A SWOT and AHP Methodology for the Formulation of Development Strategies for China's Waste EV Battery Recycling Industry

Zhu Lingyun[1] and Chen Ming[1]
[1]School of Mechanical Engineering, Shanghai Jiao Tong University, Shanghai, 200240, P.R. China
mingchen@sjtu.edu.cn

Abstract

Along with the electric vehicle (EV) boom in China, the amount of EV batteries is increasingly growing nowadays, which leads to a dual challenge on waste batteries — the disposal pressure and the recycling demand because of their environmental hazard potentials and recovery value from materials. However, so far, EV battery recycling has not yet been industrialized and a recycling network has not been established in China. In this paper, a SWOT analysis approach is employed to summarize the scrap battery recycling situation in China and sum up the main factors of these four aspects (Strength, Weakness, Opportunity and Threat). Then an Analytic Hierarchy Process (AHP) method is adopted to assess these factors by weight coefficients to identify the key factors in developing a waste EV batteries recycling industry. At last, a TOWS method is used for making development strategies according to the key factors and their weights. The overall strategies include five aspects: laws, economics, system constructions, technology and public education.These strategies, which are presented based on the actual environment of the waste EV battery recycling industry in China and come from qualitative and quantitative methods' analysis, could be useful for China to promote its EV battery recycling management in the future.

1 Introduction

In recent years, the electric vehicle (EV) industry has developed rapidly worldwide, especially in China where people call it new energy vehicle (NEV). As shown in Figure 1, in 2014, which was regarded as the "first year" of EV industry development in China, China became the second largest EV market in the world after the United States [2]. Since 2015, China has been the world's largest electric vehicle market. The proportion of EV sales in China to global sales has increased from less than 10% to around 65%. At the same time, the amount of EV batteries is also increasing. However, the EV battery often has a certain lifetime (about 5-8 years) [6], which will result in a lot of end-of-life EV batteries at some point. According to the prediction of China Automotive Technology and Research Center, the accumulated scrap of EV batteries in China will reach 350,000 tons by 2025 [7]. If not properly disposed of, they will cause environmental pollution and waste of resources. For example, $LiFePO_4$ battery's (LFP) electrolyte decomposition will produce toxic fluoride [8]. On the other hand, Lithium nickel cobalt manganese batteries (NCM) contain the heavy metals Cobalt (Co) and Nickel (Ni), which have recovery value [9].Therefore, the accumulation of scrapped batteries will be a major issue related to both environment and economy. The Chinese government has paid much attention and even attached great importance to it in a new historical height. Recently, China published "New energy vehicle battery recycling Interim Measures" to conduct waste EV battery recycling management [10]. In fact, prior to this regulation, there have been many relative policies to promote battery recycling in China, as shown in Table 3.

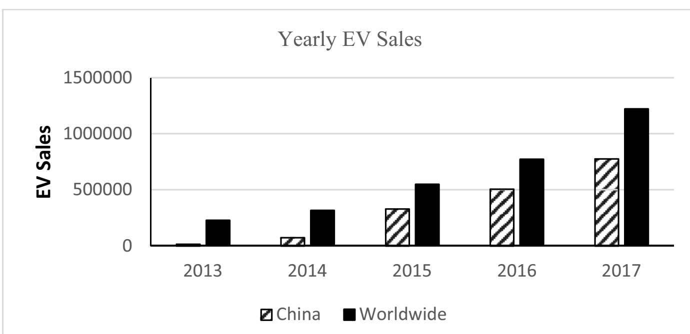

Figure 1. The EV sales between China and Worldwide (year: 2013-2017) [1-5]

However, in today's China, the desire to recycle waste EV batteries has not yet really been carried out, because a recycling network has not yet been established, the recycling industry lacks recycling and disposal specific standards, and the recycling process is not yet mature, let alone that a business model has been formed. On the other hand, regulations and policies related to battery recycling only clarified the responsibilities but did not actually reveal enforcement. A salesperson from a Beijing-based EV 4S store said that car manufacturers did not have a policy on

A. Pehlken et al. (Eds.), *Cascade Use in Technologies 2018*,
https://doi.org/10.1007/978-3-662-57886-5_11

battery recycling. Therefore, the scrapped batteries are usually handled by 4S stores themselves [11]. Consequently, prior to the massive accumulation of scrapped batteries, it is necessary to analyze the recycling situation of China's end-of-life EV batteries and formulate relative development strategies. To the author's best knowledge, not many studies on China's EV battery recycling management strategies exist yet.

In this paper, a SWOT (Strength, Weakness, Opportunity and Threat) analysis approach is employed to summarize the scrap battery recycling situation in China, and an AHP (Analytic Hierarchy Process) method is adopted to assess the keys factors for battery recycling. Then a TOWS method is used to plan the corresponding development strategies. The structure of the paper is organized as follows: Section 2 is an interpretation of the research methods. Section 3 is a SWOT analysis for the situation of the spent EV batteries recycling industry in China. Section 4 is the AHP assessment for the battery recycling development's key factors and the devising of development strategies for them by the TOWS method. Section 5 is the conclusion for this paper.

