Industrial Engineering and Innovation Management (2023)
Clausius Scientific Press, Canada
DOI: 10.23977/ieim.2023.060710
ISSN 2522-6924 Vol. 6 Num. 7

Research on Evaluation of Power Battery Recycling Efficiency of New Energy Vehicle Based on DEA

Juan Huang*, Jingjing Wen, Feiyan He

School of Economics and Management, Sichuan Tourism University, Chengdu, 610100, China
**Corresponding author*

Keywords: Power battery recycling, recycling modes, DEA, recycling efficiency

Abstract: In recent years, the new energy vehicle industry has developed rapidly, and the recovery of waste power batteries has become an increasingly serious challenge. In this context, power battery recycling recovery has become an important part of the sustainable development of the new energy vehicle industry. If this problem cannot be solved, it will directly affect the development of new energy vehicles. This paper summarizes and analyzes the existing four main power battery recycling modes, and evaluates the power battery recycling efficiency under the recycling mode led by battery manufacturers, vehicle manufacturers, lithium battery materials enterprises and third-party recycling enterprises respectively through DEA data envelopment analysis model, according to the enterprise's investment costs and operating income in the power battery recycling business. The research results indicate that under the dominant mode of third-party recycling enterprises, due to their ability to collaborate in recycling related industries and integrate resources to a certain extent, compared to individual recycling entities under the other three modes, building a closed-loop supply chain recycling model with third-party recycling enterprises as the main body is more likely to exert network circulation effects and achieve the highest recycling efficiency. To provide certain reference for the formulation of recycling strategies for relevant enterprise.

1. Introduction

In recent years, the new energy vehicle industry has developed rapidly, which enables large-scale production of new energy vehicles, and the peak of scrapping of power batteries has followed. At present, the power battery recycling industry of China has begun to enter the critical period of building an industrial supporting system. How to create a new energy vehicle power battery recycling model to adapt to the market, how to effectively recycle power batteries, and how to effectively improve the current power battery recycling management system are the main problems facing the current. Most of the existing studies start with the specific subject in the new energy vehicle recycling supply chain, and regard the power battery recycling as a link in the closed cycle of the entire energy vehicle supply chain, focusing on the research of recycling value and recycling strategy. Hoyer et al. (2015) created a linear analysis model for the closed-loop supply chain of lithium batteries to study the optimal selection of specific production and recycling solutions [1], Lyu et al. (2021) took the recycling of power batteries for new energy vehicles in China as an example to analyze the alliance collaboration relationships among supply chain members in the recycling process of new energy vehicles in China, and provided suggestions for improving recycling efficiency through the implementation of "subsidies + supervision" or "phased supervision" [2]. Zhou Xingjian (2022) conducted empirical analysis and quantification of recycling efficiency when creating the DEA model, and proposed a recycling supply chain model based on blockchain technology that is more effective than traditional recycling models. The recycling efficiency is highest under manufacturer led (MRL) and third-party guided (TPL) modes, followed by battery driven (BML) and automobile manufacturer driven (AML) modes [3]. Lander Laura et al. (2021) analyzed the impact of transportation distance, wages, packaging design and recycling methods on the circular economy, and proposed that reducing emissions and transportation costs as well as ensuring the material supply chain would benefit the energy battery recycling economy [4]. The evaluation of power battery recycling efficiency is a comprehensive reflection of input and output from the perspective of technology and management [5].

Based on the analysis of new energy vehicle power battery recycling recovery mode, this paper starts from the responsibility relationship of each participant in the closed-loop supply chain, and evaluates the recovery benefits under different recovery modes according to the investment cost and operating income of enterprises in power battery recycling business.

2. Power Battery Recycling Mode

2.1. Battery Manufacturer-Led Recycling Model

Under the recycling mode with the battery enterprise as the main body, the battery enterprise should recycle it, and bear the production, sales, use and recycling of the battery in accordance with the principle of producer responsibility, and use the waste battery to reverse cycle, the recycling process is shown in Figure 1, the main representative enterprises in China are Gotion High-tech, Contemporary Amperex Technology Co., Limited, GHTECH and so on.

