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End-of-life vehicle (ELV) recycling management: improving performance using an ISM approach

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Abstract: With booming of the automobile industry, China has become the country with increasing car ownership all over the world. However, the end-of-life vehicle (ELV) recycling industry is at infancy, and there is little systematic review on ELV recycling management, as well as low adoption amongst domestic automobile industry. This study presents a literature review and an interpretive structural modeling (ISM) approach is employed to identify the drivers towards Chinese ELV recycling business from government, recycling organizations and consumer's perspectives, so as to improve the sustainability of automobile supply chain by providing some strategic insights. The results derived from the ISM analysis manifest that regulations on auto-factory, disassembly technique, and value mining of recycling business are the essential ingredients. It is most effective and efficient to promote ELV recycling business by improving these attributes, also the driving and dependence power analysis are deemed to provide guidance on performance improvement of ELV recycling in the Chinese market.

Keywords: ELV recycling management; renewable resources; geographical discrepancy; driving and dependence power; interpretive structural model (ISM)

1 Introduction

The status quo of sever energy over-consumption and demand of environment-friendly economy motivates industries to perform green supply chain management and practices (Cai et al., 2018; Taticchi et al., 2015). With an increasing development of domestic automobile industry, China has been the nation with the most quantity in vehicles' production since 2009, leading to the flourish of the end-of-life vehicle (ELV) industry (Tang et al., 2018). Besides, since the vehicle consumption being the main source of exhaust emissions and energy exhaustion, green practices and sustainable management for automobile supply chain businesses are always studied as a research hotspot recently (Bulach et al., 2018; Phuc et al., 2016). To deal with the environmental effect, climate change, resource exhaustion and energy depletion, recyclable waste recycling has been regarded as crucial measures to simultaneously respond to the above-mentioned matters.

To improve the sustainable development of automobile industry, new energy vehicle (NEV) and hybrid electronic vehicles (HEV) are regarded as an alternative to resolve the mobility of people and cargos ecologically (Zhang and Bai, 2017). Techniques, influential factors and policies are studied to stimulate the development of eco-friendly auto-industry (Su et al., 2018). In addition, sustainable supply chain practices of the automobile industry also conduce to this objective, including sustainable material, design for sustainability, green production & assembly, and other sustainable supply chain activities (Govindan et al., 2016; Johnsen et al., 2017; Kirwan and Wood, 2012; Koplin et al., 2007; Lacasa et al., 2016; Luthra et al., 2017a; Mohanty and Shankar, 2017; Sonego et al., 2018; Tseng et al., 2013; Yang, S.S. et al., 2017).

In addition, the recycling operations are performed for ELVs to improve energy-saving and resource exhaustion, which has been widely applied in EOL ship and EOL aircraft (Ahmed et al., 2015; Cucchiella et al., 2016; Lu et al., 2014; Manzetti and Mariasiu, 2015; Sabaghi et al., 2015; Sawyer-Beaulieu and Tam, 2006). The philosophy of circular economy also motivates reuse, recovery and recycling operation for end-of-life vehicle (ELV) industry. However, due to the discrepant development in China, a vast majority of ELVs swarm to the black market in developing areas as second-hand vehicles (Hou et al., 2018; Zhou et al., 2016a). The lack of standardization of the Chinese market hinders the development of ELV recycling industry. Therefore, industrial organizations and academic institutions are trying to shift their eyes into this area, aiming at assisting the Chinese government to motivate ELV recycling business (Li et al., 2016). Recently, the warranty policy and extended 3R (Reuse, recovery and recycling) principles are regulated to stimulate auto factory being responsible for the normal operation, consumption and recycling of their products (Pan and Li, 2016; Zhou et al., 2018b).

There exist segmental researches on ELV recycling, for instance policy-making, operational performance, cost-benefit analysis, and recycling mechanism etc. (Chen et al., 2015; Cheng et al., 2012; Tang et al., 2018; Wang and Chen, 2013). Also, similar topics related to ELV recycling industry such as disassembly, crucial part re-manufacturing, material recycling and renewable resources etc. are studied to promote the circular recycling in domestic automobile industry (Bulach et al., 2018; Elwert et al., 2018; Fang et al., 2018; Yang, S. et al., 2017). However, to state-of-the-art, there is little systematic review on ELV recycling industry in Chinese market, when China has been the nation with the most car production and sales amount all over the world in recent ten years (Zhou et al., 2019). Even there are many studies on driving factors analysis on sustainable practices of vehicle supply chain, there is little management practice on ELV recycling industry.

The developed countries with a long history of automobiles show it maturity of end-of-life product recycling (Binnemans et al., 2013; Chen and Zhang, 2009). The ELV, regarding as a kind of recyclable resources in USA, has achieved the market-oriented operation due to the advanced recycling techniques and the perfect ELV recycling support system (Jawi et al., 2017). The awareness of limited resources and eco-friendly development in Japan stimulates automobile factories to recycle the vehicle product regulated by the national government, which aims at prolonging the usage lifespan of crucial auto-components (Che et al., 2011). To improve the efficiency of ELV recycling and sustainable development of the automobile industry, the recycling mechanism and disposal technology of EOL vehicles are exposed into the spotlight by Japanese scholars. The European Union tries to regulate and standardize the ELV recycling industry by implementing the deposit system and market access permission, which improves the recycling efficiency (Chen and Zhang, 2009; Simic and Dimitrijevic, 2013).

Compared with developed countries with vast majority of car ownership, the ELV recycling industry in developing countries such as China, India, and South Africa etc. is still at infancy (Zhou et al., 2016b). Due to multiple stakeholders and complex ingredients, it is of great difficulty to identify the crucial drivers influencing the development of ELV recycling industry.

Interpretive structural modelling (ISM) approach, proposed by Warfield in 1974, provides an effective way to probe into the various factors towards a complex system (Warfield, 2010). The ISM approach is interpretive in the sense that judgement of mutli groups enables to decompose a perplex system into a multi-level structual model. Also, it can improve management performance by identifying the driving factors (Diabat and Govindan, 2011; Ming et al., 2017). Chaple et al. (2018) adopted ISM approach to define the contextual relationship of lean practices, assisting managers to better understand the lean management implementation. To improve the performance of fresh fruit supply chain, Raut and Gardas (2018) applied the ISM method to identify the crucial barriers of sustainable transportation. ISM approach, as a systematic method, has proven to be an effective management tool to improve national management performance of sustainable supply chain for different industries. To promote green manfaucturing, the ISM approach is adopted to understand GM drivers and their interrelationships (Seth et al., 2018). Kumar and Dixit (2018) proposed a novel ISM-DEMATEL approach to identify the barriers of e-waste management, providing better understanding for performance improvement of the Indian e-waste management issues. The green implementation and sustainability philosophy has been focused by developing countries in terms of automobile manfaucturing industry (Zhou et al., 2018). To improve the green performance of auto component manfuacturing industry in India, an ISM qualitative analysis is used to study the factors influencing cleaner production by GSCM (Mathiyazhagan et al., 2013). To address the significance of knoledgement mangement for SSCM, Ming et al. (2017) adopted ISM approach to derive driving and dependence poers in SSCM within the context of knowledgement management. As reviewed above mentioned, an ISM approach shows great ability to better understand management practices in terms of SSCM issues.

