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REVIEW

End-of-life vehicles research development in Malaysia: a comprehensive review with the integrated conceptual model of innovative sustainable manufacturing elements

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Abstract
The end-of-life vehicles (ELV) issue has become an essential topic in the fast-growing automotive industry. This study utilizes comprehensive content analysis to critically review the recent ELV research developments and underpinning issues in Malaysia. Fifty relevant ELV studies in Malaysia from the year 2006 to 2021 are selected and categorized based on three innovative sub-elements (product, process, system) of sustainable manufacturing. The literature review findings show that sustainable product recovery and recyclability issues in ELV treatments are still a major concern. Current studies overlook specific research on sustainable and integrated processes for ELV treatment. There is still lack of detailed ELV implementation framework equipped with the documented procedures and appropriate industrial practices in the ELV ecosystem to optimize the ELV supply chain. ELV policy is yet to be enacted in Malaysia, and public awareness of ELV is still low. There is inadequate alignment in ELV research developments with the current National Automotive Policy 2020 in Malaysia. The proposed integrated conceptual model will provide an extensive overview for scholars, policy-makers, and ELV stakeholders to implement appropriate actions to improve present ELV businesses in line with the public readiness to enact the potential ELV directives or legislation in Malaysia.

Keywords End-of-life vehicles · Malaysia · National Automotive Policy · Automotive · Sustainable manufacturing

Abbreviations

ELV	End-of-life vehicles
EU	European Union
4IR	Fourth Industrial Revolution
NAP	National Automotive Policy
GDP	Gross Domestic Product
SM	Sustainable manufacturing
CE	Circular economy
EPR	Extended producer responsibility
IMP3	Third Industrial Masterplan
EEV	Energy efficient vehicles
BDA	Big Data Analytics
IoT	Internet of Things
AI	Artificial Intelligence
EOL	End-of-life
NRAA	National Roadmap for Automotive Aftermarket
AM	Additive manufacturing
GUI	Graphical user interface
PV	Passenger vehicles
QFD	Quality Function Deployment
ANN	Artificial neural networks
AHP	Analytic hierarchy process
OEM	Original equipment manufacturers
CLSC	Close-loop supply chain
EV	Electric vehicle

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Introduction

Resource shortages and environmental pollution have become global concerns issues. One of the critical problems the world is presently dealing with is the enormous demand for multiple resources to fulfill the consumer's needs [1]. It is inevitable that the number of end-of-life vehicles (ELV) in the automotive industry will skyrocket in the coming decades due to the tremendous rise in vehicle ownership [2]. According to European Directive on ELV (2000/53/EC), ELV is defined as "any junk vehicle, whether or not it includes a material or object that the last owner intends to discard or does not wish to keep" [3]. If the ELV issues are not properly addressed, severe social and environmental problems will arise, resulting in huge economic losses. Therefore, the European Union (EU) enacted the ELV Directive (2000/53/EC) in 2000 to encourage the reuse and recycling of ELV components and reduce ELV waste for environmental protection. The ELV guideline mandates a recovery rate at above 95% from 1st January 2015. Europe has already had almost 20 years of experience regulating ELV activities since 2003 [4]. The ELV supply chain system in Europe has been thoroughly comprehended and well adapted to the ELV guideline. Although ELV are treated as substantial cause of environmental pollution, it also possesses high economic value due to its recoverable components and valuable recyclable materials that can be salvaged when appropriately processed in ELV treatment. With the rapid rise of ELV numbers, it was projected that more ELV legislation and policy would be introduced to increase the recovery system efficiency [5]. However, Malaysia has not enacted any ELV-related legislation because most Malaysians are still uncertain about the action taken in the ELV implementation [6]. This showed that the ELV development in Malaysia is still very slow and lags compared with other developed countries.

Automotive has become one of the essential industries in the Fourth Industrial Revolution (4IR), as per Malaysia's National Policy on Industry 4.0 [7]. The founding of national automotive corporations like Proton in 1985 and, later, Perodua in 1993 served as a stimulus for the rapid growth of the automotive industry in Malaysia. This transforms the country from vehicle assemblers to vehicle manufacturers, thus accelerating the expansion of local automotive component manufacturers and their supply chains. The latest National Automotive Policy (NAP) or NAP 2020 anticipated that the automotive sectors will be generating RM104.2 billion for Gross Domestic Product (GDP) by 2030 [8]. The local vehicle industries are expected to recover from the impact of the Covid-19 pandemic. It is projected that the total number of new passenger and commercial vehicles registered annually in Malaysia will steadily increase from 604,200 in 2022 and hit 662,100 in 2025 [9]. However, the passenger vehicle market in Malaysia is expected to reach saturation in 2030, with 12 million active vehicles and half a million ELV to be produced in that year [10]. The NAP 2020 also aimed to reach RM 10 billion in export for remanufactured automotive parts and components by 2030 [8]. The large quantity of ELV collected is essential to provide sufficient input for secondary raw materials and promote sustainable resource circulation to minimize waste. However, the ELV management system in Malaysia is still at the beginning or infancy level, similar to other emerging nations.

Vehicle manufacturers would prefer their vehicles to last for 15 years; those vehicles which exceed this age limit are classified as ELV [11]. In contrast, most public respondents (38.9%) in Malaysia preferred the vehicle age to be limited to 10 years [12]. However, most Malaysians had driven their vehicles for more than 10 years in the actual situation [13]. The number of vehicles operating on the road between 10 and 15 years is anticipated to exceed five million [14]. This leads to the possible risks of having vehicle breakdown issues and causing safety hazards to drivers and road users. ELV in Malaysia will typically transfer to rural regions after being operated on for lengthy periods. The vehicles are deemed safe on the road if they still meet the required inspection, safety, and environmental standards. Vehicle owners in Malaysia would commonly choose to preserve their vehicles until the end of the product life cycle. Purchasing a new car is costly and not affordable for most low-income families. Many ELV are refurbished and used as "second-hand" cars in rural areas, thus drastically reducing the recycling rate for ELV. The majority of respondents agreed that the automobile industry's commitment to achieving environmentally sustainable growth would positively impact national economic development [15]. Sadly, many owners still choose to abandon their obsolete or unwanted vehicles improperly and irresponsibly, which has caused considerable challenges in sustainable manufacturing (SM) issues such as negative environmental impact, social issues, and financial loss.

This study of ELV is limited to the Malaysian context as it is one of the fast-emerging industries and plays a critical role in sustainable development. Many studies have focused on Malaysia's ELV management system and recovery issues. However, there is still a lack of comprehensive research to investigate the ELV progressive research development and sustainability issues to increase the recovery rate. To the best of the authors' knowledge, no review paper has emphasized assessing the ELV research development in Malaysia. Hence, it would be worthwhile to investigate the key issues of ELV phenomena more holistically and explicitly in Malaysia to narrow the research gaps. Therefore, this study aims to identify several key subjects related to ELV development issues in Malaysia and recommend a future research direction. The review will generate some implications for academicians and practitioners to better understand the underpinning issues of ELV in Malaysia. The proposed ELV model will guide the relevant parties in establishing a strategic plan and regulatory framework to solve the ELV problems in Malaysia. The ELV stakeholders and policy makers can take effective actions to improve current ELV approaches in line with the NAP in preparation for implementing the ELV management system policy.

