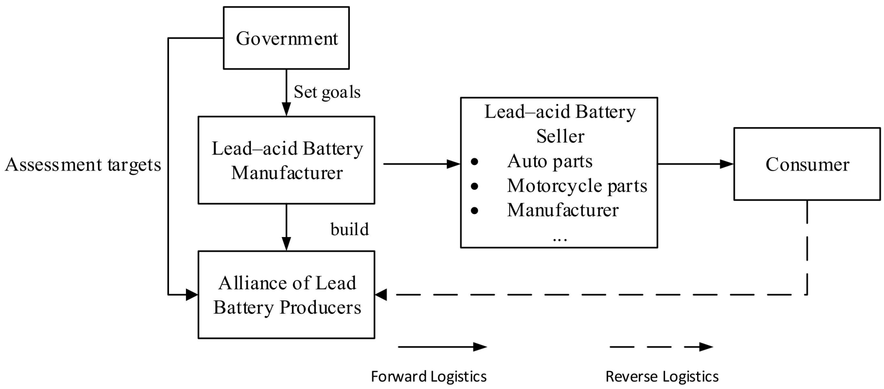

Figure 2. Reverse recycling diagram of lead-acid battery manufacturers.

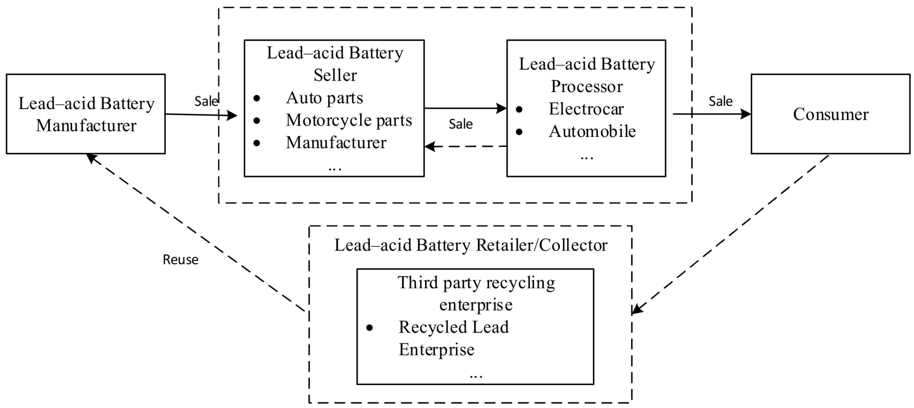

Figure 3. Third-party social recycling model.

2.1.2. Alliance Recovery Mode

The alliance model has the advantage of scale in terms of utilization and final disposal of waste compared to the producer's recycling system model. However, in terms of recycling waste, it is still a problem to ensure that consumers will hand over the waste to the producer alliance, rather than throwing it away or selling it to outside parties, resulting in the waste ending up in illegal use channels. In this regard, the solution is the same as the producer's recycling system, and there are two main types of solution: First, the producer alliance must adopt a deposit system, "trade-in," "sales and collection ratio of 1:1," and other ways to incentivize consumers to give the waste to the seller or producers. The relevant government departments should guide and monitor the implementation of the deposit system by the union. Second, consumers must put waste in the designated place at the proper time, and the union will be responsible for transporting the waste away. If not, the government authorities will impose penalties on consumers.

2.1.3. Third-Party Social Recycling Mode

The third-party recycling model means that after the lead battery is sold, the producer does not participate in the recycling and reuse process but delegates the responsibility to a third-party recycling entity. The third party is responsible for the recovery by paying the corresponding fees [12]. Third-party recycling includes professional recycling companies, recycled lead companies, etc. Third-party entities establish an organized and standardized recycling network for waste lead storage batteries. They sign an agreement with the producer: commissioned recycling. Figure 3 shows that third-party recycling entities need to set up their outlets and purchase equipment for transportation, sorting, storage, and dismantling. They sell the processed recycled lead, recycled plastics, and other recycled raw materials to manufacturers.

Most scholars advocate a third-party socialized recycling model [13]. Its advantage is that production companies outsource the recycling business to third-party entities through the outward allocation of resources, reducing their operational risks. Third-party recycling companies are professional recycling entities. Their service radius is wide. Within this radius, they can serve multiple enterprises simultaneously, forming logistics business sharing among customers. This can significantly improve resource utilization and reduce unit operating costs. However, there are many shortcomings in this model [14]. For example, the third-party recycling company's proposed cost will directly affect the cooperative relationship between them and the producer.

Therefore, how do lead-acid battery manufacturers choose an effective recycling model? Under different recycling modes, which recycling method can maximize the respective benefits of lead battery manufacturers, alliances, and third parties? This requires an analytical model: a closed-loop supply chain recycling modeled by the manufacturer to determine the optimal strategic choice under different channels.

2.2. Basic Assumptions

According to the comparison of recycling models in Section 2.1, we can construct theoretical models for the prominent participants in the lead-acid battery recycling system: manufacturers, alliances, third-party companies, and consumers:

1. Assuming that the unit recovery cost of the production enterprise is R_0, and the recovery rate is τ, then $\frac{t_{\text{cycle}}}{t_{total}} * 100 = \tau$. This article assumes that the variable cost is zero for waste lead batteries recycled by the production enterprise to simplify the theoretical model.
2. The manufacturer's price of recycling lead-acid waste batteries is b. At this point $b > R_0$, companies need to face several costs in the actual recycling process, such as transportation and storage. Suppose the unit investment in fixed assets is I. Among them: $I(\tau) = K\left(\frac{t_{\text{cycle}}}{t_{total}} * 100\right)^2$, the convexity and incrementality of this function reflect that producers need to increase investment in the collection process if they want to achieve a higher rate of return. K stands for other influencing factors the company faces in the recycling process.
3. Assuming that the unit cost is R_τ if the recycled lead storage battery is used to produce new lead storage battery products. The unit cost of using virgin materials to make lead storage batteries is R_m, and the new product is homogeneous, then the unit cost of producing lead storage batteries is:

$$R = R_m\left(1 - \frac{t_{\text{cycle}}}{t_{total}} * 100\right) + R_r\frac{t_{\text{cycle}}}{t_{total}} * 100 = R_m - (R_m - R_r)\left(\frac{t_{\text{cycle}}}{t_{total}} * 100\right)^3 \quad (1)$$

Therefore, only when the cost advantage of recycling and remanufacturing products is higher than the cost of recycling, and recycling can bring sure corporate profits, will production companies have the enthusiasm to recycle waste lead batteries. We will express $R_m - R_r$ as $\Delta = R_m - R_r$, which represents the cost savings in the recycling process.

4. Assume that the demand function for lead-acid battery recycling is $D(p)$,$D(p) = \varphi - S$, φ for the size of the entire market. Among them: $\varphi > S > 0$. Since the production company can recycle it independently, it can also entrust a third party and seller. Therefore, there is a channel selection behavior during the recovery process. Based on the above conditions, and Savaskan and Van (2006) [15], Zheng et al. (2021) [16], and Zhao et al.'s (2020) [17] research and conclusions, we will discuss the behavioral choices of producers in different situations to obtain the best profit selection channels for manufacturers.

2.3. Analysis of the Model of Recycling Channels Dominated by Production Enterprises

The Stackelberg model emphasizes that participants have a series of production decisions and response behaviors [18]. Pioneers dominate and know the action plans of follow-up participants. Therefore, the latter can choose a profit maximization plan based on the actions of the former. The producer is the market leader in the producer-led reverse supply chain model, while retailers and third-party companies follow the recovery task [19].

Under the EPR system, complete specific recycling targets for waste lead batteries must be met. If the recycling rate is not standard, or the recycling process causes environmental pollution, the system will penalize it. Manufacturers can choose to recycle independently or jointly [20]. At this time, the recycling channels of waste lead storage batteries can be divided into three types: independent recycling by producers, entrusting a third party, and entrusting distributors.