2 Methodology

This article aims to analyze and evaluate the development prospects of China's waste EV battery recycling and plan a strategic management for the development directions before the recycling industry has reached scale and been industrialized. In consequence, the first step is to conduct a strategic analysis, which is based on the waste EV battery recycling industry's background in China. SWOT analysis is a general method in strategic decision-making, which is derived from the analysis of the internal and external environments of the recycling industry. The internal analysis includes strengths and weaknesses aspects, while the external analysis includes the opportunities and threats aspects [12].The SWOT analysis' results will be represented by a matrix filled with these four aspects and its main factors. In fact, there are some studies on waste management strategies that use SWOT analysis, dealing with MSWM (municipal solid waste management) [13], e-waste [14] and construction waste [15].

However, the SWOT method cannot rank the factors independently by quantitative analysis, which is the basis for strategy-making and prioritizing the development strategies according to the various decision-making factors [16-17]. Analytical Hierarchy Process (AHP) is a suitable method to be used in conjunction with the SWOT matrix [17]. AHP is a classic qualitative and quantitative analysis method for decision-making, which decomposes the relative factors into goal, criteria and alternatives levels [18]. By establishing a hierarchical structure and constructing a comparative judgement matrix, the weight coefficients of each factor are evaluated in the alternatives level. In this paper, the AHP method will rank the factors in the alternatives level to identify the key factors for strategy-making.

In terms of factors ranking, one method is even called A'WOT, which stands for the SWOT and AHP hybrid method. Specifically, this means that SWOT provides the basic frame to perform an analysis of the situation and AHP assists in carrying out SWOT more analytically [19]. Related to end-of-life vehicle recycling research, Junjun Wang and Ming Chen [20] employed the SWOT and AHP method to study the development strategies of used automotive electronic control components recycling industry in China, and Zhang Hongshen and Chen Ming [21], based on this method, conducted research on the recycling industry development model for typical exterior plastic components of end-of-life passenger vehicles. Because of the limited space of the paper and extensive use of AHP method, the principles of AHP are not described in detail.

In regard to strategy-making, by a TOWS analysis method which is derived from the SWOT analysis matrix [22], the development strategies of waste EV battery recycling will be achieved based on the total alternatives weights. The TOWS method [23] is designed to match the environmental threats and opportunities with the company's weaknesses and strengths for development strategy formulation, as Table 1 shows. According to the TOWS method, the strategies consists of four strategic aspects (SO, WO, WT and ST strategies) based on the alternatives level's weight distribution. In detail, SO strategies aim to use its strengths to pursue opportunities, WO strategies intend to take advantage of opportunities to overcome weaknesses, WT strategies are designed to minimize weaknesses and avoid threats, and ST strategies mean to take advantage of the company's strengths to reduce threats.

Table 1. The concept of TOWS method

	Internal Strengths (S)	**Internal Weaknesses (W)**
External Opportunities (O)	**SO:** *"Maxi-Maxi" Strategy* Strategies that use strengths to maximize opportunities	**WO:** *"Mini-Maxi" Strategy* Strategies that minimize weaknesses by taking advantage of opportunities
External Threats (T)	**ST:** *"Maxi-Mini" Strategy* Strategies that use strengths to minimize threats	**WT:** *"Mini-Mini" Strategy* Strategies that minimize weaknesses and avoid threats

In a summary, the research methodology process mainly includes three parts, which are SWOT situation analysis, AHP analysis and TOWS development strategy-making. In the first step, the factors of the waste EV battery recycling situation are integrated into four aspects: Strengths, Weaknesses, Opportunities, and Threats. In the second step, the main factors of these four aspects will be ranked by weight coefficients to identify key factors. In the last step, combination strategies (SO, WO, ST, WT) will be proposed according to the key factors and their weights.

3 SWOT Analysis of Waste EV Battery Recycling in China

In order to conduct a situation analysis, the authors study the external environment and internal environment of waste EV battery recycling in China. According to Hitt's interpretation [24], the former includes the general, industry and competitor environments, and the latter includes resources, capabilities, core competencies, and competitive advantages. Obviously, this classification is based on the perspective of a company's strategic development. However, this paper aims to plan a strategic development at the national level, which will be more inclined to the country's perspective and will also pay attention to the development of the overall EV battery recycling industry. Therefore, similar to the PEST analysis model, the authors integrate environments related to EV battery recycling and divide them into five categories: economics, politics/laws, society, technology, and natural environment. Based on these categories and main factors, the Strengths, Weaknesses, Opportunities and Threats will be summarized.