The entire paper is outlined as follows: Sect. 1 introduces the ELV overview in Malaysia and the problem identification. Section 2 presents the literature review of Malaysia's NAP and ELV research development issues. This is followed by the critical analysis of the sustainability issues at the product, process, and system levels. Next, the methodological approach employed is described in Sect. 3. Section 4 explains the synthesis and discusses the results derived from the critical literature review. Further categorization of innovative SM sub-elements is developed to obtain insights into sustainable ELV development. The ELV policy and public knowledge of sustainable ELV development are discussed. Next, the integrated conceptual model of innovative SM elements is proposed. Lastly, Sect. 5 concludes the study and suggests future research directions.

Literature review of NAP and ELV research development in Malaysia

The Scopus database was searched within the 'Article Title, Abstract, and Keywords' using the exact phrase "end-of-life vehicle" with the selection year ranging from 2006 to 2021. It resulted in a total of 797 articles. Figure 1 depicts the number of documents published for ELV by country or territory (extracted from the Scopus database). China (127) and Japan (84) are the top two countries actively involved in ELV research and development. The Chinese government has implemented several recycling policies that have influenced the practices of the industry players, and effective subsidy policies have improved the recovery rate of ELV [16]. Both Japan and the EU are in the vanguard of ELV management and have implemented several effective policies to promote ELV recycling [17]. The market-based ELV recycling stream had been well developed in Japan before the ELV Recycling Act was enacted in 2005 to govern ELV management [18]. The ELV directive primarily leads the circular economy (CE) of vehicles in the EU with emphasis on the concept of extended producer responsibility (EPR), in which the automobile makers and importers are accountable for recycling expenses [19]. Meanwhile, Malaysia (42) is ranked as one of the top ten countries contributing considerably to ELV-related studies. This clearly showed that ELV issues are becoming a hot topic and receiving great attention from Malaysian researchers. Hence, performing a critical review on ELV, particularly in the Malaysian context, is worthwhile. However, Malaysia still does not have an ELV regulatory structure, unlike the EU or Japan [20]. This indicated most Malaysian are still not yet ready for the ELV implementation. The close collaboration of all the ELV stakeholders and the support from the government are vital to accelerating the potential ELV development in Malaysia. Malaysia should adopt feasible ELV management practices and look into the successful experiences of policy implementation in other countries. Therefore, this review study is essential to provide novel perspectives on ELV issues and serve as a reference guide for ELV players in other developing countries with similar business settings.

The NAP was initially launched in 2006 as part of the Third Industrial Masterplan (IMP3), 2006–2020 to make the automotive industry one of the major contributors to the Malaysian economy [8]. It emphasized supply chain integration and planned to equip the local automotive stakeholders to become more efficient and competitive. The second iteration of NAP was launched in 2009 to enhance capabilities and create a favorable investment environment in the local automobile industry. The third version of NAP 2014 was released in 2014, focusing on green initiatives, market expansion, and strengthening the entire automotive ecosystem through technological, human capital, and supply chain growth. The NAP 2014's objective was to position Malaysia as a regional energy-efficient vehicle hub for energy efficient

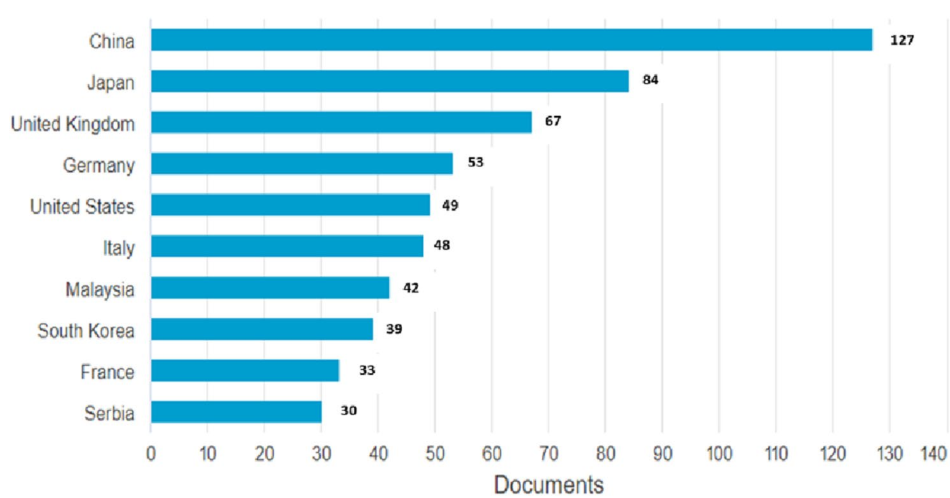

Fig. 1 Number of ELV published documents by country or territory (extracted from Scopus database)

vehicles (EEV) by 2020 [8]. With the latest technological intrusions and ripples hitting global markets, Malaysia's automotive industry was struggled and suffered a tough time since the beginning of 2020, especially facing global competitive challenges during the 4IR. Therefore, NAP 2020 (the current fourth edition) seeks to enhance Malaysia's automotive industry to partake in the digital industrial transformation waves from 2020 to 2030. NAP 2020 is launched to boost the continuous growth of Malaysia's automotive industry via enhancing "Connected Mobility". The application of smart automotive, connected mobility, and integrated technology has grown tremendously in vehicle development. The Industry 4.0 elements such as autonomous robots, Big Data Analytics (BDA), Internet of Things (IoT), Artificial Intelligence (AI), and so on have mainly altered the business's environment setting by introducing smart features to expedite the vehicle's digital transformation. The fast emergence of Industry 4.0 development can deal with the unpredictability of end-of-life (EOL) product quality by applying smart processing and analyzing complex data to facilitate remanufacturing [14]. Figure 2 shows the evolution of NAP in Malaysia, which began with a policy-driven approach in NAP 2006 to the recent focus on vision drives policy in NAP 2020 to cope with the latest challenges in the digital industrial transformation era.

Remanufacturing is the process of restoring discarded EOL products to a "like-new" functional state with a matching warranty [21]. Remanufacturing would be a valuable recovery strategy for ELV as Malaysia aggressively adopts and embeds advanced Industry 4.0 technologies or tools in the automotive sectors [22]. The automotive industry had included remanufacturing as one of its strategic roadmaps in NAP 2014, and the scope is continually expanding in NAP 2020. The National Roadmap for Automotive Aftermarket (NRAA) has set up detailed criteria to enhance the remanufacturing standards and methodologies for domestic automotive stakeholders to make Malaysia an ASEAN automotive remanufacturing center. NRAA had included recommendations for strengthening component recycling and reuse efficiency using emerging technologies like BDA. This is in line with NAP 2020's National Automotive Vision, which targeted to improve the local vehicles in auto part manufacturing and promote sustainable remanufacturing. An in-depth discussion on ELV began in Malaysia since 2006 by focusing on the automotive industry's evolution plan [23]. Table 1 shows an extensive literature study conducted on ELV research development in Malaysia from the latest year (2021) to the oldest year (2006) of publication on identified subgroups: SM elements, scope of study, research method, key findings, and limitations of the study.

