

## Article

# Development, Critical Evaluation, and Proposed Framework: End-of-Life Vehicle Recycling in India

Zambri Harun <sup>1</sup>, Altaf Hossain Molla <sup>1,\*</sup>, Mohd Radzi Abu Mansor <sup>1</sup> and Rozmi Ismail <sup>2</sup>

<sup>1</sup> Department of Mechanical and Manufacturing Engineering, Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia (UKM), Bangi 43600, Malaysia

<sup>2</sup> Faculty of Social Sciences and Humanities, University Kebangsaan Malaysia (UKM), Bangi 43600, Malaysia

\* Correspondence: altafhossain1994@gmail.com; Tel.: +60-1123-307-859

**Abstract:** Over the last couple of decades, the automobile sector in India has seen dramatic growth, following the phenomenal booming of engenders rapid proliferation of end-of-life vehicles (ELVs). Therefore, efficient and sustainable handling of ELVs is paramount. India has been striving to establish a practical regulatory framework to handle ELVs sustainably. This study explores India's current ELV recycling system to promote sustainable development. Subsequently, this article evaluates the present ELV recycling system to determine the existing issues in ELV recycling to prevent failure and enhance and standardize the processes involved in ELV recycling to achieve the optimum standard for product and process quality. This paper proposes pragmatic frameworks and offers recommendations for setting up an efficient ELV recycling system to resolve current issues and expedite sustainable development. This study has been performed through a mixed-method approach; a literature and policy review accompanied by detailed structured interviews with major stakeholders and industrial visits. This investigation reveals that India's ELV recycling system is at the embryonic stage and struggling against numerous inherent impediments. However, the proposed frameworks, together with practical recommendations, provide a paradigm for expediting materials recycling from ELVs and resolving perennial issues. This research may assist the government of India in implementing any upcoming regulatory and legal framework.

**Keywords:** end-of-life vehicle (ELV); recycling; framework; sustainable development



**Citation:** Harun, Z.; Molla, A.H.; Mansor, M.R.A.; Ismail, R. Development, Critical Evaluation, and Proposed Framework: End-of-Life Vehicle Recycling in India. *Sustainability* **2022**, *14*, 15441. <https://doi.org/10.3390/su142215441>

Academic Editor: Paolo Rosa

Received: 26 September 2022

Accepted: 3 November 2022

Published: 21 November 2022

**Publisher's Note:** MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.



**Copyright:** © 2022 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

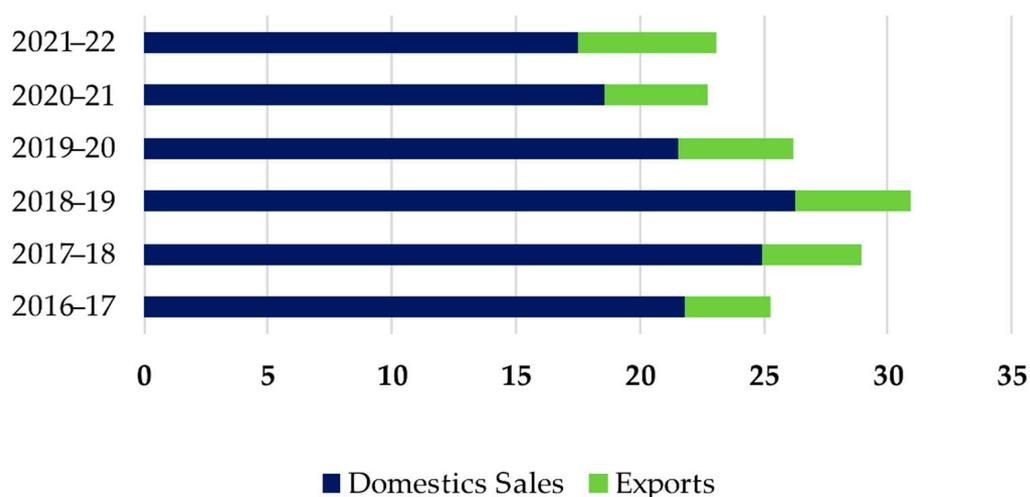
## 1. Introduction

An end-of-life vehicle (ELV) is a vehicle that must be disposed of since it is no longer functional, owing to a mechanical issue [1]. ELV recycling has been particularly resonant in recent decades [2], as ELV incorporates a plethora of precious metallic and non-metallic substances [3–5]; these are economically significant and industrially essential [6,7]. As well as having substantial salvage value, it also encompasses noxious pollutants that impose threats to society in a myriad of aspects, to a substantial degree [8–10]. Hence, addressing ELVs in an effective and sustainable way is imperative. India has witnessed a phenomenal expansion of the automobile industry, rapid economic prosperity, and extensive industrialization, prompting an overwhelming demand for vehicles. Consequently, the number of cars on the road is proliferating, eventually contributing directly to the corresponding ELVs. In 2021–22, India manufactured 22.9 million vehicles encompassing passenger, commercial, two-wheeler, three-wheeler, and quadricycle vehicles; India's domestic and import automobile market is snowballing significantly to 17.5 million domestic sales and 5.6 million exports, respectively [11]. Table 1 enumerates vehicle production in India from 2016 to 2022. Figure 1 depicts India's domestic sales and export of automobiles from 2016 to 2022.

**Table 1.** Automobile production in India from 2016 to 2022 in millions [10].

Category	2016–17	2017–18	2018–19	2019–20	2020–21	2021–22
Passenger vehicles	3.8	4.02	4.028	3.42	3	3.6
Commercial vehicles	0.81	0.895	1.1	0.75	0.624	0.8
Three-wheeler	0.78	1.02	1.27	1.1	0.614	0.75
Two-wheeler	19.9	23.15	24.49	21	18.34	17.7
Quadricycle	0.00158	0.001713	0.005388	0.006	0.003	0.004
Total	25.3	29.09	30.91	26.35	22.65	22.93

### Domestics Sales & Exports (in Millions)

**Figure 1.** Domestic sales and export of automobiles in India from 2016 to 2022.

India strives to supply virgin materials to its automobile sector as the natural resources are depleting dramatically due to extensive extraction activities [12]. Scrap vehicles contain many distinct materials that are economically viable and industrially valuable; it also incorporates a series of potentially detrimental substances and harmful components that potentially causes environmental pollution [13,14]. Through an effective and sustainable regulatory framework, ELVs can be recycled and reused; consequently, they can act as a secondary source of materials to occupy the raw materials' deficiencies in industries [14–16], and the incorporated deleterious substances that can contribute to pollution can be disposed of effectively to mitigate the environmental impact [17–19]. India's current ELV recycling system is exceptionally unorganized, and informality in this sector is prominent [20]. The absence of practical and effective frameworks for recycling ELVs in India thwarts the development and degenerates environmental issues by contributing to greenhouse gases emission and land pollution [21]. The material extraction and the recycling rate are limited and below the standard; only 7 % of aluminum and 76% of iron recovered from ELVs have been successfully recycled [22]. The recycling industries are not well-equipped with advanced technologies that enable them to recover and recycle certain economically valuable and rare materials, resulting in losses of these critical metals [23].

The strict law, accompanied by a stringent policy and practical guidelines, is required to establish an effective ELV recycling system to improve the materials recovery rate, reduce energy consumption, mitigate greenhouse gas emissions, and eventually ensure road and vehicle safety [24]. Countries such as China, Japan, the EU, and the USA have well-defined laws and policies regarding ELV recycling that enables a well-established and well-built ELV recycling system [25,26]. Still, India does not have stringent regulations relating to ELV recycling, even though India has taken specific rudimentary initiatives. India's ELV recycling system is predominant in the informal sectors, which are the units engaged in

ELV recycling with the primary objective of maximizing economic benefits [22]. Most ELVs are not dismantled environmentally soundly in their practices as they disregard any standard guidelines. The final product of ELV recycling, automotive shredder residue (ASR), is disposed of without proper treatment, even though ASR is metal-rich and contains significant salvage value [10,27]. Additionally, little is known about their operations. In this regard, well-defined laws and policies are required to set up an environmentally sound framework and procedure to promote sustainability in ELV recycling [28,29].

Conspicuously observed, researchers have performed an insignificant number of studies on ELV recycling in India to elucidate the ELV recycling system's current status and develop a comprehensive understanding of how the ELV recycling system works in different parts of India. This development, in a sense, is instrumental in enhancing the material extraction rate from ELV by preserving the environment and conserving natural resources [30]. It will educate and make individuals aware of ELV recycling promoting sustainable development for a thriving and prosperous future. A limited number of evaluative studies have been performed on India's ELV recycling system to address the perennial and persistent challenges in ELV handling, enhance and standardize the process, prevent failure, and promote sustainability [12]. This creates a knowledge gap that necessitates a deeper investigation into this issue. Although few research studies have proposed a framework for ELV recycling, these studies concentrate on one ELV recycling hub in a state in India. Hence, the lack of a comprehensive and inclusive study that investigates the significant number of ELV recycling hubs across India before proposing a framework is evident in the literature, which creates a severe lack of consideration [22]. The absence of practical and beneficial suggestions for future strategies to resolve the persistent issues in ELV recycling from experts and research scholars is quite apparent.

Numerous research and knowledge gaps have been identified in the ELV recycling system in India. This study is inspired in response to the challenges that India's ELV system is struggling against. This study investigates the current ELV recycling system in formal as well as informal ELV recycling sectors in India, along with shedding light on laws and policies regarding ELV handling in India to develop a comprehensive understanding of how the country's formal and informal ELV recycling sectors operate and stringency of India's rules and policies regarding ELV recycling. This paper critically evaluates the present ELV recycling system to determine the existing issues in ELV recycling to prevent failure and enhance and standardize the processes involving ELV recycling to achieve the optimum standard for product and process quality. This study also suggests a pragmatic framework and makes recommendations for setting up an efficient ELV recycling system to resolve the current issues and expedite sustainable development. This research adopts an explorative method to meet the aims of this study, as field investigations, together with the interviews with stakeholders, are instrumental in unveiling the ground-level practices and persistent issues and recording the attitudes and aspirations of stakeholders. The suggested frameworks, along with offered recommendations, may facilitate the stakeholders involved in ELV recycling to enhance the materials recovery and recycling rates from ELVs. This study may be significant in India's ELV recycling and have a profound contribution to recycling sectors, society, and the environmental aspect as this study emphasizes resource recovery and sustainability. This research may assist the government of India in implementing any upcoming regulatory and legal framework and eliminate the informality from the ELV recycling sector.