With regards to the economic aspect, the composition of the EV battery guarantees its recycling value, especially the recovery of Co and Ni metal, which are contained in the electrode as shown in Table 2. However, in China's electric vehicle market, LFP batteries have been widely used in EVs during the past few years, such as SAIC Motor Corp.[1] and BYD Co., Ltd.'s[2] products, which reduce the total recycling value of China's EV batteries. On the other hand, the recovered materials need to undergo some upgrading process before being used as a secondary material in battery production [26], which will cause rising costs for battery recycling. In addition, both the battery manufacturers and the customers worry whether a battery using secondary materials can meet the function and safety requirements [27]. In terms of labor costs, China's abundant labor force is conducive to low costs, but the birth control policy of the past decades leads to a gradual increase in labor costs.

Table 2. Electrode Elements Composition of three types Li-ion Battery [25]

Elements \ Type	$LiNi_{0.8}Co_{0.15}Al_{0.05}O_2$	$LiFePO_4$	$LiMn_2O_4$
Lithium (Li)	1.90%	1.10%	1.40%
Nickel (Ni)	12.10%	0.00%	0.00%
Cobalt (Co)	2.30%	0.00%	0.00%
Aluminum (Al)	0.30%	0.00%	0.00%
Oxygen (O)	8.30%	9.00%	12.40%
Iron (Fe)	0.00%	7.80%	0.00%
Phosphorus (P)	0.00%	4.40%	0.00%
Manganese (Mn)	0.00%	0.00%	10.70%
Titanium (Ti)	0.00%	0.00%	0.00%
Graphite (C)	16.50%	15.30%	16.30%

In the politics/laws aspect, China has comprehensive laws and regulations system related to waste EV battery recycling as Table 3 shows, which includes contents of recycling requirements, responsibility determination, supervision and punishment, etc. The Technical Policy for the Recovery of Automobile Products states that EV manufacturers should be responsible for recycling and treating of sold EV batteries. The Circular Economy Promotion Law of the People's Republic of China regulates the recycling of waste products, such as batteries, which are included in the mandatory recycling list. The Planning for the Development of the Energy-Saving and New Energy Vehicle Industry (2012–2020) regulates the establishment of cascade utilization and recycling management systems for EV batteries. The Automotive Power Battery Industry Specification rules that battery production enterprises must meet the environmental system and occupational health & safety system, recycle or treat the wastes during the manufacturing phase, and cooperate with the vehicle manufacturer for the disposal procedure of used vehicle batteries. The Industry Standard Conditions of New Energy Vehicle Used Battery Utilization and Interim Administrative Measures regulate the relative recycling and disposal technologies and their efficiency requirements, and the distribution of recycling and disposal responsibilities among the stakeholders. The New Energy Vehicle Battery Recycling Interim Measures regulate car manufacturers should be responsible for the recycling and recovery of used batteries and proposes the supervision and management mechanism. However, these legal policies and laws have never been enforced, and there are few detailed

[1] SAIC Motor Corp. is a Chinese vehicle manufacturer in Shanghai

[2] BYD Co. is a Chinese electric vehicle manufacturer in Shenzhen, Guangdong province

implementation rules and standards to follow, although the division of responsibility has already been specified and even the supervision mechanism been proposed.

Table 3. Chinese laws and policies related to waste EV battery recycling

Published year	Legal and policy documents
1989	Environmental protection law of people's republic of China
2001	Hazardous waste pollution prevention technology policy
2003	Waste battery pollution prevention technology policy
2004	Hazardous waste operating license management approach
2006	Renewable resource recovery management regulations
2006	Automotive product recycling technology policy
2008	Circular economy promotion law of the people's republic of China
2012	Planning for the development of the energy-saving and new energy vehicle industry (2012–2020)
2014	Guiding opinions on accelerating promote the use of new energy vehicles
2015	Automotive power battery industry specification
2016	Industry standard conditions of new energy vehicle used battery utilization and interim administrative measures
2016	Specification for comprehensive utilization of waste batteries for new energy vehicles
2016	Electric vehicle battery recycling technology policy
2017	Extended producer responsibility system implementation plan
2018	New energy vehicle battery recycling interim measures

With regards to the technology aspect, the Chinese government has contributed a great deal of support to research on the recycling and cascade use of waste EV batteries, such as National Natural Science Foundation and "863 program". Meanwhile, many environmental protection companies have made significant progress in battery recycling and material recovery, such Brunp Recycling Technology Co.[3], Ltd. and GEM Co., Ltd.[4] . However, the government lags behind the industry's demand for constructing a recycling standards system. Until now, there are only two battery recycling and treatment standards for used EV batteries' residual capacity test and dismantling specification. In addition, the gap in the recycling process between Chinese companies and other international environmental protection companies, such as Umicore, Toxco and OnTo[5], is very obvious. Consequently, China's waste EV battery industrialization is still a long way to go.