2.3.1. Independent Recycling Channels for Production Companies (M)

The producer sells directly in the entire information market, and the producer first determines the self-recovery price P_d and recovery rate τ. The independent recycling channels of production enterprises are shown in Figure 4.

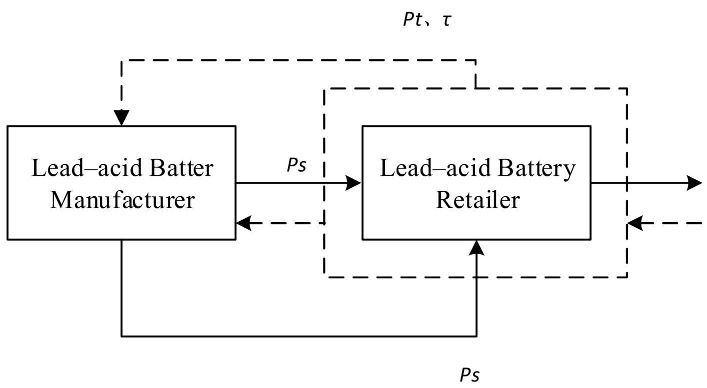

Figure 4. Diagram of independent recycling channels of production enterprises.

The profit function of the production company is as follows:

$$\max_{p_t} \pi_m^M = (p_t - p_s)\left(\frac{1 - \eta - p_t + \eta p_d}{1 - \eta^2}\right). \tag{2}$$

p_s the wholesale price for the entire market, the manufacturer is the leader of the Stackelberg game, and the calculation of the balance solution must be based on the decision sequence. η is the competitive elasticity of substitution between channels, when $\eta \to 1$, the channels can be fully substituted. In addition to the market wholesale price faced by the manufacturer, the seller's profit maximization is:

$$\begin{aligned} \max_{p_s, p_d, \tau} \pi_R^M &= \left(p_s - R_m + \Delta \frac{t_{\text{cycle}}}{t_{total}} * 100\right)\left(\frac{1-\eta-p_s+\eta p_d}{1-\eta^2}\right) \\ &- \left(P_d - R_m + \Delta\left(\frac{t_{\text{cycle}}}{t_{total}} * 100\right)\right)\left(\frac{1-\eta-p_d+\eta p_t'}{1-\eta^2}\right) - K\left(\frac{t_{\text{cycle}}}{t_{total}} * 100\right)^2 \end{aligned} \tag{3}$$

p_s is determined by the market wholesale price, the direct self-recovery price P_d, and the recovery rate $\tau = \frac{t_{\text{cycle}}}{t_{total}} * 100$. In this game model, the manufacturer will first determine the product's sales price and then choose the recycling price based on the sales price [21]. According to the recovery price, we select the recovery rate of the third-party recovery company under the condition of maximizing profit. Because p_s, P_d are strictly quasi-concave, according to the optimal decision of the production enterprise, we find the price of the producer's independent recycling channel p_d^{M*}, the price of entrusting the seller to sell the lead storage battery p_t^{M*}, production enterprise equilibrium profit π_m^{M*}, then:

$$p_{d,M}^{*} = \frac{4K(1+\eta)(1+R_m) - \Delta^2(3+\eta)}{8(1+\eta)K - (3+\eta)\Delta^2}, \tag{4}$$

$$\pi_m^{M*} = \frac{K(3+\eta)(1-R_m)^2}{8(1+\eta)K - (3+\eta)\Delta^2}, \tag{5}$$

$$\tau_m^{M*} = \frac{\Delta(3+\eta)(1-R_m)}{8(1+\eta)K - (3+\eta)\Delta^2}. \tag{6}$$

2.3.2. Commission Alliance Recycling Channels (R)

The process of entrusting sellers to recycle is basically: First, the manufacturer decides the wholesale price p_s, direct recycling channel price P_d, and repurchase price b. The recovery price decided by the alliance is p_t and the recovery rate τ. The affiliate recycling model is shown in Figure 5.

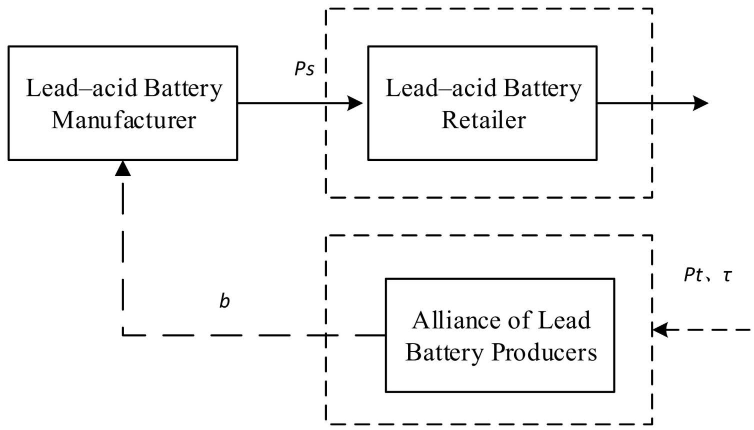

Figure 5. Recycling diagram of entrusted sellers.

In this case, the union participates in the traditional product sales and collects used lead batteries. Producers sell wholesale lead-acid batteries and buy back waste lead-acid batteries from the union at a price b. Producers have a passion for collecting and reusing waste lead batteries [22]. The price b should not exceed the cost of recycling; thus, for a given p_s, P_d and τ, the maximum profit condition of the alliance is:

$$\begin{aligned} \max_{p_{t,\tau}} \pi_R^R &= (p_t - p_s) + \left(\frac{1-\eta-p_t+\eta p_d}{1-\eta^2}\right) \\ &+ b\left(\frac{t_{\text{cycle}}}{t_{total}} * 100\right)\left(\frac{1-\eta-p_d+\eta p_t}{1-\eta^2} + \frac{1-\eta-p_t+\eta p_d}{1-\eta^2}\right) - K\left(\frac{t_{\text{cycle}}}{t_{total}} * 100\right)^2 \end{aligned} \tag{7}$$

Since the objective function π_m is quasi-concave at p_t and τ, using the above function's first-order conditions, the producer's best response function can be obtained:$p_t(p_s, p_d, b)$ and $\tau(p_s, p_d, b)$. The producer predicts the decision of the lead-acid battery alliance, and the alliance determines the recycling price p_t, manufacturer's independent recycling channel price p_d, and recovery rate τ. The conditions for maximizing the producer's profit are:

$$\begin{aligned} \max_{p_{t,\tau,b}} \pi_m^R &= \left(p_t - R_m + (\Delta - b)\left(\frac{t_{\text{cycle}}}{t_{total}} * 100\right)\right)\left(\frac{1-\eta-p_t+\eta p_d}{1-\eta^2}\right) \\ &+ \left(p_d - R_m + (\Delta - b)\left(\frac{t_{\text{cycle}}}{t_{total}} * 100\right)\right)\left(\frac{1-\eta-p_d+\eta p_t}{1-\eta^2}\right) \end{aligned} \tag{8}$$

According to related research by Savaskan and Van (2006) [15], the profit optimization problem of producers is usually based on the following two steps: First, when the repurchase price b is given, the objective function is quasi-concave at the affiliate's return channel price p_t and the manufacturer's independent return channel price p_d. The first-order condition of $\max\limits_{p_{t,\tau,b}} \pi_m^R$ can be used to describe the optimal value of the recycling price and the affiliate's recycling channel price. At this time, the optimal profit of the affiliate is:

$$\max_{b} \pi_R^{R*} = \frac{(3+\eta)K(1-R_m)^2}{4b^2(1+\eta) - 2b\Delta(3+\eta) + 8(1+\eta)K}. \quad (9)$$

