

End-of-Life Vehicles (ELVs) and the Startup Ecosystem: Bridging Informality and Sustainable Solutions via Artificial Intelligence

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Abstract

The rapid growth of India's automobile sector, driven by globalization and industrialization, has led to a surge in End-of-Life Vehicles (ELVs, hereinafter). ELVs are those vehicles that are no longer considered roadworthy, no longer validly registered, or declared unfit as per the automated fitness centre. However, with an increase in the automobile sector, management of ELVs becomes critical and requires attention.

Currently, ELV recycling in India is managed by an informal sector, resulting in significant environmental hazards and inefficient resource recovery. ELVs contain hazardous substances such as oil, lubricants, waste batteries, etc., causing significant environmental contamination, and the recovery of these materials is of greater concern. The paper emphasizes that it is crucial to mitigate environmental impacts associated with vehicle disposal, wherein Artificial Intelligence (AI, hereinafter) and Machine Learning (ML, hereinafter) can be increasingly used to optimize an efficient recycling process and pave the way for our very own startup ecosystem and sustainable ELV practices.

Further, the paper examines the challenges and opportunities within the existing ELV recycling framework to explore the potential of startup innovations vis-à-vis AI & ML to formalize and improve the process. Using doctrinal research and secondary data analysis, the study identifies critical policy gaps and compares global best practices with the Indian scenario. The findings reveal that, while initiatives such as guidelines for ELVs coupled with government-authorized recycling startups are emerging, a comprehensive and robust legal framework is still essential to facilitate sustainable waste management and promote a circular economy in the automobile sector.

Keywords: *End-of-Life Vehicles (ELVs), Circular economy, Recycling startups, Registered Vehicle Scrapping Facility (RVSF), Waste Management*

I. Introduction

With the advent of liberalization, privatization, and globalization (LPG), the Indian automobile sector has been burgeoning, and India has acquired a prominent place among the major global auto manufacturer stakeholders. Currently, India is the second largest manufacturer of two-wheelers, followed by the largest manufacturer of three-wheelers, and the third largest manufacturer of cars in the world [1]. Moreover, the significant variation of thirty-three percent from 2019 to 2024 in the production of all vehicles is notable [2]. The ownership of vehicles in India has always held a symbol of consumer lifestyle, a reflection of personality, sentimental value, and a revered worth. As the person climbs the socio-economic ladder, he endeavors to own a better vehicle that aligns with his status quo. The entire focus goes on the manufacture and purchasing of the vehicle, and a little attention is paid to what happens at the end of the pipeline, i.e., disposal and afterlife of the vehicle. This article aims to explore and focus on 'that' end of the pipeline.

II. ELV: An emerging issue

The proliferation of automobiles on the roads has indeed become a significant concern from an environmental and sustainability lens. That said, it becomes pertinent to state that every vehicle that will come on the road shall venture towards its journey to become an end-of-life vehicle (ELV) – sooner or later [3]. ELVs are those vehicles that are no longer validly registered or declared unfit as per the Automated Fitness Centre (AFC, hereinafter), or those vehicles whose registration has been cancelled by the order of the court, or even those that are self-declared as waste vehicles by the legitimate owner of the vehicle [4]. According to Motor Vehicles (Registration and Functions of Vehicle Scrapping Facility) Rules, 2021; ELV is defined under Rule 3 (f) as those vehicles whose usage is cancelled under Chapter IV of the Motor Vehicles Act, 1988 or due to order of Court of Law or self-declaration or even through the declaration by the owner of vehicle due to any of the circumstances in the Rule.

STATEMENT OF PROBLEM

The increased emphasis on ELVs came to light due to the recent deterioration in its impact on the environment. There is a significant rise in the registration of vehicles in India,

as represented in Figure 1, with a total of 39,87,78,427 registrations, of which Uttar Pradesh constitutes 51,674,798 registrations [5]. What's striking, though, is that the expected number of vehicles that are about to reach their end-of-life is also set to rise by 2.18 crores, which is alone for two-wheelers, which accounts for 80% of the total ELVs by 2025, as compared to 87 lakhs in 2015 [6]. The rising numbers come against the backdrop of increasing population, urbanization, changing consumer lifestyle, intra-state migration, and relocation of people towards metro cities in pursuance of better education, jobs, health facilities, and opportunities.