To improve performance of the ELV recycling management, this study employed interpretive structural modelling (ISM) approach to analyze the interrelationships amongst the ingredient factors. The research questions highlighted in this paper are as follows: ① what is the status quo of ELV recycling industry? ② what are the interrelationships among the ingredient factors? ③ what are the driving and dependence powers to improve the performance of ELV recycling management?

To penetrate into the development situation and understand the status quo of Chinese EVL recycling industry, the literature review of ELV recycling is preformed, as well as specific operations conducted in Chinese market. To promote the development and flourish of ELV recycling industry, an interpretive structural modelling approach is employed and performed to portray the hierarchical interrelationships among a variety of ingredient factors, as well as the driving power analysis. The contributions of this study are as follows: ① a systematic literature review in terms of Chinese ELV recycling industry is presented; ② an ISM model is constructed to identify hierarchical interrelationships of highlighted factors; ③ the strategic countermeasures are suggested to improve ELV recycling management performance through driving and dependence power analysis. Furthermore, this study also contributes to the automobile supply chain management by providing theoretical insights of recycling business.

The reminder of the paper is organized as follows. Section 2 provides an overview of the theoretical and industrial background of ELV recycling management in China. Then, the ISM-based research methodology is presented in Section 3. Subsequently, the results and discussions are obtained and derived. Section 5 provides theoretical and managerial implifications in terms of ELV recycling management performance improvement. Conclusions are drawn in the final section.

2 Theoretical and industrial background

Faced with the resources-exhaustion situation and prevailing circular economy tendency, the ELV recycling, regarding as a hotspot in sustainable supply chain practice, has proven to be effective to improve the sustainability of the vehicle industry. In this section, the theoretical and industrial background of ELV recycling management is presented. The ELV recycling, regarded as a crucial sustainable business for sustainabile supply chain practice of vehicle industry, is motivated by sustainability demands. To probe into the driver of ELV recycling industry and better understand the Chinese ELV recycling market, the status quo of ELV recycling management practice is summarized from the industrial viewpoint.

2.1 Sustainable supply chain practices of automobile industry

The automobile industry shows a significant influence on the sustainable development of society and environment. Diabat and Govindan (2011) investigated the various drivers of green supply chain management using an interpretive structural model. Mathivathanan et al. (2018) studied the interrelationship and interactional influence among automobile sustainable practice from a multi-stakeholder perspective using the Decision-Making Trial and Evaluation Laboratory (DEMATEL) method. Ahmed et al. (2015) developed an extended fuzzy AHP method to evaluate the end-of-life vehicle management alternative, promoting the sustainability of ELV management. Deng et al. (2017) developed a logical relationship using questionnaire and simulation method, which helps local government to motivate products consumers' participation and recycling policy decision-making.

To achieve sustainability of the automobile industry, sustainable management and practice in vehicle supply chain are performed in recent publications (Tseng et al., 2015; Zhou et al., 2018a). Green management activities involving sustainable design, purchasing, logistics, assembly, material, equipment, crucial part re-manufacturing and end-of-life vehicle product recycling etc. (Govindan et al., 2016; Govindan et al., 2015; Luthra et al., 2017a; Mohanty and Shankar, 2017; Tseng et al., 2013). ELV recycling management, as an efficient solution, has proven to be beneficial to renewable resources utilization and sustainability improvement (Daniels et al., 2004; Zhou et al., 2018a).

2.2 Status of the ELV recycling management

To study ingrident factors of Chinese ELV recycling management, the status of industrial background of Chinese ELV recycling management is summarized in this section.

(1) ELV recycling operations

The full understanding of the ELV recycling process laid foundation for the ingredient factors analysis. To better understand drivers of ELV recycling industry, the prevailing ELV recycling procedure and crucial activities need to be investigated at first. The ELV recycling operations have experienced for several stages illustrated in Fig. 1 in Chinese market, involving in ELV owners, recycling organizations, dismantling plant, and specific reusing, recovery and recycling operations (Zhou et al., 2018a).

The end-of-life vehicle products or parts flow to recycling workshop, and the dismantlabiltiy evaluation is performed subjecting to multi criteria (Börjeson et al., 2000). The recyclable products will be delivered to the dismantling plant including brief disassembly and recycling (Andersson et al., 2017). Andersson et al. (2016) illustrated the status quo of scarce metals recycling in Swedish ELV industry by tracing the material flows, and results showed that the only a few of scarce metals are functionally recycled despite the overall recycling rate of Swedish ELVs being high. Ortego et al. (2018) developed an assessment method for ELV down-cycling using a SEAT Leon III model based on thermodynamic rarity.

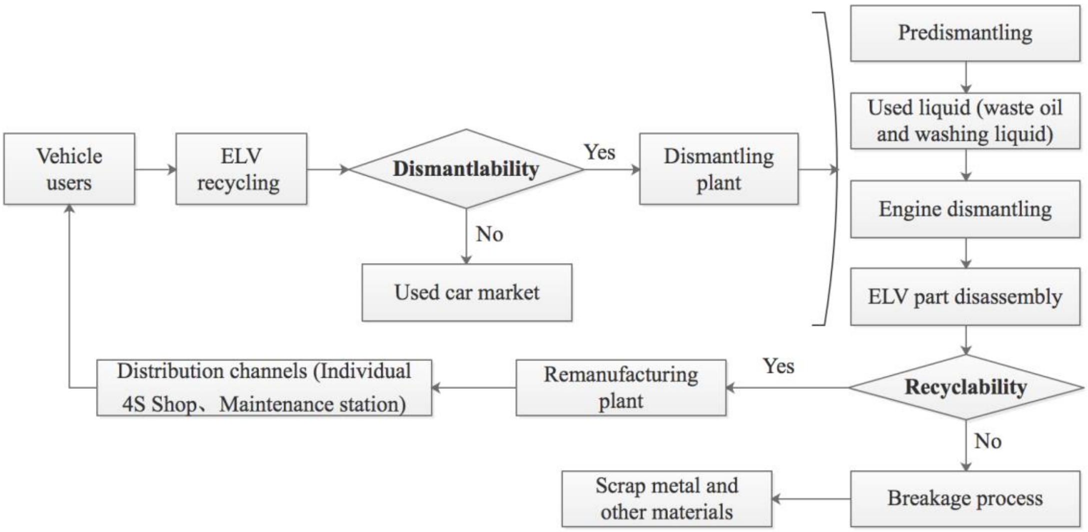

Fig. 1 ELV recycling operations in Chinese market

As the Fig. 1 illustrated, the ELVs are collected from individual consumers including car-users and used-owners due to the prevalence of used cars. Both of them are the providers of ELVs, and local governments would make some subsidies. Automobile manufacturing factories and renewable organizations are responsible for the ELV recycling. The disassembly operations lay foundations for following recycling oeprations: re-use, recovery, and re-manufacturing. Besides, whether the ELVs can be completely decomposed is of great of the recycling efficiency (Zhou et al., 2018). Those redundant parts which can be re-manufactured will flow to remanufacturing plant, and other useful parts can be processed in a sustainable way using material recycling or energy recovery. The re-manufacutring channel, as the most efficient way, has been regarded as a big triumph to improve sustainability for the Chinese automobile industry.