ELV sustainability issues at the product level

The evaluation of the rheological properties of recycled polypropylene with virgin polypropylene and a product that incorporates recycled polypropylene from ELV are developed [27]; however, the sustainability of the recycled materials is still yet to be verified. A new way to produce thermal insulation sandwich panels is provided using ELV waste from headlamps and seats [28]. The key performances of the thermal insulation sandwich panels in terms of social, economic, and environmental need to be assessed for broader industry application. A framework is proposed as a benchmarking tool to certify the quality assurance of remanufactured components by issuing aftermarket warranties [31]. This framework mainly targeted to certify the remanufactured components with evaluated relevant quality

Fig. 2 Evolution of NAP in Malaysia [8]

Table 1 Critical review of ELV research development in Malaysia

No	References	SM elements	Scope of study	Research method	Key findings	Limitations of the study
1	[6]	System	ELV policy implementation	Survey	Public awareness and acceptability of ELV applications are relatively poor	Lack of suggested solutions to improve the public perception of ELV policy implementation
2	[23]	System	ELV management ecosystems	Observation	Recommendations for ELV management ecosystems and implementation were highlighted	The sustainable ecosystems for the reverse logistic supply chain in ELV are not emphasized
3	[24]	System	Supply chain optimization for ELV recycling	Literature review	The supply chain system for ELV recycling is still in its early stages	This study did not evaluate the sustainable supply chain performances
4	[25]	System	ELV safety issue and policy	Literature review	ELV initiative must be started to improve the safety features plans to minimize the risk of fatal road accidents	Lack of discussion on the safety standard in ELV with regard to SM elements and policy
5	[26]	System	Awareness and understanding of ELV implementation	Survey	Most respondents have low knowledge of ELV and agreed about the ELV implementation	There is lack of discussion on sustainable ELV development from the other relevant industry players
6	[27]	Product	The potential of recycled polypropylene in ELV	Laboratory testing	The rheological test indicated that recycled polypropylene best operates at 190 C	The sustainability of the recycled materials is still yet to be verified
7	[14]	System	Challenges and opportunities in Malaysian remanufacturing industries	Literature review	Five current challenges with mitigation strategies and two future opportunities have been identified for SM	A comprehensive framework is needed to evaluate the current remanufacturing system performances
8	[22]	System	Supply chain disruption risks in the automotive remanufacturing industry	Semi-structured interviews and site visits to 3 companies	The most significant disruption element in production planning is obtaining replacement parts	The identified disruption factors are not supported by the relevant literature in enhancing the sustainable supply chain management
9	[28]	Product	ELV waste recycling is used for sandwich panels	Laboratory testing	ELV waste can be recycled to develop valuable, sustainable thermal insulation	The methods used are still required to be qualified to enhance sustainable performances
10	[29]	Product	Automotive component design for reparation using the additive manufacturing (AM) technology	Industrial visit	Advanced AM technologyoffers a great ability to reduce restrictions in manual repair and restoration of EOL cores	Lack of discussion on how the design for remanufacturing automotive components can be applied with the AM technology in SM
11	[13]	System	ELV recovery issues and factors	Survey	The five factors enhancing ELV recovery are subject to dynamic changes in the aftermarket chain	Lack of details discussion on the corresponding sub-factors with the sustainable ELV recovery system
12	[11]	System	Performance evaluation tool for ELV management system	Survey	The overall score of the ELV management system implementation in Malaysia is equal to 2.13, indicating an average performance level	There is still a lack of critical SM elements incorporated in the performance evaluation tool on ELV management system implementation

Table 1 (continued)

No	References	SM elements	Scope of study	Research method	Key findings	Limitations of the study
13	[30]	System	ELV recovery factors	Interviews	The aftermarket cognitive map depicts the interconnections between the ELV recovery factors and recovery effectiveness	Lack of investigation of the identified recovery factors in analyzing the significance of their relationships in the proposed model
14	[31]	Product	Remanufacturing quality-certifying framework for remanufactured components	Literature review and survey	The key factors of remanufacturing quality control were established	The concern on sustainability issues is not considered when establishing the quality factors
15	[32]	Process	Concept of processing framework for ELV recycling	Literature review	The construction industry can utilize ELV waste in dismantling and shredding operations	The compatibility of raw materials recovery from both industries needs to be evaluated to enhance the sustainable production metrics
16	[33]	Process	Remanufacturing knowledge support system to facilitate the remanufacturing process of brake callipers	Interviews, observations, and documentation review (mixed method)	The remanufacturing of brake callipers has been made easier using a Java-based prototype graphical user interface (GUI) assistance system	The knowledge is gathered from a local company only, which lacks practical validation on standardizing the process steps
17	[10]	System	Estimation of the number of ELV generated in Malaysia until 2040	System dynamics modeling	The passenger vehicles (PV) market is expected to approach saturation in 2024 while the number of ELV continues to rise	Insufficient focus on ELV estimation with regard to the future sustainable development issues
18	[34]	System	Problems and gaps in the EOL remanufacturing of electronics and automobiles	Literature review	Addressed the study of remanufacturing in the automobile industry from the system perspective as an integrated approach	Lack of focus on the remanufacturing stakeholder's analysis in dealing with the sustainable operations issues
19	[35]	Product	ELV recovery factors and the connection to product design strategies	Literature review	The initial recovery model employs a system dynamics method to link product design tools with recovery variables	The proposed model is still yet to be validated in the actual scenario, and thus needs further input from the expert
20	[36]	Product	ELV recovery model in relation to ELV design strategies	Interviews	EOL design strategies that affect the effectiveness of ELV recovery were developed using system dynamics	The model is still incomplete and lacks relevant data to support reflecting the actual situation
21	[37]	Product	Quality assurance of remanufactured components in ELV	Literature review	The quality of the remanufactured ELV components in terms of quality assurance and quality after business is vital	The essence of quality of the remanufactured ELV components is not shown via its impact on ELV performances
22	[12]	System	ELV policy and public perception	Database review	The government still encounters several challenges when implementing the ELV policy in Malaysia	The proper ELV plan needs to be accomplished with sustainable practices in the automotive ecosystem
23	[38]	System	Key success factors for ELV management system	Survey	The eight success factors and 33 underlying items are identified and discussed	The 33 underlying items in these eight key success factors are not explained in this study

Table 1 (continued)