When the producer's profit is optimal, the affiliate can decide based on the producer's optimal profit and the recovery price b. When both the manufacturer and the affiliate make the best decisions, the earnings of the two parties reach equilibrium. The affiliate's optimal return channel price p_t and the producer's independent recycling channel price p_d:

$$p_{t,R}^* = \frac{32K(1+\eta)^3(3-\eta+(1+\eta)R_m) + \Delta^2(3+\eta)^2[(1-\eta)R_m - 5 + 3\eta]}{4\left[32(1+\eta)^3K - \Delta^2(1+\eta)(3+\eta)^2\right]}, \quad (10)$$

$$\pi_R^* = \frac{4(1+\eta)(3+\eta)K(1-R_m)^2}{32(1+\eta)^2K - (3+\eta)^2\Delta^2}, \quad (11)$$

$$\tau_R^* = \frac{\Delta(3+\eta)^2(1-R_m)}{32(1+\eta)^2K - (3+\eta)^2\Delta^2}. \quad (12)$$

2.3.3. Entrusting a Third-Party Enterprise to Recycle the Channel (C)

When entrusting a third party to collect, the producer will hand over the work of recycling lead-acid batteries to a third party [23]. The operation process of this collection method is as follows: First, the producer determines the price of the self-recycling channel p_d, wholesale prices p_s, and repurchase price b. Third-party collectors (including retailers) assess the cost p_t of recycling channels, and the third-party collector determines the recovery rate τ; model optimization should be considered from the perspective of third-party collectors. The model diagram of entrusting third-party recycling is shown in Figure 6.

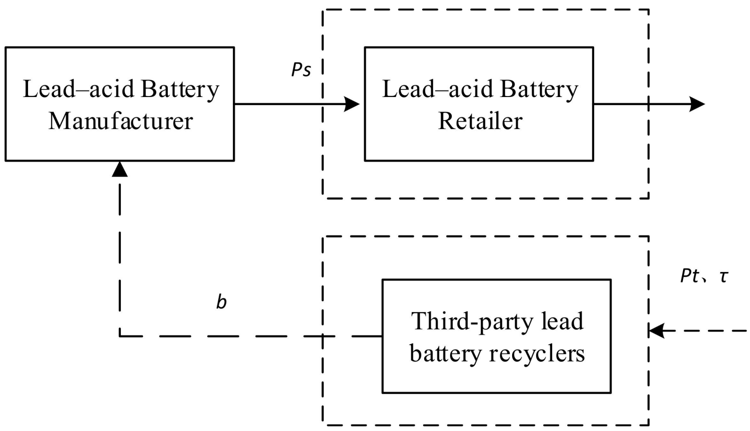

Figure 6. Diagram of third-party recycling of lead-acid batteries.

For a given producer's independent recycling channel price p_d, wholesale prices p_s, and the repurchase price b, the profit maximization condition of the third-party collector is:

$$\max_{\tau} \pi_c^c = b\left(\frac{t_{\text{cycle}}}{t_{total}} * 100\right)\left(\frac{1-\eta-P_d+\eta P_t}{1-\eta} + \frac{1-\eta-P_t+\eta P_d}{1-\eta^2}\right) - K\left(\frac{t_{\text{cycle}}}{t_{total}} * 100\right)^2 \quad (13)$$

According to the price of third-party recycling channels, retailers can also get the maximum profit:

$$\max_{P_t} \pi_r^c = (P_t - P_s)\left(\frac{1-\eta-P_t+\eta P_d}{1-\eta^2}\right). \tag{14}$$

Because of π_c^c and the recovery rate τ being pseudo-concave, π_r^c is quasi-concave at P_t. Therefore, given the choice of production enterprises, retailers and third-party collectors have the best choice. When P_t is given, $P_t = \frac{1}{2}(1+P_s-\eta+\eta P_d)$. When $\tau = \frac{b(3-P_s+\eta-(2+\eta)P_d)}{4(1+\eta)K}$ their options are maximized; for producers, retailers, and third-party collectors, the conditions for maximizing the profits of producers are:

$$\begin{aligned}\max_{P_s,P_d,b} \pi_m^c &= \left(P_s - R_m + (\Delta - b)\left(\frac{t_{\text{cycle}}}{t_{total}} * 100\right)\right)\left(\frac{1-\eta-P_t+\eta P_d}{1-\eta^2}\right) \\ &+\left(P_d - R_m + (\Delta - b)\left(\frac{t_{\text{cycle}}}{t_{total}} * 100\right)\right)\left(\frac{1-\eta-P_d+\eta P_t}{1-\eta^2}\right)\end{aligned} \tag{15}$$

Considering the producer's optimization function, for a given recycling price b, we can choose the best producer's independent recycling channel price p_d, wholesale prices p_s, and repurchase price b. The optimal value of the producer's profit is:

$$\max_{b} \pi_m^{c*} = \frac{(3+\eta)K(1-R_m)^2}{2b(b-\Delta)(3+\eta)+8(1+\eta)K}. \tag{16}$$

In the process of entrusting third-party recycling, the producer owns the recycling channel p_t, wholesale prices p_s, and the optimal values of and the recovery rate τ is:

$$p_{t,c}^* = \frac{4K(1+\eta)(3-\eta+(1+\eta)R_m)-\Delta^2(3+\eta)}{16(1+\eta)K-\Delta^2(3+\eta)}, \tag{17}$$

$$\pi_c^* = \frac{2(3+\eta)K(1-R_m)^2}{16(1+\eta)K-(3+\eta)\Delta^2}, \tag{18}$$

$$\tau_c^* = \frac{\Delta(3+\eta)^2(1-R_m)}{16(1+\eta)K-(3+\eta)\Delta^2} \tag{19}$$

2.4. Subsection

From the recovery channels M, R, and C, through the reverse induction method, the available equilibrium solutions are:

$$\left\langle \begin{aligned} p_{d,M}^* &= \frac{4K(1+\eta)(1+R_m)-\Delta^2(3+\eta)}{8(1+\eta)K-(3+\eta)\Delta^2} \\ p_{t,R}^* &= \frac{32K(1+\eta)^3(3-\eta+(1+\eta)R_m)+\Delta^2(3+\eta)^2[(1-\eta)R_m-5+3\eta]}{4\left[32(1+\eta)^3K-\Delta^2(1+\eta)(3+\eta)^2\right]} \\ p_{t,c}^* &= \frac{4K(1+\eta)(3-\eta+(1+\eta)R_m)-\Delta^2(3+\eta)}{16(1+\eta)K-\Delta^2(3+\eta)} \end{aligned} \right. ,$$

$$\left\langle \begin{aligned} \tau_m^* &= \frac{\Delta(3+\eta)(1-R_m)}{8(1+\eta)K-(3+\eta)\Delta^2} \\ \tau_R^* &= \frac{\Delta(3+\eta)^2(1-R_m)}{32(1+\eta)^2K-(3+\eta)^2\Delta^2} \\ \tau_c^* &= \frac{\Delta(3+\eta)^2(1-R_m)}{16(1+\eta)K-(3+\eta)\Delta^2} \end{aligned} \right. ,$$

$$\left\langle \begin{aligned} \pi_m^* &= \frac{K(3+\eta)(1-R_m)^2}{8(1+\eta)K-(3+\eta)\Delta^2} \\ \pi_R^* &= \frac{4(1+\eta)(3+\eta)K(1-R_m)^2}{32(1+\eta)^2K-(3+\eta)^2\Delta^2} \\ \pi_c^* &= \frac{2(3+\eta)K(1-R_m)^2}{16(1+\eta)K-(3+\eta)\Delta^2} \end{aligned} \right. .$$

As shown in Table 1, this article compares independent producer recycling (M) and commissioned third-party recycling (C). Based on $0 < \eta < 1$ the competition between channels should be a number between (0,1). So $(1 + R_m) < (3 - \eta + (1 + \eta)R_m)$, and $8(1 + \eta)K - (3 + \eta)\Delta^2 < 16(1 + \eta)K - \Delta^2(3 + \eta)$, the optimal channel price for independent recycling by the producer is higher than the commissioned third party. This article compares trusted affiliate and third-party recycling:

$$\Delta^2(1+\eta)(3+\eta)^2 > \Delta^2(3+\eta),$$
$$4\left[32(1+\eta)^3K - \Delta^2(1+\eta)(3+\eta)^2\right] < 4\left[32(1+\eta)K - \Delta^2\frac{(3+\eta)^2}{(1+\eta)}\right],$$
$$4\left[32(1+\eta)K - \Delta^2\frac{(3+\eta)^2}{(1+\eta)}\right] < 4\left[32(1+\eta)K - \Delta^2(1+\eta)\right].$$
$$4\left[32(1+\eta)K - \Delta^2(1+\eta)\right] > 16(1+\eta)K - \Delta^2(3+\eta)$$

Table 1. Comparison of selection modes of producer recycling channels.

