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Recycling-Based Reduction of Energy Consumption and Carbon Emission of China's Electric Vehicles: Overview and Policy Analysis

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Abstract

Electric vehicles maintain the fastest development in China and undertake the responsibility of optimizing energy consumption and carbon emission in the transportation field. However, from the entire life cycle point of view, although electric vehicles have a certain degree of energy consumption and carbon emission reduction in the use phase, they cause extra energy consumption and carbon emission in the manufacturing phase, which weakens the due environmental benefits to some extent. The recycling of electric vehicles can effectively address the issue and indirectly reduce the energy consumption and carbon emission in the manufacturing phase. China is setting up the recycling system and strengthening regulation force to achieve proper energy consumption and carbon emission reduction benefits of electric vehicles. Under the current electric vehicle recycling technologies, China can reduce about 34% of carbon emission in electric vehicle manufacturing phase. Traction battery recycling is even more important. Taking NiCoMn lithium-ion battery as an example, about 40% of carbon emission in manufacturing phase can be reduced by adopting appropriate recycling technology. With the rapid development of battery recycling technology, the proportion will continue to rise. If China would like to obtain environmental benefits sufficiently, recycling enterprises should be encouraged to adopt advanced recycling technology and the government should adopt more strict supervision measures. China has followed the examples of Europe and the U.S. to set up the extended producer responsibility recycling system. Due to late start of China, the benefits have not been reflected yet.

Introduction

As the country with world's largest auto market, China's automobile production and sales volume have exceeded over 25% of the global level [1]. Meanwhile, the new energy vehicle industry in China is also growing fast. Taking Electric Vehicle (EV) as an example, the production and sales of EVs in China has maintained annual growth rate of over 100% from 2014 to 2016, and the annual growth rate has even reached 420% in 2015 [2]. This situation brings new opportunities and challenges for China's automotive manufacturing. In fact, energy consumption and carbon emission of EV manufacturing are much higher than those of traditional vehicles [3], and the difference may even exceed 60% [4]. As the share of EVs in China automotive market is becoming larger, it may influence the total energy consumption and carbon emission of automotive industry, and even possibly offset the energy and carbon emission reduced in the use phase of EV.

The issue of energy consumption and carbon emission reduction is extremely pressing for China as a large carbon emission country. Since 2013, carbon emission in China has reached 90 tons, accounting for over 25% of the global carbon emission [5] and the proportion is still rising. Therefore, Chinese government made a commitment in the Nationally Determined Contributions (NDC) in 2015 that China would reach the peak value of carbon emission before 2030 and reduce 60% - 65% units of GDP carbon emission compared with it in 2005 [6]. In this context, the promotion of EVs has been deemed as a significant measure to fulfill the commitment. If the performance of EVs in energy consumption and carbon emission is unsatisfactory, it may affect the holistic carbon emission reduction target of China.

Based on the conditions mentioned above, reduction of energy consumption and carbon emission generated from EV manufacturing in China will become increasingly important. Besides adopting more advanced manufacturing technologies and optimized processes, reducing the consumption of raw materials through recycling is also an effective way, which can not only reduce the potential pollution of End-of-Life Vehicles (ELVs) on environment, but also apply most of the recycled materials to new vehicle manufacturing. Due to the technologies and materials used for traction battery manufacturing, recycling will become a puzzling environmental issue and a great opportunity for energy consumption and carbon emission reduction.

This paper aims to systematically summarize the EV recycling in China. The evaluation of energy consumption and carbon emission reduction through EV recycling is carried out, together with the analysis on recycling technology and relevant policies. In addition, this paper analyzes the effectiveness of regulations in China in comparison with those worldwide. Finally, since a large number of EVs in China have not been recycled properly, this paper predicts and analyzes the possible situations of future EV recycling in China under the premise of adequate implementation of regulations.