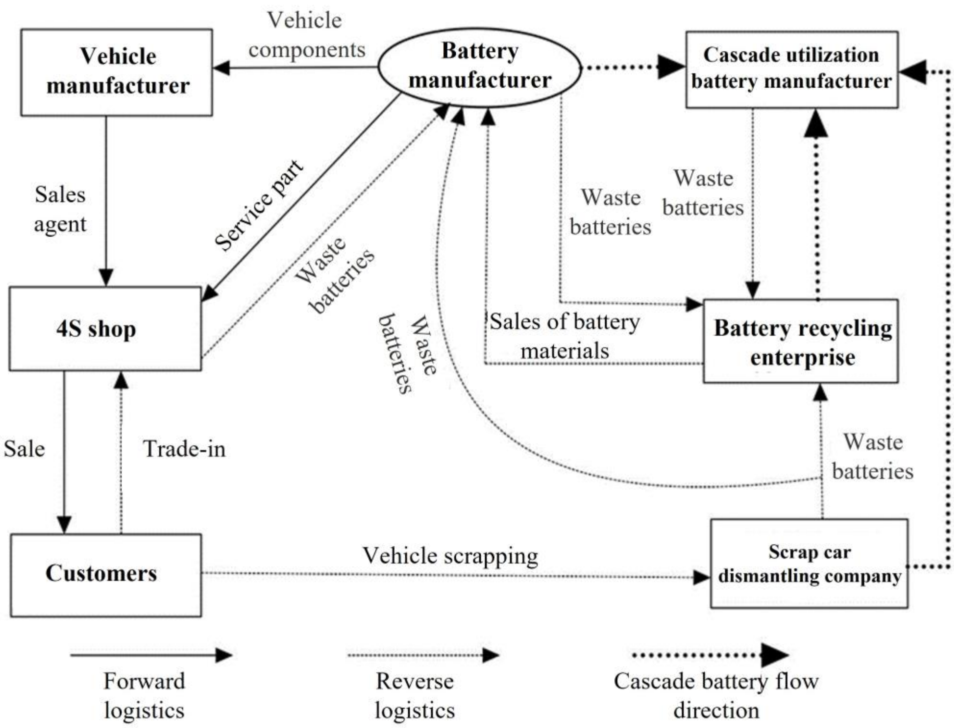

Figure 1: Battery manufacturer-led recycling model.

2.2. The Recycling Model Led by Vehicle Production Enterprises

Under the recycling model led by the vehicle production enterprise, the vehicle production enterprise bears the main responsibility for recycling. The specific process means that when the power battery reaches its service life due to the use of new energy vehicles by consumers or needs to be repaired or replaced due to other reasons, the vehicle manufacturer will assume the responsibility of battery recycling, and the vehicle manufacturer will send the battery to the battery disposal organization for corresponding disposal. The recycling process is shown in Figure 2, and the representative enterprises are SAIC Motor Group, GAC Group, BYD, etc.

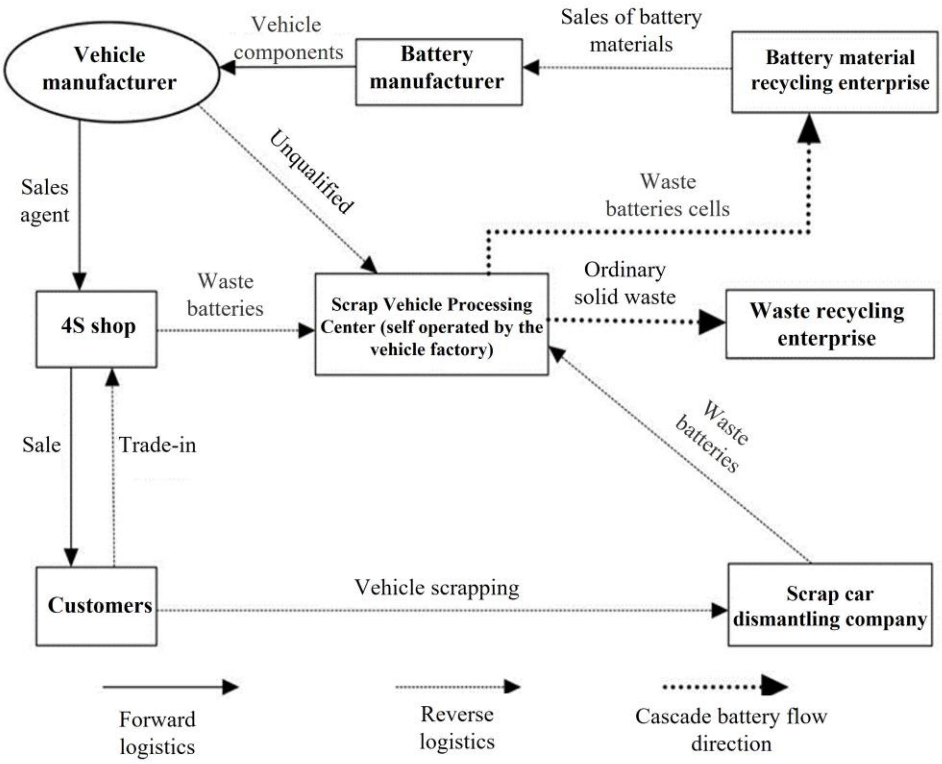

Figure 2: The recycling model led by vehicle production enterprises.