Model	p	Compare Results
Model M	$\frac{4K(1+\eta)(1+R_m)-\Delta^2(3+\eta)}{8(1+\eta)K-(3+\eta)\Delta^2}$	$p^*_{d,M} > p^*_{t,c}$
Model R	$\frac{32K(1+\eta)^3(3-\eta+(1+\eta)R_m)+\Delta^2(3+\eta)^2[(1-\eta)R_m-5+3\eta]}{4\left[32(1+\eta)^3K-\Delta^2(1+\eta)(3+\eta)^2\right]}$	
Model C	$\frac{4K(1+\eta)(3-\eta+(1+\eta)R_m)-\Delta^2(3+\eta)}{16(1+\eta)K-\Delta^2(3+\eta)}$	
	τ	
Model M	$\frac{\Delta(3+\eta)(1-R_m)}{8(1+\eta)K-(3+\eta)\Delta^2}$	$\tau^*_m > \tau^*_c > \tau^*_R$
Model R	$\frac{\Delta(3+\eta)^2(1-R_m)}{32(1+\eta)^2K-(3+\eta)^2\Delta^2}$	
Model C	$\frac{\Delta(3+\eta)^2(1-R_m)}{16(1+\eta)K-(3+\eta)\Delta^2}$	
	π	
Model M	$\frac{K(3+\eta)(1-R_m)^2}{8(1+\eta)K-(3+\eta)\Delta^2}$	$\pi^*_R > \pi^*_m > \pi^*_c$
Model R	$\frac{4(1+\eta)(3+\eta)K(1-R_m)^2}{32(1+\eta)^2K-(3+\eta)^2\Delta^2}$	
Model C	$\frac{2(3+\eta)K(1-R_m)^2}{16(1+\eta)K-(3+\eta)\Delta^2}$	

$64K(1 + \eta)^3(1 + R_m) > 8(8K(1 + \eta)(1 + R_m)) > 8K(1 + \eta)(1 + R_m)$, therefore, it is impossible to reach the optimum level of recycling between the commissioned affiliate and the third party.

From the perspective of comparing the recovery rates of independent producer recycling, commissioned affiliate recycling, and third-party recycling:

$$\left\langle \begin{array}{l} \tau^*_m = \frac{\Delta(3+\eta)(1-R_m)}{8(1+\eta)K-(3+\eta)\Delta^2} \\ \tau^*_R = \frac{\Delta(3+\eta)^2(1-R_m)}{32(1+\eta)^2K-(3+\eta)^2\Delta^2} \\ \tau^*_c = \frac{\Delta(3+\eta)^2(1-R_m)}{16(1+\eta)K-(3+\eta)\Delta^2} \end{array} \right. .$$

From the above formula: because $0 < \eta < 1$, τ_M, τ_R, $\tau_c \in [0,1]$, so: $32(1 + \eta)^2K = 2 \times 16(1 + \eta)(1 + \eta)K > 16(1 + \eta)K > 8(1 + \eta)K$, that is, the recovery rate is highest when the producer recycles independently, followed by entrusting third parties and affiliate.

When comparing profit rates:

$$\begin{cases} \pi_m^* = \frac{K(3+\eta)(1-R_m)^2}{8(1+\eta)K-(3+\eta)\Delta^2} \\ \pi_R^* = \frac{4(1+\eta)(3+\eta)K(1-R_m)^2}{32(1+\eta)^2K-(3+\eta)^2\Delta^2} \\ \pi_c^* = \frac{2(3+\eta)K(1-R_m)^2}{16(1+\eta)K-(3+\eta)\Delta^2} \end{cases}.$$

$16(1+\eta)K - 2(3+\eta)\Delta^2 < 16(1+\eta)K - (3+\eta)\Delta^2$, therefore, it can be seen that the profit rate of independent recycling by producers is higher than that of entrusting third-party recycling. $3+\eta < 4$, $32(1+\eta)K - 4(3+\eta)\Delta^2 < 32(1+\eta)K - (3+\eta)^2\Delta^2$. $\frac{1}{4}\frac{(3+\eta)}{1+\eta} < 1$, $\frac{1}{4}\frac{(3+\eta)}{1+\eta}^2 < \frac{(3+\eta)}{1+\eta}$, $\frac{1}{4}\frac{(3+\eta)}{1+\eta}^2 < \frac{(3+\eta)}{1+\eta} < (3+\eta)$. It can be seen that the profit rate of independent recycling by producers is lower than that of recycling by commissioned affiliates.

Finally, from the comparison of third-party recycling channels, we can simplify:

$$4(1+\eta)^3K - \frac{1}{32}\Delta^2(1+\eta)(3+\eta)^2 < 4(1+\eta)K - \frac{1}{4}\Delta^2(3+\eta)$$

$$\begin{cases} p_{d,M}{}^* = \frac{4K(1+\eta)(1+R_m)-\Delta^2(3+\eta)}{8(1+\eta)K-(3+\eta)\Delta^2} \\ p_{t,R}{}^* = \frac{K(1+\eta)^3(3-\eta+(1+\eta)R_m)+\frac{1}{32}\Delta^2(3+\eta)^2[(1-\eta)R_m-5+3\eta]}{4(1+\eta)^3K-\frac{1}{32}\Delta^2(1+\eta)(3+\eta)^2} \\ p_{t,c}{}^* = \frac{K(1+\eta)(3-\eta+(1+\eta)R_m)-\frac{1}{4}\Delta^2(3+\eta)}{4(1+\eta)K-\frac{1}{4}\Delta^2(3+\eta)} \end{cases},$$

due to $1+\eta > 1$,$K(1+\eta)^3(3-\eta+(1+\eta)R_m) > 4K(1+\eta)(1+R_m)$ and $8(1+\eta)K - (3+\eta)\Delta^2 > 8(1+\eta)K - \Delta^2(1+\eta)(3+\eta)^2$, $8(1+\eta)K - \Delta^2(1+\eta)(3+\eta)^2 > 4(1+\eta)^3K - \frac{1}{32}\Delta^2(1+\eta)(3+\eta)^2$. The channel price of the producer's self-recovery is higher than that of the entrusted affiliate; $K(1+\eta)(3-\eta+(1+\eta)R_m) > K(1+\eta)(3-\eta+(1+\eta)R_m) - \frac{1}{4}\Delta^2(3+\eta)$, $4(1+\eta)^3K - \frac{1}{32}\Delta^2(1+\eta)(3+\eta)^2 < 4(1+\eta)K - \frac{1}{4}\Delta^2(3+\eta)$, the cost of entrusting sellers to recycle is higher than that of authorized third parties [24]. Comparing the recycling methods, the recycling rate of the recycling network built by the producer is the highest. Comparing channel prices, the lowest channel price is from entrusting to a third party [25]. Therefore, the recycling of lead-acid batteries should adopt a third-party socialized recycling model. With the maximization of profits, a high recovery rate can be achieved.