Analysis of EV Recycling Technology

An EV consists of body, chassis, powertrain (electric motor etc.), transmission system, battery and tires [7]. According to the dismantling process, the battery and tire will be disassembled in the initial stage and recycled by other recycling institutes. The rest will be recycled in accordance with the vehicle recycling process similar to traditional vehicles [8]. Therefore, this paper will separately introduce the vehicle recycling and battery recycling. Tire recycling will not be discussed in detail due to the relatively small amount.

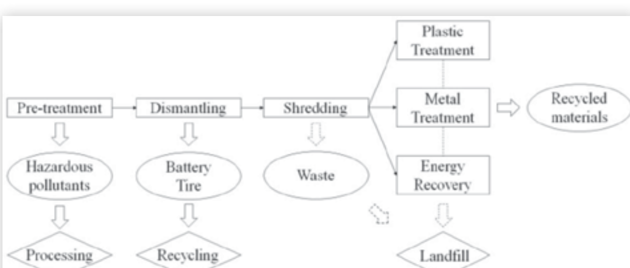
Vehicle Recycling Technology

The vehicle recycling technology is mature in developed countries. Taking the most advanced European vehicle recycling technology as an example, it includes anti-pollution pre-treatment, dismantling, shredding and after treatment process. The shredding after treatment process includes metal treatment, plastic treatment and energy recovery [8]. The complete recycling process is indicated in Figure 1.

Pre-treatment aims to remove the hazardous pollutants that may cause large negative impacts on environment, such as acid fluids in vehicles. Some parts that may cause negative impacts on subsequent recycling process should also be removed, such as the airbag. About 3% of the total weight will be reduced in this step [9].

Dismantling is the basic step of vehicle recycling. Recycling enterprises dismantle the entire vehicle and recover several components for sale such as the transmission, while the rest will enter the next step. At the same time, some other high value components that cannot be recovered easily will be sold to other professional institutions. For example, traction batteries in EVs are generally lithium-ion batteries with relatively high value, which are unable to be recycled through ordinary technologies. Therefore, professional battery recycling enterprises will purchase and recycle them. To ensure the efficiency and accuracy, most of the dismantling work is completed manually, while some hard works have to be done through machines [10].

FIGURE 1 Vehicle recycling flow chart [8]



Shredding is the transitional step of vehicle recycling. Owing to dozens of different material types spreading in different components, it is difficult to separate one from another directly. Therefore, recycling enterprises will reduce them in size through shredding, which can make post-shredding treatment more effective [11]. The relatively advanced shredding technology is operated through dedicated equipment, which enables to initially separate the metals such as iron and copper to lower the cost of the subsequent process [12].

Most of the advanced recycling technologies are applied in post-shredding treatment, including metal treatment, plastic treatment and energy recovery. Metal treatment refers to the separation of different metals according to their physical or chemical properties. The approaches include scan-based selection through different volume of metal blocks, gravity separation through different densities of metals, and magnetic separation through different magnetic properties of metals [8]. In fact, the weight of ferrous metals accounts for more than 70% of separated products and above 95% of separation efficiency can be reached through these approaches. Similar treatments can be adopted to process some nonferrous metals such as copper and aluminum, which feature low separation cost and high value [13]. More than 60% of the post-shredding materials are treated during metal treatment, which is the most primary step during vehicle recycling [14].

High level technology is required for plastic treatment [15], and it is generally conducted after metal treatment. The vehicle plastics mainly include polypropylene (PP), polyvinyl chloride (PVC) and acrylonitrile-butadiene-styrene (ABS), accounting for more than 60% of all post-shredding plastics [16]. In order to reduce cost, the treatments of these three kinds of plastics are based on their physical and chemical properties, including density, stiffness and malleability, which can help effectively separate them from each other [17]. However, the recycled plastics cannot be directly used like virgin materials and further treatments are necessary. Although plastics are important materials, they may hinder the follow-up recycling process if treated inappropriately. For example, PP plastic will become wax after being heated and PVC plastic will contaminate the pyrolysis gas of chloromethane [12].

Energy recovery refers to taking the remaining separated products that can be used as fuels, not simply processing as landfill [12]. Since most of the rest cannot be directly combusted and some may generate noxious gas during combustion, the requirements for separation technology are quite higher.