The development of ELV recycling industry is realized by the sustainable practice of the ELV recycling activities at each stage. The dismantling procedure, regarded as the most crucial stage, shows a significant influence on recycling efficiency, which is closely related to disassembly techniques. Wang et al. (2005) proposed a classification method, contributing to the recycling efficiency improvement by dividing ELV parts to three divisions (recycle directly, re-manufacturing and discard disposal). The system dynamics modeling method was applied to discover the dismantler's dilemma on the basis of the established simulation model, and results in Indian market showed that unregulated market contributed to lower dismantling capacity (Mohan and Amit, 2018).

To reflect the sustainability performance of ELV recycling, a sustainability index considering a multi-scale and multi-dimensions is proposed to depict the sustainability performance in the long term both economically and environmentally (Pan and Li, 2016). The ELV recycling routes optimization also needs to consider the sustainable performance. Sun et al. (2017) proposed a bi-level programming model to optimize the distribution center network of ELVs. To improve the recycling efficiency, the three-phase algorithm is proposed to optimize the two-echelon revers logistics network, and a novel hybrid heuristic method integrating Clarke-Wright savings with Non-dominated Sorting Genetic Algorithm-II is developed to reduce the environmental pollution (Wang et al., 2018).

The connection with other industries also may improve recycling efficiency. An industrial practice by Wong et al. (2018) indicated that the ELV waste in dismantling and shredding operations could be applied by the construction industry, which improves the utilization efficiency of the ELV recycling activities. In addition, the processing framework has built connection between the ELV recycling industry with the construction industry.

To improve the recycling efficiency, the advanced techniques and cost-effective tools are usually developed to deal with the EOL part disposal. The solid state shear milling (S^3M) technology is developed to improve the recycling efficiency of automotive shredder residue, which has proven to be a simple, cost-efficient, green and potential prevailing technique for non-structural EOL products (Yang, S. et al., 2017). Facing with the diversity of the multi-material auto products, Soo et al. (2017) has proposed a joint technology to reduce ELV recycling waste.

(2) Renewable resources distribution

The cost-effective ELV recycling patterns are reuse and recovery, especially for those reliability redundant crucial parts with high value (Zhou et al., 2016a). Besides, the re-manufacturing workshop also provides an alternative for sustainable recycling. However, all of these activities are the foundation of the proper dismantling, requiring advanced disassembly techniques and special equipment (Mohan and Amit, 2018).

In addition to perform re-use, recovery and re-manufacturing, recycling activities also assist the industry achieves to sustainability. The end-of-life products and parts can be recycled from both resource saving and environment protection points of view (Fang et al., 2018). Based on the ELV recycling operation procedures, the renewable resources are summarized and distributed following by recycling activities in Fig. 2. The recyclable metals such as iron, aluminum and platinum are main renewable resources, while other materials like plastic and scarce metals shows a low recycling rate (Andersson et al., 2017). With the advancement and development of disassembly technique and grinding technology, industrial factories try to improve recycling rate with multi kinds of recyclable metal.

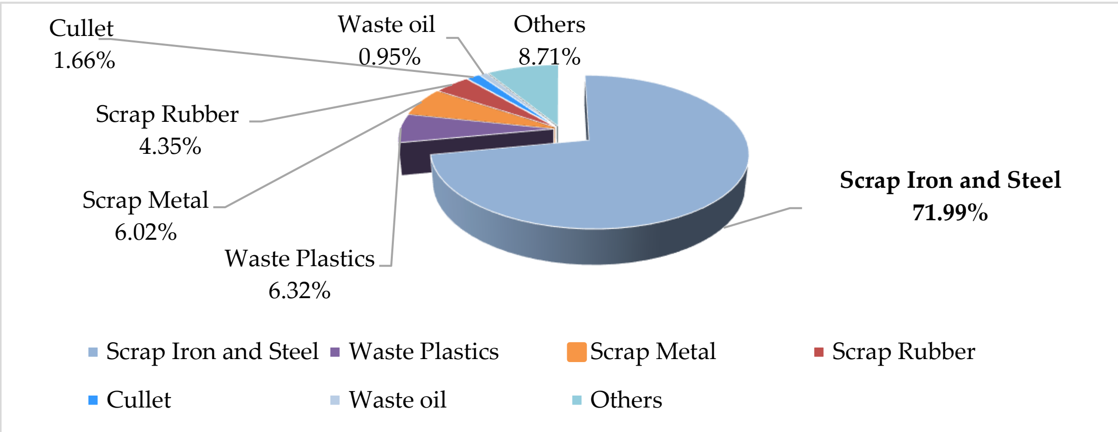

Fig. 2 Renewable resources of ELV recycling in China

As can be seen from the Fig. 2, the scrapped iron and steel are the main composition, and then follows the waste plastic. Due to the limit of the disassembly techniques, the utilization rate of steel and iron is not optimistic with lower efficiency comparing with developed nations (Miller et al., 2014). The increasing tendency of lightweight and moudable vehicle materials brought challenges for plastics recycling, leading to much more plastics landfilled

(Miller et al., 2014). The more advanced recycling techniques and equipment need to be developed to promote the utilization rate of renewable resources in Chinese ELV recycling industry.

(3) Regional discrepancy of ELV recycling

The unbalanced development of the automobile industry in China has led to the regional discrepancy of ELV recycling, as well as the car ownership and technique levels etc (Hu and Wen, 2017). The ELV recycling amount in three quarters is illustrated in Fig. 3, and we can see the dramatic gap between different regions.