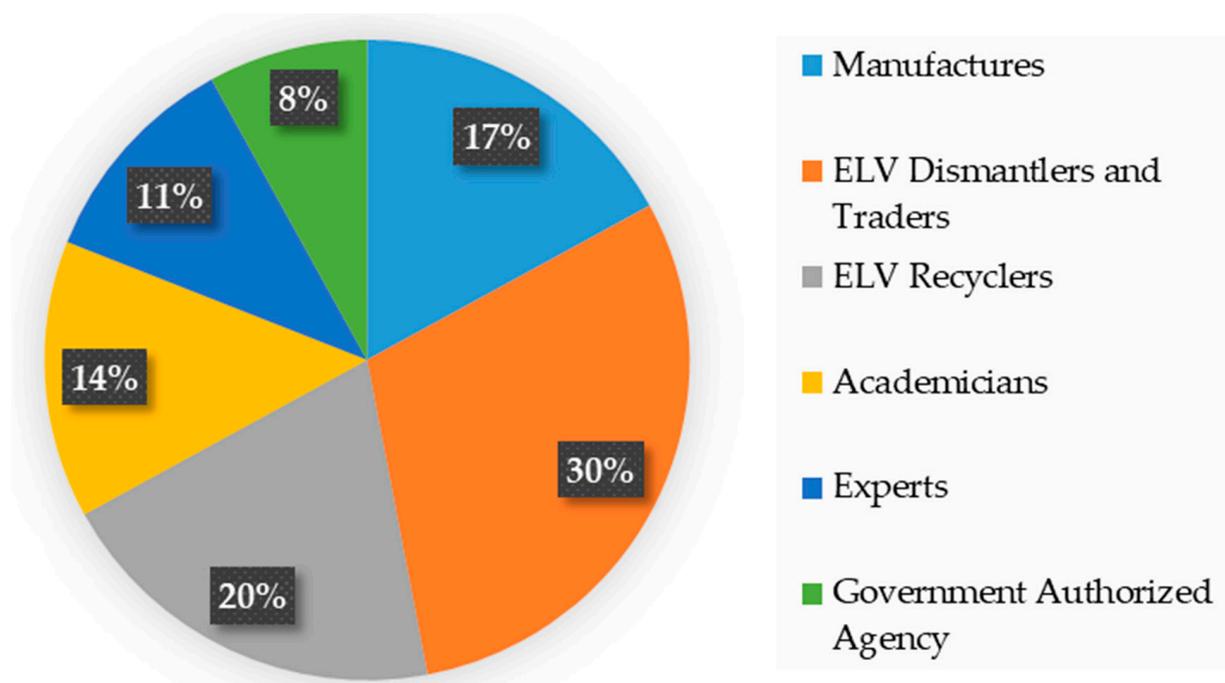
## 2. Methodology

This study delves into the current scenario of ELV recycling systems in India by adopting an explorative and integrated bottom-up approach. The research is based on the original primary as well as secondary research. Through primary research, this study has obtained valuable information, data, and insights and recorded the current practices to meet the aims of the study, while secondary research involves gathering the data and information from previously conducted studies in different countries to provide a foundational

understanding of this research. Both qualitative and quantitative approaches have been employed in primary research.

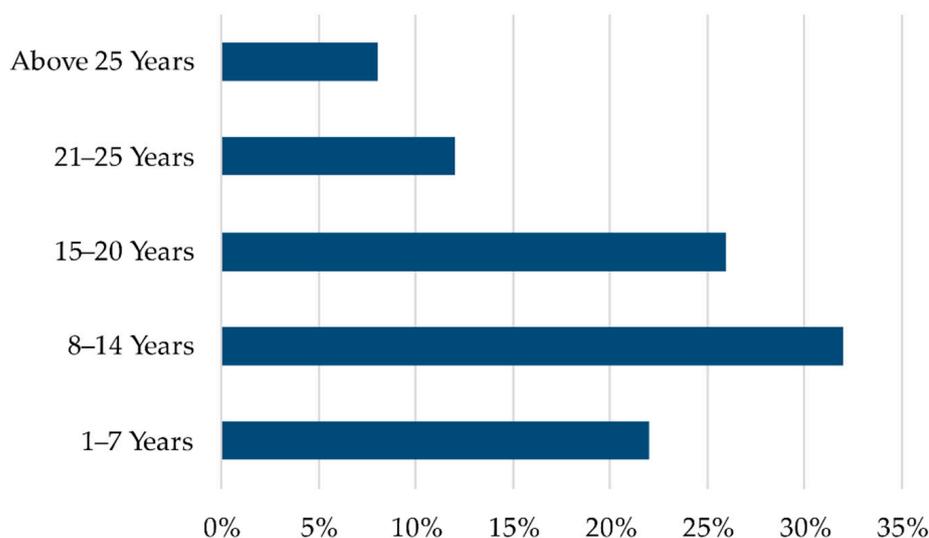
### 2.1. Research Design and Sampling

This research aims to elucidate the current status of the ELV recycling system in India, critically evaluate India's present ELV recycling sector, propose pragmatic frameworks, and offer recommendations for future strategies for setting up an efficient ELV recycling system based on Indian values. This paper concentrates on five influential Indian automobile sectors, namely, Kolkata, Chennai, Mumbai, Delhi, and Jamshedpur, to understand the current practices of ELV handling in India in a broader aspect. This research employs a mixed-method approach incorporating quantitative and qualitative techniques to achieve its objectives. The concerned key stakeholders, formal as well as informal, encompassing manufacturing industries, automobile organizations, environmental protection boards, formal sector recyclers, transport department authorities, ELV traders, dismantlers, third-party vendors, workers, and academicians have all interacted with a structured questionnaire reviewed and approved by prominent research scholars in the ELV recycling field as well as government authorized agencies. There have been interactions with a total of 537 selected individuals. Figure 2 shows the interviews of all key stakeholders involved in ELV recycling.



**Figure 2.** Interview composition involving stakeholders.

Figure 3 depicts the years of working experience of the stakeholders in the ELV recycling sector. The primary aim of these interviews was to apprehend and understand the status of the ELV recycling system, existing persistent problems in ELV recycling concerning the law and policy, technology, skills, and information of the ELV recycling system, since the comprehensive knowledge of these critical elements is of paramount importance to critically evaluate the present ELV recycling system in India and, consequently, address the perennial issues regarding ELV recycling system in India.



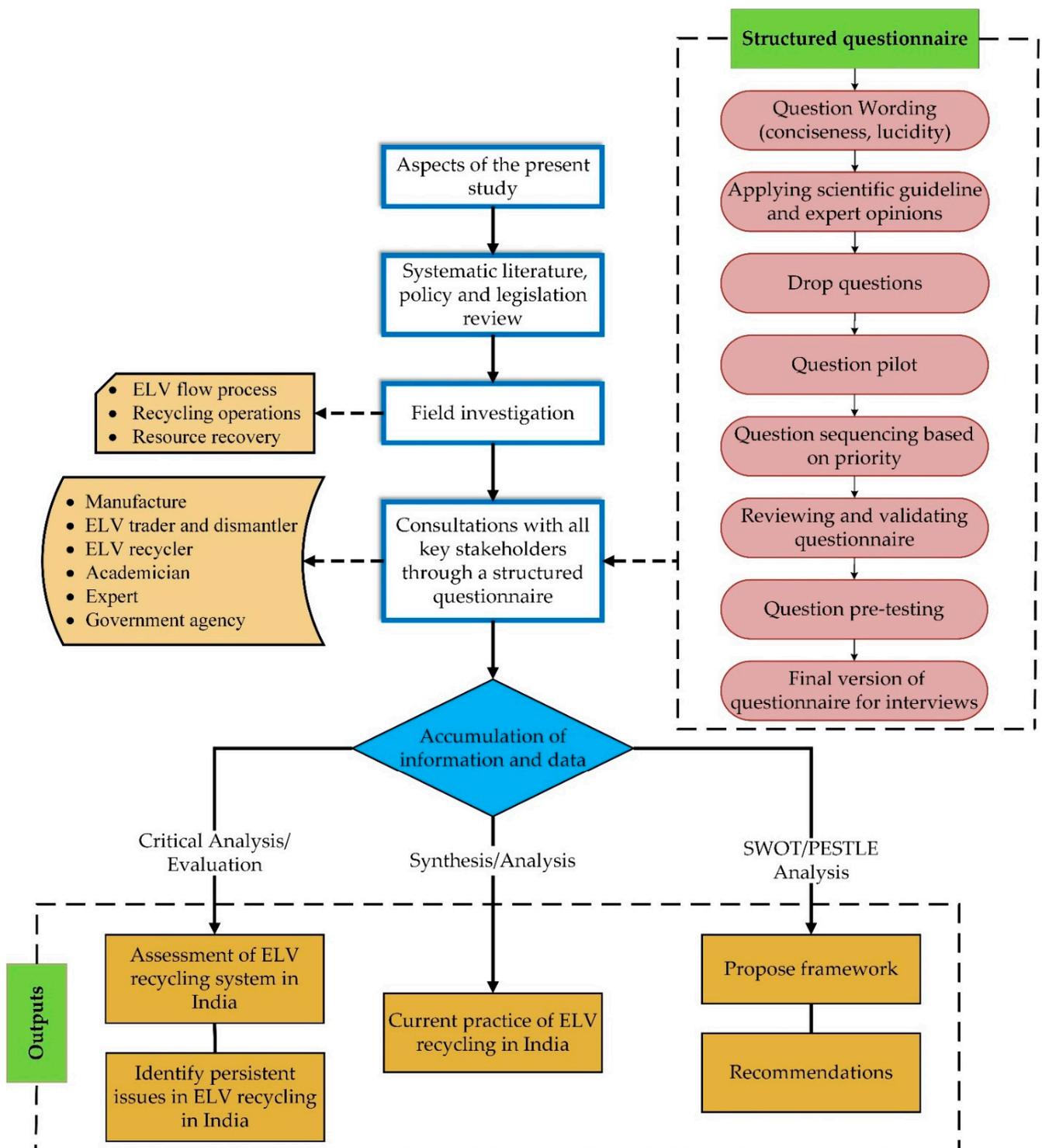
**Figure 3.** Years of working experience in the ELV recycling sector.

### 2.2. Qualitative Data

Through systematic interviews and focus group discussions (FGDs) with all crucial stakeholders involved in the ELV recycling system, guided by a structured questionnaire, coupled with a thorough field investigation of the five mentioned automobile hubs, respectively, we have obtained insights, information, data, and experience regarding the current practice of ELV recycling in different automobile hubs in India in a broader aspect. The obtained information and data are organized systematically for analysis. This research has performed thematic and narrative analyses to interpret and analyse the qualitative data. Based on this knowledge, information, and expertise, this investigation addresses the current issues pertinent to ELV handling through critical analysis to prevent failure and enhance and standardize the processes involving ELV recycling to achieve the optimum standard for product and process quality. Qualitative research is instrumental in exploring current practices and issues and offering recommendations [31].

### 2.3. Quantitative Data

Quantitative data was instrumental in corroborating these research findings. We have collected quantitative data through a standard questionnaire recommended and approved by preeminent research scholars in this contemporary epoch by administering the questionnaire to the crucial stakeholders involved in ELV recycling. The selected people (based on their expertise and insights) in five automobile hubs have responded to the questionnaire. The obtained data and information through quantitative research are organized systematically for analysis. This paper has conducted a descriptive analysis to interpret the quantitative data. The acquired data buttresses findings, assists in critical analysis, and proposes frameworks for ELV recycling in this paper. This data is imperative for our ongoing evaluative project about India's ELV recycling system, and this article is a part of that project. Quantitative research is essential for generating objective data [32]. Figure 4 represents the general methodology of this study.



**Figure 4.** The study's general methodology.

#### 2.4. Secondary Research

Secondary research was indispensable to developing a fundamental understanding and knowledge of the ELV system in India and the other countries that already have a well-established ELV recycling system. Through an extensive literature survey, we have developed the foundation of this study. India's laws and policies regarding end-of-life vehicles have been studied from the literature to provide clear information regarding government directives towards automobile dismantling procedures. This study also proposes pragmatic

frameworks for setting up an efficient ELV recycling system in India based on Indian values to encounter the persistent problems in ELV handling [33,34]. An extensive literature review and a regulation review have been conducted to perform Strength-Weakness-Opportunity-Threat (SWOT) and Political-Economic-Social-Technological-Legal-Environmental (PESTLE) analysis; this is instrumental in proposing an efficient ELV system and design, re-built and implementing a new policy regarding ELV handling. Literature reviews regarding the advanced countries with efficient ELV systems, together with insights acquired from practical interactions with key stakeholders involved in ELV recycling, this article makes pragmatic recommendations to enhance the materials recycling rates and expedite sustainable development.