No	References	SM elements	Scope of study	Research method	Key findings	Limitations of the study
24	[39]	System	Sustainable ELV management	Survey	A multi-criteria decision-making method can be useful for choosing criteria and evaluating alternatives	Future studies can explore the factors that affect the criteria selection and add in more critical criteria from other sources in this field
25	[40]	System	Sustainable ELV management	Survey	The eight criteria are consistent with the requirements of selecting sustainable ELV management alternatives	Lack of description of the criteria and dimensions for sustainable alternatives evaluation
26	[41]	System	Public perception of ELV recovery in Japan and Malaysia	Survey	More than half of respondents in both countries were doubtful about their readiness to engage in ELV endeavors	Lack of attention to economic and environmental elements to improve ELV recovery issues
27	[42]	Product	ELV conceptual design	Case study (brake calliper)	An evaluation of the product upgradability at the conceptual design stage using Quality Function Deployment (QFD) application	The operational performances of the upgraded parts toward SM can be further improved via the continuous product life-cycle assessment
28	[15]	System	Automotive remanufacturing roadmap and overview of actual implementation	Survey	The research and development in automotive remanufacturing is still at the very low level	The strategic application of remanufacturing concept toward sustainable automotive manufacturing in mitigating the current challenges still needs to be developed
29	[43]	System	Success factors in ELV management system	Literature review	A set of preliminary factors were identified and categorized in the survey instrument	The survey instrument design is yet to be validated by experts to go for the pilot study
30	[44]	System	ELV management and future transformation	Literature review, discussion with experts and academician	Sustainable ELV management is needed to make standard legislation and directive for future transformation	Lack of in-depth discussions on the enablers and inhibitors of the sustainable ELV management directive
31	[45]	System	ELV management system's practices	Literature review	ELV are presently handled in three ways: operated on the road, left abandoned, and disposed of in the landfills	The study did not discuss the factors that affect the sustainable ELV management system and practices
32	[46]	System	Public community knowledge on the reuse of ELV	Survey	The knowledge of ELV in the public community needs to be enhanced	Lack of emphasizing the challenges and implications of ELV reuse in sustainable development issues
33	[47]	System	Framework for ELV recycling system in Malaysia	Interviews	A comprehensive framework adapted from the ELV management success in other countries	The framework focused on the overview of ELV system process flow but did not look into the perspective of the sustainable value chain
34	[48]	Product	ELV design process and management	Literature review	Designs for recycling, recycling technology, and ELV management were reviewed	Lack of discussion on the relationship between the ELV design process and the management system

Table 1 (continued)

No	References	SM elements	Scope of study	Research method	Key findings	Limitations of the study
35	[49]	Product	Optimization of the disassembly sequence	Case example	The genetically optimized disassembly sequence is critical to enhancing the product reusability	Lack of discussion on the critical factors that impact the disassembly sequence
36	[50]	System	Conceptual model of the automotive ecosystem in Malaysia	Focus group discussions and literature review	A conceptual model of the domestic automotive ecosystem and mapping of the NAP 2009 measures was developed in the study	The conceptual model needs to be practically validated by the car users and industry to improve the feasibility of NAP measures
37	[51]	Product	Design for ELV value framework	Case study	The presented framework consists of 4 main steps for vehicle design and development	The guideline for vehicle design and development process needs to be aligned with the legislation
38	[52]	Product	A framework of integrated recyclability tools for automobile design	Literature review	A framework of integrated recyclability tools has been introduced to improve the recyclability	The framework focuses on the design environment, the economy and social dimensions that can be explored for further enhancement
39	[53]	Process	Remanufacturing practices in the automotive industry	Survey	It is needed to validate the influence of remanufacturing on product quality	Lack of discussion on the standard remanufacturing practices in dealing with the sustainable development issues
40	[54]	Product	Disassemblability of ELV	Literature review	To identify the optimum stage of ELV disassembly for recovering all commercially viable components	The factors that will be affecting the evaluation of disassemblability selection are not discussed in detail
41	[55]	Product	Optimization of reusability in automotive components	Case study	Reliability, material, and AI are vital factors in optimizing the vehicle reuse concept	The proposed artificial neural network model needs to be tested in a robust environment for SM
42	[56]	Product	Disassembly for reuse in ELV	Survey	Optimization of disassembly for reuse in the local industry can improve the recoverability of ELV's components	There are three respondents involved in this survey, which is a lack of generalizations
43	[57]	Product	Design framework for ELV recovery	Survey	Optimization of ELV disassembly sequence using genetic algorithm approach	The proposed model is still developing; more real-life case validation is needed
44	[58]	Product	ELV disassemblability and recyclability	Software analysis	Decision-making software to evaluate the disassemblability of design and examine their recyclability	The critical factors that will be affecting the disassembly cost and time need to be thoroughly assessed to improve the economic efficiency
45	[59]	Product	Automotive component reuse	Interviews	The identified organizations have never reused the automobile components in newly manufactured vehicles	Factors that affect the sustainable development for products recovery can be explored from the supply chain and demand perspectives
46	[60]	Product	The evaluation methods of disassemblability	Literature review	The recycling and disassembly elements must be examined thoroughly in the ELV's product design process	Lack of detailed discussion on the integrated design for disassembly with its performance metrics evaluation

Table 1 (continued)

No	References	SM elements	Scope of study	Research method	Key findings	Limitations of the study
47	[61]	Product	A tool for Design for End-of-Life Value	Software prototype (case study)	Proposed the two primary methodologies: recycling function deployment and value analysis	When performing the value analysis assessment, there is a lack of involvement from the customer's perspective in value-added creation
48	[62]	Product	The application of AI to optimize the reuse of automotive components	Analysis and modelling	The artificial neural networks (ANNs) and genetic algorithms can be adopted to solve the design for reuse components	Thesustainability assessment needs to be performed to optimize reuse components' durability and reliability
49	[63]	Product	ELV recovery: process, impact, and research direction	Literature review	The research framework for the ELV recovery concept was proposed with a conceptual approach	The concepts of sustainable development and ELV recovery needs to be enhanced to extend the life cycles of the vehicles
50	[64]	Product	The key element to the vehicle design process	Literature review	Four aspects of the vehicle design process had been developed based on the current situation in ELV Directive	Other key elements need to be identified to meet the latest industry requirement for SM in ELV development

factors; however, the concern on sustainability is still not emphasized.The quality of remanufactured ELV components in emerging nations determined that quality assurance and quality certification aftermarket services are the most notable findings in Malaysia [37]; however, the quality of remanufactured ELV components can be further assessed to meet the customer acceptance to achieve a higher level of assurance in the sustainable remanufacturing industry. The artificial neural network is applied to increase the reliability of the proposed reuse component and material selection as optimization tools to improve the stress analysis of a body-in-white car door [55]; however, the critical performances of the automotive components for reuse need to be assessed to incorporate the SM elements.

An optimization model is developed for disassembly sequences of an engine block using the genetic algorithms method, which can achieve the minimum disassembly time [49]; however, this dissambly process's efficiency was not quantified in terms of actual cost saving or economic benefits. A study of numerous disassemblability approaches for ELV is presented to determine the optimal stage of disassembly to enhance the product recovery [54]; however, the factors that will affect the evaluation of disassemblability selection and its impact on the disassembled product's quality are not discussed in details. The optimal disassembly stage is vital and rigorous disassembly for reuse to increase product recovery in the Malaysian automobile sector [56]. The results are only obtained from three local automotive component manufacturers in Malaysia, which lacks generalization to other ELV stakeholders in the automotive industry. The design framework using a genetic algorithm method is developed to evaluate EOL product disassembly by adopting the principles and guidelines of design for disasembly into design [57]; however, the proposed model is still in the development stage, and more real-life studies need to perform to verify it's applicability. A decision-making software is developed to assess the disassemblability of ELV component's designs, determine their eligibility for recycling, and examine their recyclability [58]. The various critical factors affecting the disassembly cost and time need to be thoroughly assessed to improve economic efficiency. A system dynamics method is proposed to connect the product design approaches with other recovery factors to deal with complicated challenges in the automotive industry [35]; however, the proposed method is still yet to be validated in the actual scenario; thus, this requires further input from industry expert for enhancement.