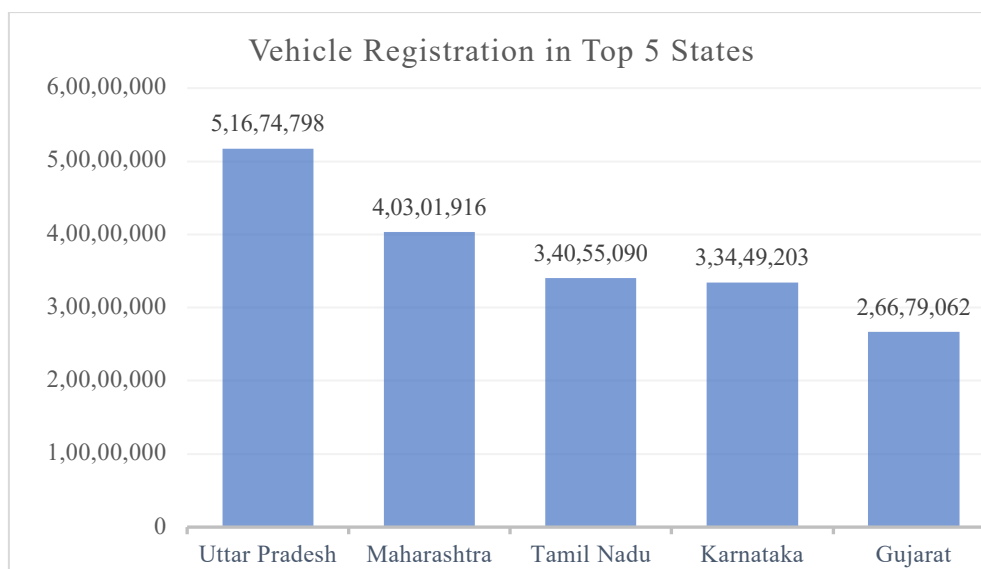


Figure 1: Vehicle Registration in the Top 5 States

Source: Ministry of Road Transport & Highways [5]

Another potential reason contributing to the rise of ELVs is the availability of ready-made replacement parts for vehicles in the local markets. This scenario exacerbates the condition even more, as the vehicle has already reached the stage of obsolescence, yet its use is being continued. However, the question regarding ELVs still hinges on not only how it poses a concern for the environment but also how it reveals broader systemic inefficiencies. The problem lies deep within, as India continues to overlook the potential of startups, which could prove to be a golden opportunity to lead in the circular economy.

OBJECTIVE OF THE PAPER

The paper aims to examine the emerging problem of ELVs in India and assess the various impacts that they cause on the environment and economy. The paper aims to identify the potential factors contributing to the dominance of the informal sector in the ELV recycling industry while proposing measures to plug the gaps by transitioning the informal sector into a startup ecosystem that promotes employment opportunities/generation and the circular economy. The paper shall also examine global best practices that have already leveraged Artificial Intelligence and Machine Learning (AI & ML) into their waste management practices, thereby identifying the current challenges and suggesting robust recommendations for India to adopt ELV recycling strategies through green-tech.

METHODOLOGY

The paper adopts doctrinal research and incorporates secondary data. The study identifies critical policy gaps and compares global best practices with the Indian status quo. It draws on existing government reports, policy documents, journals, research reports, case studies, and national and international legal documents to substantiate the findings.

III. ELVs vis-à-vis Environmental Impact

With the mushrooming of diverse industries, the environmental aspect cannot remain isolated from its influences, especially with the rise of the automobile industry. Building on this, India ranks 176th out of 180 countries in the Environmental Performance Index (EPI) [7]. This leads us to the critical dimension of inquiry, i.e., the repercussions that the automobile sector poses on the environment.

There are commercial vehicles to heavy vehicles, which when reach their end-of-life, contain hazardous substances, fluids, toxic emissions, gases, etc. Due to the low economic value of these materials, they are often dumped in the ground or even roadside, leading to landfills, wherein they tend to become a haven for the dumping of more waste, which becomes a genuine concern for local communities and residents as it poses various health and environmental risks. The ELVs contain harmful components like lead batteries, refrigerant gases, mercury, and oils, which are also accompanied by the artificial leather that makes up the seat cover, hard plastics, and Persistent Organic Pollutants (POPs), which, if burnt directly

in cause air, soil, and groundwater pollution. This warrants acknowledgement that POPs are toxic chemicals that can last for several years before they break down, and that they are difficult to trace, as chemicals released in one part of the world can be deposited at a far distance from their original position [8]. All these consequences impede the Sustainable Development Goals (SDGs), such as life below water (SDG 14) and life on land (SDG 15).