Concerning the environment and society aspects, because of the increasing amount of scrapped EV batteries and people's awareness of environmental protection, the battery recycling industry will have a promising development prospect. The government has put much effort into environmental protection infrastructure construction, such as battery recycling bins, but there is no dedicated box for EV batteries recycling. Some environmental protection associations have participated in promoting battery recycling by bringing the relevant stakeholders together to discuss recycling and cooperation mechanisms. For example, the Alliance of Auto Recovery Technology Innovation (AARTI), which is devoted to research and development of general technology for the automobile product recycling industry, including EV and EV batteries in China, was established in 2010 to promote the industry's technological progress in energy conservation, emission reduction and comprehensive utilization of waste resources [21]. Before the industrialization model was eventually formed, some informal small enterprises impacted the battery recycling market by their price advantage, which causes a waste of resources and secondary pollution. Due to the low level of automation in China's battery recycling industry, people's employment problems have been alleviated. But employment in this industry also brings health and secondary pollution problems because the battery's treatment process is not standardized and safe.

Finally, based on the above classification and discussion, a SWOT analysis matrix is formed, as Table 4 shows. Basically, the factors from Opportunities to Threats in the external environment are corresponding to macro policy, environment protection, recycling economy and recycling standards. The factors from Strengths to Weaknesses in the internal environment are symmetrical to recycling market, labor costs, recycling value, recycling technology and waste battery management/cooperation.

[3] Brunp is a Chinese waste vehicle and battery recycling company in Foshan, Guangdong province

[4] GEM is a Chinese waste vehicle and battery recycling company in Shenzhen, Guangdong province

[5] Umicore, Toxco and OnTo are the leading company in resource recovery including waste EV battery recycling

Table 4. The SWOT analysis matrix of China's EV battery recycling industry[6]

Opportunities	Weight	Threats	Weight
O1 Support from national policies and legal systems	0.1874	**T1** Inadequate implementation of policies with little or no penalties	0.0659
O2 Public awareness of environmental protection and waste recycling increased	0.032	**T2** Weak infrastructure and recycling outlets which causes citizens to be unable to participate directly	0.0134
O3 The resources used in the battery are relatively scarce which may have a major impact on the country's economic development	0.0836	**T3** The use of LFP reduces the overall value of recycling which leads to insufficient market forces	0.0263
O4 Recycling standard system is being drafted and formed	0.0320	**T4** Recycling standards are not sound enough to support the entire recycling industrialization	0.0594
Strengths	**Weight**	**Weaknesses**	**Weight**
S1 The number of waste batteries is huge	0.0657	**W1** Recycling network has not yet formed which hinders the development of recycling industrialization	0.0397
S2 Labor costs are relatively low in China	0.0182	**W2** Family planning leads to slowing population growth, a general increase in salary	0.0114
S3 Recycling value of material included in EV battery	0.1129	**W3** Unexplained application prospects of recycled materials	0.0701
S4 Many companies have made breakthroughs in waste EV battery recycling in China	0.0395	**W4** The recycling process has not reached the international advanced level which may lead to recycling value reduced, workers' health threats and secondary pollution	0.1097
S5 Some waste management organizations were established to accelerate internal integration and cooperation in the industry and promote the industrialization of EV battery recycling	0.0138	**W5** Non-qualified recycling companies in the market cause unfair competition which results in unreasonable allocation of resources within the industry	0.019

4 AHP Analysis and Strategies Making for Waste Batteries

4.1 AHP Analysis for Key Factors

In this paper, a hierarchical structure of SWOT factors and AHP analysis is applied as shown in Figure 2. The total environment is the goal level, the internal and external environment and SWOT group form the criteria level, and SWOT factors constitute the alternatives level. After building a clearly structural hierarchy, the next step is to calculate the weight distribution in criteria and alternatives levels. The expert survey method is employed as shown in Table 5, which determines the comparison matrix elements' value. At the criteria level, the internal and external environments are considered 'equally important', as are Strengths and Weaknesses. The Opportunities are regarded as in-between 'equally important' and 'more important'. Therefore, the corresponding weight coefficients are obviously, as shown in Figure 2, according to AHP's 1 to 9 scale ranking of importance. In respect to the alternatives level, four pairwise comparison matrixes (A, B, C, D for S, W, O, T, respectively) should be used to present the results of the expert survey method. Then the maximum eigenvalue (VA, VB, VC, VD) and corresponding eigenvector (TA, TB, TC, TD) of each comparison matrix are calculated as follows.

[6] Because of layout constraints, weights of the SWOT factors, which are calculated and ranked by AHP method in the 4th chapter, are added in table 3.