The disassemblability evaluation methods and functional system requirements are analyzed to assess the impact on various design aspects of automotive components [60]. However, there is still lack of detailed discussion on the integrated product design for disassembly with performance metrics evaluation in the later disassembly stage to enhance the overall design strategy and concept in ELV. The pre-assessment of a chosen automotive component (brake calliper) is conducted to evaluate its conceptual design with the intention of upgradeability using the QFD application [42]. The operational performances of the upgraded parts toward SM can be further improved via the continuous product life-cycle assessment in the actual application stage. An ELV design process and management review were performed to improve the product's recyclability [48]. There is lack of description of the relationship between ELV design protocols and management systems to improve recycling efficiency. The design for the EOL value framework is developed to provide the design evaluation for the vehicle's recyclability in the early design stage [51]. The design guideline for recycling in ELV and the corresponding development process implementation need to be aligned with the established legislation of the EU Directive on ELV. A framework for an integrated recyclability tool is presented to enhance automotive design and development in product recyclability [52]. The framework focuses on the design environment part; it is suggested to incorporate the social and economic dimensions to improve the recyclability decisions.

A tool for design for the environment is proposed for EOL value and recyclability assessment in the automotive industry [61]. The value analysis highlighted mainly emphasizes the economic parameters but lacks involvement from the customer's perspective in value-added creation for economic sustainability. The model is developed to assess the design for automotive components' reuse using AI methods at the lowest costs [62]. The sustainability assessment needs to optimize reused components' durability and reliability. The reuse of automotive components is not adopted by original equipment manufacturers (OEM) on new vehicles but is only used for parts replacement [59]. Factors that affect the adoption of automotive component reuse on sustainable development for product recovery can be explored from the supply chain perspective and demand. A research framework is presented for the ELV recovery concept that incorporates recyclability concerns throughout the product design process [63]. The concepts of sustainable development and ELV recovery in the vehicle development process phase need to be further enhanced to facilitate the automotive manufacturing process. Vehicle designers must address four key EOL requirements during vehicle design and development: design aspects, materials factors, cost, and directive requirements [64]. It is important to explore other critical elements to improve the vehicle design process based on the current ELV development in meeting the industry requirement for SM. The design guidelines for repair and restoration utilizing AM technology for product life-cycle extension are highlighted [29]. The utilization of advanced product design approaches to address the common failure modes in automotive components can be further improved to achieve a higher level of sustainable product development. A preliminary model is developed to assess the effectiveness of ELV recovery in reacting to dynamic changes in the automotive industry [36]. The authors highlighted that this model is still incomplete and lacks relevant data to support the effectiveness of EOL product design strategies.

ELV sustainability issues at the process level

A Java-based prototype GUI knowledge-based system is designed to aid the step-by-step remanufacturing process using brake callipers as a case study [33]. However, the knowledge is only gathered from one local company, which still lacks practical validation on standardizing the process steps in enhancing remanufacturing efficiency. The majority of the respondents from the survey indicated that a comprehensive investigation is needed to evaluate the influence of the remanufacturing process on product quality [53]; however, there is lack of discussion on the standard remanufacturing practices in dealing with sustainable development issues. An integrated processing framework for utilizing ELV waste is proposed for the automotive and construction industries [32]. However, the compatibility of raw materials recovery from both industries needs to be evaluated to enhance sustainable production in the ELV processing business.

ELV sustainability issues at the system level

The research and development of the actual implementation of automotive remanufacturing in Malaysia are still in the infancy stage [15]. The strategic application of remanufacturing concept toward sustainable automotive manufacturing in mitigating the current challenges still needs to be developed. The various industry stakeholders' ELV management practices are examined based on their knowledge and involvement in this field [23]. The sustainable ecosystems for the reverse logistic supply chain in ELV were not emphasized as part of this study's proposed ELV Recycling Zone implementation. The factors that improve ELV recovery in the aftermarket chain are studied [13]. However, there is still lack of detail discussion on the corresponding sub-factors with the sustainable ELV recovery system. A comprehensive performance evaluation method is developed based on the analytic hierarchy process (AHP) to determine the eight key critical success factors for continuously improving Malaysian ELV management systems [11]. There is still lack of essential elements of SM incorporated in the performance evaluation tool on ELV management system implementation. The ELV recovery model is developed based on the identified factors that affect the ELV recovery effectiveness in Malaysia from the various perspectives of five key stakeholders [30]. However, there is still lack of investigation of the identified recovery factors in analyzing the significance of their relationships in the proposed model.

An integrated model is developed to assess sustainable alternatives for effective ELV management [40]. However, this model still lacks a detailed description of the criteria and dimensions used for sustainable alternatives evaluation. A model is developed to choose the sustainable dimensions and criteria for assessing the best compromise ELV's management alternative [39]. Future studies can explore the influential factors affecting criteria selection and add more critical criteria from other sources in this field. A framework containing the factors and items is created for a proper ELV management system in Malaysia [38]; however, this study does not explain the 33 underlying items in these eight key success factors. A survey instrument is designed to assess the success factors in adopting the ELV management system in Malaysia [43]. However, this survey instrument developed is yet to be validated by the experts for the pilot study. The present situation of ELV management is analyzed to promote sustainable growth in ELV for future transformation in Malaysia [44]. However, there is a lack of in-depth discussions on the driving forces and critical inhibitors that can impact the sustainability consideration of the ELV management directive. There is an urgent need for a proper ELV management system to cope with the harmful impacts caused by the ELV issues in Malaysia [45]. However, the study did not discuss the factors affecting the sustainable ELV management system and practices. A framework for the ELV recycling system is developed to highlight the current practices being applied in Malaysia and emphasize the coordination of relevant ELV stakeholders [47]. The proposed framework focused on the overview of ELV system process flow but did not specifically look into a sustainable value chain perspective.

Five main issues are identified in the closed-loop supply chain optimization to address the ELV recycling problems [24]. However, this study did not evaluate these issues' sustainable supply chain performances. The disruptions and sub-factors that affect the supply chain system risks in the automotive remanufacturing industry were analyzed [22]. However, the relevant literature did not support the identified disruption factors in enhancing sustainable supply chain management. There are relatively few models and research focused on automobile remanufacturing operations topics at the system level [34]. Four key issues have been discussed from the findings; however, there is still lack of focus on the remanufacturing stakeholder's analysis in dealing with the sustainable operations issues. The public knowledge and acceptability of ELV adoption in Malaysia are fairly poor [6]. However, there is still lack of focus on suggested solutions to improve the public perception of ELV policy implementation. The public community has a low knowledge of ELV, but the majority have shown positive responses about the ELV implementation in Malaysia [26]. However, there is lack of discussion on sustainable ELV development from the other relevant industry players. ELV initiative must be started to improve the safety features plans to minimize the risk of fatal road accidents [25]; however, there is lack of discussion on the safety standard in ELV with regards to SM elements and policy.