Beyond this, to secure the demand of the automobile consumers, natural resources are too depleted dramatically due to extraction activities. Such demand is likely to increase from developing countries where the population, fuel, infrastructure, and livelihood have to be met simultaneously. Notably, the automotive industry is the most resource-intensive sector. Given the foregoing, according to the United Nations Environment Programme (UNEP), India consumed 5 billion tons of resources, of which 42% were renewable resources and 38% were nonrenewable, such as metals. By 2050, India's resources are only expected to increase by five times the 2010 level, wherein the share of non-renewable (abiotic) resources will grow at a faster pace, that is, about four times the renewable (biotic) ones [9]. ELVs hold the potential to be a rich source of secondary materials. Even though a lot of components could have been recycled but due to an insufficiency of knowledge about their recyclability, their impact on the ecosystem, and a lack of informal structure, it remains a liability rather than an agent of regenerative value.

IV. An Unregulated Afterlife: ELV in the informal sector

ELVs contain a plethora of materials that are recoverable from them, ensuring a steady supply to the automobile industry. Presently, the recycling of ELVs is at an incipient stage, which is quite haphazard and chaotic, and is poorly managed. ELVs in India are predominantly managed by the informal sector. More than 10,000 family units are involved in the ELV dismantling, which specifically involves informal management centers [10]. Most of these informal centers either refurbish these materials and sell them in the second-hand market or recover these components to send for recycling, which is mostly downcycling. Notably, recycling rates are limited, and only 7% of the aluminum and 76% of the iron are recoverable [11]. Vital and high-value materials such as copper wires, cobalt, and platinum from the catalytic converters are not even recovered due to a lack of cutting-edge technologies. It is

imperative to note that when such a task, which has multi-dimensional challenges, is handled and driven by the informal sector in a directionless manner, then the earning profit becomes the main focal point, and issues such as scattered management, ecological challenges, and informed-consumer practices are sidelined.

Currently, the informal sector is playing a dominant role in the collection of ELVs, dismantling procedures, spare-part recovery, and recycling procedures. All these functions are performed using low-level technology that yields less. Even so, the working conditions are not up to the mark, manual dismantling of ELVs, the release of toxic gases and fluids, warrant health concerns. Nonetheless, the informal sector in the automotive industry acts as a consistent source of livelihood and employment for most of the rural and suburban population. According to a study, it has been found that at least 100,000 recycling workers face severe health threats due to low-level facilities in an informal setup that offers employment to 15,000 people directly and 80,000 people indirectly [12]. ELVs make their way into the informal sector due to numerous underlying reasons discussed as follows.

a. Higher salvaging price on account of low operating costs

The informal dismantling of the ELVs has lower costs than formal dismantling. It is evident that the process, when formalized, requires sufficient incentives and compliance costs to carry out the procedure intricately and involve every step, which includes conducting the depollution process and extracting the vital secondary material, which is otherwise neglected in informal recycling practices. This way informal sector stays out of the grasp of taxes, regulations, and environmental norms and operates the entire ELV sector on low operating costs. The older vehicles are easy to mend and repair their automotive parts due to their simple structure, and since they often undergo regular servicing, they give better salvage value and work on low operating costs even if they go beyond the obsolescence stage. Overall, a lower salvage price for ELV is offered by the formal sector than the informal

b. Lack of technology and technical expertise

The present technology does not offer safe and efficient dismantling of the auto-components of ELVs. Vehicle dismantling is mainly conducted using small-scale technology that gives low

yield and capacity [13]. The modern vehicles are made up of complex materials that are difficult to recycle, as there are various processes involved in recycling ELVs, such as depollution, dismantling, shredding, treatment of automobile shredder residue (ASR, hereinafter), followed by recovery and recycling of secondary solid. Furthermore, there are sensitive wastes, such as combustible substances, heavy ASRs, and chlorofluorocarbons (CFCs), that require dedicated methodologies and technologies to collect, treat, and recycle. Along with this technology, it is essential to understand the technical know-how and specialized actors involved in the process. This consequently calls for cutting-edge technology to dismantle them in a pollution-free way. Therefore, the technology should not only be of high-level but also environmentally sound technology (EST, hereinafter). Moreover, the advent of AI & ML has significantly transformed our lives by becoming a fundamental element of the current industrial revolution, popularly referred to as 'Industry 4.0'. Presently, the development of various smart technologies, integration of digital technology, while enabling intelligent decision-making and smart manufacturing that can be leveraged to a more efficient ELV waste management.