2.3. The Recycling Model Led by Lithium Battery Material Enterprises

In the resource recycling method based on lithium batteries, the main content of lithium electronic resource recycling is the recycling of battery raw materials. Taking lithium battery material enterprises as the main body, using relevant recycling channels to collect waste power batteries, recycle lithium, cobalt, nickel and other key resources in waste power batteries, producing battery raw materials, and selling them to battery manufacturers, thus forming an industrial cycle. As shown in Figure 3, the most representative enterprises such as Xiamen Tungsten, Huayou Cobalt, Ganfeng Lithium, etc.

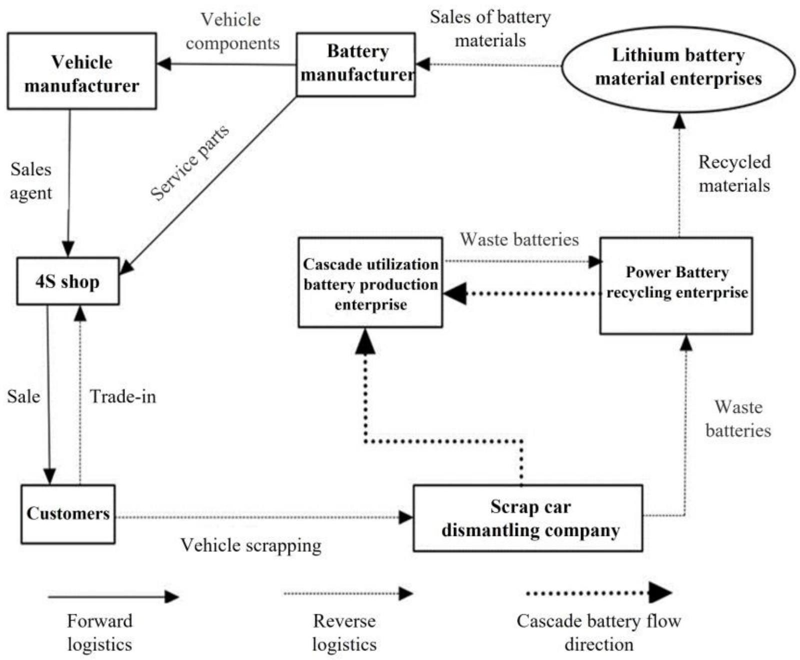

Figure 3: The recycling model led by lithium battery material enterprises.

2.4. The Recycling Model Led by Third-Party Recycling Enterprises

Under the recycling mode dominated by third-party recycling enterprises, third-party recycling enterprises assume the main responsibility for recycling. Through commercial cooperation with manufacturing enterprises, third-party recycling enterprises form a third-party recycling network by using the downward recycling business points of the partners, so that waste batteries flow into their recycling network. The recycling process is shown in Figure 4. The representative enterprises are China Tower, Greenmei, Camel, etc.