3. Results and Discussion

By implementing the extended producer responsibility system, the lead-acid battery recycling method stipulates the producer's responsibility [26]. In the recycling process, what then is the actual preference of the producer? In the recycling, storage, and transfer stage, what production options do producers have? Understanding the producers' importance in the recycling process and solving existing problems can promote the orderly execution of producers' responsibility performance [27]. Based on the survey data on the recycling behavior of lead battery producers, we learned about the production and operation costs, recycling, storage, transfer, disposal, and reuse of the company. To assess the performance of the responsibility extension system of lead-acid battery manufacturers, we verified the above theoretical analysis.

To analyze the production, recycling, and reuse behaviors of lead-acid battery manufacturers, we investigated many lead-acid battery manufacturers. We mainly selected Lin'an District in Hangzhou City, Zhejiang Province, Jingxiu District in Baoding City, Hebei Province, and Xiangyang City, Hubei Province. We conducted behavior analyses of enterprises in Fancheng District and Changxing County in Huzhou City, Zhejiang Province. These four companies are all lead battery manufacturers operating for many years. They have extensive experience in the recycling and reuse of lead-acid batteries. The four companies have established a reverse recycling network for lead-acid waste batteries that meets the inspection requirements in this section.

First, we investigated the production of lead-acid batteries in the sample enterprises. As shown in Figure 7, from the perspective of the average annual output of lead batteries, the highest output was 102 million/kVAh for enterprises in Huzhou; in terms of average annual sales, the highest was 238.9 million/kVAh for a company in Xiangyang. In addition, the company had the most significant yearly recycling and processing volume of waste lead batteries, which were 12.75 million/kVAh and 1260/kVAh, respectively. It can be inferred that this did not wholly match the average annual output and annual recycling processing volume for lead-acid battery producers. More lead batteries are produced, but the recycling rate should be lower [28,29].

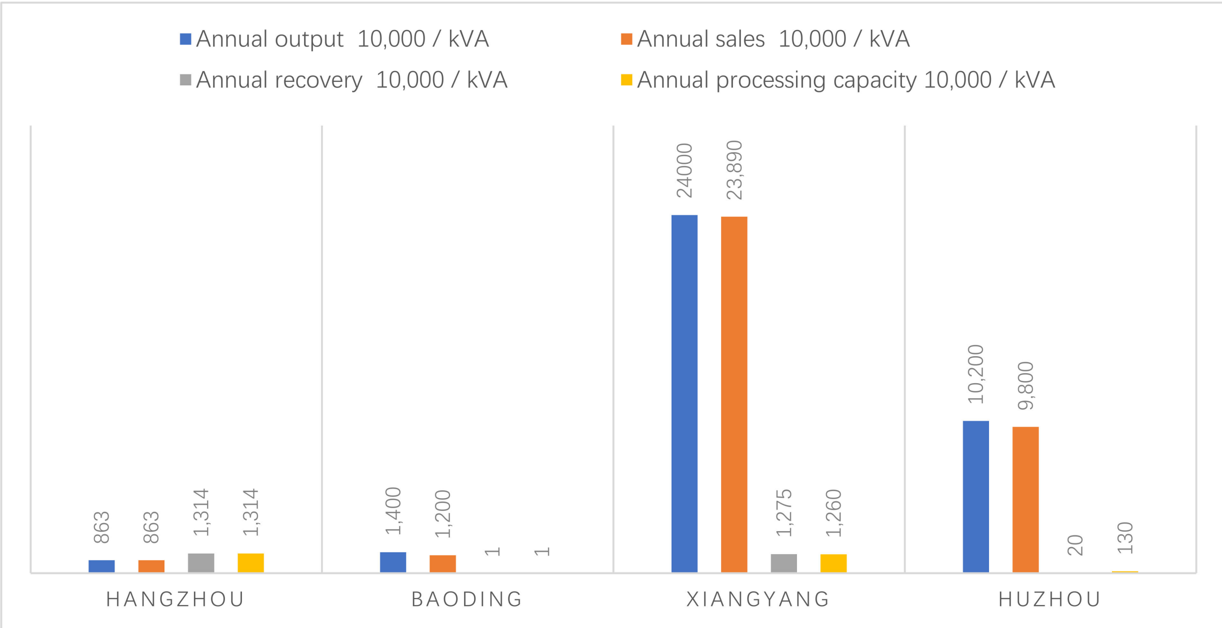

Figure 7. Production and operation overview of sample enterprises.

We further examined the main cost links in the lead-acid battery producers' recycling and reuse processes. As shown in Figure 8, most companies indicated that the cost was mainly the result of reuse and recycling in lead storage battery processing.

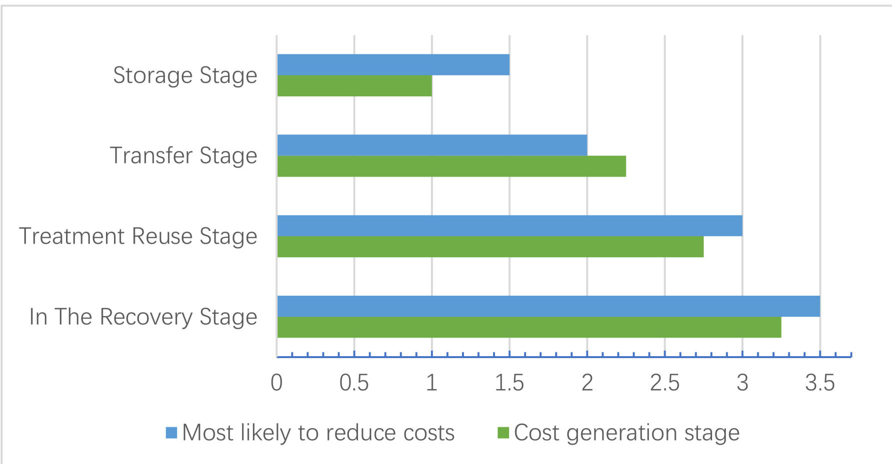

Figure 8. Links of recovery and reprocessing costs.

After further investigation, we found that the Hangzhou enterprises' lead storage battery manufacturer adopted a self-built recycling network. Its recycling cost was about 267 CNY/ton in carrying out the recycling and processing of waste lead storage batteries. The Xiangyang enterprises chose the method of multi-enterprise joint recycling. The utilization rate of the Xiangyang enterprises' recycling network was 10%, and the recycling cost was 185 CNY/ton. From the perspective of cost recovery, the theoretical model of this article was also derived. When comparing independent producer recycling (M) and commissioning third-party recycling, based on $2\left[4K(1+\eta)(1+R_m) - \Delta^2(3+\eta)\right] < 8K(1+\eta)(1+R_m) - \Delta^2(3+\eta)^2$, and $2\left[8(1+\eta)K - (3+\eta)\Delta^2\right] < 16(1+\eta)K - \Delta^2(3+\eta)$, the conclusion was relatively high in terms of the price level of the company's self-built recycling network.

When comparing the prices of commissioned affiliate and third parties, we found $64K(1+\eta)^3(1+R_m) > 8(8K(1+\eta)(1+R_m)) > 8K(1+\eta)(1+R_m)$. Therefore, it was impossible to reach the recovery costs of a trusted affiliate or third-party recyclers from corporate recovery costs. We further verified this from the perspective of the recovery rate.

When investigating whether the company had a self-built waste lead battery recycling system, we saw that all four companies had established a recycling system. Different companies chose the waste lead storage, battery recycling, and reuse based on their production and management characteristics. As shown in Figure 9, except for a lead storage battery company in Hangzhou, which used a self-built recycling network, all used a combination of independent recycling and joint recycling. Among them, 90% of the recycling in Xiangyang enterprises came in the form of multi-enterprise communal recycling (commissioned affiliate). The company's average annual processing volume of waste lead storage batteries reached 12.6 million tons, and the unit recycling cost was only 7970 CNY/ton; the Huzhou lead storage battery manufacturer, through its self-built recycling network, had an average annual recycling rate of 61–70%, but the cost was about 8700 CNY/ton, reaching the highest recovery cost of the four companies. This verified the conclusion of this article: that the relatively high price was in the form of independent recovery by the producer.