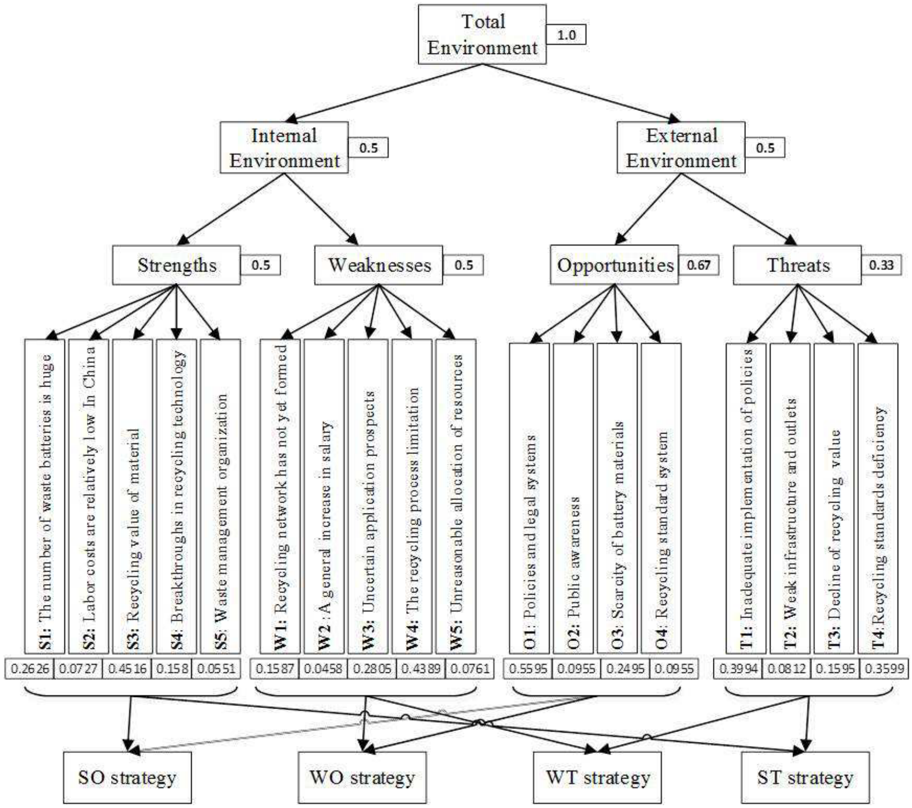

Figure 2. The hierarchical presentation of SWOT and AHP analysis

Table 5. The AHP's expert survey form

Value	1	2	3	4	5	6	7	8	9
Comparison	same importance	median value	more important	median value	obviously more important	median value	strongly more important	median value	extremely more important
Factor X[7]	1	2	3	4	5	6	7	8	9
Factor Y[8]		1/2	1/3	1/4	1/5	1/6	1/7	1/8	1/9

$$A = \begin{pmatrix} 1 & 5 & 1/3 & 2 & 5 \\ 1/5 & 1 & 1/5 & 1/3 & 2 \\ 3 & 5 & 1 & 3 & 5 \\ 1/2 & 3 & 1/3 & 1 & 3 \\ 1/5 & 1/2 & 1/5 & 1/3 & 1 \end{pmatrix} \qquad B = \begin{pmatrix} 1 & 5 & 1/3 & 1/5 & 5 \\ 1/5 & 1 & 1/5 & 1/7 & 1/3 \\ 3 & 5 & 1 & 1/3 & 5 \\ 5 & 7 & 3 & 1 & 7 \\ 1/5 & 3 & 1/5 & 1/7 & 1 \end{pmatrix}$$

$$C = \begin{pmatrix} 1 & 5 & 3 & 5 \\ 1/5 & 1 & 1/3 & 1 \\ 1/3 & 3 & 1 & 3 \\ 1/5 & 1 & 1/3 & 1 \end{pmatrix} \qquad D = \begin{pmatrix} 1 & 5 & 3 & 1 \\ 1/5 & 1 & 1/3 & 1/3 \\ 1/3 & 3 & 1 & 1/3 \\ 1 & 3 & 3 & 1 \end{pmatrix}$$

$$[V_A, V_B, V_C, V_D] = [5.2084, 5.4449, 4.0435, 4.1155]$$

7 The 3rd row's value is from factor X comparing with factor Y

8 The 4th row's is from factor X comparing with factor Y

$$[T_A]=\begin{bmatrix}0.4746\\0.1313\\0.8161\\0.2856\\0.0996\end{bmatrix}, [T_B]=\begin{bmatrix}0.262\\0.0664\\0.4321\\0.8541\\0.1035\end{bmatrix}, [T_C]=\begin{bmatrix}0.8919\\0.1522\\0.3977\\0.1522\end{bmatrix}, [T_D]=\begin{bmatrix}0.7048\\0.1433\\0.2814\\0.6352\end{bmatrix}$$

Prior to the weight coefficients calculation, the consistency of the comparison matrix needs to be examined based on the formula (1) and (2). If the C.R. value is less than 0.1, the comparison matrix will be a satisfactory consistency matrix, and the corresponding eigenvector will be used as the initial weight coefficient after being normalized. If not, the comparison matrix will be reviewed and revised.

$$C.I. = (V - n)/(n-1) \quad (1)$$
$$C.R.= C.I./R.I. \quad (2)$$

Where,
V is the maximum eigenvalue.
n is the order of the comparison matrix.
C.I. is the consistence index.
R.I. is the random consistency index whose value is shown in Table 5.
C.R. is the consistence ratio.