c. Poorly informed consumer practices

The lack of awareness about the meaning, impact, and concerns related to ELVs leads to such practices. The consumers want to get rid of their obsolete vehicles; therefore, the owners tend to sell their old vehicles to local actors or informal scrap dealers or even exchange them at a considerable rate under a buy-back option offered by some dealers. The dearth of information about scrappage programs, sustainable practices, and eco-friendly choices has led informal players to dominate the scene of the ELV sector. However, it is evident that in a cost-sensitive country like India, the financial incentives offered to customers are insufficient to motivate consumer behavior towards environmentally conscious choices [14]. This inconsistency not only exists at the consumer level, but it also prevails at a social level, as there is limited participation of local authorities, producers, and manufacturers in spreading awareness.

d. Weak regulatory framework

Currently, a developing country like India lacks a streamlined approach towards ELVs. There is a lack of recycling models to facilitate the structured processing of ELVs. Central Pollution Control Board (CPCB, hereinafter) issued guidelines in the year 2016, namely, “Guidelines for the Environmentally Sound Management of ELVs in India” which received recommendations and suggestions from various stakeholders such as Society of Indian Automobile Manufacturers (SIAM), Ministry of Environment, Forest & Climate Change (MOEF&CC), Tata Steel, etc., which thereafter was further revised and the guidelines were issued in 2019 by (CPCB, 2019) that focused on Environmentally Sound Management (ESM) of all the wastes.

Notably, these are just the guidelines, which are advisory. Currently, there is no dedicated law governing the ELVs. Either it gets governed via multifarious waste management policies or pollution-centric Acts, as exhibited in **Table 1** below, but specifically, there is no focused policy on automobile waste. Consequently, it results in downcycling, wherein the absence of such a framework gives an edge to informal players to bypass the environmental, legal, and ethical norms.

Table 1: List of applicable laws and regulations on vehicle recycling

LAW/REGULATION	YEAR	OBJECTIVE
Water (Prevention and Control of Pollution) Act	1974	Prevention and control of water pollution
Air (Prevention and Control of Pollution) Act	1981	Preventing, controlling, and abating air pollution
Environmental (Protection) Act	1986	Umbrella legislation for the protection and improvement of the environment
The Motor Vehicles Act	1988	Provides a regulatory framework concerning

		vehicles and their (de)registration
Solid Waste Management Rules	2016	Mandated proper channeling of recyclable dry waste to authorized recyclers
Hazardous and Other Wastes (Management and Transboundary Movement) Rules	2016	collection, storage, transport, treatment, and disposal of hazardous & other wastes (tyres, oils, metal scrap, etc.)
Plastics Waste Management Rules	2016	Covers end-of-life disposal, control, and recycling of plastic wastes
Automotive Industry Standard 129	2021 (further revised via Amendment no 2 (05/2023)	Covers dismantling, scrapping, and recycling facilities and recyclers of all types of automotive waste products
The Motor Vehicles (Registration and Functions of Vehicle Scrapping Facility) Rules	2021	set the operational standards for Registered Vehicle Scrapping Facilities (RVSFs).
Battery Waste Management Rules	2022	All waste batteries are to be collected and sent for recycling with a focus on

		Extended Producer Responsibility (EPR)
E-Waste (Management) Rules	2022	collection, storage, recycling, and environmentally sound disposal of electronic assemblies, with the introduction of an environmental compensation mechanism for non-compliance.
Environment Protection (End-of- Life Vehicles) Rules	2025	Encourages recycling and reuse of vehicle components and materials to reduce the demand for new raw materials

Source: Author's compilation based on official government acts and policy documents.

V. Bridging the Gap: ELV Ecosystem through Formal Facilities and Innovation

The current linear approach does not enable closing the loop that begins with production and extends to consumption and the secondary market. Presently, the process of recycling is haphazard and generates waste at every stage. An old vehicle pollutes 8 times more than a new one, and a 15-year-old truck is responsible for polluting the air 10 times more than a new one [15]. Nevertheless, the non-scientific manner in which this process is carried out leads to low material recovery but also lacks transparency, accountability, and visibility. Such consequences call for explorative research to develop a thorough understanding of socio-economic and environmental practices, as it would assist in making practical recommendations concerning the ongoing practices in the ELV recycling system.