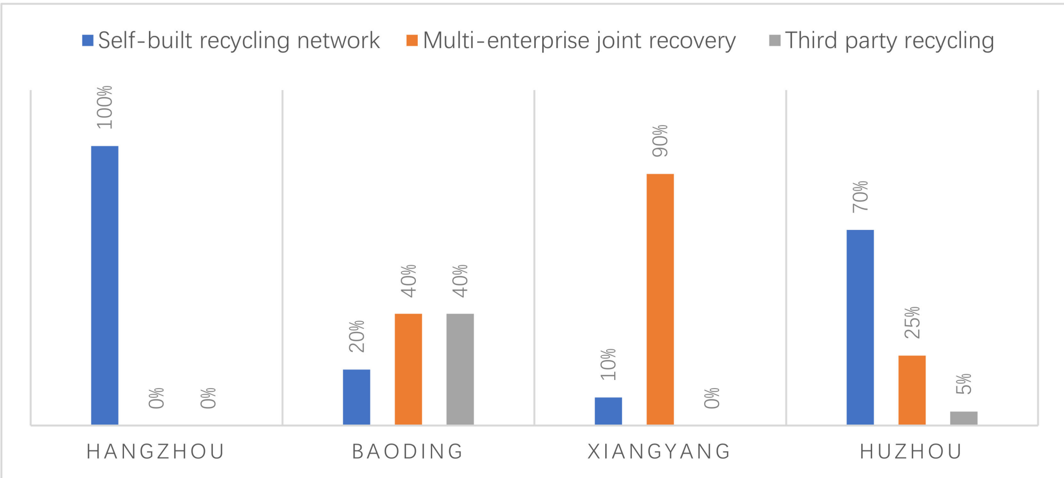

Figure 9. Compotion of the sample companies' recycling systems.

Next, in terms of the main costs of recycling and processing waste lead batteries, as shown in Figure 10, most companies said they mainly occurred in the recycling and reuse stage. If they can be reduced, the recycling rate will be effectively improved. This conclusion was related to the theoretically derived $R_m - (R_m - R_r)\left(\frac{t_{\text{cycle}}}{t_{total}} * 100\right)^3$, and only when recycling can bring specific cost savings and corporate benefits will producers be enthusiastic about repurchasing waste lead batteries. Figure 7 compares the average annual output, sales, recycling, and disposal of lead-acid batteries in these four companies. It can be seen that their average yearly output and sales volume were respectively higher than the average annual recycling volume and processing volume for Xiangyang and Huzhou enterprises. We learned that companies used recycled lead as a percentage of the overall material in the production process of new batteries. As shown in Figure 10, a lead storage battery company in Baoding City reached 90%. It was followed by the enterprises in

Xiangyang City, which reached 70%. About 40–50% of the enterprises in Hangzhou and Huzhou used recycled lead from waste lead batteries that were independently recycled. Enterprises in Baoding and Xiangyang also accounted for more than 95%, and enterprises in Huzhou accounted for 20%.

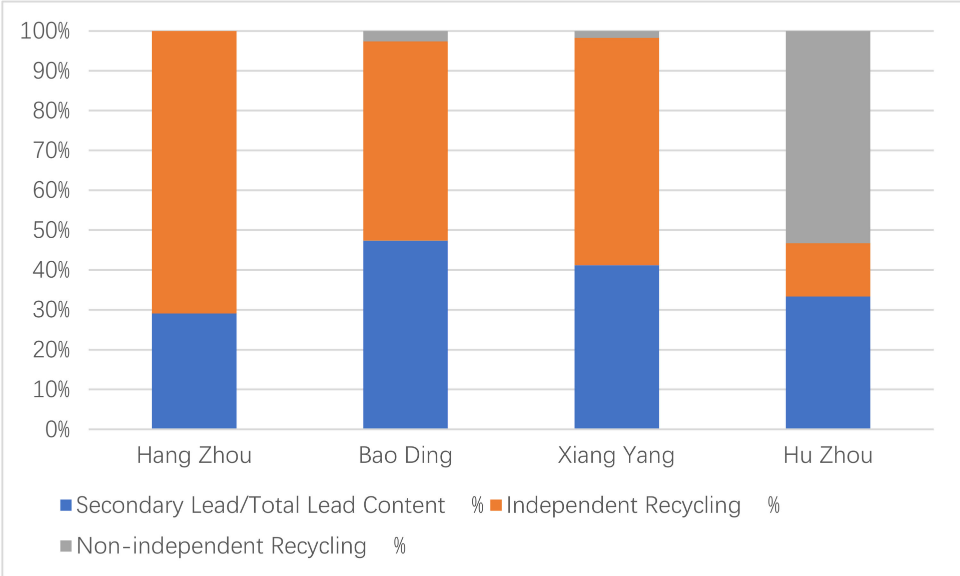

Figure 10. Utilization of recycled lead in lead-acid battery manufacturers.

In Figure 7, we also find that Hangzhou companies' recycling and processing volume was lower than the average annual sales volume and output, which differed from the other three companies. Why were there such high recovery and high processing rates but low sales volume and output? Does the high cost in the recycling phase of waste lead storage batteries affect the total production of lead storage batteries? To further examine the recovery costs of lead battery manufacturers, we further conducted a questionnaire survey on eight lead battery manufacturers, including Henan-Jiyuan, Shandong-Qufu, Hebei-Xiongan New District, Zhejiang-Huzhou, Jiangsu-Huai'an and Hubei, China–Xiangyang, including four lead storage battery production enterprises, three regenerated lead enterprises, and one professional recycling enterprise.

Based on the completeness and accuracy of data collection, we screened them for further comparison between the Qufu, Xiangyang, and Huzhou enterprises. The three companies were all lead-acid battery manufacturers. The basic production situation of the enterprises is shown in Figure 11. The average annual production capacity of lead-acid batteries was 2.6 million/kVAh, the average annual recycling capacity was 700,000/kVAh, and the average annual processing capacity was 700,000/kVAh for enterprises in Qufu. The average annual production volume, sales volume, and processing volume of enterprises in Huzhou City reached the highest value of the three companies, 576 million/kVAh (2 million tons), 34.56 million/kVAh (1.2 million tons), and 206.0 million/KVA (700,000 tons). The enterprises in Xiangyang City followed, with 27,985,500/kVA, 14,306,400/kVA, and 14.9692 million/kVA. These three companies' annual production volume was greater than the average annual processing and recycling volume. Except for the average annual recycling volume of enterprises in Huzhou City, which was less than the average annual processing volume, the other two enterprises were the same. In the form of recycling, the Qufu company's recycling of waste lead batteries mainly adopted the form of recycling by the company's self-built network (60%). It mainly took the form of multi-enterprise joint recycling for enterprises in Huzhou City and Xiangyang City (85 and 89.35%). However, the enterprises in Huzhou City that chose multi-enterprise joint recycling failed to achieve the same effect of the average annual processing volume and recycling volume of Xiangyang enterprises. The reasons can be inferred from the following points:

1. The cost of self-recovery of waste lead batteries by enterprises: Qufu City was 7500 CNY/ton, Xiangyang City was 7970 CNY/ton, Huzhou City was 8650 CNY/ton, which was the highest. That is, the repurchase price b was higher and $\max_{b} \pi_R^{R*}$ was lower;
2. When comparing the types of recycling enterprises entrusting to a third party, the unit cost of recycling waste lead batteries was 7600 CNY/ton for Qufu enterprises and 8560 CNY/ton for Huzhou enterprises (Xiangyang enterprises did not entrust to third parties for recycling). At this time, the repurchase price b for charging a third party for recycling was also higher. $\max_{\tau} \pi_c^c$ greatly increased the cost of using recycled lead in production enterprises;
3. We inferred $R_m - (R_m - R_r)\left(\frac{t_{\text{cycle}}}{t_{total}} * 100\right)^3$ from the theoretical model. When the lead battery manufacturer's remanufacturing cost advantage was higher than the recycling cost, companies were more enthusiastic about recycling waste lead batteries. The unit investment in fixed assets was about 11,000 CNY/ton in the production line of waste lead storage battery processing and utilization of enterprises in Huzhou City. This cost was higher than the investment levels of the enterprises in Xiangyang and Qufu, which increased the cost of the production of recycled lead.