In China, the vehicle recycling industry is in a relatively primary stage and the development of technology is restricted to some extent. At present, the separation and recycling of different metals can only be achieved by several leading enterprises. Most of the vehicle recycling enterprises can merely separate the steel and iron scraps from ELVs. There is only a few enterprises that can realize comprehensive recycling technology such as plastic recycling in developed countries [18].

Traction Battery Recycling Technology

With the development of EVs, traction battery industry is booming in recent years, as well as the recycling technologies. According to the current traction battery market and future development plan in China, NiCoMn (NMC) lithium-ion battery will become the major traction battery [2]. Taking NMC battery recycling as an example, the mainstream recycling technologies include pyrometallurgical process and hydrometallurgical process. The hydrometallurgical recycling technology has more development potentials. In this study, these two technologies will be discussed respectively.

Pyrometallurgical recycling technology refers to recycling through metal melting, which consists of smelting, casting and sintering etc. The whole process includes pre-treatment, smelting and casting, electrolysis, subsiding and sintering [19], as indicated in Figure 2.

The key process is smelting and casting, which acquires metals such as nickel, cobalt and manganese by their different melting points. Finally, $Li(Ni_xCo_yMn_{1-x-y})O_2$ can be obtained by sintering with lithium carbonate in the subsequent process. Pyrometallurgical recycling technology is relatively simple, and has relatively low requirements for equipment. However, it consumes massive energy, which will indirectly result in huge carbon emission.

Hydrometallurgical recycling technology is optimized by Retriev Technologies (once named as Toxico). The whole process includes pre-treatment, soak, edulcoration and sintering [20], as indicated in Figure 3.

Pre-treatment mainly refers to squashing the batteries and screening the waste. Soak refers to putting the residual into sodium hydroxide solution to remove impurities such as aluminum. Edulcoration can be conducted via acid liquor and oxidation to eliminate the residual impurities. Finally, lithium carbonate is added in sintering to acquire the ternary lithium materials. Hydrometallurgical recycling technology consumes much less energy than pyrometallurgical recycling technology, but it will consume many more materials such as acid-base solution. Besides, aluminum cannot be obtained due to the soak process, which causes some loss. However, since the efficiency, cost and development prospect of hydrometallurgical recycling technology is higher than those of pyrometallurgical recycling technology, the mainstream lithium-ion battery recycling enterprises in China mainly adopt hydrometallurgical recycling technology at present, which is more likely to become the future mainstream technology.

FIGURE 2 Battery recycling by pyrometallurgical process flow chart [19]

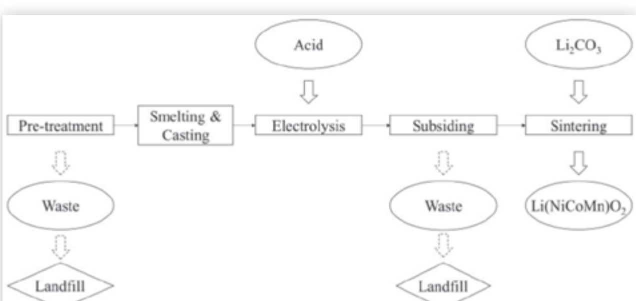
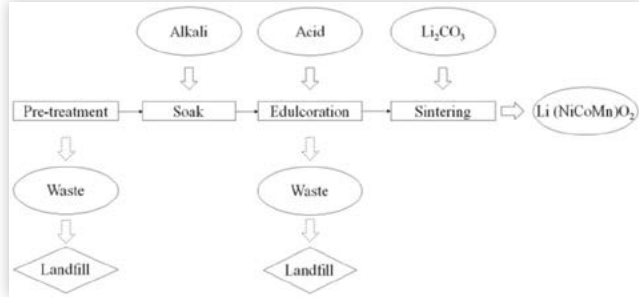


FIGURE 3 Battery recycling by hydrometallurgical process flow chart [20]



Other Recycling Technologies

Other recycling technologies include the recycling of components such as tires and electronic parts. Since the electronic parts account for only a few of the total weight, this section will mainly introduce the tire recycling technology.