Circularity and sustainable development represent converging imperatives in the evolving landscape of ELV recycling. Implementing a circular approach would ensure that products could be developed in a simple design that is easier to recycle, thus encouraging recovery from the waste [9]. Although, as per the Central Pollution Control Board, many steel scrapyards are managed by semi-formal units to recover material, yet are poorly organized [4]. It is also imperative to note that semi-formal channels, too, suffer from manual processing, resulting in a failed de-pollution process that involves equivalent risks as those of informal. Thus, there is a need to integrate formal and informal setups, which has been advocated for in recent years.

A. Framework of ATS and RVSF: Mayhem to Method

Ministry of Road Transport and Highways (MoRTH, hereinafter) has been emphasizing setting up Automated Testing Station (ATS, hereinafter) and Registered Vehicle Scrapping Facility (RVSF, hereinafter), under the umbrella of Voluntary Vehicle Fleet Modernization Program (V-VMP) in 2021. This Vehicle Scrapping Policy aims to create an ecosystem to phase out the unfit and polluting vehicles in an environmentally friendly manner. The registration process is conducted via the National Single Window System (NSWS, hereinafter), wherein the approved details of ATS are transmitted from NSWS to the Automated Fitness Management System (AFMS, hereinafter). AFMS acts as a digital backbone that links ATS to the government database, like VAHAN. The ATS is a facility for testing the fitness of vehicles scientifically using the latest equipment, without any manual intervention. Thus, if the vehicle fails any or all the tests, it can apply for a retest after rectifying the defect, and in case the vehicle is not issued a fitness certificate in two attempts, then it shall be recommended for scrapping. This is where the RVSF steps in as a key player. RVSF is an authorized facility that legally scrapes old, abandoned, or unfit vehicles, presenting a potential opportunity for a startup venture. RVSF shall be authorized to make entries in the VAHAN database regarding the scrapping of vehicles, along with the issuance of a Certificate of Deposit (CoD, hereinafter) and Certificate of Scrapping. It has been developed with an endeavor to formalize the existing informally dominated automobile recycling. In line with this, Automotive Industry Standard-129 (AIS 129, hereinafter) was also released with the acknowledgment of the fact that alone

regulations cannot be the sole solution for an environmentally friendly process; rather, an entire mechanism of collection, dismantling, tech-infrastructure, and maintenance of in-service vehicles plays an equally crucial role. AIS 129 lays down a detailed procedure for the powers and obligations of RVSF, which will also include verifying the records of vehicles with the assistance of the National Crime Records Bureau (NCRB) and local police to check if the vehicle has been stolen before it is scrapped, and an electronic record shall be maintained for the same [16]. Further, if the vehicle is not found to be stolen, it shall proceed to the scrappage. RVSF can be operated by any legal entity: an individual, organization, society, or trust. It is subject to the possession of a PAN Card, Certification of Incorporation, Valid GST registration, and permission letter to set up a valid RVSF facility from the State/Union Territory where it is located. For instance, currently, 18 states are live on NSWS and accepting applications for VVMP [17]. However, certain vehicular criteria need to be qualified by vehicles to undergo scrapping by a Registered Scrapper, such as **those vehicles**:

- i) which are **not granted a certificate of fitness certificate**
- ii) **not renewed Certificate of Registration** per Rule 52 of the Central Motor Vehicles Act, 1989
- iii) which have been **damaged due to fire, riot, natural disaster, accident, or any calamity**
- iv) which have been **certified as scrap by the owners** of the vehicles
- v) which are **declared obsolete or surplus, or beyond economic repair**, as per the Central/State organization
- vi) **bought by RVSF in an auction** for vehicle scrappage
- vii) vehicles **damaged during transportation** from vehicle OEMs to dealers, which suffer from a manufacturing defect.

Along with issuing a certificate of vehicle scrappage, RVSF will also ensure that the parts are properly dismantled before sending them to recyclers. For instance, vehicles will not be scrapped until oil, fuel, antifreeze, and other gases are drained and collected in certified standard containers in a manner consistent with an eco-friendly way [18]. To perform the recycling procedure, a scrap yard and collection centre too, shall be set up. This shall focus

on minimizing human intervention to create a safe working space to comply with safety regulations. It also ensures that there is zero leakage of pollutants and that there is a designated, adequately safe storage place for hazardous automotive parts.