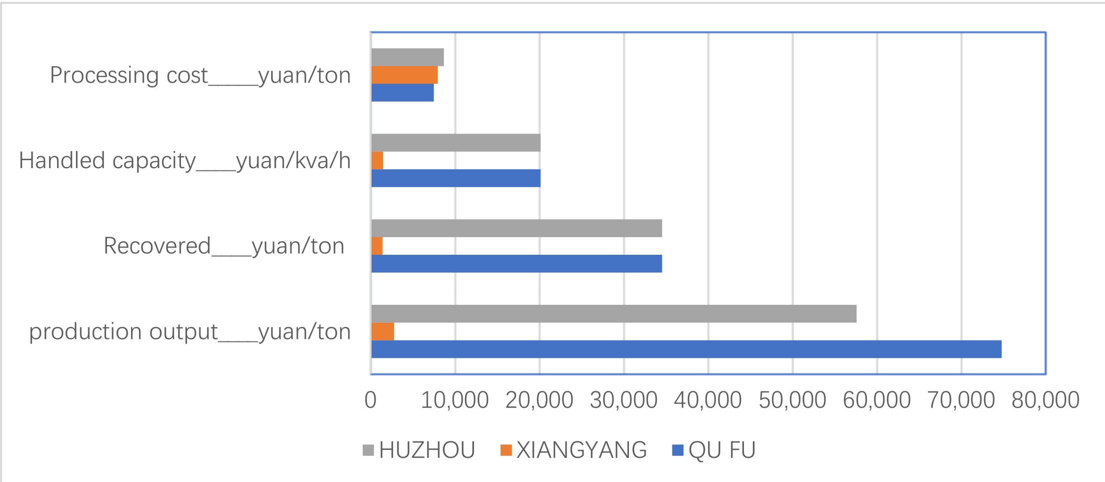

Figure 11. Basic situation of enterprise production.

When comparing the average annual recovery rates of the three companies, the average annual recovery rate of recycled lead batteries was 31–40% for enterprises in Qufu City, 51–60% for enterprises in Xiangyang City, and 61–70% for enterprises in Huzhou City. The average annual recovery rate of enterprises in Huzhou City was higher than that of the other two enterprises. These enterprises adopted the method of self-recycling waste lead batteries. Their average annual profit was higher than that of enterprises in Qufu and Xiangyang, which was about CNY 50–100 million. This result was consistent with the outcome of the theoretical derivation in this paper:

1. First of all, the profit margin of independent recycling by producers is higher than that of entrusted third-party recycling, but the price level is also relatively high, which will affect the cost of enterprises using recycled lead to put into production;
2. The optimal channel price for independent recycling by producers is higher than that of commissioned affiliate and third-party collectors. Compared with companies that recycle independently, companies that commission affiliates or third parties to recycle have an average annual recovery rate that is generally higher than that of companies that choose self-recycling networks;

3. Compared with the self-recycling method, except for enterprises in Xiangyang City, when a third party was entrusted to recycle, the recycling price of enterprises in Qufu was 100 CNY/ton lower than that of the entrusted third party, and 50 CNY/ton lower than that of enterprises in Huzhou. Compared with other companies, similar results also appeared. Enterprises in Xiong'an New Area independently recycled waste lead batteries. The average unit price was about 700 CNY/ton lower than that of entrusted third parties, and 500 CNY/ton lower for enterprises in Yantai;
4. In terms of the cost of dismantling and processing waste lead storage batteries, Xiangyang enterprises needed to invest 1400 CNY/ton, while Huzhou enterprises only needed to invest 650 CNY/ton. The theoretical derivation conditions of this paper $\Delta = R_m - R_r$ were that in the remanufacturing process, when the saved cost was lower, dismantling waste lead batteries was higher. Because of dismantling costs, Xiangyang enterprises adopted independent recycling methods to carry out recycling and reuse activities, reducing the company's profit level. The three companies all stated that the extraction of recycled lead from waste lead batteries would save 10–20% of the cost of production compared to the production of directly using lead raw materials.

4. Conclusions

It is necessary to implement the extended producer responsibility system and encourage enterprises to independently recycle and reuse waste lead batteries. This is an effective measure to increase the resource recovery rate. The extended producer responsibility system is a long-term and orderly implementation method. It is also an important measure to promote a green and low-carbon cycle and reduce environmental pollution. From the perspective of selecting recycling methods for lead-acid battery producers, this article analyzed the profits of companies' selection of recycling channels. It provides a reference for exploring the optimal path for lead-acid battery producers to fulfill the EPR system. The specific conclusions are as follows: (1) The profit of the enterprise affects whether the producer performs the EPR responsibility. Recycling rate, corporate yield, and recycling price determine how producers choose to recycle used lead batteries and each participant's strategic choices. (2) When the manufacturer elects to recycle independently, the recycling rate increases the recycling price. This increases the production cost of the company's recycled lead. (3) In terms of cost savings and profit levels in recycling, each has its advantages for its independent recycling and entrusted affiliate recycling channels. When the input cost is high, and the producers cannot establish a separate reverse recycling channel, they will choose the two recycling channels. Companies that are more inclined to corporate profits and recovery rates may choose to commission affiliates to recover.

Based on this, this article proposes: (1) The government should further optimize the institutional environment for producers to perform EPR and ensure the standardized implementation of the EPR system. The enthusiasm of production enterprises to participate in the performance of the EPR system should be increased and market access strictly controlled. (2) For those compliant producers who choose to recycle themselves, the government can help them establish a reverse recycling network. However, China has introduced a series of management policies to recycle and reuse waste lead batteries. Legislation on solid waste recycling has also been enacted. Tax incentives are given to renewable resource enterprises. However, because of the vast and scattered sources of waste lead storage batteries, the emergence of informal enterprises and individuals seeking illegal benefits has frequently caused problems in the unlawful disposal of waste lead storage batteries, causing environmental pollution. Therefore, in further optimizing the recycling system of waste lead storage batteries, we can jointly encourage producers to recycle with professional recycling companies. The government must promote the establishment of a co-construction recycling network and reverse recovery channels must be established to reduce the cost pressure on producers. In supply chain management, the principal value of producers, sellers, and third parties should be fully explored. While effectively increasing the recycling rate, it also enhances the autonomy and enthusiasm of participating entities. (3) In implementing EPR responsibilities, the government should continuously improve the reward and punishment mechanism. Under the effective incentives of the reward and punishment mechanism, production companies will be more motivated to establish a reverse logistics supply chain, innovate green lead-acid battery networked production technology, and improve the efficiency of waste lead-acid battery reuse. This will reduce the original pollution sources of lead-acid batteries when the production process is transferred to the recycling and regeneration process.

This paper analyzed the optimal recycling path for lead batteries in China. Since the empirical evidence in this paper was mainly based on questionnaires, the collected data were also cross-sectional. Future research can use a follow-up survey to examine the ways manufacturers choose to recycle lead batteries, and the time can be increased to 3–5 years. The indexes examined can also be extended to include policies and market conditions, using empirical analysis to investigate the choice behavior of producers in recycling lead batteries.