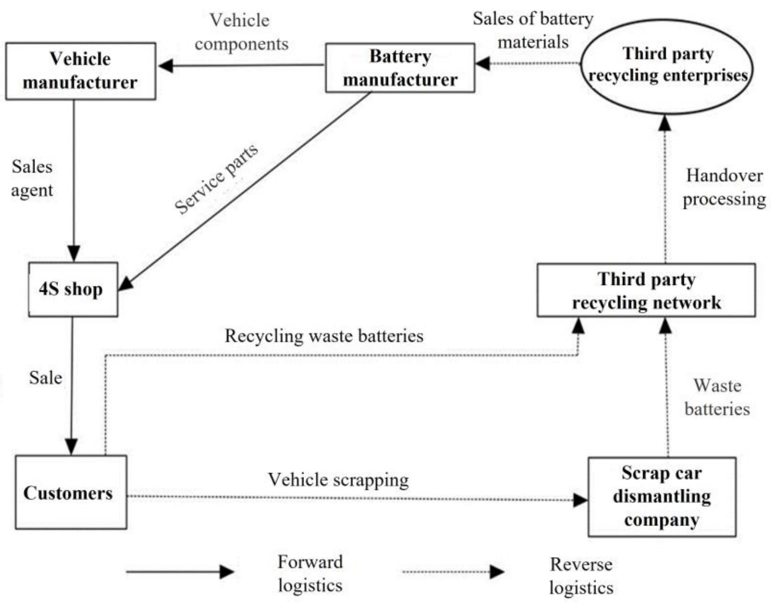

Figure 4: The recycling model led by third-party recycling enterprises

3. DEA Model

3.1. Introduction of DEA Model

Data envelopment analysis (DEA) is a commonly used efficiency evaluation method. Based on the basic idea of evaluating relative efficiency, Linear programming method is used to evaluate the relative efficiency of a type of comparable units based on several inputs and outputs [6]. In DEA, the evaluated individual or institution is referred to as a decision-making unit (DMU). The DEA method selects several different inputs and outputs from multiple decision-making units, and uses linear programming methods to use them as yield constraints to construct a data envelope curve. The effective points will be located on the leading edge, with an efficiency value of 1. The invalid point is outside the leading edge, and its corresponding efficiency value is between 0 and 1.

3.2. CCR Model

Based on the project benefit concept of "single input and single output", assuming that the Returns to scale is unchanged, an input oriented Linear programming model is constructed [7]. Assuming there are s enterprises, each of which has n types of investments, m types of outputs can be obtained. Y_{jk} represents the j-th output of the k-th enterprise, x_{ik} represents the i-th input quantity of the k-th enterprise. Using the principle of Linear programming, the efficiency value of the k-th enterprise θ can be represented as following:

$$\begin{cases} \min\theta \\ \text{s.t. } \sum_{j=1}^{s} X_j\lambda_j \leqslant \theta X_k \\ \text{s.t. } \sum_{j=1}^{s} Y_j\lambda_j \geqslant Y_k \\ \lambda_j \geqslant 0, j = 1,2,\cdots,s \end{cases} \tag{1}$$

Where x_i represents the input vector of the j-th decision unit when m outputs, Y_j represents the output vector of the j-th decision unit with n inputs, λ_j is the weight. The technical efficiency can be obtained by performing an s-th linear solution for each company. When using the best company as the standard, the technical efficiency represents the percentage of investment required for the k-th company when its output is constant.

3.3. BCC Model

Extending the CCR model, Banker RD and others proposed a BCC model assuming variable Returns to scale in order to evaluate the technology input of different production sectors, considering the problem of "multiple inputs and multiple outputs" [8]. Considering that in actual business activities, input and output are affected by various factors, new energy vehicle power battery recycling enterprises can adjust their input according to their operating conditions, and since the data collected are enterprises with relatively good operating efficiency. This article focuses on investment oriented research and evaluates the problem of minimizing investment at a fixed output level. The BCC model divides technical efficiency (TE) into pure technical efficiency (PTE) and scale efficiency (SE). Efficiency value θ It is the kth enterprise's pure technical efficiency (PTE), and the BCC model is as follows:

$$\begin{cases} \quad\quad min\,\theta \\ \text{s.t. } \sum_{j=1}^{s} X_j\,\lambda_j \leqslant \theta X_k \\ \text{s.t. } \sum_{j=1}^{s} Y_i\,\lambda_j \geqslant Y_k \\ \text{s.t. } \sum_{j=1}^{s} \lambda_j = 1 \\ \lambda_j \geqslant 0, j = 1,2,\cdots,s \end{cases} \tag{2}$$

Using the above two models, calculate the technical efficiency (TE) and pure technical efficiency (PTE) of each DMU, with scale efficiency SE=TE/PTE. By using the scale efficiency value, the recycling efficiency of each enterprise can be compared.

4. Evaluation of Recycling Efficiency Based on DEA

This paper only discusses the recovery efficiency of enterprises with different recovery modes, and makes Data envelopment analysis of standard CCR and BCC using the input and output cross-section data recovered by enterprises. The input cost and operating income of 12 enterprises in the power battery recycling business in 2021 under the above four recycling modes are quantitatively analyzed, and the recovery efficiency is compared with the DEA model characteristics.

Using 12 enterprises as 12 decision-making units (DMU_j, j = 1, 2, …, 12), data statistics and processing were conducted based on the actual input and output of the 12 enterprises' recycling business in 2021, and data tables related to the input of recycling costs and the output of recycling benefits were formed to calculate the comprehensive technical efficiency (TE), pure technical efficiency (PTE), and scale efficiency (SE) values of the 12 enterprises, as shown in Table 1.

Table 1: DEA analysis results of recycling efficiency of 12 enterprises in 2021.