B. Pathways to Formalisation via Startup Ventures

India ranked 63rd in the World Bank's Doing Business Report (DBR), 2020, jumping 79 positions from 142nd rank in 2014 (Embassy of India). Moreover, India also owns 3rd position when it comes to the startup ecosystem in the world [19]. This improvement has been possible because of the government's support in understanding the value chains, the use of innovation, and easing technicalities by switching towards digitalization. Promotion of ATS and RVSF shall not only foster sustainability but also enhance the ease of doing business in the arena of sustainability. NSWs shall provide a database to investors as an all-in-one approval repository, a real-time application for tracking status and query management. This process streamlines the process for both the State government and the investor. As the government endeavours to digitalize the data of vehicles through VAHAN modules, investors can leverage this data to manage the end-to-end lifecycle of the vehicles at ATS and RVSF, which includes scheduling, booking appointments, document verification, and issuance of certificates.

To further the entry of startups, investment, and ease of doing business in domains of ELV recycling, the government has also set up E-Auction Portals for Government Vehicles by Metal Scrap Trade Corporation (MSCT) and Government E-Marketplace (GeM) to facilitate structured exchange of government vehicles which is older than 15 years among Centre, State, Public Sector Undertakings (PSUs) and RVSF [20]. Moreover, the module has been designed in such a manner that vehicle owners can register at any RVSF and negotiate the scrap value for an old vehicle.

C. Sustainable Stories

Sensing the need for organized key players in the arena of ELV paving way for further startups, companies like 'Mahendra Accelo' (a Mahendra group company), with the collaboration of MSTC (Enterprise of the Government of India and administered by the

Ministry of Steel), came up with India's first ever organized ELV recycling joint-venture by the name 'CERO'. CERO recognized the growth potential of this industry and entered into the recycling business in 2018 with a target of zero waste and zero pollution. It is capable of recycling two-wheelers, three-wheelers, cars, trucks, and buses; all in tandem with legal and environmental norms issued by CPCB. It aims to ensure zero spillage of hazardous wastes such that steel, which forms 70% of the vehicles like cars, goes back to the melting furnaces where it can be converted into secondary steel. CERO provides an RVSF facility that is present in more than 40 cities across the country. It also provides the customers with a fairly negotiated salvage value. After the vehicle scrapping process by the RVSF, the government shall offer incentives for each CoD. Moreover, the vehicle shall also be de-registered from RTO without any plea of misuse of the vehicle after handing it over to RVSF. This is how CERO is trying to integrate sustainability and enterprise. The other key players that have unleashed the hidden potential of this industry are Maruti Suzuki Toyotsu (MSTI), which again is a joint venture of Maruti Suzuki and Toyota, with the capacity of dismantling scrap up to 2000 units per month. Driven by the motive, Tata Motors also opened its RSVF with the name 'Re.Wi.Re', which means 'Recycle with Respect' across various cities like Bhubaneswar, Delhi NCR, Jaipur, Lucknow, Raipur, and Surat. the facility is fully digitalized and represents a ground-breaking leap towards fostering the circular economy [21].

D. Alignment with AI & ML

Automation and the Internet of Things (IoT) are revolutionizing the waste management approach. With the rapid advancement of AI & ML, its adoption is visible in various sectors, including the automobile, transportation, and sustainability sectors. While AI holds potential to change the present state-of-the-art technology, its scientific and ethical integration into the vehicle recycling industry can improve efficacy, dismantling, and resource recovery. AI can augment decision-making, optimise operations, reduce human errors, manage large data sets, and predict outcomes by identifying patterns. In ELV domains, it can assist in smart sorting by optimizing disassembly sequences. All these attributes of AI can be used as a leverage to the management of ELV waste and facilitate

global transition towards a circular economy. Moreover, blockchain technologies can also be used to ensure the ESM of hazardous wastes. It is imperative to note that the adoption of AI could potentially increase waste recycling by 20-30% and reduce operational costs by 10-15% [22]. Overall, it shall result in a reduction of greenhouse gas emissions from garbage trucks by 30-50%, and a reduction of at least 15-20% in soil and water pollution [22]. This, in turn, will not only ease the waste management procedure but also reduce landfills and conserve valuable resources.