### 3. Status Quo of End-of-Life Vehicle Recycling in India

#### 3.1. Law and Policy

ELVs are an essential secondary source of materials [35–37]; in contrast, they contribute significantly to environmental pollution as they contain harmful substances [38,39]. The requirement of stringent regulations and a practical regulatory framework is instrumental to the handling and properly disposing of ELVs [40–42]. At this moment, India does not have strict rules regarding ELV recycling. In contrast, the developed and advanced nations, namely Japan, the EU, and the USA, already have well-established robust regulations that compel the last owner to recycle the scrap vehicle [21,43,44]; consequently, through a regulatory framework, they dispose of scrap vehicles in environmentally sound ways and recover higher values from ELVs [45]. Even though the existing policies and regulations governing the ELV recycling system and the environment are lenient and limited, the Indian government understood the need for comprehensive laws to handle ELV recycling, waste recycling, protect the environment, and promote sustainable development. Hence, the Indian government has taken a few initiatives, but these have not sufficed. The legislated statutes and policies the Indian government has taken so far are listed in Table 2.

**Table 2.** The list of recycling and environmental protection regulations in India.

Law	Year	Vision/Mission
Water (Prevention and Control of Pollution) Act	1974	• To control pollution and protect the environment
Air (Prevention and Control of Pollution) Act	1981	• To increase the quality of air and mitigate the pollution level
Environmental (Protection) Act	1986	• To protect the environment
The Central Motor Vehicles Act	1988	• To provide a regulatory framework for the registration and deregistration of vehicles.
The Hazardous Wastes (Management and Handling) Rules	1989	• To dispose of the wastes in environmentally sound ways.
The Municipal Solid Waste (Management and Handling)	2000	• To dispose and recycle solid waste in cities
The Ozone Depleting Substances (Regulation and Control) Rules	2000	• To protect the environment
The Batteries (Management and Handling) Rules	2001	• To recycle batteries and promote sustainability
The National Environment Policy	2006	• To legalize and boost the informal sector for collecting and recycling various materials
The National Action Plan for Climate Change	2009	• It aims to find solutions to environmental problems in India
The e-waste (Management and Handling) Rules	2011	• To recycle and dispose of the e-waste
The Plastic Waste (Management and Handling) Rules	2011	• To recycle plastics and control the pollution
Hazardous and Other Wastes (Management and Transboundary Movement) Rules	2016	• To protect the environment and enhance recycling
Solid Waste Management Rules	2016	• To recycle solid waste and dispose properly
Plastic Waste Management Rules (Amendment)	2016	• To recycle plastics and control the pollution

With the compliance of the provided guidelines and provisions by the United Nations (UN) to enhance the recycling of materials, promote sustainability in recycling, and protect the environment, the collaboration of the Automotive Research Association of India (ARAI), Society for Automobile Association (SIAM), and Automotive Industry Standards Committee (AISC), has prepared the Automotive Industry Standards for ELVs (AIS 129), the guidelines and the provisions for the ELV recycling in environmental sounding ways. These guidelines and conditions have been discussed in detail in the following sections.

The Indian government (through the Ministry of Road, Transport, and Highway, MORTH), in the Union Budget for 2021–2022, has initiated Vehicle Scrapping Policy. This policy includes legislation about vehicle fitness tests, conditions, the vehicle deregistration process, taxes, registration fees, and guidelines for vehicle manufacturers. In this regard, compulsory testing of vehicles will be most likely to begin from June 2023, although the successful implementation of this regulation is dependent on information authority.

### 3.1.1. Registered Vehicle Scrapping Facility (RVSF)

In Automotive Industry Standards for ELVs (AIS 129), the guidelines and the provisions for ELV recycling in environmentally sounding ways, introduced by the collaboration of the Automotive Research Association of India (ARAI), Society for Automobile Association (SIAM), and Automotive Industry Standards Committee (AISC), Registered Vehicle Scrapping Facility (RVSF) defines as that any organization has a “Registration for Vehicle Scrapping” issued by the authority for conducting the proper operations of ELV recycling such as depolluting, dismantling, shredding, and other functions. The RVSF aims to dispose of unfit and abandoned vehicles environmentally friendly way. It assesses the fitness of the vehicle through an automated testing facility, and if a vehicle fails the fitness test, it will be recommended for scrapping. The RVSF has been developed to endeavor to formalize the current informality-dominated ELV recycling sector and encourage vehicle owners to recycle abandoned vehicles at RVSF.

#### Terms and Conditions for RVSF

Automotive Industry Standards for ELVs (AIS 129) lucidly mentions the terms and conditions to meet the eligibility criteria for RVSF. The crucial eligibility criteria are as below:

- I. Ownership of the RVSF is open to any legitimate entity, whether it is an individual, an organization, a society, or a trust.
- II. The entity must have a valid PAN card, valid GST registration, and a certificate of incorporation.
- III. The entity must have the permission letter for setting up an RVSF from the state or union territory authority where it is to be located.
- IV. The entity shall commit to meeting the basic technical requirements for ELV recycling operations specified by the Central Pollution Control Board.
- V. The entity should have sufficient human resources to conduct ELV recycling operations in environmentally sound ways.
- VI. The entity should possess ISO 9001 (quality management system)/ISO 14001 (environmental certification)/ISO 45001 (occupational health and safety) quality certifications, a permission letter to operate from State Pollution Control Board, and necessary cyber security certifications.
- VII. The entity should adhere to provisions for labor and other laws and regulations.

#### Minimum Technical Requirements for RVSF

Automotive Industry Standards for ELVs (AIS 129) conspicuously specifies the technical requirements to meet the eligibility criteria for RVSF. The minimum technical requirements for an RVSF are as follows.

- A. RVSF should have an impervious surface, like concrete for spillage collection, decanters, and degreaser operations.

- B. RVSF should have appropriate and sufficient storage for recovered spare components, like tires.
- C. RVSF should have suitable and proper containers and storage tanks to store batteries, filters/ plastic circuit board (PCB)/ plastic circuit Polycyclohexylenedimethylene terephthalate (PCT)-containing condensers, and other fluids.
- D. RVSF should have equipment and facility for removing batteries and fluid tanks, neutralizing explosive substances recovered from ELVs, and removing catalysts.
- E. RVSF should have equipment for recovering the metal parts from ELVs made of Copper, Aluminum, Magnesium, and other heavy metals in a sustainable way to recycle for further uses.
- F. Recovering significant plastic components are recommended; the recovery of glass from ELVs should be performed effectively.

Automotive Industry Standards for ELVs (AIS 129) recommends a list of equipment that RVSF should possess for different operations of ELV recycling. Table 3 enumerates the recommended equipment for RVSF.

**Table 3.** Recommended equipment for RVSF.

Operation	Equipment
Pre-treatments	<ul style="list-style-type: none"> <li>• Vehicle Lift</li> <li>• Pry bar</li> <li>• Center Punch</li> <li>• Wheel Popper</li> <li>• Hydraulic Tube Cutter</li> <li>• Pneumatic Air Gun</li> <li>• Windshield removal tool</li> </ul>
Depolluting	<ul style="list-style-type: none"> <li>• Air-conditioning gas recovery unit</li> <li>• Exhaust gases neutralization system</li> <li>• Filter Wrench</li> <li>• Airbag deployment unit</li> <li>• Piercing equipment</li> <li>• Suction equipment</li> <li>• Bleeding system</li> <li>• Container</li> <li>• Draining Tray</li> </ul>
Dismantling	<ul style="list-style-type: none"> <li>• A set of screwdrivers</li> <li>• Spanner</li> <li>• Mallet</li> <li>• Ratchet</li> <li>• Cutter</li> <li>• Cutting Plier</li> <li>• Windscreen Cutter</li> </ul>
Shredding	<ul style="list-style-type: none"> <li>• Shredder</li> <li>• Bailing press unit</li> </ul>

### 3.2. ELVs Flow

India's ELV recycling system is at the nascent stage but fledging, developing across megacities and automobile industrial hubs. India's ELV recycling sector has been divided into formal and informal sectors. Formal recycling sectors are authorized and registered recycling centers that operate environmentally friendly by following proper guidelines and regulations provided by the authority. Whereas informal recycling sectors are unauthorized and unregistered recycling centers consisting of individuals, groups, and small businesses

driven by economic gain, their operations are not environmentally friendly and don't follow standard guidelines.

The informal sector dominates the current ELV recycling system, even though they operate with significantly higher material recycling and recovery rate and play an instrumental role. Certain operations are not environmentally sound, harming the environment without a regulatory framework. A few formal sectors have been evolving recently; their functions are more environmentally, socially, and economically sustainable. They cannot operate beyond the scope of a regulatory framework; they are also required to compete with the informal sector regarding materials recycling and recovery. Figure 5 depicts the current practice of the ELV recycling system in India, both formal and informal sectors.

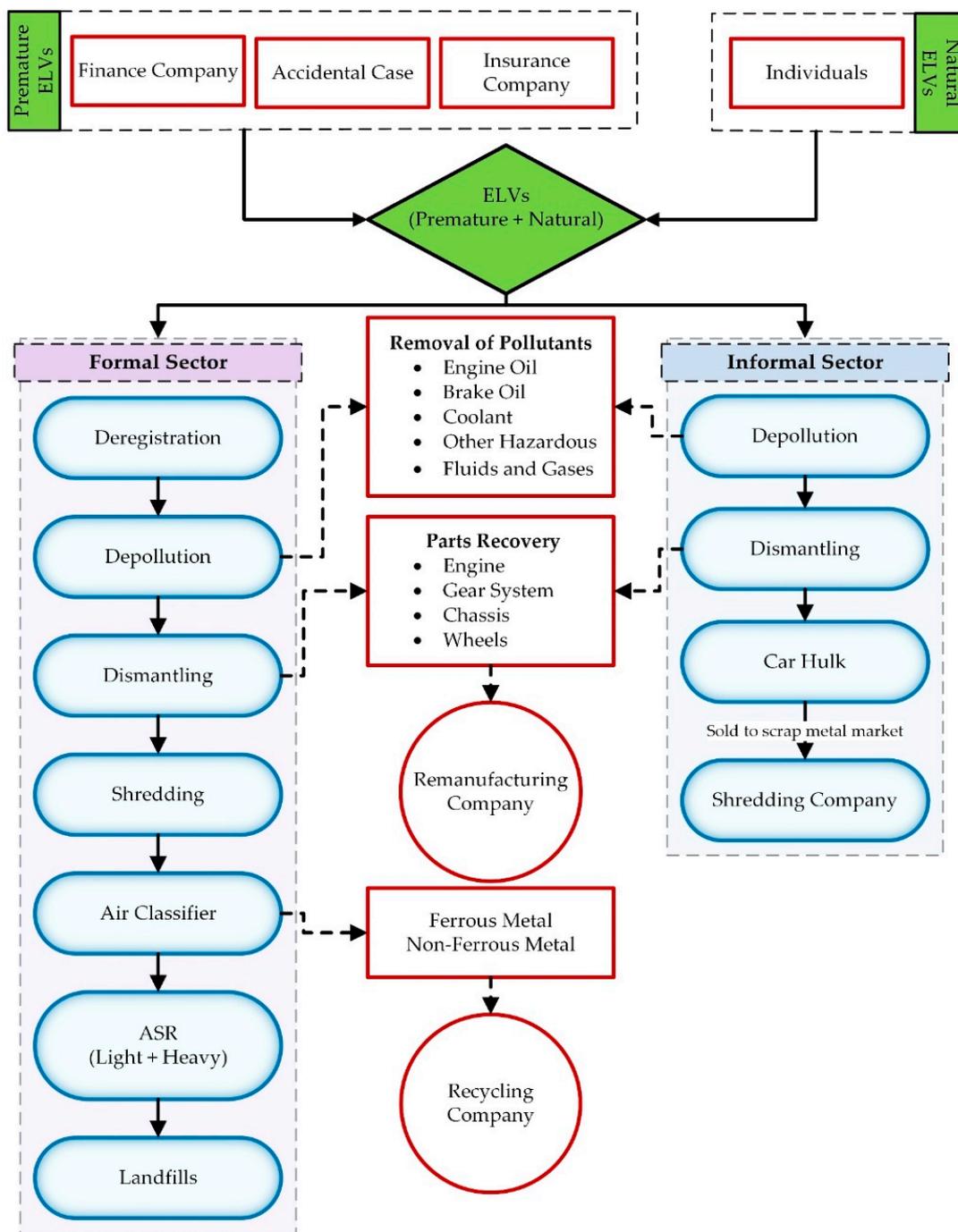


Figure 5. The current practice of ELV recycling system in India, both formal and informal sectors.