Recycling mode	DMUS	Technical efficiency	Pure technical efficiency	Scale efficiency	Return to scale
Battery manufacturer-led	DMU_1	0.447	0.447	0.998	Incremental
	DMU_2	0.067	1.000	0.067	Incremental
	DMU_3	0.466	0.549	0.848	Incremental
Vehicle production enterprises-led	DMU_4	0.105	0.702	0.150	Decrement
	DMU_5	0.075	1.000	0.075	Decrement
	DMU_6	0.539	1.000	0.539	Decrement
Lithium battery material enterprises-led	DMU_7	0.389	0.431	0.904	Decrement
	DMU_8	0.282	0.316	0.891	Decrement
	DMU_9	0.096	0.099	0.971	Incremental
Third-party recycling enterprises-led	DMU_{10}	1.000	1.000	1.000	Unchanged
	DMU_{11}	0.408	0.411	0.993	Incremental
	DMU_{12}	1.000	1.000	1.000	Unchanged
Enterprise average		0.406	0.663	0.703	-

From Table 1, it can be seen that the technical efficiency of most enterprises is relatively low, with an average value of only 0.406. Only two enterprises have comprehensive efficiency at the effective frontier, with an efficiency value of 1. In terms of pure technical efficiency, there is a significant difference in efficiency values among enterprises. Five enterprises have pure technical efficiency at the forefront, with an efficiency value of 1, while other enterprises generally have low pure technical efficiency. In terms of scale efficiency, five companies have relatively high scale efficiency and are the main forces forming the industry's frontier. Their pure technical efficiency is 0.998, 0.971, 1, 0.993, and 1, respectively. The pure technical efficiency values of the three enterprises are slightly lower, and they are in a relatively efficient state of technology. Scale efficiency is located on the effective frontier (enterprises with an efficiency value of 1), with only two enterprises under the recycling model led by third-party recycling enterprises. This indicates that under the leadership of third-party recycling enterprises, due to the ability of third-party enterprises to jointly recycle related industries and carry out a certain degree of resource integration, they play a role compared to a single recycling entity under the other three models, Building a closed-loop supply chain recycling model with third-party recycling enterprises as the main body can more easily leverage the network circulation effect and have better recycling efficiency.

5. Conclusions

The importance of new energy vehicle power battery recycling is increasingly prominent. How to form an effective recycling closed-loop supply chain and realize the healthy development of the recycling market is a problem worthy of repeated research and exploration. The paper collects the annual report data issued by representative power battery recycling enterprises, and analyzes the efficiency of power battery recycling under different recycling modes through DEA Data envelopment analysis model. The results show that the closed-loop supply chain recycling mode built by third-party recycling enterprises can more easily exert the network recycling effect and have better recycling efficiency.

Acknowledgements

This work was supported by 2022 Chengdu Philosophy and Social Sciences Research Base Megacity Fine Governance Research Base Project (TD22Z09), 2023 Chengdu Green Low Carbon Development Research Base Project (LD23YB38), and 2021 Sichuan Tourism University Campus Level Scientific Research Project (2021SCTUSK19).

References

[1] Hoyer C, Kieckhafer K, Spengler T S. (2015) Technology and capacity planning for the recycling of lithi ion electrical vehicle batteries in Germany. Journal of Business Economies, 85, 505-544.

[2] Lyu X. C., Xu Y. Y., Sun D. (2021) An evolutionary game research on cooperation mode of the NEV power battery recycling and gradient utilization alliance in the context of china's NEV power battery retired tide. Sustainability, 13, 1-27.

[3] Zhou X., Li J., Li F., Deng X. (2023) Recycling supply chain mode of new energy vehicle power battery based on blockchain technology. Computer Integrated Manufacturing Systems, 29, 1386-1398.

[4] Lander L., Cleaver T., Rajaeifar M. A. (2021) Financial viability of electric vehicle lithium-ion battery recycling. iScience, 24, 7.

[5] Wang X., Mu R., Zhou L., Dong J. (2021) An evaluation method of input-output performance of decision making units considering efficiency and effect. Chinese Journal of Management Science, 1-12.

[6] Guo S., Zhang J. (2018) Comparison of Science and Technology Innovation Efficiency and Investment Redundancy among 31 Provinces and Cities in China. Science Research Management, 39, 55-63.

[7] Charnes A., Cooper W. W., Rhodes E. (1978) Measuring the efficiency of decision making units. European Journal of Operational Research, 2, 429-444.

[8] Banker R. D., Charnes A, Cooper W. W. (1984) Some models for estimating technical and scale inefficiencies in data envelopment analysis. Management Science, 30, 1078-1092.