Table 6. The value of random consistency index [18]

n	3	4	5	6	7	8	9	10	11
R.I.	0.58	0.89	1.12	1.24	1.32	1.41	1.45	1.49	1.52

According to formula (1) and (2), the consistency test's results showed that the C.R. value are 0.0465, 0.0993, 0.0163 and 0.0433 for Matrix A, B, C and D, respectively, which are all under 0.1. But we can see that the C.R. value of matrix B is too close to 0.1, so matrix B should be revised slightly. Specifically, after rethinking and deciding, the authors enhance the importance of recycling network (W1) to recycling technology (W4) from 1/5 to 1/3, reduce the importance of recycling network (W1) to allocation of resources (W5) from 5 to 3, raise the importance of labor costs (W2) to recycling technology (W4) from 1/7 to 1/5, and decrease the importance of recycling technology (W4) to allocation of resources (W5) from 7 to 5. Then the maximum eigenvalue ($V_{B'}$) and corresponding eigenvector ($T_{B'}$) are shown below, and the C.R. value is 0.0873 which is more reasonable for a satisfactory consistency matrix.

$$B' = \begin{pmatrix}1 & 5 & 1/3 & 1/3 & 3\\1/5 & 1 & 1/5 & 1/5 & 1/3\\3 & 5 & 1 & 1/3 & 5\\3 & 5 & 3 & 1 & 5\\1/3 & 3 & 1/5 & 1/5 & 1\end{pmatrix} V_{B'} = 5.3909, [T_{B'}]=\begin{bmatrix}0.2877\\0.083\\0.5085\\0.7955\\0.1379\end{bmatrix}$$

Finally, the initial weight coefficients can be calculated by standardization of eigenvectors (T_A, $T_{B'}$, T_C, T_D) and the results are shown in Figure 2. Meanwhile, the total weight coefficients of the alternatives level can be computed based on all levels' initial weight rank by multiplication. Results are shown in Table 4.
Generally speaking, the quantitative analysis in the AHP method is derived from the experts' experienced scoring which is more or less subjective. However, it is efficient and relatively reasonable for decision-making as waste battery recycling has not yet been industrialized and a recycling network has not yet been established in China. Along with the changes and development of the industrialization of EV battery recycling, the main factors in SWOT analysis may be updated and replaced, and the development strategies should adjust accordingly.

4.2 TOWS Analysis for Strategies-Making

As the results of the total weight SHOW, seven factors' coefficient is above 0.65, one factor is close to 0.06 and THE others are below 0.04. In order to formulate more effective and direct development strategies for waste EV battery recycling, the lower weight factors are ignored and the higher weight factors are used for devising strategies as shown in Table 4. These are large amount of waste EV battery (S1, 0.0657), recycling value of material (S3,0.1129), unexplained application prospects (W3,0.0701), recycling process limitation (W4,0.1097), policies and legal systems (O1,0.1874), scarcity of battery materials (O3,0.0836), inadequate implementation of policies (T1,0.0659), recycling standards deficiency (T4, 0.0594).
Finally, the TOWS analysis is employed, as Table 1 shows, to generate four combined strategies (SO, ST, WO and WT) based on the matching and analyzing of these eight factors with higher weights.

SO strategies: utilize support from laws and policies to promote waste battery collection and recycling.

- Formulate more detailed plans for waste EV battery recycling and enforce the implementation for extended producer responsibility (EPR).
- Encourage recycling behavior of producers and their partners through subsidies or tax reductions.
- The government invests in more infrastructure to serve the recycling of EV battery.
- The government shuts down non-qualified and non-standard battery recycling companies to make resources flow to qualified companies.
- The government funds scientific research projects for companies, universities and research institutes, and accelerates the transformation of research results to improve recycling technology and value.
- The government instills the idea of green production and circular economy into the companies, and encourages the construction of strategic organizations or alliances for the battery recycling technology development.

ST strategies: continue to deepen the recycling implementation policies and improve processing standards to promote battery recycling.

- The government establishes a recycling system based on EPR principles and strengthens the construction of an information traceability system to improve the definition of responsibility and the level of reverse logistics management.
- The government promotes awareness of environmental protection to citizens and launches the whole society to supervise.
- The relevant government departments continue formulating recycling processing standards to support the development of the battery recycling industry.
- The government establishes more detailed treatment standards on all steps of reverse logistics to support the battery recycling industrial chain.

WO strategies: Strengthen the technical cooperation of recycling process and look for the downstream market of secondary materials.

- The government encourages the reuse of secondary materials and promulgates related management measures and enterprise access conditions.
- The government assists battery recycling companies to explore the recovery market for recycled materials.
- Develop cascade use of waste batteries to other areas to increase their overall value.
- Recycling companies strengthen their cooperation with domestic and foreign battery recycling corporations to introduce the advanced experience in the recycling process and recycling value.