At present, tire recycling technology is mature worldwide. Mainstream enterprises in China adopt the dynamic desulfurization technology, one of the globally recognized technologies. The whole process include shredding, grinding, dynamic desulfuration and remodeling, and butadiene styrene rubber will be obtained ultimately [21]. The core treatment is dynamic desulfuration, which consists of adding active and soft agent, and putting the ground tire waste into dynamic desulfuration tank under a certain temperature and pressure. The desulfurized rubber may be obtained after a certain time of churning. In general, due to the relatively smaller weight of tires, the reduction of energy consumption and carbon emission of tire recycling is only a little. The significance of tire recycling mainly lies in rubber resource recovery and its relevant economic benefits.

Comprehensive Analysis of Recycling Technologies

Overall description and contrastive analysis between different parts and their recycling technologies are indicated in Table 1.

In general, the recycling technologies of vehicle, battery and other parts are quite different. After many years of development, vehicle recycling technology has been quite mature, but it remains in initial stage and have due benefits of energy consumption and carbon emission reduction. For example, an end-of-life EV recycled can reduce about 32.1 GJ energy

TABLE 1 Comprehensive contrast between recycling technologies of different parts

	Vehicle	Battery	Others
Maturity	High	Low	High
Technical impediment	Low	High	Low
Efficiency	High	Normal	High
Environmental benefits	Normal	High	Low
Development potential	Low	High	Low

consumption and 5.1 t CO_2eq emission [22]. On the other hand, the development of battery recycling is inadequate and different technology roadmaps remain to be selected by Chinese enterprises. Due to large resource and energy consumption in battery manufacturing, battery recycling has great development potential. In addition, the recycling technologies for others represent the recycling of tires, electronic parts and so on. Due to the small proportion of these parts in weight, they have relatively small effect on environmental benefits when considering the entire EV. Take tire recycling as an example, the relevant reduction of energy consumption and carbon emission only accounts for about 2% of the total reduction of an entire EV recycling [22].

Analysis of Studies on Reduction of Energy Consumption and Carbon Emission

The Energy Consumption and Carbon Emission of EV Manufacturing Phase in China

Because of rapid development of EVs, many scholars have conducted analysis of full life cycle of EVs or just EV manufacturing, as indicated in Table 2.

Globally, different vehicles with different curb weights, which refer to the weight of manufactured vehicles, are studied based on regional preferences. Since the energy structure, manufacturing technology and material processing technology are quite different in various countries and regions, energy consumption and carbon emission will have large regional disparities in EV manufacturing phase. For example, in the developed areas like Europe and the U.S., due to the advanced equipment and relatively large proportion of renewable energy in energy structure, the energy consumption and carbon emission of manufacturing per ton of EV are remarkably lower than those of other countries. In China, energy consumption and carbon emission are higher than the world advanced level due to relevant impediments such as technical conditions. In fact, carbon emission of manufacturing per ton of EV in China is about 60% higher than that in the U.S.

Therefore, if China would like to benefit from EVs to achieve the carbon emission reduction commitment by 2030, the extra environmental impacts brought by EV manufacturing must be considered. It includes extra energy consumption and carbon emission brought by manufacturing technologies, high-emission factors brought by coal-based energy structure and extra consumption brought by material processing technologies. However, EV recycling can largely reduce raw material consumption, namely, reducing the energy consumption and relevant carbon emission, and has enormous potential environmental benefits.