Five challenges with mitigation strategies and two future opportunities have been identified for SM in Malaysia's remanufacturing industries [14]. A comprehensive framework is needed to evaluate the current remanufacturing system performances in terms of SM approach. The government still encounters several challenges when implementing the ELV policy in Malaysia [12]. The proper ELV plan needs to be accomplished with sustainable practices in the automotive ecosystem. More than half of respondents in Japan and Malaysia were doubtful about their readiness to engage in ELV endeavors due to the uncertainty of the ELV concept [41]. However, this study mainly emphasizes the socio-technical perspective but still lacks attention to the economy and environmental elements to improve ELV recovery issues. Public community knowledge of ELV reuse has to be improved to enhance sustainable automotive growth in Malaysia [46]. However, the concept of reuse on ELV can be further explained by emphasizing the challenges and implications of sustainable development issues. A conceptual model of the domestic automotive ecosystem and mapping of the NAP 2009 measures was developed [50]. However, the conceptual model must be practically validated by car users and the industry to improve the feasibility of NAP measures. The PV market in Malaysia is expected to approach saturation in 2024 while the number of ELV continues to rise [10]. However, there is still a lack of discussion for the ELV estimation regarding sustainable development issues and recommendations for future action plans.

Methodology

ELV research development and the implementation of ELV policy are important to develop the strategic roadmap to support the NAP 2020. This study started with the literature review on the overview of the NAP revolution and ELV research development in Malaysia. Since this research aims to study the ELV development issues in Malaysia; Therefore, the search for documents that cover the scopes of ELV and Malaysia was selected as the data collection method. To limit the number of papers selected for review and to identify the most relevant articles, the following search criteria were applied:

- The keywords used to search the relevant publications for review were the combination of "end-of-life vehicle" OR "ELV" AND "Malaysia" using the "OR" / "AND" boolean operators.
- The papers were limited to peer-reviewed English-language publications only.
- The data range was chosen from publication years from 2006 to 2021 (excluding the latest year in 2022).

In the first stage of paper collection via the Google Scholar (https://scholar.google.com/) database, 1730 papers appeared in the search results. The identification and screening of the suitable papers were conducted using the steps explained as follows:

1. The document's 'title, abstract, and keywords' were screened to decide whether it is relevant to the ELV research subjects and suits the scope of review during the initial screening.
2. Papers that are mismatched or not related to the field of study in ELV, duplication and do not fulfill the scope of review criteria were removed.
3. Subsequently, the suitable papers found were read through the entire content to check whether they had included Malaysia and ELV as key focus studies in fulfilling the research scope for further review.

After the screening process in Google Scholar, 43 papers were finally selected for detailed reading and thoroughly reviewed. Next, the same steps were adopted for documents searched within 'All fields' in the Scopus (www.scopus.com) database, generating 374 papers in the search results. After the screening process, another seven pertinent documents were chosen for further review. In addition, literature searched within 'All fields' in the Web of Science (https://clarivate.com/webofsciencegroup/solutions/web-of-science/) database was performed by applying the above steps, generating 240 papers. After the screening process, 15 suitable papers were found; however, these papers were duplicated with the previously chosen papers in Google Scholar or Scopus. Finally, altogether 50 papers were selected and reviewed in this study, as listed in Table 1.

Content analysis facilitates observational research by allowing researchers to evaluate the symbolic content of all sorts of recorded documents in a systematic manner [65]. A structured literature review was conducted using the content analysis method on these 50 papers to discover the critical issues and research gaps associated with ELV development in Malaysia. The sustainable topics for these selected papers were further grouped and assessed based on the three innovative SM (product, process, and system) sub-elements. This is followed by a discussion of the ELV policy and public knowledge of ELV development for SM in Malaysia. Lastly, the integrated conceptual model was proposed as guidance to mitigate the ELV development issues in Malaysia.

Results and discussion

The necessity for SM in ELV has been prompted by scarce resource supply and the adverse environmental and socio-economic repercussions of traditional manufacturing. Integrating SM elements: products, processes, and systems in ELV sustainability are critical for resource conservation. SM would require innovation at all stages of the product, process, and system levels in manufacturing by undergoing multiple life cycles to enhance the sustainable value chain [66]. A shared responsibility framework is proposed to establish a business model with a stakeholder engagement structure to strengthen the sustainability of ELV management and material recovery in India [1]. A sustainable ELV management using a closed-loop supply chain (CLSC) strategy with the CE model is developed to deal with ELV issues and reduce waste in Qatar [67]. A systematic review is presented to identify the factors that will enhance the automotive supply chain's sustainability and improve the sustainable management performance of the Chinese ELV recycling industry [68]. Turkish automakers are accountable for the free collection of ELV from customers to rehabilitate old components in the industry under ELV regulations; therefore, a CLSC network design is created to handle the material flow of ELV [69].

In Malaysia, the first introduction of the NAP 2006 and the hot debate about ELV have been underway since 2006. However, the sustainable awareness of ELV recycling among Malaysia's public and industrial players is still low. ELV waste management is poorly managed in Malaysia due to the weak regulatory framework [44]. Therefore, there is a need for Malaysian manufacturers and government agencies to focus on design for remanufacturing in automotive and promote the growth of automotive research and technology to achieve policy optimization [15]. Malaysia can review the ELV recycling strategies and adopt the best practices of SM from those countries that have achieved great success in this area prior to developing its framework for enacting the ELV policy. Table 2 shows the literature studies of ELV development in Malaysia that are classified and adapted based on the three innovative SM elements [66]. These innovative SM sub-elements are synthesized based on the nature and aspects of the literature's content to explore various insights of SM in ELV development. The proper classification of sub-elements in SM is essential for the policy makers and industrial players to work on effective ELV strategy planning and implementation framework to deal with the underlying issues of ELV in Malaysia.

Table 2 Classification of innovative SM sub-elements for ELV development in Malaysia (adapted from [66])

SM elements	Category of sub-elements in SM	References
Product	Sustainable materials/components for products	[27]; [28]; [31]; [37]
	Advanced product design	[29]; [55]; [62]
	Effective product disassembly	[49]; [54]; [56]; [57]; [58]; [60]
	Design for reuse/recycling/remanufacturing/recovery	[42]; [51]; [48]; [52]; [59]; [61]; [63]; [64]; [35]; [36]
Process	Sustainable processes	[53]
	Integrated processes	[32]; [33]
System	Sustainable management systems	[6]; [23]; [25]; [26]; [14]; [13]; [11]; [30]; [12]; [38]; [39]; [40]; [41]; [15]; [43]; [44]; [45]; [46]; [47]; [50]; [34]; [10]
	Supply chain optimization/integration	[24]; [22]

Product innovation in sustainable ELV development

ELV recycling companies in emerging and developing countries confront major challenges in the systemic recycling of ELV in enabling the recovery of materials and parts or components to maximize economic advantages according to environmental standards [70]. The major hurdle to optimizing part remanufacturing could be affected if the returning and processing of components or materials cannot be established effectively for SM. Therefore, selecting sustainable materials or components from ELV is vital to producing value-added products. The critical literature review shows that a thorough quality assessment of the sustainable remanufactured or recycled ELV components is still lacking. The product quality of automotive's components remanufactured product, which fulfill the practical criteria, is a notable indicator of success in remanufacturing [71]. The remanufacturing company must emphasize the essence of quality management in developing ELV remanufactured products. Developing countries like Malaysia would need knowledge-based assistance and strong technical know-how to encourage remanufacturing while ensuring that the components remain in high-quality performance [33]. Therefore, the detailed assessment of the compatible material selection should be well incorporated into the product design and development stage to optimize the automotive vehicle recyclability in the downstream manufacturing processes to fulfill the customer requirements.