WT strategies: Strengthen the application of green design theory and increase safety awareness.

- Through the recovery rate and emission requirements, manufacturers are encouraged to implement the application of green design theory, such as recyclability design and detachability design to promote the recycling of spent EV batteries.
- For the unclear application prospects of recycled materials, the recycled coarse materials (raw materials and precursors) can be resold to foreign companies for initial recovery value. Meanwhile, the companies strengthen technology exchanges and cooperation to gradually master higher level recycling values.
- Enterprises improve the standardization of waste EV battery management process, and train workers' safety awareness.

To sum up, the development strategies of waste EV battery recycling can be mainly divided into five aspects including laws, economics, system constructions, technology and public education as shown in Figure 3.

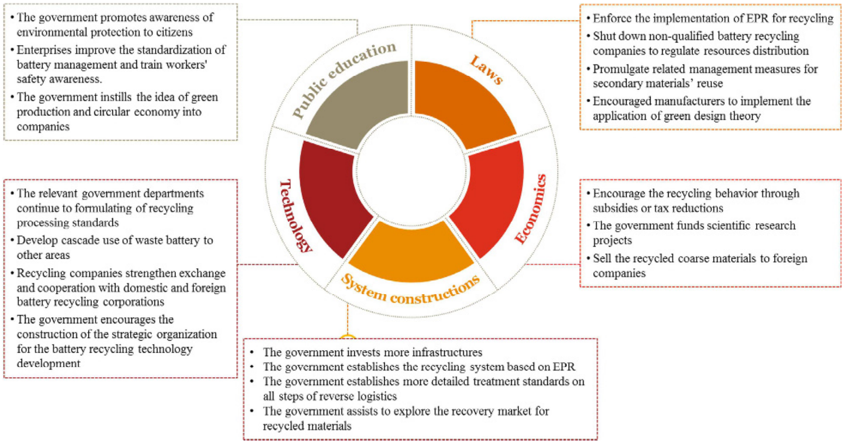

Figure 3. The total development strategies of waste EV battery recycling industry in China

5 Conclusion

In the wake of the development of electric vehicles in China, the problem of EV battery scrapping has become increasingly serious. Based on the internal and external environment of the waste EV battery recycling industry in China, this paper conducts a SWOT situation analysis and summarizes the main factors of Strengths, Weaknesses, Opportunities and Threats. In addition, an AHP method is employed to rank these factors by the weight coefficients, and based on this, a TOWS method is adopted to make development strategies for waste EV battery recycling in China. These can be summarized by five aspects: laws, economics, system constructions, technology and public education. Because the recycling of waste EV batteries has not yet been industrialized and the recycling network has not yet been established in China, it is necessary to propose development strategies for decision makers.
Along with the changes and development of the industrialization of EV battery recycling, the main factors in SWOT analysis may be updated and replaced, and the development strategies should adjust accordingly. In general, this paper combines the SWOT method for situation analysis, the AHP method for factors ranking, and TOWS method for strategy-making, which is a systematic and flexible approach structure. The research process in this article can be further extended to WEEE, waste EV and waste portable battery recycling fields.

6 Zusammenfassung

Mit dem Boom der Elektromobilität nimmt in China auch die Zahl der Antriebsbatterien zu, was die Behandlung der ausgedienten Batterien aufgrund des Entsorgungsdrucks durch potenzielle Umweltgefahren und die Recyclingforderungen zur Wiedergewinnung wertvoller Materialien zu einer zweifachen Herausforderung werden lässt. Bisher findet in China jedoch kein Batterierecycling auf industriellem Level statt und es konnte kein Recyclingnetzwerk etabliert werden. In diesem Beitrag wird eine SWOT Analyse durchgeführt, um die aktuelle Situation des Batterierecylings in China zusammenzufassen und die Hauptfaktoren der vier Aspekte (Stärken, Schwächen, Chancen und Bedrohungen) aufzuzeigen. Zur Gewichtung und Identifizierung der Schlüsselfaktoren in der Entwicklung einer Batterierecyclingindustrie wird anschließend ein analytischer Hierarchieprozess (AHP) durchgeführt. Basierend auf diesen Schlüsselfaktoren werden abschließend mittels der TOWS Methode Strategien entwickelt, die die fünf Aspekte Gesetze, Wirtschaft, Systemkonstruktion, Technologie und öffentliche Aufklärung beinhalten. Diese auf der tatsächlichen Situation des Batterierecycling basierenden sowie mittels quantitativer und qualitativer Methoden entwickelten Strategien können zur Förderung eines Batterierecyclingsystems in China genutzt werden.

Acknowledgements. The authors express their sincerest thanks to the National Natural Science Foundation of China for financing this research within the program" Fundamental Research on Catalytic Gasification of Automobile Shredder Residues (ASR): Mechanism and Its Recovery" under the Grant No. 51675343.