Reduction of Energy Consumption and Carbon Emission by Recycling

EV recycling remains a relatively new issue, and systematic studies on the reduction of energy consumption and carbon emission are few at present. Many scholars take the separation

TABLE 2 Energy consumption and carbon emission in EV manufacturing phase

Resources	[3]	[23]	[7]	[24]	[4]
Region	Europe	Australia	U.S.	Greece	China
Curb weight (t)	~1.9	~1.1	~1.4	~1.1	~1.7
Battery specification	Li-ion (NMC)	Li-ion	Li-ion (NMC)	Li-ion	Li-ion (NMC)
Battery capacity (kWh)	24	/	28	16	28
Energy consumption (GJ)	/	/	~83	/	~92
GHG emission (t-CO_2eq)	~14.7	~11.0	~8.6	~4.3	~15.0

TABLE 3 Reduction of Energy consumption and carbon emission of EV recycling

Resources	[8]	[7]	[18]	[22]
Region	Europe	U.S.	China	China
Object	Vehicle	Battery	Vehicle	Both
Weight (t)	~1.5	~0.2	~1.1	~1.9
Battery specification	/	Li-ion ($LiMnO_2$)	/	Li-ion (NMC)
Battery capacity (kWh)	/	28	/	28
Reduction of energy consumption (GJ)	/	~ – 9.2	/	~ – 32.1
Reduction of GHG emission (t-CO_2eq)	~ – 1.9	/	~ – 3.1	~ – 5.1

of vehicle recycling and traction battery recycling into consideration. Relevant studies and results of vehicle recycling and battery recycling are listed respectively in Table 3.

As shown by the table, although recycling phase causes energy consumption and carbon emission, the recycled scraps can be recovered and used instead of virgin materials in the manufacturing phase and significantly reduce its environmental impact. In China, if one 1.9 t end-of-life EV is completely recycled and the recovered materials are used for manufacturing, it can help reduce about 32.1 MJ energy consumption and 5.1 t-CO_2eq emission, which is about 34% of the total energy consumption and carbon emission of a new 1.9 t EV using virgin materials in the manufacturing phase [22]. Considering the traction battery recycling individually, the recovered materials can help reduce about 40% of energy consumption and carbon emission of the same battery using virgin materials in the manufacturing phase [22]. It can address the issue of extra energy consumption and carbon emission caused by EV manufacturing to some extent to assist China to achieve the commitment by 2030.

Analysis of Relevant Regulations in Various Countries

If China would like to realize the maximum benefits, it should adopt or develop the most suitable recycling technology and formulate relevant polies to ensure the sound development of recycling industry. Taking lead-acid battery as an example, the recycling technology is very mature and enables to recycle more than 99% of metallic lead under the circumstance of no environmental pollution. At the same time, if the wasted lead-acid batteries are not properly recycled, they will pose extremely severe heavy metal pollution on the environment. However, due to the lack of enforced regulation of the industry, illegal recycling enterprises have opportunities to adopt the recycling technologies that do not meet the standards. For example, the cancellation amount of ELVs in China in 2012 was about 4.5 million, while the registered recycling amount was only 1.1 million, meaning that about two thirds of the ELVs were treated illegally [25]. According to the standards of recycling process, illegal recycling process tends to only obtain metal scraps for sale and landfill the other parts which may contain pollutants [26]. This situation indicates tremendous hazard on the environment. In this study, relevant vehicle recycling policies in Europe, America, Japan and China are compared.

Europe

Europe has begun to implement 2000/53/EC regulations since 2000. It requires all the member states of the European Union (EU) to realize the 85% reuse and recovery rate by weight for all ELVs by 2006, while the reuse and recycling rate should reach 80% of each vehicle by weight. The levels have been raised to 95% and 85% by 2015, meaning that over 95% of the ELVs by weight should be reused and recovered, while the reuse and recycling rate should reach 85% of each vehicle by weight [27]. Manufacturers need to assume the cost of collecting, processing and recycling systems of ELVs, while owners do not need to bear any cost as stipulated. Meanwhile, government should provide funds for all or most of recycling infrastructures set up by individuals. In terms of supervision, the EU member states must set up ELV registration and write-off systems. Only the recycling institutes that meet the standards can offer write-off certifications. All the vehicles will have a write-off time limit according to the registration data. If the vehicles are not written off within the time limit, manufacturers will be penalized or even be deprived of operation qualification.

U.S.