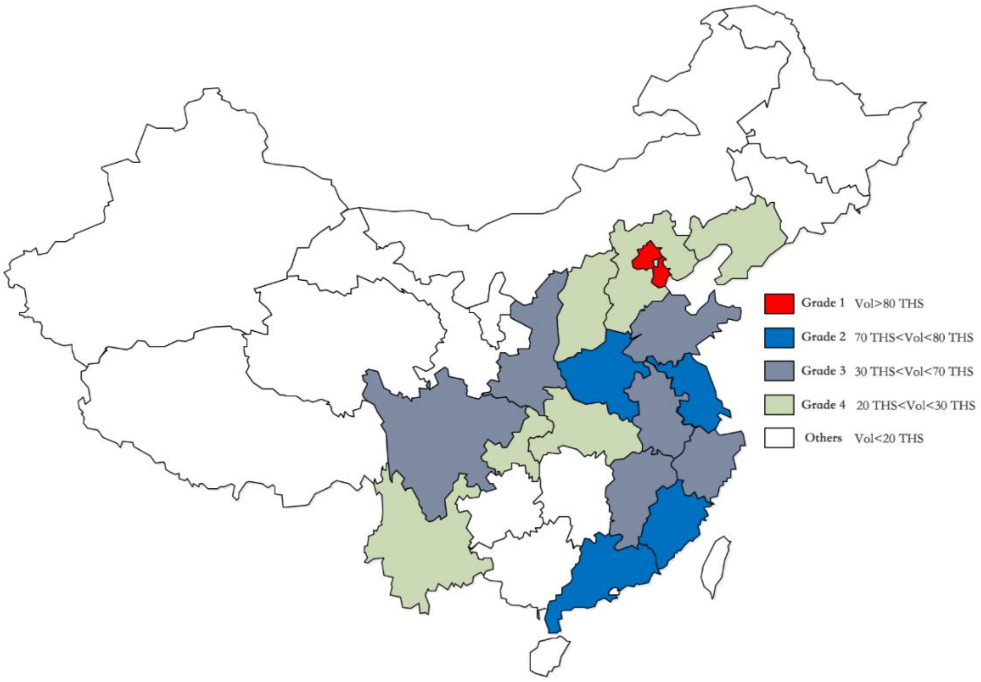

Fig. 3 ELV recycling amounts of different provinces in China

To reflect the heterogeneity of different regions in terms of ELV recycling, the regional gap is illustrauted in Fig. 3, and there are five groups based on the ELV recycling amount for Chinese provinces. Beijing and Tianjin have broken through 100 thousand, while Jiangxi, Qinghai and other remote areas have a low recovery rate of less than 2000. As can be seen in the Fig. 3, provinces whose EOL vehicles exceeds 20 thousand are marked, where are Bohai Bay Economic Zone, east-south of the China, and the economic belt of the Yangtze River. As can be seen, there exists a notable gap for Chinese ELV recycling industry in different regions (Wang and Chen, 2013).

(4) Policy and regulations

The policy support of the local government is indispensable for the sustainable development of ELV recycling industry. The policy-driven measures and eco-friendly requests are regulated to promote sustainable development in industrial practice (Xiao et al., 2018). Due to the discrepancy of business, market and regulatory atmosphere, policies and regulations in different regions are usually diverse (Sawyer-Beaulieu and Tam, 2006). The "producer responsibility principle (PRP)"-based legislations are usually employed in EU nations (Mazzanti and Zoboli, 2006), where some also adopted extended producer responsibility principle. xWang and Chen (2013) provided some strategies for the Chinese government about ELV recycling industry by comparing with developed countries. He concluded that Chinese government should focus on old-to-new replacement and extended producer responsibility (EPR) achievements. To turn the EPR and "3R principles" into realization. Tian and Chen (2014) argued that automobile industries should highlight designing for assembly in a sustainable way. A Staklberg game theory is performed to design a reward-penalty mechanism on ELV recycling (Tang et al., 2018).

ELV recycling efficiency is sensitive to the regulated policy. Simic and Dimitrijevic (2013) formulated a programming model for ELV recycling planning problem from the long run considering uncertain EU legislative context. To improve the robustness, when facing uncertainties, an interval-parameter two-stage stochastic full-finite programming method had been formulated to deal with ELV allocation management (Simic, 2016). A linear programming model was constructed to optimize steel scrap and alloying elements of ELV recycling through input-out analysis (Ohno et al., 2017). Yasuhiko studied the impact of ELV recycling law on the automobile recovery, technological innovation, material recycling and part reuse in Japanese market (Ogushi and Kandlikar, 2006).

2.3 Research goals

The practical gap between booming development of domestic automobile production and the infancy of ELV recycling requires that we need a deeper insightful understanding (Pan and Li, 2016). According to the ELV recycling procedure and management practice in China, the ELV recycling industry involves in auto-factories, renewable resource organizations, used-car consumers, ELV owner, and local governments, and it is much more difficult to identify the hierarchical interrelationships among massive ingredients. To better understand sustainable development of domestic vehicle industry and improve EVL recycling management performance, the ISM approach is employed to portray drivers and enablers from these multiple stakeholders (Wang and Chen, 2013). In addition, the ELV recycling business, as the sustainable practice, contributes to sustainability improvement of vehicle supply chain. Therefore, the ISM approach is concentrated to assist ELV recycling practitioners understand in greater depth the sustainable management performance of Chinese ELV recycling industry in following parts.

3 Solution methodology

To stimulate the development of ELV recycling industry and improve sustainability performance, a set of factors involving governments, industrial organizations and individual consumers is listed. And the ISM approach is employed to identify the driving power and dependence power through the ISM-based hierarchical portray and MICMAC analysis.

3.1 Factors listed from multi stakeholders

Through the ELV recycling operations, there are mainly three kinds of participants (government, industrial organizations and individual consumers) (Chen et al., 2015). In detail, auto-factories, renewable resource firms, auto-part factories, remanufacturing organizations, ELV owners, used-car consumers, social publics and local governments etc. To reveal the factors which may influence the development Chinese ELV recycling, we list and filter the ingredient factors through a comprehensive literature review from governmental, recycling organizational and individual perspectives illustrated in Table 1.

Table 1. Factors influencing the ELV recycling industry concerning multiple stakeholders

Stakeholder	Symbol	Ingredient factors listed and its description	Source
Government	C1	Recycling regulations for auto factories ("3R" principles: reuse, recovery and recycling): the implementation situation of the extened responsibility principle and the enthusiasm of auto factoriers on ELV recyclign business under current policies	(Chen et al., 2015; Sawyer-Beaulieu and Tam, 2006; Wong et al., 2018; Zhou et al., 2018a)
	C2	Recycling regulations for ELV recycling factories, including renewable resource organization and re-manufacturing firms etc.	(Ortego et al., 2018; Pan and Li, 2016; Sawyer-Beaulieu and Tam, 2006)
	C3	Recycling regulations and motivations for ELV owners, and the legislated policy motivated vehicl consumers to deliver ELVs to recycling plants	(Sawyer-Beaulieu and Tam, 2006)
	C4	Subsidy and motivations for used-car consumers	(Jawi et al., 2017; Wang and Chen, 2013)
	C5	Regulations and standardizations for the recycling and used-car market: the regulated policy for the application of recycled materials and parts etc.	(Sawyer-Beaulieu and Tam, 2006)
Industrial organization	C6	The eco-friendly consciousness and responsibility awareness of auto-factory, and the demand of cleaner production and sustainable practices	(Hou et al., 2018; Pan and Li, 2016)
	C7	Design and assembly for recyclability: whehter the auto parts and assembly are designed from sustainable viewpoint for dismantling and recycling	(Go et al., 2011; Mohan and Amit, 2018)
	C8	Recovery and utilization rate of renewable resources productio, including the technique matuation and the economic value of recycling activities	(Fang et al., 2018; Jody et al., 2011)
	C9	Re-use status of crucial auto parts and components, and the prevalence of the redundant or remanufactured parts	(Go et al., 2011; Jody et al., 2011; Li et al., 2016; Ogushi and Kandlikar, 2006)
	C10	Re-manufacturability of automobile parts: whether ELV parts can be processed by the remanaufacutring plants	(Andersson et al., 2016; Anthony and Cheung, 2017; Ogushi and Kandlikar, 2006)
	C11	Material recyclability of EOL auto products: the prevalence of material recycling	(Ahmed et al., 2015; Cucchiella et al., 2016)
	C12	Disassembly and recycling technique level: whether the auto parts can be completely dismantled	(Bellmann and Khare, 2000; Ortego et al., 2018)
Individual consumer	C13	Sustainable recycling awareness of ELV owners	(Pan and Li, 2016; Zhou et al., 2018a)
	C14	The acceptance degree of used-car consumers on reused parts and recovered auto products	(Andersson et al., 2017; Chen et al., 2015; Salvado et al., 2015; Zhou et al., 2018a)
	C15	Quality of economy of the recyclable parts and ELV recycling activity	(Mazzanti and Zoboli, 2006; Miller et al., 2014)
	C16	Sustainable recycling demands and consciousness of social publics	(Hu and Wen, 2017; Pan and Li, 2016)
	C17	Value of recyclable materials, and the prevalence of remanufacturing of auto parts	(Andersson et al., 2017; Anthony and Cheung, 2017; Miller et al., 2014; Sica et al., 2018)
	C18	Market recognition of the used-parts and recovery products	(Grieger, 2003; Zhou et al., 2016a)