In the informal sector, there is no vehicle deregistration procedure; ELVs directly undergo a perfunctory depollution operation to remove the pollutants from ELVs. However, the removed pollutants are not disposed of in environmentally sound ways. Through the dismantling procedure, economically valuable parts such as the engine, gear system, chassis, and wheels are recovered. The recovered parts and components from ELV are sold at the scrap metal market. After that, a shredding company purchases the left car hulk as the informal sector lacks the facility to process the car hulk to recover further values. Whereas the formal sector operates with guidelines provided by authorities; ELVs undergo proper documentation, followed by the depollution operation, dismantling procedure for parts recovery, shredding operation for further value recovery, and eventually disposal of ASR to landfills, as there is no facility for ASR treatment. Even though formal sector operations are environmentally sound, India has remarkably few formal sectors.

Table 4 details depollution operations in India's formal and informal ELV recycling sectors. The formal ELV recycling sector performs few specific depollution operations sustainably, whereas the informal sector disposes of a few basic hazardous components from ELVs. Airbags contain harmful gases. Neither the formal nor informal ELV recycling sector disposes of airbags in an environmentally sound way, which contributes to the greenhouse effect and eventually threatens society and the environment.

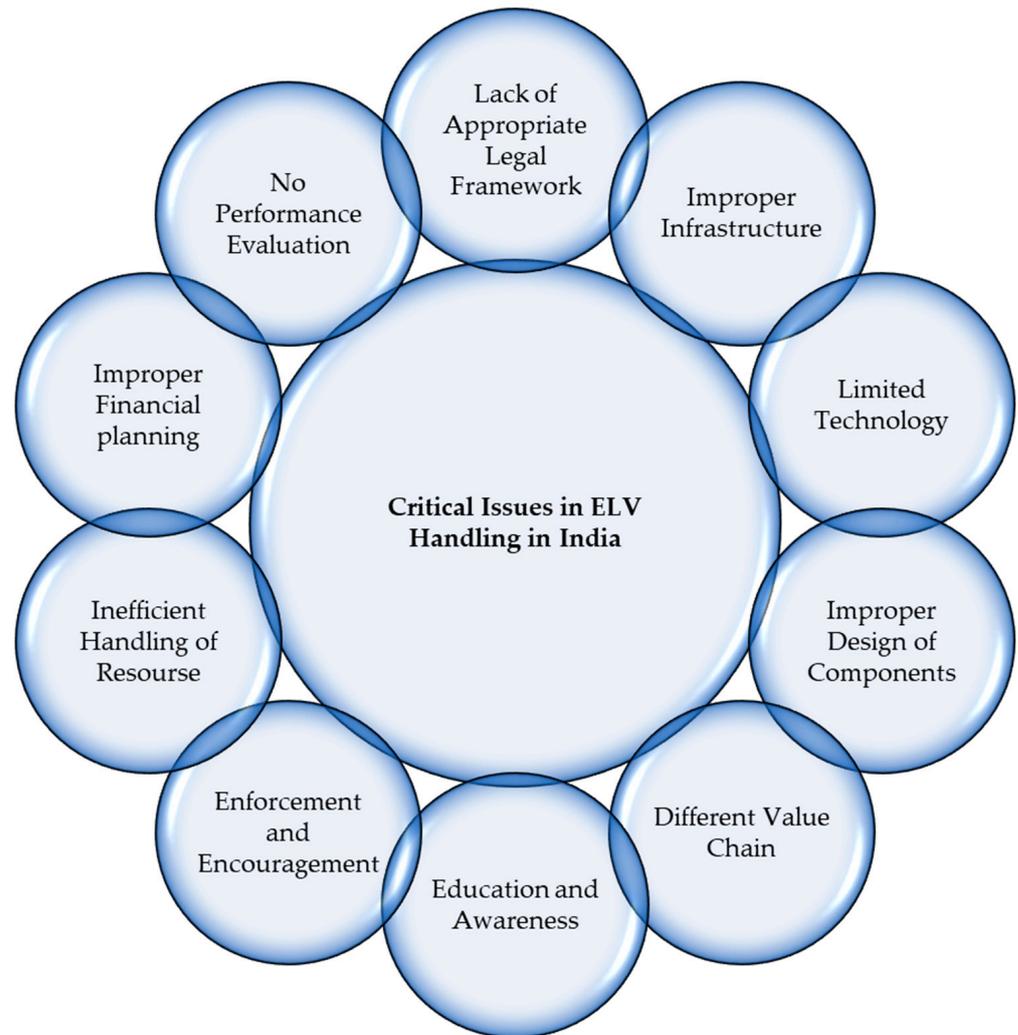
Table 4. Depolluting operations both in formal and informal sectors.

Depollution Operations	Formal ELV Recycling Sector Managing Sustainably (✓)/ Not (✗)	Informal ELV Recycling Sector Managing Sustainably (✓)/ Not (✗)
<b>Before Lifting the Vehicles</b>		
Removal of battery	✓	✓
Remove the fuel filter cap and oil filler	✓	✗
Removal of tires and wheels	✓	✓
Removal of parts containing mercury	✓	✗
Air-conditioning gases	✗	✗
<b>Lifting the vehicles on the depollution frame</b>		
Engine oil	✓	✓
Transmission oil	✓	✗
Coolant	✓	✗
Brake fluids	✓	✗
Removal of catalysts	✗	✗
Washer bottle	✓	✗
Brake/clutch reservoirs	✗	✗
Power steering reservoirs	✓	✓
Fuel tank	✓	✗
<b>After removing from the de-pollution frame</b>		
Deploy airbags and other pyrotechnics on-site (if equipped and capable of carrying out this operation).	✗	✗
Eliminate any airbags and pyrotechnics (if fitted and unable to be used in situ).	✗	✗

#### 4. Critical Evaluation

India's ELV recycling sector is now operating with various issues, albeit flourishing and proliferating mostly informal sectors [22,46]. We have observed a myriad of challenges that the ELV recycling system in India is experiencing and striving against. These challenges impede the development of the ELV sector in the techno-socio-economic aspect. For combatting climate change, mitigating greenhouse gas emissions, expediting sustainable development, and promoting energy-efficient vehicles, the government of India has been

endeavoring to create a pragmatic framework for setting up an efficient ELV management system by enacting acts and making regulations, even though certain rudimentary causative factors have identified, analyzed, and elucidated in details, can be effective in enabling authorities in evolving effective ELV management systems not only in India but also in other developing and developed nations. Figure 6 graphically depicts critical issues in ELV recycling in India.



**Figure 6.** Critical issues in ELV handling in India.

#### 4.1. Lack of Appropriate Legal Framework

India does not have a comprehensive and precise legal framework for recycling ELV sustainably other than that mentioned in Table 3. Existing policies and regulations are ineffectual in promoting recycling and managing a sheer deluge of ELVs proliferating every day [47]. Starting from the collection of ELVs, followed by a series of operations, deregistration, de-pollution, dismantling, shredding, ASR treatment, and throwing residue into landfills, in every stage, the laxity of legislation, regulation, and lack of proper guidelines are pervasive. Whereas countries such as China, Japan, the EU, and the USA have well-defined regulations [28,48,49], in terms of law, ELV recycling is mandatory for all citizens after a certain period, which is called the retirement of vehicles; the criterion of retirement varies from to country. Due to the apparent governance vacuum, ELV dismantlers and traders disregard the negative consequences of their activity and emphasize only economic gains from recycling. As a consequence of current practice, instead of expediting sustainable development and the material recovery rate,

it is causing environmental degradation and preventing advancement in the material recovery process. The government is fully accountable for forming legislation, goals, coherent strategy, code of practice, ELV regulation, and priorities to contribute to the progress of ELV management system implementation.

#### *4.2. Improper Infrastructure*

Proper and effective infrastructure is instrumental for ELV recycling [50]. Improper and ineffective infrastructure is another critical impediment to the advancement of India's ELV recycling system [51]. As the informal sector dominates India's ELV recycling system, they don't have an advanced technique to handle ELV recycling; they only recover certain economically valuable components from ELVs and dispose of other crucial and scarce materials. Hence, these materials are not recycled. No ELV dismantler deals with different vehicles, light, medium, and heavy vehicles. As India's ELV recycling system is marked by low investment, this low investment creates poor infrastructure. However, India's recently developed few formal recycling sectors are well-equipped and have proper infrastructure for ELV recycling operations. As the informal sector is predominant in India and plays an imperative role in recycling, the Indian government should assist the informal sector in having better infrastructure for ELV recycling operations.

#### *4.3. Limited Technology*

ELV treatment encompasses many convoluted and cumbersome processes, subsuming, dismantling, segregation, shredding, subsequent repair, reuse, recycling, re-manufacturing, residue management, and final disposition [52,53]. As ELV dismantlers operate with rudimentary technologies, the recycling rate, recovering rate, and materials extraction rate are comparatively poor to developed nations. ASR contains various critical and scarce materials [10]. Without recovering materials from ASR, the materials recovery and recycling rate cannot be increased; there is no facility for ASR treatment for materials recovery in the informal sector. As a consequence, the materials-rich ASR is disposed of in landfills. Hence, well-trained, consummate technicians and advanced and cutting-edge technologies are required to carry out ELV operations to maximize efficiency and enhance the rate of materials extraction. In order to improve the recovery and materials extraction rate, the authorities should look for appropriate material extraction methods in the local context so that the recycling and recovery rates are on par with developed nations.

#### *4.4. Improper Design of Components*

Inadequately designed vehicle component is the significant causative factor towards the poor performance of the ELV recycling system [54,55]. It has been observed and studied that, in present ELVs, the vehicle's components are not designed for recycling and remanufacturing, which makes the segregation, dismantling, and other subsequent operations onerous, arduous, challenging, and expensive [56]. Additionally, many component manufacturers adopt the short-term vision for product design to make their products economically inexpensive; hence, these poorly designed components cannot be recycled for future uses. Adapting the proper design method for components recycling can enhance the recovery and recycling and make the ELVs recycling operation substantially easier [57]. Automotive manufacturers and distributors should code elements and materials to make the reuse and recovery of materials more accessible.

#### *4.5. Different Value Chain*

Despite the fact that the automobile industry and ELV recycling system are potentially intertwined [58], they are not working together and collaborating. For the dismantling and other subsequent operations, the ELV dismantler needs accurate and valuable information from the manufacturers. This information can make ELV handling and parts recovery more effective [59]. In contrast, the manufacturers are also not aware of the capabilities and

technology of ELV dismantlers. The cooperation between the automobile industry and the ELV sector can enhance the recycling rate and increase the economic gains for both. The manufacturer can buy excellent quality recycled components from ELV recyclers for future use. Information about the element shared by the manufacturer can make ELV processing easier and promote sustainability.

#### *4.6. Education and Awareness*

Public awareness and education are instrumental in developing and implementing an effective ELV recycling system [60]. Indian people are generally oblivious and unconcerned about the environmental aspects [51]. Almost everyone pollutes the environment but, ironically, refuses to help clean it up; many people are only concerned with their economic interests, regardless of environmental protection. Already, Indians are inhaling toxic air and drinking polluted water; if the Indian government does not emphasize public awareness and environmental education, the environmental degradation issue will become more severe. Promoting sustainable environmental education and raising public consciousness among Indians are long-term goals that must begin by taking initiatives from the government from the primary schooling of children.