The U.S. has realized the recycling rate of more than 95% and recovery rate of 80%, meaning that about 80% of the vehicle by weight can be recovered to provide components for reuse or just recycled materials [28]. In fact, the reason why the EU and Japan are eager to establish stringent vehicle recycling mechanism lies in scarcity of landfills, while vehicle recycling in the U.S. is partly driven by the market. Recycling enterprises try to make profits by expanding capacity and improving technology. Due to the possible hazardous pollutant landfill extremely concerned by the public and the government [28], it may affect the social image of vehicle manufacturers. Therefore, they tend to invest more in developing more efficient recycling technologies.

Japan

The social characteristics of Japan are greatly different from those of the Europe and the U.S. Japan promote large automobile groups to take the responsibility of recycling and has realized the recycling rate of more than 95%, which is mainly driven by the supervision power of social organizations [29]. Japanese government passed the ELV Recycling Law in 2002, and officially put it into operation in 2005 [30]. The responsibilities of manufacturers are clearly defined in the law and recycling costs that might be taken by consumers are restricted, as well as the qualification verification of relevant recycling enterprises. The law does not only standardize the original out-of-order vehicle recycling market, but also promote the recycling rate of ELVs. Meanwhile, many Japanese non-government agencies supervise each role in the recycling chain and have great impacts among consumers. They play positive roles in promoting all parties to fulfill their obligations relying on the public force.

China

Since the promulgation of Administrative Measures on ELV Recycling (No.307) by the State Council in 2001, Chinese government has introduced a series of vehicle recycling regulations, including recycling technology and recycling responsibility, which constitute the lawful vehicle recycling systems. However, due to late start of China automotive industry, China has not yet formed a set of systematic laws and regulations like the EU, the U.S. and Japan, and vehicle recycling is still disordered in some areas [31]. In terms of EVs, Chinese government has made requirements on traction battery recycling and referred to the issue of traction battery recycling for the first time in the Energy Efficient and New Energy Vehicle Industry Development Plan in July 2012, which provided a brief restriction on battery recycling technology and markets [32]. After that, a series of regulations such as Specifications for Vehicle Battery Industry, Policies on EV Battery Recycling Technologies, etc., have been issued, which basically standardize the traction battery recycling technology. Furthermore, the Implementation Plan on Extended Producer Responsibility System passed in early 2017 emphasizes the responsibilities of all traction battery recycling participants.

On the other hand, Chinese government has already started the management on hazardous materials from EVs, which requires the manufacturers to keep the hazardous pollutants under control [33]. This regulation is similar to the 2000/53/EC regulation in Europe and aiming to restrict the usage of lead, cadmium, hexavalent chromium, mercury, polybrominated biphenyls and polybrominated diphenyl ether in passenger vehicles.

Following the examples of Europe, the U.S. and Japan, China has established a set of complete EV recycling system. Although it is not systematic enough, it has possessed strong feasibility and supervision measures, ensuring the legal recycling of future EVs in China, and aiming to obtain the required environmental benefits of EVs properly.

Contrast Analysis of Policies and Regulations

Table 4 presents the general difference between regulations in different regions, including the implement date, scope, supervision method and effect.

In general, various countries have their own measures to realize appropriate vehicle recycling: Europe relies on government supervision, the U.S. depends on market force and Japan relies on non-governmental organizations. With sufficient reference to the regulations of other countries, China formulates the manufacturer oriented recycling system in line with China's own market features. The supervision method is more similar to that of Europe. Chinese government is in charge of releasing recycling qualification licenses for manufacturers and requires them to restrict the usage of hazardous materials and take responsibilities of recycling according to law. Nevertheless, due to the short implementation time, the effects have not been reflected yet.