7 References

[1] China Association of Automobile Manufacturers. http://www.caam.org.cn/
[2] ResearchInChina. http://www.researchinchina.com/
[3] New Energy Automotive News Ev. http://www.sohu.com/a/58091045_372664
[4] D1EV. https://www.d1ev.com/news/shuju/48831
[5] D1EV Research Institute. Global New Energy Vehicle Industry Development Report (2017). Technical report, D1EV

[6] How long is the EV battery's life? http://www.sohu.com/a/76155495_377286
[7] D1EV. https://www.d1ev.com/kol/54717
[8] Niedzicki, L., Kasprzyk, M., Zukowska, G. et al. (2009). New conductive salts as potential lithium battery electrolytes tested in pc and gel-pc system. Gastroenterology, 144(5), S-314-S-314.
[9] Lupi, C., Pasquali, M., & Dell'Era, A. (2005). Nickel and cobalt recycling from lithium-ion batteries by electrochemical processes. Waste Management, 25(2), 215-220. doi:10.1016/j. wasman.2004.12.012
[10] Ministry of Industry and Information Technology of the People's Republic of China. http://www.gov.cn/xinwen/2018-02/26/content_5268875.htm
[11] National Business Daily. http://auto.163.com/17/0707/08/CONRI4D8000884N3.html
[12] Srivastava, P. K., Kulshreshtha, K., Mohanty, C. S.et al. (2005). Stakeholder-based SWOT analysis for successful municipal solid waste management in Lucknow, India. Waste Management, 25(5), 531-7. doi:10.1016/j.wasman.2004.08.010
[13] Zotos, G., Karagiannidis, A., Zampetoglou, S. et al. (2009). Developing a holistic strategy for integrated waste management within municipal planning: challenges, policies, solutions and perspectives for hellenic municipalities in the zero-waste, low-cost direction. Waste Management, 29(5), 1686-1692. doi:10.1016/j.wasman.2008.11.016
[14] Pariatamby, A., & Victor, D. (2013). Policy trends of e-waste management in Asia. Journal of Material Cycles & Waste Management, 15(4), 411-419. doi: 10.1007/s10163-013-0136-7
[15] Yuan, H. (2013). A swot analysis of successful construction waste management. Journal of Cleaner Production, 39(5), 1-8. doi: 10.1016/j.jclepro.2012.08.016
[16] Shojaei, M., Abbaszade, S., & Somayeh Aghaei, S. (2013). Using analytical network process (ANP) method to prioritize strategies resulted from SWOT matrix case study: Neda Samak Ashena Company. Interdisciplinary Journal of Contemporary Research in Business, 4(9), p603
[17] Shahabi, R. S., Basiri, M. H., Kahag, M. R., & Zonouzi, S. A. (2014). An ANP–SWOT approach for interdependency analysis and prioritizing the iran′s steel scrap industry strategies. Resources Policy, 42(42), 18-26.doi: 10.1016/j.resourpol.2014.07.001
[18] Saaty, T. L. (2001). Analytic hierarchy process. 109-121.doi: 10.1007/1-4020-0611-X_31
[19] Kangas, J., Pesonen, M., Kurttila, M., & Kajanus, M. (2001). A' WOT : Integrating the AHP with SWOT Analysis. Isahp, 189–198. doi:10.1007/978-0-387-76813-7
[20] Wang, J., & Chen, M. (2012). Management status of end-of-life vehicles and development strategies of used automotive electronic control components recycling industry in china. Waste Manag Res, 30(11), 1198-207.doi: 10.1177/0734242X12453976
[21] Zhang, H., & Chen, M. (2013). Research on the recycling industry development model for typical exterior plastic components of end-of-life passenger vehicle based on the swot method. Waste Manag, 33(11), 2341-2353. doi:10.1016/j.wasman.2013.07.004
[22] Weihrich, & Heinz. (2010). Management: a global and entrepreneurial perspective/13th ed. Economic Science Press.
[23] Weihrich, H. (1982). The tows matrix—a tool for situational analysis. Long Range Planning, 15(2), 54-66. doi:10.1016/0024-6301(82)90120-0
[24] Hitt, M. A., Ireland, R. D., & Hoskisson, R. E. (2013). Strategic management: competitiveness & globalization. South-Western Cengage Learning
[25] Gaines, L., Sullivan, J., & Burnham, A.(2011). Life-cycle analysis for lithium-ion battery production and recycling. Argonne National Laboratory
[26] Dunn, J. B., Gaines, L., Kelly, J. C., & Gallagher, K. G. (2010). Life cycle analysis summary for automotive lithium-ion battery production and recycling. doi:10.1007/978-3-319-48768-7_11
[27] Amarakoon, S., Smith, J., & Segal, B. (2013). Application of life-cycle assessment to Nano scale technology: lithium-ion batteries for electric vehicles. Evaluation. No. EPA 744-R-12-001.