The ELV recycling development is motivated by the increasing car ownership, sustainability requirements and governmental legislation. From the current status of Chinese ELV recycling management in the previous study (Wang and Chen, 2013), the involvements are mainly categorized to consumers, auto-makers and recycling & dismantling organizations. These three kinds of individuals contribute to the successful implementation from ELV recycling business to part re-utilization, leading to a circular economy. In addition, the involvement of local government plays a great role on recycling practice (Chen et al., 2015). In our research, we listed the specific drivers within the context of governments, industrial organizations and individual consumers in terms of ELV recycling industry. Detail ingredient factors related to the three stakeholders are summarized based on the previous literature and practical recycling sector in Chinese market.

3.2 Interpretive structural modelling (ISM) approach

The analytical model can be used to analyze the barriers and drivers of indsutrial development (Govindan et al., 2014; Luthra et al., 2017b). The interpretive structural modeling (ISM) method is employed to describe the interactions among the facotrs influencing the development of ELV recycling industry (Kumar et al., 2016; Ming et al., 2017).

According to the ISM, the interactive relationship among factors is derived, which are portrayed into a hierarchical structure. The specific seven steps are depicted in Fig. 4 following in previous publications, and the characteristics of ISM approach are as follows (Ming et al., 2017):

① The ISM method is interpretive and also structural. Therefore, an overall structure can be extracted from the complex set of interlaced variables.

② The method is used to impose order and direction on the complex relationships among these variables (Ali et al., 2018).

③ Although it is viewed as a group learning process, individual can also use it. Besides, the drivers and barriers among these ingredients can be identified from the structural portrayed.

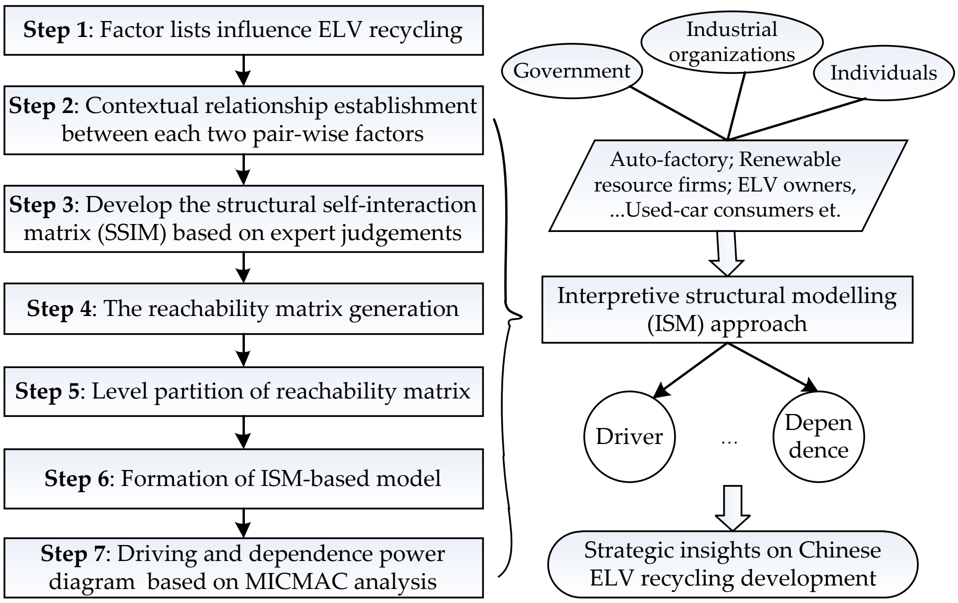

Fig. 4 ISM implementation steps (Kumar et al., 2016; Ming et al., 2017)

As illustrated in Fig. 4, the detail implementation steps of ISM approach are as follows.

Step 1: Determination of ingredient factors influence ELV recycling industry. The listed factors above-mentioned are generated based on previous literature from multiple stakeholders' perspectives.

Step 2: Based on the opinion of the expert panel, contextual relationships between each two pair-wise factors within each group are established and collected. The contextual relationship of "lead to" item is chosen, when one ingredient factor leads to another variable.

Step 3: The corresponding structural self-interaction matrix (SSIM) is assessed and formulated based on experts' judgements, indicating the pairwise relationships.

Step 4: Calculation of reachability matrix. The initial reachability matrix is generated from SSIM by transforming qualitative opinion into binary codes. The final reachability matrix for the factors is derived by incorporating the transitivity rue of the ISM approach (Mathiyazhagan et al., 2013). The SSIM indicates the direct relationships, while the reachability matrix reveals not only the direct relationships but also indirect relationships among listed factors.

Step 5: The reachability matrix formulated in the Step 4 can be partitioned into different levels through the reachability and antecedent set for each factor. The reachability set for an individual factor includes itself and other ingredients which it could assist to reach. While the antecedent set consists of the factors themeselves and other factors which may help in achieving it. We followed the partition level ruels in previous studies (Diabat and Govindan, 2011), and the final level of each factor could be obtained.

Step 6: Formation of ISM-based hierarchical model. With the assistance of the partitioned level, a hierarchical model of various ingredient factors driving to ELV recycling management from governmental, organizational and individual perspectives was developed and formulated.

Step 7: The ISM model developed in Step 6 is reviewed to check for conceptual inconsistency and necessary modifications if required. Then the driving power and dependence power of each ingredient factors are calculated and analyzed.

4 Result and discussion

4.1 Data collection

To collect the data in terms of pair-wise comparison factors, an expert panel is established under the assistance of Automotive Collaborative Innovation Center (ACIC). The expert panel comes from practical industries and academic institutes related to automobile industry, EOL recycling, re-manufacturing, SSCM and used-car marketing area etc. Based on the ELV reycling procedure and involvements of multiple roles, these factors are categrized based on multiple stakeholders, that is, from goveronmental, recycling organizaitonal and individual viewpoints (Chen et al., 2015).