The advanced product design by applying the latest Industry 4.0 technological tools is receiving great attention from industry practitioners to improve the product's efficiency and competency level. The ELV part design for recycling or remanufacturing needs to be integrated with the feasible Industry 4.0 technological elements and tools application in technical data sharing. This can facilitate the effective connection with the downstream processes to improve the product's quality and circularity. Employing modern and emerging digital technologies to strengthen relationships between product manufacturers, users, and remanufacturers are critical to establishing sustainable remanufacturing development in Industry 4.0 [72]. However, data about remanufacturing and product design-process systems are currently proprietary, and technical know-how is shared sparingly among the industry players in the remanufacturing and aftermarket industry. Therefore, it is critical to highlight how the Industry 4.0 technological enablers and the smart remanufacturing tools can trace the past data of incoming core or EOL products from the sharing system to optimize its remanufacturability.

Effective product disassembly involves adopting feasible disassembly methods and process sequences to deal with the returned product's complexity challenges. Disassembly techniques are one of the crucial factors in the Chinese ELV recycling business [68]. An appropriate disassembly sequence of ELV that combines the destructive disassembly and non-destructive approach is developed to provide a better guide for ELV recycling economic growth via the cost–benefit analysis [73]. The most significant factors in the development of the recycling industry are regulations on automation factories, disassembly procedures, and value mining [68]. The effective recycling and disassembly elements must be well considered when implementing the ELV concept in the product design stage, especially with proper disassembly evaluation [60]. However, the existing research focusing on effective product disassembly to enhance the ELV recovery rate in Malaysia is still limited to the past 10 years. Product disassembly is still largely dependent on manual labor jobs. The application of human–robot collaboration or human–machine interaction can solve complicated tasks in product disassembly operations. Therefore, there is a strong need to integrate Industry 4.0 technological tools and techniques to improve the efficiency of ELV product disassembly process steps.

The design for reuse/recycling/remanufacturing/recovery concentrates on sustainable techniques application to improve the product life-cycle development in the subsequent manufacturing stage. The challenges that arise during the remanufacturing process could be minimized if good decisions are made during the design phase [74]. The remanufacturing applications could only be advantageous and competitive if the products are intentionally made or designed for remanufacturing in the first place [75]. Therefore, the ELV treatment should focus on product optimization by integrating the design for recovery techniques into the vehicle manufacturing process. The significant external and internal operational factors affecting design for remanufacturing integration are management engagement and relationships between OEM and engineers in the product design phase [76]. From the literature review, the product recovery or recyclability issues for SM in ELV treatments are still a major concern. Design aspects of ELV components should consider the customer perspective in product specification requirements and perform stakeholder analysis to enhance the product life cycle for sustainable value creation. The vehicle design and development guidelines can incorporate green manufacturing elements to meet the latest ELV industry requirements and practices in SM.

Process innovation in sustainable ELV development

Adopting innovative approaches in green product remanufacturing can greatly increase sustainable process performances while raising the manufacturer's recovery rate in a CLSC [77]. The product cost variations are directly connected to the process uncertainty, particularly in the current dynamic manufacturing environment in cores collection [78]. The essential factors in increasing ELV recovery efficiency are advancing the processing technologies, optimal government subsidies, and public awareness of environmental protection [79]. However, it is noticeable that there is still limited study on implementing standard ELV practices and assessing technical competency for specific ELV treatment processes in Malaysia. The systematic procedures and feasible techniques need to apply to existing ELV remanufacturing or recycling to evaluate the key process performance indicators. The integrated proposing framework developed to recycle the ELV for building products is an innovative approach for ELV waste management across various industries [32]. A feasible approach for decreasing the ELV disposal issues and minimizing the raw material utilization can promote the ELV process development in line with the applicable regulations in Malaysia.

System innovation in sustainable ELV development

ELV management is critical for resource circularity, environmental preservation, and CE development [80]. From the critical literature analysis, Malaysia's reverse logistic network system still faces difficulties in dealing with sustainable operations issues. There is lack of systematic ELV management in Malaysia, and very few ELV are transported for recycling activities. A shared responsibility-based framework is developed to investigate and create a business concept with the key stakeholder engagement strategy to enhance India's ELV management sustainability [1]. A dual-cycle ELV recycling and remanufacturing system are created to describe the collaborative relationship among the ELV stakeholders under the extended producer responsibility policy [81]. It is critical to note that any recycling system needs to tailor to each country's specific needs and environments [82]. Therefore, there is a strong need to develop an implementation framework for enhancing ELV development toward SM in Malaysia. The roles of ELV interested parties involved and influenced in the sustainable management system should be thoroughly assessed via the stakeholder's analysis to formulate the strategy roadmap and enhance the cooperation to achieve a win–win situation.

A critical assessment of existing literature reveals that several studies have been conducted primarily to address ELV recovery management systems in Malaysia. However, none of these studies presented a practical implementation framework to optimize and streamline the end-to-end solutions of ELV in the supply chain network system. The studies on the supply chain as a whole system in the automotive sector are still in the early stage [83]. Several studies have proposed valuable strategies to deal with ELV management supply chain challenges [84]. However, uncertainties in managing the consistent ELV core return are still the most prominent concern for industry stakeholders in Malaysia. There is no alignment on the standardized procedures established for ELV supply chain optimization to demonstrate the best industrial practices in the automotive sectors. Therefore, it is essential to thoroughly understand Malaysia's existing ELV recycling supply chain and demand, including its underlying issues and disruption risks. The Malaysian government is presently studying a suitable approach to implement an ELV management policy and is looking at establishing an ELV framework by 2025 [85]. Therefore, the future proposal of a sustainable ELV implementation framework to streamline the reverse ELV value chain network through recycling and remanufacturing is highly required to resolve the ELV issues and optimize the automotive components' reusability.