Author Contributions: Writing—original draft, X.Z.; Writing—review & editing, D.Z. All authors have read and agreed to the published version of the manuscript.

Funding: This work is supported by the Ministry of Science and Technology of the Solid Waste Recycling "Design and Demonstration Application of the Traceability System for the Whole Life Cycle of Lead Battery" Support Project (Grant No. 2018YFC1902705).

Informed Consent Statement: Written informed consent has been obtained from the patient(s) to publish this paper.

Data Availability Statement: The data used in this study are questionnaire data from the National Development and Reform Commission, which cannot be made public at present. However, if researchers want to obtain the data, they can contact the author and obtain the data with the consent of the data owner.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Zhao, Y.; Peng, B.; Elahi, E.; Wan, A. Does the extended producer responsibility system promote the green technological innovation of enterprises? An empirical study based on the difference-in-differences model. *J. Clean. Prod.* **2021**, *319*, 128631. [CrossRef]
2. Xu, J.; Ye, M.; Lu, W.; Bao, Z.; Webster, C. A four-quadrant conceptual framework for analyzing extended producer responsibility in offshore prefabrication construction. *J. Clean. Prod.* **2021**, *282*, 124540. [CrossRef] [PubMed]
3. Maitre-Ekern, E. Re-thinking producer responsibility for a sustainable circular economy from extended producer responsibility to pre-market producer responsibility. *J. Clean. Prod.* **2021**, *286*, 125454. [CrossRef]
4. Pazoki, M.; Zaccour, G. Dynamic strategic interactions between a municipality and a firm in the presence of an extended producer responsibility regulation. *J. Clean. Prod.* **2021**, *292*, 125966. [CrossRef]
5. Wang, Z.; Wang, Q.; Chen, B.; Wang, Y. Evolutionary game analysis on behavioral strategies of multiple stakeholders in E-waste recycling industry. *Resour. Conserv. Recycl.* **2020**, *155*, 104618. [CrossRef]
6. Li, Y.; Yang, D.; Sun, Y.; Wang, Y. Motivating recycling behavior—Which incentives work, and why? *Psychol. Mark.* **2021**, *38*, 1525–1537. [CrossRef]
7. Bassi, S.A.; Boldrin, A.; Faraca, G.; Astrup, T.F. Extended producer responsibility: How to unlock the environmental and economic potential of plastic packaging waste? *Resour. Conserv. Recycl.* **2020**, *162*, 105030. [CrossRef]
8. Tian, F.; Sošić, G.; Debo, L. Stable recycling networks under the Extended Producer Responsibility. *Eur. J. Oper. Res.* **2020**, *287*, 989–1002. [CrossRef]
9. Leclerc, S.H.; Badami, M.G. Extended producer responsibility for E-waste management: Policy drivers and challenges. *J. Clean. Prod.* **2020**, *251*, 119657. [CrossRef]
10. Shooshtarian, S.; Maqsood, T.; Wong, P.S.P.; Khalfan, M.; Yang, R.J. Extended Producer Responsibility in the Australian Construction Industry. *Sustainability* **2021**, *13*, 620. [CrossRef]
11. Rahmani, M.; Gui, L.; Atasu, A. The Implications of Recycling Technology Choice on Extended Producer Responsibility. *Prod. Oper. Manag.* **2021**, *30*, 522–542. [CrossRef]
12. Hou, J.; Zhang, Q.; Hu, S.; Chen, D. Evaluation of a new extended producer responsibility mode for WEEE based on a supply chain scheme. *Sci. Total Environ.* **2020**, *726*, 138531. [CrossRef]

13. Gong Wang, C.; Juan Liu, J. *Evolutionary Game Analysis of Recycling Management of Waste Power Batteries of New Energy Vehicles*; IOP Conference Series: Earth and Environmental Science; IOP Publishing: Bristol, UK, 2021; Volume 766, p. 012077.
14. Tang, Y.; Zhang, Q.; Li, Y.; Wang, G.; Li, Y. Recycling mechanisms and policy suggestions for spent electric vehicles' power battery—A case of Beijing. *J. Clean. Prod.* **2018**, *186*, 388–406. [CrossRef]
15. Savaskan, R.C.; Van Wassenhove, L.N. Reverse channel design: The case of competing retailers. *Manag. Sci.* **2006**, *52*, 1–14. [CrossRef]
16. Zheng, B.; Chu, J.; Jin, L. Recycling channel selection and coordination in dual sales channel closed-loop supply chains. *Appl. Math. Model.* **2021**, *95*, 484–502. [CrossRef]
17. Zhao, Y.; Wang, W.; Ni, Y. EPR system based on a reward and punishment mechanism: Producer-led product recycling channels. *Waste Manag.* **2020**, *103*, 198–207. [CrossRef]
18. Dixit, A.K.; Stiglitz, J.E. Monopolistic competition and optimum product diversity. *Am. Econ. Rev.* **1977**, *67*, 297–308.
19. Ezeah, C.; Fazakerley, J.A.; Roberts, C.L. Emerging trends in informal sector recycling in developing and transition countries. *Waste Manag.* **2013**, *33*, 2509–2519. [CrossRef]
20. Fei, F.; Qu, L.; Wen, Z.; Xue, Y.; Zhang, H. How to integrate the informal recycling system into municipal solid waste management in developing countries: Based on a China's case in Suzhou urban area. *Resour. Conserv. Recycl.* **2016**, *110*, 74–86. [CrossRef]
21. Fernando, R.L.S. Solid waste management of local governments in the Western Province of Sri Lanka: An implementation analysis. *Waste Manag.* **2019**, *84*, 194–203. [CrossRef]
22. Fujii, M.; Fujita, T.; Ohnishi, S.; Yamaguchi, N.; Yong, G.; Park, H.S. Regional and temporal simulation of a smart recycling system for municipal organic solid wastes. *J. Clean. Prod.* **2014**, *78*, 208–215. [CrossRef]
23. Johannes, H.P.; Kojima, M.; Iwasaki, F.; Edita, E.P. Applying the extended producer responsibility towards plastic waste in Asian developing countries for reducing marine plastic debris. *Waste Manag. Res.* **2021**, *39*, 690–702. [CrossRef] [PubMed]
24. Li, X.; Mu, D.; Du, J.; Cao, J.; Zhao, F. Game-based system dynamics simulation of deposit-refund scheme for electric vehicle battery recycling in China. *Resour. Conserv. Recycl.* **2020**, *157*, 104788. [CrossRef]
25. Meng, X.; Wen, Z.; Qian, Y. Multi-agent based simulation for household solid waste recycling behavior. *Resour. Conserv. Recycl.* **2018**, *128*, 535–545. [CrossRef]
26. Sun, Z.; Cao, H.; Zhang, X.; Lin, X.; Zheng, W.; Cao, G.; Sun, Y.; Zhang, Y. Spent lead-acid battery recycling in China—A review and sustainable analyses on mass flow of lead. *Waste Manag.* **2017**, *64*, 190–201. [CrossRef] [PubMed]
27. Song, X.; Hu, S.; Chen, D.; Zhu, B. Estimation of waste battery generation and analysis of the waste battery recycling system in China. *J. Ind. Ecol.* **2017**, *21*, 57–69. [CrossRef]
28. Tian, X.; Gong, Y.; Wu, Y.; Agyeiwaa, A.; Zuo, T. Management of used lead acid battery in China: Secondary lead industry progress, policies and problems. *Resour. Conserv. Recycl.* **2014**, *93*, 75–84. [CrossRef]
29. Sun, M.; Yang, X.; Huisingh, D.; Wang, R.; Wang, Y. Consumer behavior and perspectives concerning spent household battery collection and recycling in China: A case study. *J. Clean. Prod.* **2015**, *107*, 775–785. [CrossRef]