#### *4.7. Enforcement and Encouragement*

Enforcement and encouragement are conducive to establishing an efficient ELV recycling system [34,61]. In a regulatory legal framework, enforcement compels vehicle owners to transfer their abandoned vehicles to the ELV processing organization through a deregistration process, award, and concession to inspire them to recycle their abandoned cars. In India's ELV recycling system, the absence of enforcement and motivation is prevalent. There is no compulsion to recycle the vehicle after the specified age and no award, which prompts the vehicle owners to recycle their obsolete cars. The Indian government is also quite reluctant to invest money in encouraging and empowering research and development programs on ELV recycling.

#### *4.8. Improper Handling of Resources*

Appropriate handling of resources is paramount to sustainable development, the circular economy, and recycling and energy recovery [62–64]. The Indian government should take the initiative to establish an independent management body to deploy and allocate resources efficiently and efficaciously, taking into account the availability of resources, competency, responsibility, and infrastructure. India's improper handling and mismanagement of resources have been observed and investigated [51].

#### *4.9. Improper Financial Planning*

Proper financial planning and the appropriate budget allocation are expedient for developing an effective ELV management system [65–67]. In India, the lack of appropriate financial planning for ELV recycling, especially for supporting the informal sector in having better infrastructure, is quite evident; even though Indian authorities invest a significant portion of their budget into sustainable development, proper ELVs recycling, and development of India as the hub for energy-efficient vehicles, but not in accurate and appropriate ways, the government attempts are futile. Now is the time for the authority to firmly establish an effective cost management system for proper planning and controlling of system costs, as well as to make provisions and allocate the necessary budget for the development of ELV management systems.

#### *4.10. No Performance Evaluation*

Indubitably, performance evaluation, together with the development of an inspection center, enhances the performance of a system towards specific, well-defined objectives [68]. Currently, no firmly established assessment system in India assesses the employee, process, method, equipment, tools, and other subsequent factors. The lack of performance assess-

ment and inspection prompts, especially the informal recyclers, to disregard environmental impacts to maximize profit. An effective strategy should be developed for periodically monitoring the system, maintaining the documentation of records, and promoting through incentives, tax relaxation, and awards.

## 5. Proposed Frameworks

### 5.1. ELV Recycling System

Through critical analysis, identified issues and challenges in the ELV recycling system in India need to resolve by following a practical, systematic, and efficient framework that would not only enhance the material extraction rate but also promote sustainability in ELV recycling. Figure 7 represents a practical, efficient, and systematic framework for ELV recycling based on Indian values. This framework delineates directives lucidly at every stage of ELV recycling; it begins with the collection process of ELVs and terminates by proposing an efficient approach to handling the ASR. In India, there are no laws that govern the compulsory recycling of abandoned vehicles, proper collection process of ELV, and deregistration process. For the depollution process, the ELV recycler removes certain harmful fluids but not all potential pollutants, and removed pollutants are not disposed of properly; the suggested framework delineates the proper depollution process to protect the environment and promote sustainability by proposing a safe center for the disposal of stripped detrimental substances. The government should develop the proposed safe center to dispose of hazardous substances. The dismantling process is unorganized and chaotic; this framework shows the directives toward a systematic and organized dismantling process that can significantly enhance the materials recovery process. Presently, India has no ASR processing system to improve the recycling and recovery rate. The proposed framework has delved into this issue and taken into account this, and this study has emphasized ASR treatment and offered a systemic and effective ASR processing system.

The collaboration among the government, manufacturers, and ELV recyclers is instrumental in establishing a practical framework for ELV recycling. Still, there is no information-sharing facility among them. No fund management system supports informal and formal recyclers in depolluting, collecting ELVs, sustainable ASR disposal, and other operations. As this proposed framework delineates a fund management system where the authority should allocate funds to assist the stakeholders in collecting ELVs, deregistration process, depollution process, dismantling process and ASR treatment, and monitoring stakeholder's operations. This framework introduces an information management system and a fund management system. These management systems would help each other by providing the required and valuable information needed to establish a practical framework. The fund management would enable the ELV recycling sector to improve the infrastructure to boost the recovery and recycling rate and promote sustainability in ELV recycling.

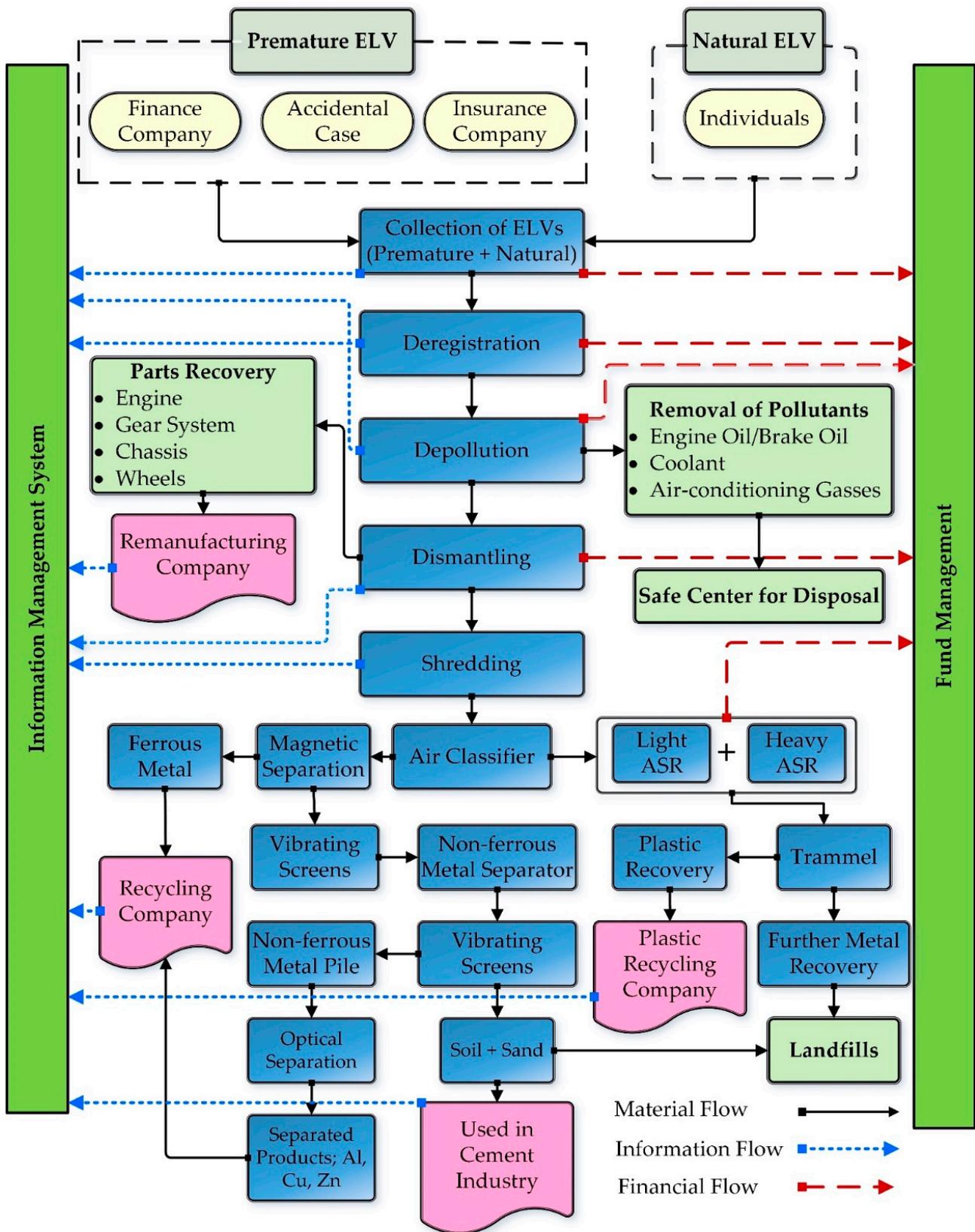


Figure 7. Proposed framework for ELV recycling system in India.

## 5.2. Policy Framework

Currently, there is no comprehensive and complete set of rules and regulations to govern the ELV recycling system in India. The ELV recycling system is complex and convoluted due to the numerous stages involved. To effectively handle and regulate the ELV system, every step involved in ELV recycling requires well-defined directives [69]. Firstly, there is no comprehensive regulation regarding the declaration of the ELV, a fitness test of the vehicle, and the deregistration process; the government should provide clear directives and guidelines about identifying the ELV, a fitness test of the vehicle, and the deregistration process. Secondly, for recycling, individuals voluntarily direct their abandoned vehicles to ELV recyclers; no existing law regulates the collection of ELV; authority should enact the regulation that would compel the car owner to recycle their cars after a specified age. Thirdly, no authorized management system monitors and accesses the de-pollution process of ELV, dismantling operation, shredding, and ASR treatment; hence informal recyclers perform these operations with disregard for environmental impacts; consequently, it causes environmental degradation [70]. The government should form an agency to access and monitor ELV recycling processes. Fourthly, the Indian ELV recycling sector is dominated by the informal sector. They do not follow the environmentally sound procedure for ELV recycling operations. They do not have the facility and technology to operate sustainably; hence, the materials recycling and recovery rates are comparatively low. The government should provide guidelines regarding materials recycling and recovery.

As mentioned above, the lack of regulations regarding declaration, deregistration, collection of ELVs, depolluting, dismantling, shredding, and disposal of the final product, ASR, hinders the sustainable development of ELV recycling in India. The policy and legislation should address the existing regulatory vacuum to make the Indian ELV recycling system viable in a sustainable manner. The Ministry of Transport, Human Resources, Natural Resources and Environment, Domestic Trade, Cooperation and Consumerism, and Finance must work together to control and monitor the sustainable management of ELV recycling.

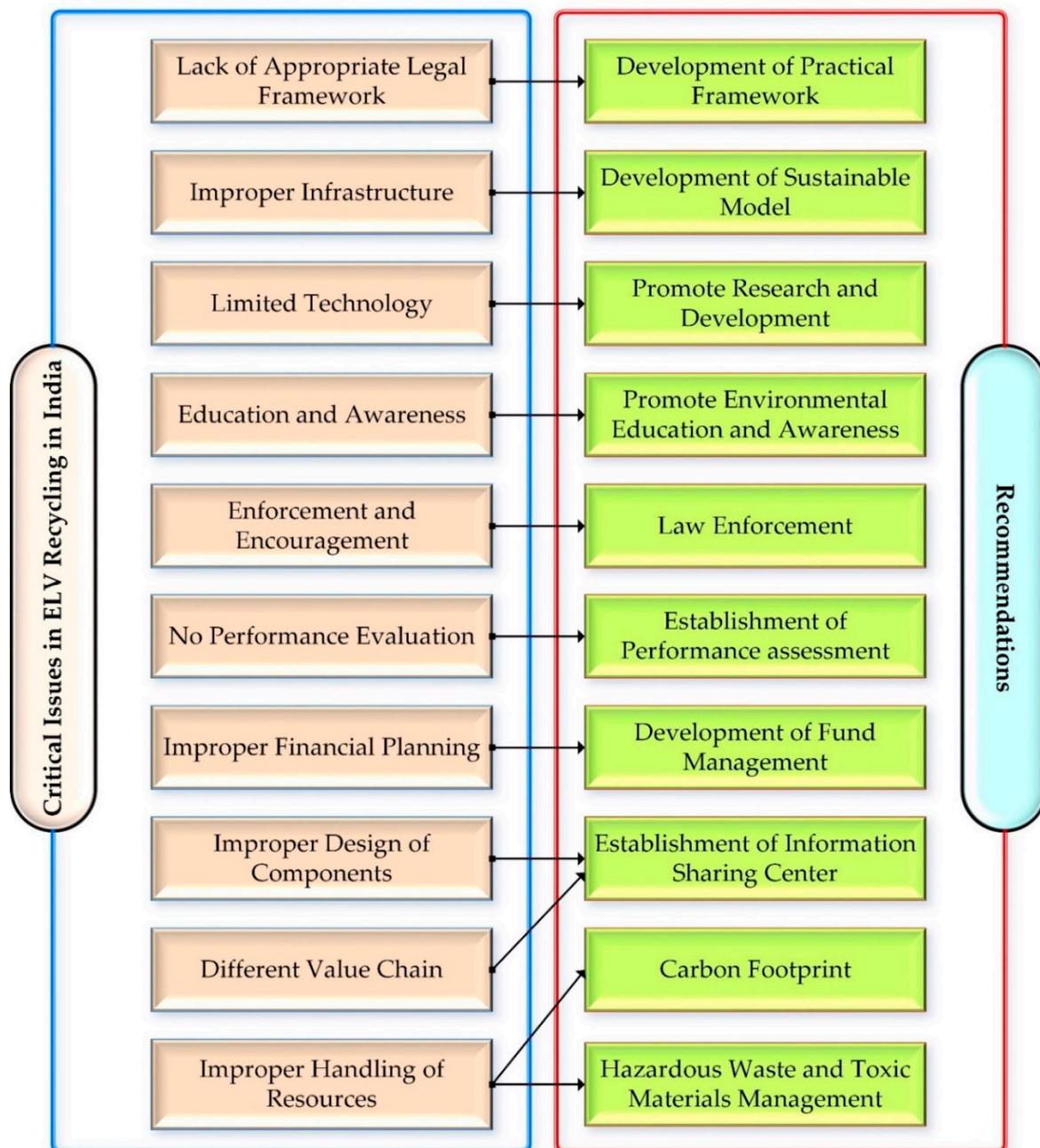
### Objectives of the Policy on ELV

The objectives of policy and regulation regarding ELV recycling in India should be emphasized on