The contextual relationship among these factors is collected from academy and industry professionals of the established expert panels. Data collection was performed in two phases : ① Determination of the listed factors from multiple stakeholders; ② Evaluaiton of the pair-wise comparison of ingredient factors to ELV recycling based on the opinion of expert panels, obtained using brainstorming and normial techniques (Ming et al., 2017; Moktadir et al., 2018).

To portray the hierarchical structure and interactions among the factors in each system, the following symbols are defined in advance (finding in Table 2), demonstrating the direction of the relationship between each pair-wise factors (factor *i* and *j*).

Table 2. Symbol of relationship between two pair-wise factors

Symbol	Meaning
V	Factor *i* will assist to achieve factor *j*
A	Factor *j* will assist to achieve factor *i*
X	Factor *i* and *j* will assist to achieve each other
O	Factor *i* and *j* are unrelated

4.2 Structural self-interaction matrix (SSIM)

Implementation of ISM approach comes from the structural self-interaction matrix is generated through the contextual interrelationships between each pair-wise factors. It is concrete and interpretive since the judgement of the expert panel determines whether and how the factors are interacted through a graphical portrayal (Singh and Kant, 2008).

There are five expert members from ACIC were asked to judge the relationships among listed factors. Firstly, the listed factors from multiple stakeholders were delivered to the expert panel with further confirmation. Secondly, all five experts were asked to perform pair-wise comparison by answering that "do you think the factor *i* directly influence factor *j*". However, there may occurred the different judgements on the same pair-wise comparison of two factors. According to the principle of "the minority is subordinate to the majority" (Gan et al., 2018; Shen et al., 2016), the contexutal realationship among listed factors in each group was determined if three or more expert agree. Based on the consensus from the established expert panels, the contextual influence among each two pair-wise factors is consulted in Table 3-Table 5.

Table 3. Contextual relationships between each two factors (Governmental view)

Factor item	Ingredients (Governmental view)	Ingredients (Governmental view)			
		C5	C4	C3	C2
C1	Policy on auto-factory	O	V	V	V
C2	Policy on ELV recycling firms	V	V	V	
C3	Government's policy on ELV owners	V	O		
C4	Subsidy on used-car consumers	V			
C5	Policy on recycling market	X			

Table 4. Contextual relationships between each two factors (Organizational view)

Factor item	Ingredients (Organizational view)	Ingredients (Organizational view)					
		C12	C11	C10	C9	C8	C7
C6	Consciousness of auto-factory	A	A	A	A	O	V
C7	Design/assembly for recyclability	A	V	V	V	O	
C8	Utilization rate of renewable resource	O	A	A	A		
C9	Reuse of crucial parts	A	O	X			
C10	Re-manufacturability of key parts	A	O				
C11	Material recyclability of ELV	A					
C12	Disassembly and recycling technique	X					

Table 5. Contextual relationships between each two factors (Individual view)

Factor item	Ingredients (Individual view)	Ingredients (Individual view)				
		C18	C17	C16	C15	C14
C13	Recycling awareness of ELV owners	A	A	V	O	A
C14	Attitude of the used-car consumers	V	A	V	A	
C15	Quality of economy of ELV activity	V	A	V		
C16	Sustainable consciousness of publics	A	A			
C17	Value of recyclable material and part	V				
C18	Market recognition of the used-parts	X				

4.3 Reachability matrix

In this stage, the reachability matrix is developed from SSIM. Firstly, the initial reachability matrix format is formulated by converting the value in each cell of SSIM into the binary value. Table 6, 7 and 8 show the final reachability matrix for four kinds of variables

Table 6.Final reachability matrix from governmental view

Factor item	Ingredients influenced the Chinese ELV recycling industry	Factor item C1	C2	C3	C4	C5	Driving Power
C1	Policy on auto-factory	1	1	1	1	0	4
C2	Policy on ELV recycling firms	0	1	1	1	1	4
C3	Government's policy on ELV owners	0	0	1	0	1	2
C4	Subsidy on used-car consumers	0	1	0	1	1	3
C5	Policy on recycling market	0	0	0	0	1	1
	Dependence power	1	3	3	3	4	14

Table 7.Final reachability matrix from the organizational view

Factor item	Ingredients influenced the Chinese ELV recycling industry	Factor item C6	C7	C8	C9	C10	C11	C12	Driving Power
C6	Consciousness of auto-factory	1	1	0	0	0	0	0	2
C7	Design/assembly for recyclability	0	1	0	1	1	1	0	4
C8	Utilization rate of renewable resource	0	0	1	0	0	0	0	1
C9	Reuse of crucial parts	1	0	1	1	1	0	0	3
C10	Re-manufacturability of key parts	1	0	1	1	1	0	0	4
C11	Material recyclability of ELV	1	0	1	0	0	1	0	3
C12	Disassembly and recycling technique	1	1	0	1	1	1	1	6
	Dependence power	5	3	4	4	4	3	1	23

Table 8.Final reachability matrix from the organizational view

Factor item	Ingredients influenced the Chinese ELV recycling industry	Factor item C13	C14	C15	C16	C17	C18	Driving Power
C13	Recycling awareness of ELV owners	1	0	0	1	0	0	2
C14	Attitude of the used-car consumers	1	1	0	1	0	1	4
C15	Quality of economy of ELV activity	0	1	1	1	0	1	4
C16	Sustainable consciousness of publics	0	0	0	1	0	0	1
C17	Value of recyclable material and part	1	1	1	1	1	1	6
C18	Market recognition of the used-parts	1	0	0	1	0	1	3
	Dependence power	4	3	2	5	1	4	20

4.4 Level partitions

In this step, reachability and antecedent sets for each variable are obtained from the final reachability matrix. Table 9 – 11 shows the results of level partitions.

Table 9 Level partitions for objectives in governmental group

Factor item	Reachability set	Antecedent set	Intersection set	Level
C1	1,2,3,4,5	1	1	III
C2	2,5	1,2	2	II
C3	3,5	1,3	3	II
C4	4,5	1,4	4	II
C5	5	1,2,3,4,5	5	I

Table 10 Level partitions for objectives in organizational group

Factor item	Reachability set	Antecedent set	Intersection set	Level
C6	6,7,8,9,10,11	6,12	6	III
C7	7,8,9,10,11	6,7,12	7	IV
C8	8	6,7,8,9,10,11,12	8	I
C9	8,9,10	6,7,9,10,12	9,10	II
C10	8,9,10	7,9,10	9,10	II
C11	8,11	6,7,11,12	11	II
C12	6,7,8,9,10,11,12	12	12	IV

Table 11 Level partitions for objectives in individual group

Factor item	Reachability set	Antecedent set	Intersection set	Level
C13	13,16	13,14,15,17,18	13	I
C14	13,14,16,18	14,15,17	14	III
C15	13,14,15,16,18	15,17	15	IV
C16	16	13,14,15,16,17,18	16	I
C17	13,14,15,16,17,18	17	17	IV
C18	13,16,18	14,15,17,18	18	II

4.5 Formation of ISM model

Followed by the implementation steps of the ISM approach in Fig. 4, the reachability matrixes are calculated step by step. And the hierarchy ISM model from governmental, industrial organizational and individual perspectives.