TABLE 4 Contrast between vehicle recycling regulations in various countries

	Europe	U.S.	Japan	China
Implement time	2000	/	2002	2001 & 2015
Scope	Vehicle	Vehicle & battery	Vehicle	Vehicle & battery
Method	Official power	Market	Unofficial power	Official power
Effect	95% reuse and recovery rate	95% recycling rate & 80% recovery rate	95% recycling rate	Only a few ELVs recycled properly

Discussion on Future EV Recycling in China

According to the analysis of EV recycling technologies and regulations in various countries mentioned above, the development of future EV recycling in China should be focused on four following aspects:

1. Technical standards should be defined clearly. As mentioned above, China has paid attention to vehicle recycling since 2001, and the technologies allowed for vehicle recycling have been defined through a series of regulations. However, only a few regulations are focused on the traction battery recycling so far, which are not clear enough to guide the development of EV recycling industry. For instance, the Ministry of Industry and Information Technology has already issued the regulation named Recycling of Traction Battery Used in Electric Vehicle - Dismantling Specification in May 2017 [34]. This regulation is focused on the dismantling stage, but does not involve the technologies or environmental impacts of major processes during battery recycling.
2. Strict supervision should be carried out with the regulations. Although Chinese government has already set up a series of regulations on recycling responsibilities and hazardous materials management, the lack of supervision restricts the influence significantly. As mentioned above, in the last decade, plenty of illegal vehicle recycling enterprises existed in China. Most of them adopted illegal recycling technology and caused huge pollution and waste. This kind of situation must not repeat in the field of EV and battery recycling. The government should pay much more attention to the law enforcement and consider use the power of market or third party institutions, just the U.S. or Japan does.
3. Continue to refine the responsibilities of each participants throughout the EV recycling chain. Chinese government has already done a lot about the responsibility partition on EV recycling. At present, the EV manufacturers should take most of the responsibility, which is similar to the developed countries in Europe. There is no doubt that it is a good beginning, but is needs continuous improvements to adapt to the changeable EV industrial chain. For instance, most EV manufacturers in China do not produce traction batteries, they should establish the battery recycling system under the help of battery manufacturers. However, the responsibilities have not been defined clearly between EV manufacturers and battery manufacturers, which may cause supervision loopholes in the future.
4. Consider supporting leading enterprises which reach the standards by subsidies or tax cuts. Unlike the developed countries such as Japan, China is a large country with a complicated EV recycling industry, which makes it difficult to supervise each enterprise. Furthermore, China is a large country with long transportation distance for ELVs, which reduces the efficiency of vehicle

recycling. Regional recycling enterprises are necessary to improve this situation, even if they are smaller than other leading enterprises. Therefore, one method is to concentrate the management on several leading enterprises whose technologies meet the requirements, and encourage them to operate in different regions. In order to reach this target, government deposits on the batteries or tires collection and recycling fees may help.

In short, China is a large country with complicated EV recycling industry, which is quite different from the developed countries. The government cannot simply adopt all the methods taken by Europe, the U.S. or Japan, but some of the regulations are valuable in the field of technology and supervision.

Conclusion

This paper analyzes the technological development of EV recycling in China, the relevant benefits on energy consumption and carbon emission, and policies and regulations. It highlights the features and development directions of China in establishing EV recycling technologies and institutions by contrast with the developed countries such as Europe, the U.S. and Japan. Precisely speaking, according to the current EV recycling technologies, China can reduce about 34% of the energy consumption and carbon emission in EV manufacturing phase if completely recycled and all the recovered materials are used instead of virgin materials. Traction battery recycling has even larger benefits. Taking NMC lithium-ion battery as an example, about 40% of carbon emission in manufacturing phase can be reduced by complete recycling and recovery. With the rapid development of battery recycling technologies, the proportion will continue to rise. If China would like to obtain environmental benefits sufficiently, recycling enterprises should be dedicated to adopting the appropriate recycling technologies, while strict supervisions are necessary. China has already realized the significance and follows the examples of Europe and the U.S. to set up the extended producer responsibility recycling system. Due to late start of China, benefits have not been reflected yet.

Although the current situation in China has been reasonably analyzed, the factors such as technology, regulation and market stay in a stage of rapid changes due to the emerging of China's EV recycling industry and relevant analysis results may change accordingly. The subsequent studies must focus on the latest conditions to obtain more scientific results.

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Definitions/Abbreviations

ABS - Acrylonitrile-butadiene-styrene
ELV - End-of-life vehicle
EV - Electric vehicle
NMC - NiCoMn
PP - Polypropylene
PVC - Polyvinyl chloride

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