- 10R-strategies (Refuse, Rethink, Reduce, Reuse, Repair, Refurbish, Remanufacture, Repurpose, Recycle, Recovery) to promote sustainability in ELV recycling in India.
- Promoting circular economy in India.
- Mitigation of pollution levels and improving environmental quality.
- Efficient use of natural resources.
- Reduce open dumping for ELV.
- Implementation of a solid waste management system.
- Enhance the resilience factors and productivity in ELV recycling.
- Development of proper infrastructure for ELV recycling.

## 6. Recommendations

The ELV recycling system in India is beset by a plethora of rudimentary issues, challenges, and threats, impeding the development of the ELV recycling sector in India [51]. Appropriate directives and initiatives by authorities are instrumental in the thriving and flourishing ELV recycling sector sustainably. Based on our observations and analysis in the previous section, we have identified a host of critical and persistent issues in ELV recycling. Without resolving these perennial issues in ELV recycling, further development and enhancement are elusive. In this section, we have made practical recommendations for efficiently encountering the problems identified in recycling for the long-term viability of ELV recycling. Figure 8 represents critical issues and corresponding recommendations regarding the ELV recycling system in India.



**Figure 8.** Critical issues and corresponding recommendations regarding ELV recycling system in India.

### 6.1. Development of Practical Framework

Developing a practical framework is the first crucial element toward sustainability [71,72]; authorities cannot provide appropriate directions to the ELV recycling sector without a realistic framework. In the Indian ELV sector, informality is prevalent because of the absence of a practical framework from authority. The Indian government should develop a pragmatic framework based on Indian values for ELV recycling to eliminate the informalities and malpractices and promote sustainability in ELV recycling. This practical framework will assist the ELV recycler by providing appropriate guidelines regarding ELV recycling operations, inevitably enhancing the material extraction rate.

### 6.2. Establishment of Information Sharing Center

The lack of collaboration among ELV recyclers, manufacturers, and authorities is thwarting the prosperity of ELV recycling; hence an information-sharing center is required to establish. The information-sharing center will preserve all data shared by key stakeholders, manufacturers, government authorities, and car owners. This system will have numerous interfaces for all key stakeholders, manufacturers, car owners, and management. They will upload the components, operations, material flow information, and information about hazardous waste. This system will assist all crucial parties involved in recycling by providing accurate and authentic pieces of information. This system will have a profound impact on the ELV recycling system.

### 6.3. Development of a Sustainable Model

By considering socio-economic-environment aspects and the long-term viability of ELV recycling, the government of India should develop a sustainable model for ELV recycling, which will not only enhance the recycling and recovery rate but also preserve the environment [73,74]. By adopting the 4Rs (reuse, recycle, remanufacturing, repair) standardization, authorities can create a sustainable model which will guide the automotive sector toward obtaining the highest possible standard of product and operation, safeguarding the environment, and consumer safety. This model will cherish business sustainability and increase competitiveness.

### 6.4. Promote Research and Development

ELV recycling involves numerous convoluted processes. Technology plays an imperative role in development and advancement [75]. Because of poor technology, India's ELV recycling performance is limited. In order to enhance the materials extraction and recovery rate, the ELV recycling sector requires advanced technology. The Indian government, together with vehicle manufacturers, should allocate funds to promote research and development to establish an effective recycling system. This allocated fund should be given to the government and vehicle manufacturer research and development institute to promote sustainability in ELV recycling.

### 6.5. Development of Fund Management

The treatment of abandoned vehicles for recycling is associated with a significant cost as many processes are involved. The car manufacturer or car owner can cover this expense for operations of ELV for recycling; still, the government has yet to define who is accountable for the expense of recycling. The Indian authority should establish fund management for ELV recycling, which will be responsible for the relevant expense of recycling. It encompasses various expenses, including recycling fees, subsidies, rewards, costs associated with waste management, and social awareness. The vehicle manufacturer, the government, and the vehicle owner should all contribute to this fund. Different countries have different policies regarding the fees for recycling vehicles accordingly to their economic and social aspects. In countries like India, vehicle manufacturers and car owners should bear the entire cost of recycling in equal proportion. Whereas, the government should monitor and audit this fund. This fund should be utilized to promote green technology for the long-term viability of ELV recycling. This fund should be used to dispose of hazardous and toxic waste properly.

### 6.6. Performance Assessment

Performance evaluation is crucial in enhancing the recycled product quality and operations involved in recycling. India has yet to establish a proper performance evaluation process to assess the recycled product's quality, operation, environmental impact, and waste management. Performance evaluation, together with appropriate inspection, will assist the Indian government in achieving the well-defined objectives of ELV recycling.

### 6.7. Promote Environmental Education and Awareness

Long-term goals, such as promoting sustainable environmental education and raising public awareness among Indians, must begin with children. Indians are generally unaware and unconcerned about environmental issues. It is expected that public awareness programs and training for organization members and stakeholders will improve general society's level of knowledge and awareness of ELVs and practitioners' competency and skills in performing ELVs processes.

### 6.8. Carbon Footprint Application

Numerous distinct power tools are used in the ELV recycling system during the operations of ELVs; this equipment requires a lot of energy and produces a significant quantity of greenhouse gases [76,77], which is detrimental to the environment. The application of carbon footprint, which measures the total amount of greenhouse gas emissions, can assist the ELV recycler in evaluating energy consumption and reducing energy consumption.

### 6.9. Law Enforcement

The relevant ELV recycling laws are paramount to properly governing and regulating the Indian ELV recycling sector. The Indian government has yet to enact the appropriate and suitable rules and regulations in different aspects, incorporating environment, transport, use of resources, waste disposal, and business model. The quality of the environment in India has become a critical concern and has been deepening significantly because of the absence of proper regulation.

### 6.10. Hazardous Waste and Toxic Materials Management

The detrimental automotive shredder residue, toxic materials, poisonous electronic waste, waste fluid, oil, battery, and other unwanted debris should not be disposed of randomly. To meet this demand, we can construct a hazardous waste and toxic materials processing center in each major city, as Indian people's environmental awareness is low. Hazardous waste should be disposed of at a hazardous waste and toxic materials processing center. The hazardous waste and toxic materials processing center should deal with toxic electronic waste and hazardous and toxic scrap automobile waste. It will keep the materials used in ELV shells as clear as possible.

## 7. Discussions and Future Implications

This study delineates the status quo of the ELV recycling system holistically in India, which is a combination of current law and policy analysis and ELV flow in formal and informal sectors, respectively. This research summarizes the relevant laws regarding recycling and environmental protection and thoroughly sheds light on recent drafting about ELV recycling and RVSF. This analysis reveals that India does not yet have rigorous regulations governing the recycling of ELVs, and lax and insufficient laws and regulations govern the current ELV recycling sector. As this research demonstrates the existing vacuum of regulation to regulate the ELV recycling sector, which may draw the attention of Indian authorities to devise and enact an appropriate set of rules to regulate and monitor the ELV recycling sector sustainably and systematically.

This investigation reveals the ELV recycling practice in both formal and informal sectors and finds that India's ELV recycling system is still in its infancy and the informal sector dominates the current ELV recycling system. The ELV dismantling operations in the informal sector are not environmentally friendly, contributing significantly to environmental degradation. The materials recovery and recycling rates are below standard in the informal sector compared to other developed nations. The Indian government should develop an appropriate and practical framework for ELV recycling based on Indian values and provide this framework to stakeholders to upgrade their operations and practices.

This research critically evaluates the current ELV recycling system in India to address the persisting perennial critical issues that the ELV recycling system is encountering.

These challenges hinder the development of the current ELV recycling system. The identified issues in the critical evaluations section may assist and encourage the authority to appropriate counter measurement to promote sustainability in the ELV recycling sector.

Aside from critical evaluations, this paper proposes pragmatic and efficient frameworks based on Indian values that would enhance materials recovery and recycling rates, promote sustainability in ELV recycling, and provide appropriate directions in terms of law and policy. The proposed frameworks in this study may assist the stakeholders in enhancing materials recovery and recycling rates and cherishing sustainability in the ELV recycling sector. At the same time, these frameworks provide lucid directives in terms of law and policy for the authority to devise and enact an appropriate set of regulations to regulate the ELV recycling sector sustainably.

Eventually, this study has provided practical and valuable recommendations for effectively addressing the highlighted issues for the long-term sustainability of ELV recycling. These recommendations may assist the government of India in setting up an efficient ELV recycling sector by addressing persistent issues in the ELV recycling sector. The findings of this research may encourage the authorities and stakeholders to adopt and implement the proposed frameworks to enhance the recycling rate while respecting the environment. The outcomes of this study can be useful for other countries in the Indian subcontinent.

## 8. Research Limitations

This research has a few potential limitations.

- This research has investigated the ELV recycling system in India, and the frameworks in this study are proposed based on Indian values; therefore, the outcomes of this study might be limited to the Indian subcontinent. Therefore, other developing countries may not benefit from the results of this investigation.
- This investigation has been performed in five well-known automotive sectors: Mumbai, Kolkata, Chennai, Jamshedpur, and Delhi. This research could have provided a more holistic ELV recycling practice in India by incorporating additional automobile hubs.
- Aside from field investigation, literature, and policy review, there have been interactions with 537 chosen people, including all key stakeholders, academicians, and government officials. This study could have provided more accurate outcomes with a higher number of interactions.
- Very little research has been performed on ELV recycling in India. The lack of literature about ELV recycling in India initially made it challenging to develop the fundamental basis of this research.

## 9. Future Prospects and Suggestions

This study emphasizes the development, critical evaluation, and proposed framework for ELV recycling in India. As well as that, this study suggests specific vital topics that require in-depth analysis to advance the ELV recycling system in India.

- Materials recycling and recovery rates are imperative in ELV recycling. Measuring and comparing the materials extraction rates between formal and informal sectors requires further exploration.
- A carbon emission assessment is instrumental for monitoring the air quality around the automotive hubs. Assessing and comparing the carbon emission from formal and informal sectors requires in-depth study.
- ELV contains several hazardous materials. Appropriate disposal methods for these detrimental substances require further thorough investigation.
- Recycling industries depend on manufacturing industries. Hence, exploring the synergy between recycling and manufacturing industries needs to be evaluated thoroughly.