Then the driving power and dependence power of each critrion are calculated by incorporating 0 and 1 representing the transitivity (Ming et al., 2017). After the deduction of the reachability matrix, the structural model from multiple stakeholders is generated with directed arrow lines, illustrated in Fig. 5.

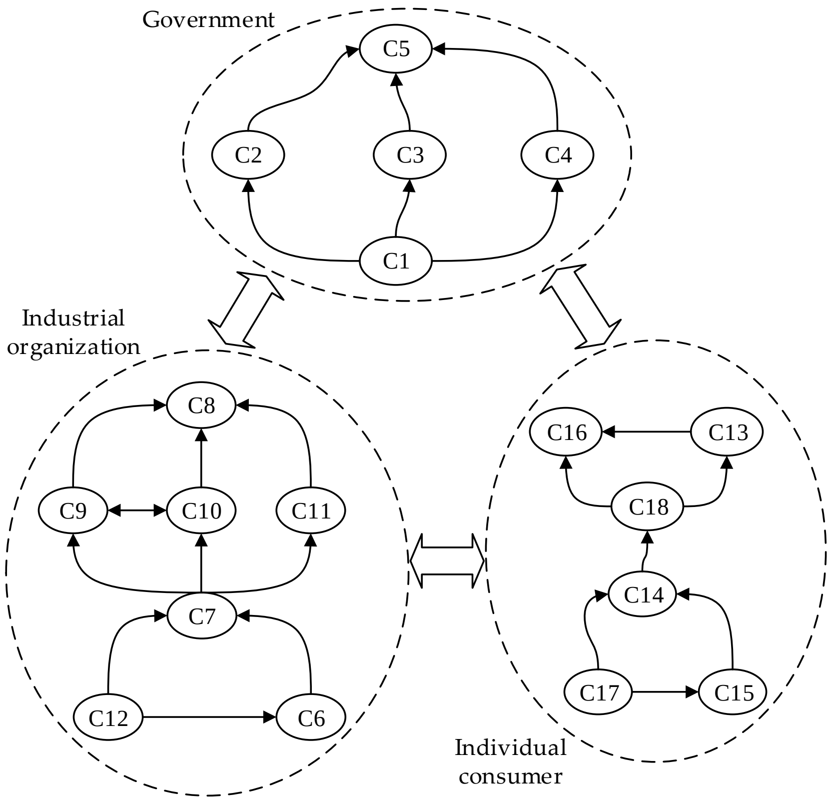

Fig. 5 ISM-based graph from multiple stakeholders

The hierarchical intererlationships are identified through ISM-based steps concerning multiple stakeholders, which provide meaningful observations in relation to influential factors. As can be seen from Fig. 5, from the governmental view, it is essential for government to regulate policies and regulations for auto-factories (C1) to stimulate the sustainable development of Chinese ELV recycling industry. The related legislation on auto-factory will contribute to the regulation development on renewable recycling organizations (C2), ELV owners (C3), and used-vehicle consumers (C4). With the improvement of elemental legislation, regulations can be implemented and standardized on recycling market (C5).

As for the industrial organizations, it is much of significance to improve the disassembly technique (C12) to promote sustainability. Besides, eco-friendly consciousness and sustainable awareness of auto-factory (C6) also shows great importance on sustainability achievement, influenced by state-of-the-art technique level. Driven by these factors, domestic automobile industries try to design and assembly for recyclability (C7), which lays the foundation on the ELV recycling industry. These stimulate specific ELV recycling operations including re-use (C9), re-manufacturing (C10) and material recycling (C11) business. The improvement of recycling and renewable resource utilization rate is realized by the enhancement of the abovementioned factors.

The added value analysis and discovery (C17) is also an original driver to promote Chinese ELV recycling development, as well as the quality of economic criteria (C15). The cost-effective and reliable product enables used-car consumers have access to acceptance on reused parts or recovered products, which will contribute to the market cognition of re-manufactured products (C18). With the prevailing utilization of the re-used parts and re-manufactured products in Chinese market, sustainable recycling awareness of ELV owners and social publics will be strengthened as well, leading to a healthy circular economy (C13, C16).

4.6 MICMAC analyses

To discover crucial ingredients influencing ELV recycling industry from multiple stakeholders, driving and dependence power analysis enable to provide some useful observations to promote

Chinese ELV recycling performance. Matriced'Impacts croises-multipication applique' and classment is abbreviated as MICMAC, and it is based on multiplication properties of matrices. The driving power and dependence power can be identified by using the MICMAC analysis, which is depicted in the following Fig. 6.

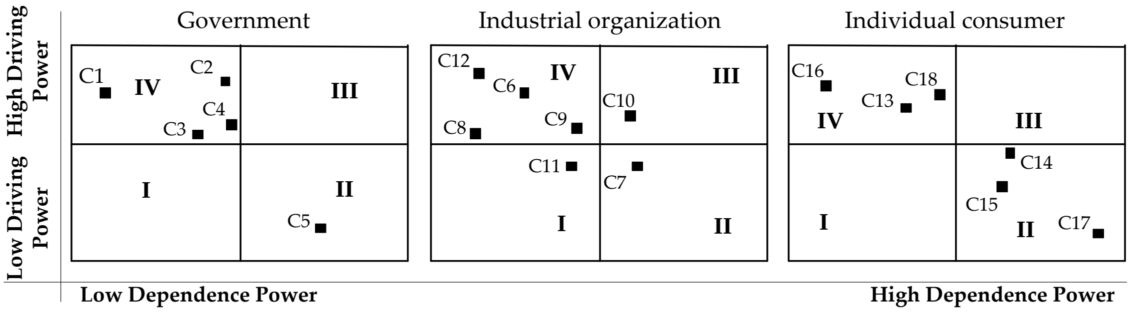

Fig. 6 Driving and dependence power of Chinese ELV recycling industry

According to the driving power and dependence power obtained, the ingredient drivers in the presented case are divided into four categories as follows:

(1) Autonomous drivers (Quadrant I): this kind of ingredient factors has weak driving power and weak dependence power. They are marked in Quadrant I, regarded as few links with the ELV recycling management system.

(2) Dependent drivers (Quadrant II): this kind of ingredient factors has weak driving power and strong dependent power. They usually perform a direct influence on ELV recycling, and are affected by other ingredient drivers. The governmental regulation (C5) falls this sector, which means the policy motivation on the market is affected by the motivation on segmental participants.

(3) Linkage drivers (Quadrant III): this kind of factor has strong driving power and strong dependent power. They are mapped in Quadrant III, and play a significant role on linking the drivers influencing the ELV recycling management performance.

(4) Independent drivers (Quadrant IV): this kind of ingredient factors has strong driving power and weak dependent power, which can be regarded as the crucial influential drivers for its higher driving power.