E. Global Trends in ELV Management

The European Union has published Directive 2000/53/EC to promote environmentally friendly management of ELVs. The directive acknowledges that every year, 8 to 9 million tonnes of waste are produced due to ELV, which needs to be managed correctly [23]. The underlying principles are precautionary, preventive, recyclability, and recoverability of the wastes. Moreover, Para 22 of the Directive also exhibits the incorporation of **Extended Producer Responsibility** (EPR). Furthermore, incorporation and adaptation of the latest technology is also emphasized in Para 29. The EU nations like Sweden, the Netherlands, and the United Kingdom have pioneered policies for ELV. The Netherlands has created "Auto Recycling Netherlands (ARN)", which collects and manages vehicle collection and dismantling. According to (Auto Recycling Netherlands, 2021), 98.7% of all scrapped vehicles were recycled by weight. ARN also focuses on producer responsibility for batteries in electric vehicles as well. The regulation of ELV law in Japan is also the corollary of EPR, which is based on "**shared responsibility**". Japan is the leading and largest industry of automobiles and thus, it is more prone to the rate of vehicles falling into the ELV category. Japan has also ensured that the cost of recycling must be paid when the owner purchases the vehicle. Japan enacted the ELV Recycling Act to promote the proper dismantling and disposal of ELVs at the end of their lifespan. Chapter I of the Act deals with the general provisions, in which Art. 3 of the Act deals with the responsibilities of manufacturers through devising designs, Art. 4 extends responsibilities of the Related Business Operators, Art. 5 extends responsibilities to Automobile Owners, Art. 6 promotes the State responsibilities of promoting R&D related to ELV and must endeavour to

promote sustainability through educational and publicity activities, and finally Art. 7 extends responsibility to the local government [24].

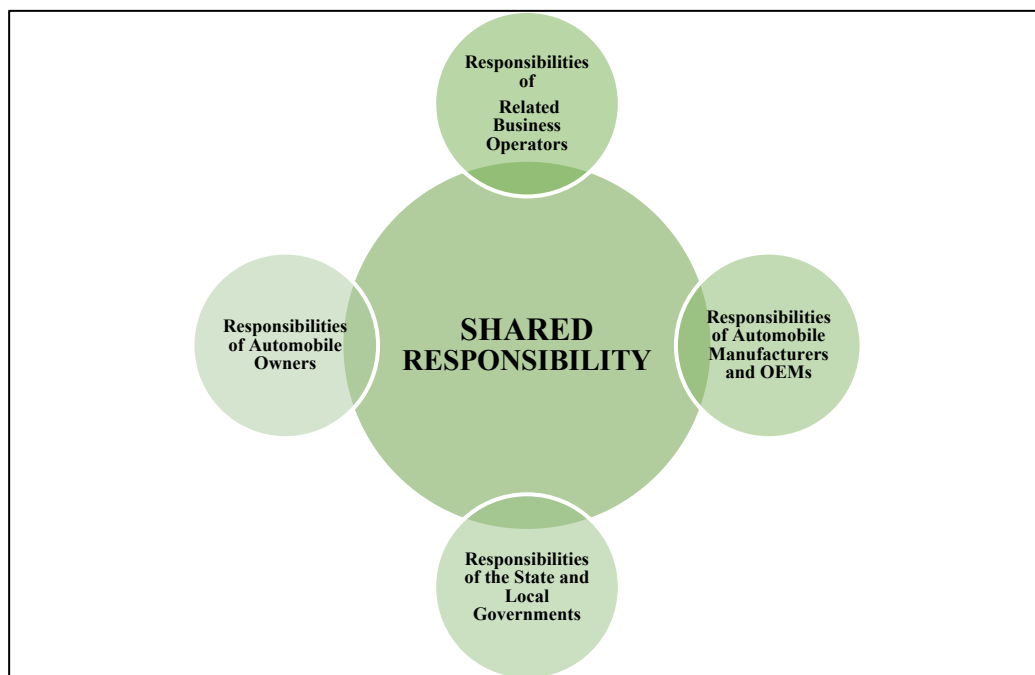


Figure 2: Japanese ELV Law framework of the “shared responsibility”

South Korea also drafted its first special law on ELV regulation on similar lines to the preventive principle in 2007, creating a framework of “self-declaration” to hold producers and importers responsible for their use of resources. Interestingly, there is no dedicated ELV framework in the United States of America. In developing countries like Malaysia, the ELV framework is still being developed, although there have been past attempts to introduce a National Automotive Policy in 2004, but it suffered a severe backlash and had to be withdrawn. According to the study by Neilson in 2014, Malaysia has the highest number of vehicle owners in Southeast Asia, and this demand continues to grow, while there is no regulation on ELV, which is a pressing concern. The initial withdrawal of the ELV regulation was due to a lack of research, which had many loose ends (Ismail, et al., 2022). However, there is increasing reliance on state-of-the-art technology and AI & ML to tackle waste management such as Ukraine is increasingly relying on intelligent containers and automated sorting systems. Such systems are also being adopted in South Korea, such

as the EcoAs system that promotes recycling of automobile and electric products to manage the whole process from production to the end-of-life. The EcoAs system is based on the preventive policy principle to reduce environmental burden. Similarly, in Singapore, AI-powered sensor systems and ML algorithms have reduced the landfills by 30% and increased the recycling waste to 20% [22].