## 10. Conclusions

This study has delved deeper into India's ELV recycling system and elucidated the current practice of ELV recycling in formal and informal sectors in India in a greater context to develop a profound understanding that is instrumental in expanding the ELV sector by obtaining the best potential values from ELVs. This study's findings reveal that ELV recycling in India is at the embryonic stage and struggling with a host of challenges in different aspects. Currently, there is no comprehensive and complete set of rules and regulations to govern the ELV recycling system in India. The vacuum of appropriate policy engenders a prevalence of informality in India's ELV recycling sector.

After reflecting on current practice, this research has critically evaluated the existing ELV recycling system in India and identified the impediments thwarting the development of the ELV recycling system in India. The lack of practical frameworks, lax laws and policies, and inappropriate technology are the critical deterrent to sustainability in recycling in India.

Identification of hindrances was the first step to encountering the existing impediments. This study has proposed pragmatic frameworks and made practical recommendations to approach the identified issues and expedite sustainable development. The proposed frameworks and practical suggestions are made based on Indian values to assist in developing an efficient ELV recycling system in India to cherish sustainable growth and expand the ELV sector without affecting the environment and conserving natural resources. This research may encourage informal ELV recyclers to adopt the sustainable ELV recycling model, which will assist in formalizing the Indian ELV recycling sector and reducing landfills. This study may increase the public awareness level of sustainable ELV recycling. The proposed framework is likely to assist the government of India in implementing any upcoming regulatory and legal framework regarding ELV recycling. These frameworks and recommendations are also suitably applicable to other developing nations in the Indian subcontinent.

**Author Contributions:** Each author's contributions are listed as follows: Conceptualization, A.H.M.; Methodology, A.H.M.; Software, A.H.M.; Validation, A.H.M.; Formal Analysis, A.H.M.; Investigation, A.H.M.; Resources, Z.H. and A.H.M.; Data Curation, A.H.M.; Writing—Original Draft Preparation, A.H.M.; Writing—Review and Editing, Z.H. and R.I.; Visualization, A.H.M. and Z.H.; Supervision, Z.H.; Project Administration, Z.H.; Funding Acquisition, Z.H. and M.R.A.M. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research was supported by the Transdisciplinary Research Grant Scheme TRGS/1/2020/UKM/02/1/1 and UKM internal grant GUP-2018-012.

**Institutional Review Board Statement:** The study was conducted according to the guidelines of the International Conference of Harmonization Good Clinical Practice, and approved by the Research Ethics Committee of The National University of Malaysia (UKM PPI/111/8/JEP-2021-595, 11 November 2021).

**Informed Consent Statement:** Not applicable.

**Data Availability Statement:** The data presented in this study are available in this published article.

**Acknowledgments:** The authors would like to thank the anonymous reviewers for their help.

**Conflicts of Interest:** The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## References

1. Korica, P.; Cirman, A.; Žgajnar Gotvajn, A. Comparison of end-of-life vehicles management in 31 European countries: A LMDI analysis. *Waste Manag. Res. J. Sustain. Circ. Econ.* **2022**, *40*, 1156–1166. [\[CrossRef\]](#)
2. Zhou, F.; Lim, M.K.; He, Y.; Lin, Y.; Chen, S. End-of-life vehicle (ELV) recycling management: Improving performance using an ISM approach. *J. Clean. Prod.* **2019**, *228*, 231–243. [\[CrossRef\]](#)
3. Karagoz, S.; Aydin, N.; Simic, V. End-of-life vehicle management: A comprehensive review. *J. Mater. Cycles Waste Manag.* **2020**, *22*, 416–442. [\[CrossRef\]](#)
4. Petronijević, V.; Đorđević, A.; Stefanović, M.; Arsovski, S.; Krivokapić, Z.; Mišić, M. Energy Recovery through End-of-Life Vehicles Recycling in Developing Countries. *Sustainability* **2020**, *12*, 8764. [\[CrossRef\]](#)

5. Abdollahifar, M.; Doose, S.; Cavers, H.; Kwade, A. Graphite Recycling from End-of-Life Lithium-Ion Batteries: Processes and Applications. *Adv. Mater. Technol.* **2022**, *early view*. [[CrossRef](#)]
6. Crespo, M.S.; González, M.V.G.; Peiró, L.T. Prospects on end of life electric vehicle batteries through 2050 in Catalonia. *Resour. Conserv. Recycl.* **2022**, *180*, 106133. [[CrossRef](#)]
7. Go, T.; Wahab, D.; Rahman, M.; Ramli, R.; Azhari, C. Disassemblability of end-of-life vehicle: A critical review of evaluation methods. *J. Clean. Prod.* **2011**, *19*, 1536–1546. [[CrossRef](#)]
8. Rovinaru, F.I.; Rovinaru, M.D.; Rus, A.V. The Economic and Ecological Impacts of Dismantling End-of-Life Vehicles in Romania. *Sustainability* **2019**, *11*, 6446. [[CrossRef](#)]
9. Nakano, K.; Shibahara, N. Comparative assessment on greenhouse gas emissions of end-of-life vehicles recycling methods. *J. Mater. Cycles Waste Manag.* **2015**, *19*, 505–515. [[CrossRef](#)]
10. Williams, K.S.; Khodier, A. Meeting EU ELV targets: Pilot-scale pyrolysis automotive shredder residue investigation of PAHs, PCBs and environmental contaminants in the solid residue products. *Waste Manag.* **2020**, *105*, 233–239. [[CrossRef](#)]
11. Society of Indian Automobile Manufactures. Available online: <https://www.siam.in/statistics.aspx?mpgid=8&pgidtrail=9> (accessed on 5 May 2022).
12. Arora, N.; Bakshi, S.K.; Bhattacharjya, S. Framework for sustainable management of end-of-life vehicles management in India. *J. Mater. Cycles Waste Manag.* **2018**, *21*, 79–97. [[CrossRef](#)]
13. Zhang, L.; Ji, K.; Liu, W.; Cui, X.; Liu, Y.; Cui, Z. Collaborative approach for environmental and economic optimization based on life cycle assessment of end-of-life vehicles' dismantling in China. *J. Clean. Prod.* **2020**, *276*, 124288. [[CrossRef](#)]
14. Numfor, S.A.; Takahashi, Y.; Matsubae, K. Energy recovery from end-of-life vehicle recycling in Cameroon: A system dynamics approach. *J. Clean. Prod.* **2022**, *361*, 132090. [[CrossRef](#)]
15. Jang, Y.-C.; Choi, K.; Jeong, J.-H.; Kim, H.; Kim, J.-G. Recycling and Material-Flow Analysis of End-of-Life Vehicles towards Resource Circulation in South Korea. *Sustainability* **2022**, *14*, 1270. [[CrossRef](#)]
16. Mallampati, S.R.; Lee, B.H.; Mitoma, Y.; Simion, C. Sustainable recovery of precious metals from end-of-life vehicles shredder residue by a novel hybrid ball-milling and nanoparticles enabled froth flotation process. *J. Clean. Prod.* **2018**, *171*, 66–75. [[CrossRef](#)]
17. Ghosh, S.K.; Ghosh, S.K.; Baidya, R. Circular Economy in India: Reduce, Reuse, and Recycle Through Policy Framework. In *Circular Economy: Recent Trends in Global Perspective*; Springer: Singapore, 2021; pp. 183–217. [[CrossRef](#)]
18. Sato, F.E.K.; Furubayashi, T.; Nakata, T. Application of energy and CO<sub>2</sub> reduction assessments for end-of-life vehicles recycling in Japan. *Appl. Energy* **2019**, *237*, 779–794. [[CrossRef](#)]
19. Numfor, S.; Omosa, G.; Zhang, Z.; Matsubae, K. A Review of Challenges and Opportunities for End-of-Life Vehicle Recycling in Developing Countries and Emerging Economies: A SWOT Analysis. *Sustainability* **2021**, *13*, 4918. [[CrossRef](#)]
20. Mohan, T.V.K.; Amit, R.K. Dismantlers' dilemma in end-of-life vehicle recycling markets: A system dynamics model. *Ann. Oper. Res.* **2018**, *290*, 591–619. [[CrossRef](#)]
21. Chen, Y.; Ding, Z.; Liu, J.; Ma, J. Life cycle assessment of end-of-life vehicle recycling in China: A comparative study of environmental burden and benefit. *Int. J. Environ. Stud.* **2019**, *76*, 1019–1040. [[CrossRef](#)]
22. Sharma, L.; Pandey, S. Recovery of resources from end-of-life passenger cars in the informal sector in India. *Sustain. Prod. Consum.* **2020**, *24*, 1–11. [[CrossRef](#)]
23. Andersson, M.; Söderman, M.L.; Sandén, B.A. Challenges of recycling multiple scarce metals: The case of Swedish ELV and WEEE recycling. *Resour. Policy* **2019**, *63*, 101403. [[CrossRef](#)]
24. Khan, S.A.R.; Godil, D.I.; Thomas, G.; Tanveer, M.; Zia-Ul-Haq, H.M.; Mahmood, H. The Decision-Making Analysis on End-of-Life Vehicle Recycling and Remanufacturing under Extended Producer Responsibility Policy. *Sustainability* **2021**, *13*, 11215. [[CrossRef](#)]
25. Yu, J.; Wang, S.; Serrona, K.R.B. Comparative Analysis of ELV Recycling Policies in the European Union, Japan and China. *Investig. Linguisticae* **2019**, *XLIII*, 34–56. [[CrossRef](#)]
26. Zhang, L.; Lu, Q.; Yuan, W.; Jiang, S.; Wu, H. Characterizing end-of-life household vehicles' generations in China: Spatial-temporal patterns and resource potentials. *Resour. Conserv. Recycl.* **2022**, *177*, 105979. [[CrossRef](#)]
27. Khodier, A.; Williams, K.; Dallison, N. Challenges around automotive shredder residue production and disposal. *Waste Manag.* **2018**, *73*, 566–573. [[CrossRef](#)]
28. Soo, V.K.; Doolan, M.; Compston, P.; Duflou, J.R.; Peeters, J.; Umeda, Y. The influence of end-of-life regulation on vehicle material circularity: A comparison of Europe, Japan, Australia and the US. *Resour. Conserv. Recycl.* **2021**, *168*, 105294. [[CrossRef](#)]
29. Rosa, P.; Terzi, S. Improving end of life vehicle's management practices: An economic assessment through system dynamics. *J. Clean. Prod.* **2018**, *184*, 520–536. [[CrossRef](#)]
30. Yi, S.; Lee, H. Economic analysis to promote the resource circulation of end-of-life vehicles in Korea. *Waste Manag.* **2021**, *120*, 659–666. [[CrossRef](#)]
31. Li, Y.; Liu, Y.; Chen, Y.; Huang, S.; Ju, Y. Estimation of end-of-life electric vehicle generation and analysis of the status and prospects of power battery recycling in China. *Waste Manag. Res.* **2022**, *40*, 1424–1432. [[CrossRef](#)]
32. Sitinjak, C.; Ismail, R.; Bantu, E.; Fajar, R.; Samuel, K. The understanding of the social determinants factors of public acceptance towards the end of life vehicles. *Cogent Eng.* **2022**, *9*, 2088640. [[CrossRef](#)]
33. Wang, J.; Sun, L.; Fujii, M.; Li, Y.; Huang, Y.; Murakami, S.; Daigo, I.; Pan, W.; Li, Z. Institutional, Technology, and Policies of End-of-Life Vehicle Recycling Industry and Its Indication on the Circular Economy- Comparative Analysis Between China and Japan. *Front. Sustain. Food Syst.* **2021**, *2*, 13. [[CrossRef](#)]