The Fig. 6 demonstrates the driving and dependence power of each criterion. From the governmental viewpoint, regulations on recycling market have the low driving power and high dependence power, and the rest of the factors are all have high driving power and low dependence power. That means the improvement of regulations on segmental roles will give impetus to the market maturity. As for industrial organizations, the re-manufacturing of auto parts has strong driving power and dependence power, which will affect other factors and also be influenced by the counterparts. The same analysis results can be discovered from the Fig. 6. Overall, the graphical diagram enables to reveal the characteristics of the collected factors influenced Chinese ELV recycling industry.

4.7 Discussion

The formulated ISM-based model provides a better understand the interrelationships among ingredient factors from governmental, industrial organizational and individual viewpoints. From the ISM-based model in Fig. 5, it is evident that the legislation on auto-factories (C1) is crucial driver to assist the regulations on other involving particpants (vehicle consumers, organizations, and ELV recycling market) from the governmental perspective. This result is similar to the previous study and arguments that auto-factories should be responsible for ELVs (Chen et al., 2015). From the viewpoint of industrial organization, the disassembly technique (C12) is the crucial driver to achieve efficient recycling operations, and it caters to the recent focus on dismantling techniques of ELVs (Go et al., 2011; Sabaghi et al., 2015). The design for recyclability, regarding as a linkage driver, also plays great role on the ELV recycling business (Wang et al., 2005). Tian (Tian and Chen, 2014) highlighted the significance of dismanlting of ELVs, and regarded the design for dismantling approach as an effective tool to improve performance of ELV processing. From the individual consumers' perspective, value and cost-benifits of recyclable parts (C17, C15) are the main drivers to help ELV recycling achievements. It is the prevalence and adoption of economical spare parts that stimulate the re-use and re-manufacutring sector of ELV parts (Chen et al., 2015; Mazzanti and Zoboli, 2006).

From the MICMAC map in Fig. 6, we can identify independent drivers and dependent drivers to ELV recycling management. The driving factors are located in the Quadrant IV. Regulations on auto-factories (C1), renewable organizations (C2), and individuals (C3, C4) motivates to the legislative improvement on ELV recycling market, and the similar to the other two groups. The dependent drivers are those mapped in Quadrant II with weak driving power and strong dependent power. The design for recyclability (C7) is affected by technique level (C12) and eco-friendly awareness (C6), contributes to the operation efficiency of ELV recycling. The result caters to the argument that the sustainable practices at each phases lead to sustainability acheviement of vehicle supply chain, and the design for recyclability is conducive to ELV recycling and is also influenced by manafuctring techniques (Tian and Chen, 2014; Zhou et al., 2018).

Through the formulated ISM-based model, regulations on auto-factory, disassembly technique, and value mining of recycling business are the basic ingredients for sustainability performance improvement of ELV recycling. In addition, the driving power and dependence power using MICMAC analysis assists to better understand the drivers of ELV recycling management.

5 Theoretical and managerial implications

This research serves both scientific and practical contributions to ELV recycling management practices by providing some theoretical and practical implications. In this section, we present the theoretical implications to ELV recycling management and provides managerial implications for practical industries.

5.1 Implications to theoretical knowledge

This study contributes to theoretical knowledge by exploring the drivers of ELV recycling management, thereby probe into better insights for Chinses ELV recycling development. The theoretical background of Chinese ELV recycling industry towards SSCM is presented, and the current status of ELV recycling management is highlighted from a systematic way. The ISM approach employed facilitates industrial managers to portray the complex interrelationships among drivers of ELV recycling in a decision-making process. The theoretical implication of the ISM-based model is that it can study the detail drivers based on an explained multi-level hierarchy.

This paper reveals that influential factors from governmental, organizational and individual perspectives show discrepant driving power towards ELV recycling performance. Also, the legislation for auto-factories, disassembly technique and cost-effective value attributes is decisive drivers of ELV recycling.

5.2 Implications to practice and managerial insights

This study includes a few implications for ELV recycling industries to improve performance within the sustainable context. The ingredient factors from multi-stakehoulders are highlighted based on literature and practical industry, and the ISM-based model is constructed and formulated.

Implications to practice of this study includes to take advantage of the experts' knowledge to provide better understanding of a complex situation followed by a course of countermeasures for probelem-solving and performance improvement. From the ISM-based model and MICMAC analysis, the decisive drivers of ELV recycling management are identified. To improve performance of ELV recycling management, those crucial drivers from multi stockholders including industrial organizations, individual consumers and local governments should be focused and promoted. Fistly, the legislations and policies on automobile industry can be improved by motivating auto-factories, vehicle consumers and renewable organizations, and the used-car black market is also need to be regulated. Secondly, dismantling and re-manfuacturing techniques should be improved by R&D investment. The complete disassembly not only contributes to multiple recycling channel, but also assists to the recycling efficiency improvement (Go et al., 2011). Besides, the hierarchy model derived in this study suggests how the drivers are interrelated and interacted for ELV recycling management from the different perspective. It is significant to promote this driving factors to improve sustainable performance of the industry. This study could assist industrial practitioners, governmental regulators and ELV recycling industry professionals to concentrate their efforts towards achieving high performance through identified ingredient factors. Finally, the study assists to achieve sustainability of vehicle supply chain and will improve management performance of ELV recycling using the visible drivers.

6 Conclusion and future directions

ELV recycling management contributes to the sustainability achievement of the automobile supply chain. Recently, there are many segmental studies on disassembly, ELV recycling partner, material recycling and policy review topics etc. (Cholake et al., 2018; Fang et al., 2018; Wong et al., 2018; Xiao et al., 2018). However, very few studies address the problems of the Chinese ELV recycling practice combining literature review and systematically analytical approach. Particularly, on the foundation that China has been the biggest country with vehicle production and sales since 2009. To highlight the research gap, this research tries to study the ELV recycling management by identifying criteria of Chinese ELV recycling, as well as providing guidance on performance improvement.

On the basis of the systematic literature review, the ELV recycling practices are investigated concerning multiple stakeholders including government, industry organizations and individual consumers. To promote sustainable development of Chinese ELV recycling industry, interpretive factors are identified and investigated using an ISM approach. Driving and dependence power analysis is performed to guide performance improvement of Chinese ELV recycling.

This study carries some limitations. Firstly, the collection of influential factors comes from recent publications, which may lead to the not being considered comprehensively. More ingredient factors have not been taken into account and not categorized. Secondly, we perform the influential factor analysis from governmental, industry organizational and individual perspectives. Due to the development of technique and ELV recycling industry, the interactions among these three kind are not stable and interact each other with high time-sequence characteristic. The research angle of this study is based on the ELV recycling procedure and its mainly involvements, and the more complex interrelationships and precise interaction among different stakeholders need the further qualitative study using game-based theory. Thirdly, even though the absolute advantage of the ISM-based approach, the disadvantages of the method limits this study. All in all, to state-of-the-art, this study, firstly, aims at improving performance of Chinese ELV recycling industry through ISM-based approach. In the future study, more various criteria and complex interactions under the dynamic environment can be also highlighted, which provides much more precise guidance on the ELV recycling management performance improvement.

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