COUNTRY	LAW/ REGULATION	YEAR
European Union (Sweden, Netherlands, U.K.)	Directive 2000/53/EC of the European Parliament and the Council on ELV	2000
Japan	End-of-Life Vehicle (ELV) Recycling Law	2002
Korea	Act for Resource Recycling of Electrical and Electronic Equipment and Vehicles	2007
India	The Environment Protection (End-of-Life Vehicles) Rules	2025
U.S. A	NO DEDICATED LAW ON ELV	—
Thailand	NO DEDICATED LAW ON ELV	—
Malasiya	NO DEDICATED LAW ON ELV	—

Table 2: Global regulations on ELV

VII. Navigating Roadblocks and Reimagining Pathways

The current challenges are associated with various risks, challenges, improper strategic implementation, a lack of performance audit, and awareness. The present approach suffers from rudimentary and structural problems, which require a profound framework that has been discussed along with—

a. Exclusivity of informal sector/players

The formal venture, which is to be integrated into the ELV sector, offering a better salvage value than the informal sector, will attract more customers, which in turn will impact the employment of informal players. While the guidelines by CPCB [4] and the Motor Vehicle (Registration and Functions of Vehicle Scrapping facility) Rules, 2021, adopted a futuristic approach by laying down detailed procedures of vehicle shredding, dismantling, and RVSF, they did not seem to take into consideration informal scrappers and dealers. The ELV sector holds potential to generate startups, sustainable business models, and create employment opportunities. Formalising the informal players involved in the scrapping process is suggested, as they are more well-versed with the associated nuances and practical intricacies in the automobile industry.

b. Barriers to the sectoral entry

There is a lack of formalized competition between recycling players across the country, as only leading companies are involved in the ELV recycling industry. To further bridge this gap, the government can provide incentives or assist in setting up common infrastructure for the existing informal players to form some cooperative or association units. The lack of maintenance of the database also impedes the implementation of disincentive tools such as a green tax, which can encourage vehicle owners to discard old vehicles rather than pay recurring taxes.

c. Research and Training deficit in green-tech

The underlying reason for the absence of proper infrastructure and advanced techniques is low investment in the research arena, as leading companies also stepped into this industry very recently. Therefore, there must be an endeavour from the government to encourage the establishment of research and development (R&D) sites on resource recycling, taking a lesson from the case study of Malaysia. The prominent example of such a research site is the Automobile Recycle Technical Center established by Toyota. Such pursuit shall not only foster in development of vehicular designs, dismantling technologies, and recognizing environmental problems, but also reinforce the interest of budding scholars and academicians towards the circular economy. Likewise, it will also

help to build skilled and trained professionals in the field of AI & ML. The reasons beneath it are the discourse of traditional education without practical exposure, and unwillingness or inability to adapt to the state-of-the-art technologies. Therefore, targeted education, training, and policy initiatives are necessary to cultivate a sustainable output.

d. Logistical impediments

According to MoRTH, all over India, there are only 174 RVSF set up that too across only a few States and UTs, mostly in the urban areas, excluding the rural and semi-urban peripheries [25]. Similarly, there are only 144 ATS confined to a few states like Gujarat, Uttar Pradesh, etc. India does not have a mandatory vehicle retirement policy, which discourages the owners from adopting voluntary vehicle scrapping, although Delhi is apparently approaching vehicle retirement, especially older than 15 years.

CONCLUSION

There is a dire need to bridge the gap between policy and implementation by gluing it well with profound research and fostering citizen-centric initiatives and models, such as Japan, wherein the community is reinforced to adopt and adapt sustainable choices when it comes to consumerism. The government should also take lessons from instances from other developed nations to incubate EPR and shared responsibility in the Indian framework on ELV. While initiatives like VVMP are a welcome step yet there is a long road for us to go. Imposing an instant blanket ban on vehicles based on their age criteria seems unjust to the commuters, as road-worthiness of a vehicle is a scientific and technical issue, and only a balanced policy can ensure protection of the environment, phasing out old vehicles, and paving the way for sustainable startups. At this juncture, the story of end-of-life vehicles should not be presumed as 'the end' but 'an end'—a medium, to the doors of opportunity it opens towards entrepreneurship, startups, and environment-resilient pursuit.

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