34. Yu, Z.; Tianshan, M.; Rehman, S.A.; Sharif, A.; Janjua, L. Evolutionary game of end-of-life vehicle recycling groups under government regulation. *Clean Technol. Environ. Policy* **2020**, 1–12. [[CrossRef](#)]
35. Yu, Z.; Khan, S.A.R.; Zia-Ul-Haq, H.M.; Tanveer, M.; Sajid, M.J.; Ahmed, S. A Bibliometric Analysis of End-of-Life Vehicles Related Research: Exploring a Path to Environmental Sustainability. *Sustainability* **2022**, *14*, 8484. [[CrossRef](#)]
36. Sanz, V.M.; Serrano, A.M.; Schlummer, M. A mini-review of the physical recycling methods for plastic parts in end-of-life vehicles. *Waste Manag. Res.* **2022**, *40*, 0734242X221094917. [[CrossRef](#)]
37. Swain, B.; Park, J.R.; Lee, C.G. Industrial recycling of end-of-life vehicle windshield glass by mechanical beneficiation and complete recovery of polyvinyl butyral. *J. Clean. Prod.* **2022**, *334*, 130192. [[CrossRef](#)]
38. Edun, A.; Hachem-Vermette, C. Energy and environmental impact of recycled end of life tires applied in building envelopes. *J. Build. Eng.* **2021**, *39*, 102242. [[CrossRef](#)]
39. Zhang, Z.; Malik, M.Z.; Khan, A.; Ali, N.; Malik, S.; Bilal, M. Environmental impacts of hazardous waste, and management strategies to reconcile circular economy and eco-sustainability. *Sci. Total Environ.* **2022**, *807*, 150856. [[CrossRef](#)]
40. Zimon, D.; Madzík, P. Standardized management systems and risk management in the supply chain. *Int. J. Qual. Reliab. Manag.* **2020**, *37*, 305–327. [[CrossRef](#)]
41. Farahani, S.; Otieno, W.; Barah, M. Environmentally friendly disposition decisions for end-of-life electrical and electronic products: The case of computer remanufacture. *J. Clean. Prod.* **2019**, *224*, 25–39. [[CrossRef](#)]
42. Wang, L.; Chen, M. Policies and perspective on end-of-life vehicles in China. *J. Clean. Prod.* **2013**, *44*, 168–176. [[CrossRef](#)]
43. D’Adamo, I.; Gastaldi, M.; Rosa, P. Recycling of end-of-life vehicles: Assessing trends and performances in Europe. *Technol. Forecast. Soc. Change* **2020**, *152*, 119887. [[CrossRef](#)]
44. Li, Y.; Fujikawa, K.; Wang, J.; Li, X.; Ju, Y.; Chen, C. The Potential and Trend of End-Of-Life Passenger Vehicles Recycling in China. *Sustainability* **2020**, *12*, 1455. [[CrossRef](#)]
45. Blume, T.; Walther, M. The End-of-life Vehicle Ordinance in the German automotive industry—Corporate sense making illustrated. *J. Clean. Prod.* **2013**, *56*, 29–38. [[CrossRef](#)]
46. Govindan, K.; Shankar, M.; Kannan, D. Application of fuzzy analytic network process for barrier evaluation in automotive parts remanufacturing towards cleaner production—A study in an Indian scenario. *J. Clean. Prod.* **2016**, *114*, 199–213. [[CrossRef](#)]
47. Luthra, S.; Kumar, V.; Kumar, S.; Haleem, A. Barriers to implement green supply chain management in automobile industry using interpretive structural modeling technique: An Indian perspective. *J. Ind. Eng. Manag.* **2011**, *4*, 231–257. [[CrossRef](#)]
48. Hu, S.; Wen, Z. Monetary evaluation of end-of-life vehicle treatment from a social perspective for different scenarios in China. *J. Clean. Prod.* **2017**, *159*, 257–270. [[CrossRef](#)]
49. Li, Y.; Liu, Y.; Chen, Y.; Huang, S.; Ju, Y. Projection of end-of-life vehicle population and recyclable metal resources: Provincial-level gaps in China. *Sustain. Prod. Consum.* **2022**, *31*, 818–827. [[CrossRef](#)]
50. Al-Quradaghi, S.; Zheng, Q.P.; Betancourt-Torcat, A.; Elkamel, A. Optimization Model for Sustainable End-of-Life Vehicle Processing and Recycling. *Sustainability* **2022**, *14*, 3551. [[CrossRef](#)]
51. Molla, A.H.; Shams, H.; Harun, Z.; Ab Rahman, M.N.; Hishamuddin, H. An Assessment of Drivers and Barriers to Implementation of Circular Economy in the End-of-Life Vehicle Recycling Sector in India. *Sustainability* **2022**, *14*, 13084. [[CrossRef](#)]
52. Cossu, R.; Lai, T. Automotive shredder residue (ASR) management: An overview. *Waste Manag.* **2015**, *45*, 143–151. [[CrossRef](#)]
53. Tarrar, M.; Despeisse, M.; Johansson, B. Driving vehicle dismantling forward—A combined literature and empirical study. *J. Clean. Prod.* **2021**, *295*, 126410. [[CrossRef](#)]
54. Sinha, A.; Mondal, S.; Boone, T.; Ganeshan, R. Analysis of issues controlling the feasibility of automobile remanufacturing business in India. *Int. J. Serv. Oper. Manag.* **2017**, *26*, 459–475. [[CrossRef](#)]
55. Nag, U.; Sharma, S.K.; Govindan, K. Investigating drivers of circular supply chain with product-service system in automotive firms of an emerging economy. *J. Clean. Prod.* **2021**, *319*, 128629. [[CrossRef](#)]
56. Wahab, D.; Blanco-Davis, E.; Ariffin, A.; Wang, J. A review on the applicability of remanufacturing in extending the life cycle of marine or offshore components and structures. *Ocean Eng.* **2018**, *169*, 125–133. [[CrossRef](#)]
57. Mayyas, A.; Omar, M.; Hayajneh, M.; Mayyas, A.R. Vehicle’s lightweight design vs. electrification from life cycle assessment perspective. *J. Clean. Prod.* **2017**, *167*, 687–701. [[CrossRef](#)]
58. Ropi, N.M.; Hishamuddin, H.; Wahab, D.A. Analysis of the Supply Chain Disruption Risks in the Malaysian Automotive Remanufacturing Industry—a Case Study. *Int. J. Integr. Eng.* **2020**, *12*, 1–11. [[CrossRef](#)]
59. Zhao, Q.; Chen, M. A comparison of ELV recycling system in China and Japan and China’s strategies. *Resour. Conserv. Recycl.* **2011**, *57*, 15–21. [[CrossRef](#)]
60. Sitinjak, C.; Ismail, R.; Tahir, Z.; Fajar, R.; Simanullang, W.F.; Bantu, E.; Samuel, K.; Rose, R.A.C.; Yazid, M.R.M.; Harun, Z. Acceptance of ELV Management: The Role of Social Influence, Knowledge, Attitude, Institutional Trust, and Health Issues. *Sustainability* **2022**, *14*, 10201. [[CrossRef](#)]
61. Kaya, D.I.; Pintossi, N.; Dane, G. An Empirical Analysis of Driving Factors and Policy Enablers of Heritage Adaptive Reuse within the Circular Economy Framework. *Sustainability* **2021**, *13*, 2479. [[CrossRef](#)]
62. Tan, J.; Tan, F.J.; Ramakrishna, S. Transitioning to a Circular Economy: A Systematic Review of Its Drivers and Barriers. *Sustainability* **2022**, *14*, 1757. [[CrossRef](#)]
63. Grafström, J.; Aasma, S. Breaking circular economy barriers. *J. Clean. Prod.* **2021**, *292*, 126002. [[CrossRef](#)]

64. Kayikci, Y.; Kazancoglu, Y.; Lafci, C.; Gozacan, N. Exploring barriers to smart and sustainable circular economy: The case of an automotive eco-cluster. *J. Clean. Prod.* **2021**, *314*, 127920. [[CrossRef](#)]
65. Lindahl, P.; Robèrt, K.-H.; Ny, H.; Broman, G. Strategic sustainability considerations in materials management. *J. Clean. Prod.* **2014**, *64*, 98–103. [[CrossRef](#)]
66. Mamat, T.N.A.R.; Saman, M.Z.M.; Sharif, S.; Simic, V. Key success factors in establishing end-of-life vehicle management system: A primer for Malaysia. *J. Clean. Prod.* **2016**, *135*, 1289–1297. [[CrossRef](#)]
67. Modoi, O.-C.; Mihai, F.-C. E-Waste and End-of-Life Vehicles Management and Circular Economy Initiatives in Romania. *Energies* **2022**, *15*, 1120. [[CrossRef](#)]
68. Mamat, T.N.A.R.; Saman, M.Z.M.; Sharif, S.; Simic, V.; Wahab, D.A. Development of a performance evaluation tool for end-of-life vehicle management system implementation using the analytic hierarchy process. *Waste Manag. Res.* **2018**, *36*, 1210–1222. [[CrossRef](#)] [[PubMed](#)]
69. Harun, Z.; Wan Mustafa, W.M.S.; Abd Wahab, D.; Abu Mansor, M.R.; Saibani, N.; Ismail, R.; Mohd Ali, H.; Hashim, N.; Mohd Paisal, M. An Analysis of End-of-Life Vehicle Policy Implementation in Malaysia from the Perspectives of Laws and Public Perception. *Jurnal Kejuruteraan* **2021**, *33*, 709–718. [[CrossRef](#)]
70. Darom, N.A.M.; Hishamuddin, H.; Ramli, R.; Nopiah, Z.M.; Sarker, R.A. Investigation of Disruption Management Practices and Environmental Impact on Malaysian Automotive Supply Chains: A Case Study Approach. *Jurnal Kejuruteraan* **2020**, *32*, 341–348. [[CrossRef](#)]
71. Melo, A.C.S.; Braga, A.E.; Leite, C.D.P.; Bastos, L.D.S.L.; Nunes, D.R.D.L. Frameworks for reverse logistics and sustainable design integration under a sustainability perspective: A systematic literature review. *Res. Eng. Des.* **2020**, *32*, 225–243. [[CrossRef](#)]
72. Kaviani, M.A.; Tavana, M.; Kumar, A.; Michnik, J.; Niknam, R.; de Campos, E.A.R. An integrated framework for evaluating the barriers to successful implementation of reverse logistics in the automotive industry. *J. Clean. Prod.* **2020**, *272*, 122714. [[CrossRef](#)]
73. Pigosso, D.C.A.; De, M.; Pieroni, P.; Kravchenko, M.; Awan, U.; Sroufe, R.; Bozan, K. Designing Value Chains for Industry 4.0 and a Circular Economy: A Review of the Literature. *Sustainability* **2022**, *14*, 7084. [[CrossRef](#)]
74. Hina, M.; Chauhan, C.; Kaur, P.; Kraus, S.; Dhir, A. Drivers and barriers of circular economy business models: Where we are now, and where we are heading. *J. Clean. Prod.* **2022**, *333*, 130049. [[CrossRef](#)]
75. Bockholt, M.T.; Kristensen, J.H.; Colli, M.; Jensen, P.M.; Wæhrens, B.V. Exploring factors affecting the financial performance of end-of-life take-back program in a discrete manufacturing context. *J. Clean. Prod.* **2020**, *258*, 120916. [[CrossRef](#)]
76. Liu, Z.; Adams, M.; Cote, R.P.; Chen, Q.; Wu, R.; Wen, Z.; Liu, W.; Dong, L. How does circular economy respond to greenhouse gas emissions reduction: An analysis of Chinese plastic recycling industries. *Renew. Sustain. Energy Rev.* **2018**, *91*, 1162–1169. [[CrossRef](#)]
77. Harun, Z.; Molla, A.H.; Khan, A.; Zainal Safuan, U.; Azman, M.S.S.; Hashim, H. End-of-Life Vehicle (ELV) Emission Evaluation using IoT in Malaysia. In Proceedings of the 2022 9th International Conference on Information Technology, Computer, and Electrical Engineering (ICITACEE), Semarang, Indonesia, 25–26 August 2022. [[CrossRef](#)]