ELV policy and public knowledge in sustainable ELV development

ELV policy and public awareness are essential in the ELV recovery management system. The public survey results showed that most respondents still lack exposure to ELV laws and are unwilling to pay more on disposal fees [6]. Most survey respondents agreed with the concept of a vehicle age restriction regulation based on their economic stability (income level and car status) and vehicle age factor [12]. The vehicle owners' attitudes about vehicle maintenance are likely impacted by the financial situation and regional factors (urban or rural) in mapping to the NAP 2009 measure No. 12 [50]. The Malaysian government still confronts some hurdles in adopting the ELV policy in the country. More than half of respondents in Japan and Malaysia communities were doubtful about their desire to engage in ELV activities, indicating a lot of scepticism about the concept of ELV in reuse and remanufacturing [41]. Close cooperation between government and industry is vital in increasing public knowledge and understanding to ensure the compelling implementation journey of ELV recovery. Most public communities had little awareness about ELV; however, most respondents agreed that ELV implementation should be carried out in Malaysia [26]. The sustainable growth of remanufacturing businesses in Malaysia can encourage other emerging economies with similar business prospects to adopt SM practices [14]. However, the ELV policy is still not in place in Malaysia's automotive environment [86]. The public acceptance of ELV policy enactment from a vehicle safety viewpoint is essential, considering the consumers' economic implications [25]. Therefore, the implementation of the ELV policy in Malaysia needs to be thoroughly explored to assure that the public can buy-in early and effectively embrace it.

Integrated conceptual model of innovative SM elements

ELV-related laws enacted in other countries were studied, and several recommendations were made to deploy ELV policy in Malaysia based on regulation and public perception [6]. This indicated that the public's voice and readiness are essential to the government when conducting the study to implement ELV policy and regulations to address the ELV issues. A preliminary review on implementing an efficient CLSC system for ELV recycling suggested that future similar research can focus explicitly on the ELV remanufacturing aspects from different viewpoints in Malaysia in line with the NRP [24]. Manufacturers are permitted to use whichever techniques they like due to the lack of a clearly defined ELV policy [25]. Hence, the standard remanufacturing process as part of ELV recovery practice in Malaysia could not be immediately put into progressive action. The public still perceives that remanufacturing is a type of reuse that does not create value-added operations and has poor profit returns. The government and industry should develop and implement more ELV campaigns related to reuse to increase public knowledge, education, and in-depth understanding of this subject [87].

The sustainable awareness and ELV life-cycle thinking among the public and industrial players are still low. The essential factors to increase the ELV recovery efficiency are advancing processing technologies, optimizing government subsidies, and improving public awareness of environmental protection [79]. The public knowledge and understanding of ELV are critical in implementing the ELV policy for SM in the automotive industry. Therefore, the conceptual model of innovative SM elements with integrated ELV policy and public knowledge was proposed in this study to enhance sustainable ELV implementation in Malaysia, as shown in Fig. 3. From the critical literature analysis, these three SM elements were examined independently rather than as a whole in previous ELV studies and without proper synchronization. Past studies in the automotive industry addressed the sustainable ELV research development issues; however, there is a missing link and lack of proper synchronization with the established NAP in Malaysia. This situation is understandable as the NAP 2020 has no mention of the mandated ELV policy. Therefore, the implementation of relevant ELV regulatory framework and future roadmap should be

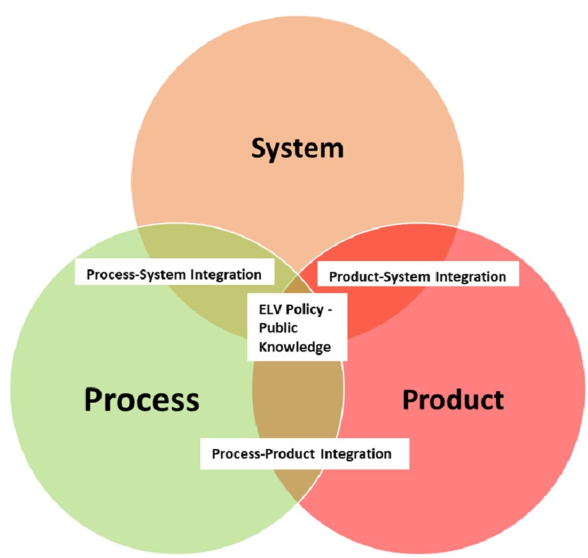

Fig. 3 Conceptual model of SM elements with integrated ELV policy and public knowledge

seriously considered. This conceptual model of integrated SM elements embedded with the ELV policy and public knowledge elements could guide the ELV stakeholders in planning the strategic directions and actions for future industrial applications in line with the latest NAP.

Conclusion

The ELV issue is becoming a hot topic in the Malaysian automotive industry. This study critically assesses ELV research development issues to identify the research gaps. By performing a thorough content analysis based on an extensive literature evaluation of 50 selected papers, this study underlined how Malaysian ELV subjects developed from 2006 to 2021, highlighting the underpinning issues regarding SM. According to the critical review findings, several prospects of key research interests were recommended to improve ELV management in Malaysia as follows:

- The product recovery for SM in ELV treatments are still a major concern. Design aspects of ELV components should consider the customer perspective in product specification requirements and perform stakeholder analysis to enhance the product life cycle for sustainable value creation.
- The specific study of sustainable and integrated processes in ELV treatment is mainly overlooked in the current research. Future studies need to improve the performance metric in ELV remanufacturing process steps.
- There is still a lack of a detailed ELV implementation framework equipped with documented procedures and appropriate industrial practices in the ELV ecosystem to optimize the ELV supply chain. A sustainable implementation framework is urgently needed to standardize and create the reverse ELV value chain network.
- ELV policy is yet to be enacted in Malaysia, and public awareness of ELV is still deficient. Future studies can focus on testing the interrelationship of ELV policy and public knowledge by identifying the critical moderating/mediating variables to evaluate their impact on the ELV sustainable management implementation.
- Previous studies in the automobile sector examined the difficulties of sustainable ELV research development; nevertheless, there is a weak connection and a lack of adequate alignment with the current NAP in Malaysia. The implementation of relevant ELV regulatory framework and future roadmap should be seriously considered.

The proposed conceptual model, which integrates the three critical sub-elements of SM (product, process, and system) with effective ELV policy and strong public knowledge, will facilitate ELV implementation in the Malaysian automotive industry in line with NAP. This critical review provides scholars, industry players, or policy makers interested in the ELV field with references and valuable insights into designing a sustainable implementation framework or policy for Malaysia's automotive ecosystem. Other developing countries can benefit by identifying the current state of ELV management practices and adopting the proposed conceptual model to deploy the right strategy and mitigate the underpinning ELV issues. The key results will support the ELV stakeholders in implementing appropriate actions to improve their present ELV businesses following the latest NAP 2020 in readiness to enact potential ELV directives or legislation in Malaysia. In the early phases of attempting to adopt ELV in Malaysia, firms will benefit from the study's insights to enhance SM applications and navigate the proper action plan. The present research's article selection is confined to the Google Scholar, Scopus and Web of Science databases, which is a limitation of this study. This study does not include other related papers beyond these databases. A detailed analysis could be conducted by expanding the large sample size of articles and having documents from various sources to improve the reliability of the findings. An in-depth study is needed to establish a comprehensive SM framework for smooth ELV management system implementation with the integration of Industry 4.0's technological elements and aligned with the Malaysian government's policy. Since the global topic of electric vehicle (EV) development is gaining popularity and has been emphasized in the NAP 2020, it is recommended that future EOL management can focus explicitly on this area from the SM perspective. Future real-life case studies can be conducted to verify the feasibility of this proposed integrated conceptual model by including the critical success factors and examining their inter-relationships to sustainable ELV development performances.

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