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ARTICLE

Resource Retrieval from End-of-Life Passenger Cars in the Informal Sector of Morocco

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ABSTRACT

Sustainably managing vehicles at their end-of-life stage (ELVs) presents significant potential forresource recovery, effectively addressing resource scarcity through the closure of the material loop.While ELVs in countries like Morocco have traditionally been treated as waste rather than secondaryresource material (SRM), they have the potential to reduce reliance on primary materials when usedjudiciously. Despite policymakers aiming for increased resource efficiency in the automobile sector,there is limited research exploring the role of the informal sector in recovering materials and parts fromELVs. This study investigates the ELV processing scenario at Salmia scrap market, recognized as one ofAfrica's largest informal markets for ELVs. Using a mass-balance approach, the disposal of sedan cars isexamined, and a conceptual

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framework illustrating the process flow and interactions among multiplestakeholders is developed. From sampled sedan cars, approximately 7% of aluminum and 76% of iron,by weight, are recovered. These findings contribute to estimating the potential for recycling andrecovering materials from ELVs processed by the informal sector in Morocco. In a standard operationalcontext, estimations suggest that the sector holds substantial potential to recover aluminum and iron by2030. This underscores the importance of formalizing operations and integrating informal players intothe value chain to effectively address resource scarcity within a circular economy.

Keywords: Secondary Resource Material; Mass Balance Analysis; Informal Sector; Recyclability; Recoverability; Circular Economy

1. Introduction

Morocco faces pressing challenges in modern industrialization, specifically in material recovery and environmental pollution. While discussions often focus on conventional sources like solar energy, wind power, and waterpower for renewable energy in Morocco, everyday products offer untapped potential as renewable energy sources through recycling. Waste forms such as paper, plastic, rubber, and communal waste contain components with high energy potential, making waste and waste management valuable sources of renewable energy in Morocco[1].

End-of-life vehicles (ELVs) in Morocco pose a complex issue requiring an efficient recycling model aligned with environmental requirements and sustainability goals. ELVs, considered hazardous and generating 5% of global industrial waste, necessitate a shift towards eco-friendly solutions and repeatability in recycling processes[2–4]. In Morocco, the preference is for energy recovery, recycling, and reuse over disposal and landfilling. Industry experts forecast that Morocco will be able to produce one million cars by 2030 and will soon overtake Italy in vehicle production[5].

The challenging ELV waste processing, with its complex structure and varied composition, emphasizes recycling rates and higher sustainability indicators in proposed Morocco strategies[1, 6, 7]. Developed countries often have structured systems for managing ELVs, as exemplified by the European Union's Directive on ELVs (2000/53/EC) and related standards[8–10]. However, the situation in many developing countries like Morocco remains different. These nations often face challenges like a significant presence of the informal sector handling ELVs and rapid growth in vehicle numbers, putting immense pressure on resource extraction.

For each kilogram of steel scrap recycled at the end of a product's life, it is possible to save 1.5 kg of CO_2e missions, 13.4 MJ of primary energy, and 1.4 kg of iron ore. These savings represent reductions of 73%, 64%, and 90%, respectively, compared to using 100% primary production methods[11]. These figures highlight the substantial potential of recycling ELVs in addressing resource scarcity.

In response to the existing gap in literature on Morocco's ELV sector management, this paper aims to contribute by focusing on the informal sector, which holds significant potential for establishing a circular economy and addressing resource scarcity challenges in the country. Specifically, the study (1) presents the realities of the informal ELV sector in Morocco; (2) assesses the recyclability and recoverability efficiency of ELV dismantling units; and (3) evaluates the potential for obtaining secondary resource materials from sedan variants, representing over 50% of post-consumption passenger vehicles in Morocco. This research, highlighting an informal sector case study, is among the few addressing ELV disposal in Morocco and quantifying its role in promoting resource efficiency and a circular economy.

2. Methodology

The research sought to understand the operational facets of Morocco's informal sector for disposing of ELVs and assess its ability to mitigate resource scarcity. It examined three key aspects: the flow of materials, operational efficiency, and the extraction of secondary resource materials.

2.1. Study Area and Data Collection

The study focused on Salmia, a significant scrap market in Casablanca, known for handling ELVs. This market,

housing approximately 900 units, deals with discarded vehicles and scrap metal from both domestic and international sources.

Various shops within the market handle different types of metal received through a network of scrap dealers and haulers. Despite being a hub for employment opportunities and business ventures, the informal nature of the processing units in Salmia results in unscientific and unhygienic practices for dismantling various vehicles, from bicycles to large trucks at the end of their life.

Figure 1 provides a visual representation of the on-site conditions at Salmia scrap market, highlighting the informal dismantling and material recovery processes ELV.

Figure 1. On-site Conditions at Salmia Scrap Market, the Largest Market in Morocco for ELVs.

Various methods, including field observations, interviews, and stakeholder consultations, were used for primary data collection at the Salmia scrap market in Morocco. Despite challenges due to the informal setting, field visits occurred between June 2022 and August 2023. The market, lacking basic amenities, faces issues like vehicle theft and counterfeiting. Due to a negative image from a few traders, stakeholders were hesitant to interact. Socio-economic differences among traders, dismantlers, and laborers further complicated data gathering. Compiling data necessitated weeks of visits, and photography was restricted. Uncovering details about the complete ELV dismantling and management chain proved challenging, and we could only manage information on four ELVs at most.

Highlighting the importance of sedan vehicles, which make up nearly half of the total passenger vehicle fleet, the study takes into account the average lifetime of passenger cars and SUVs registered in both 2021 and 2030 as 18 years.

After establishing contact with twelve traders and dismantlers in Morocco, we successfully gathered primary data on end-of-life sedan variants of Fiat, Renault and Peugeot. The sample specifically included genuine ELVs, ensuring they had reached their end of life due to age and not just damage. Additionally, the vehicles selected had been operational for 15 to 18 years, adhering to the maximum life guideline set by the Central Pollution Control Board [12]. The data collection spanned six months (February to July 2023), aligned with the availability of ELVs meeting the specified criteria.

It required several weeks and multiple visits to compile even basic information. Any person found taking photographs is instructed to delete them and discard the memory card.

Besides researching market operations, the study also gathered primary data for characterizing sedan passenger vehicles through field visits. The evaluation involved dismantling four vehicles (V1 to V4), with permissions secured from stakeholders in the value chain. Given the challenging conditions, obtaining information on the complete dismantling and management chain for an ELV was difficult, and the study managed to analyze four ELVs.

The study meticulously monitored the treatment, dismantling, and subsequent processing of all the samples to quantify their material composition. Recovered materials were categorized into metals, polymers, elastomers, glass, fluids, MONM (modified organic natural materials), and others. The weight of each category was recorded. This categorization adhered to the Automotive Industry Standard AIS-129 set by the Automotive Research Association of India, and the data were organized based on the field inventory data sheet [13].

In addition to primary data, secondary data on registered vehicles were obtained from the Moroccan Ministry of Equipment, Transport and Logistics. This information was used to estimate the number of ELVs based on registration years, gauging the potential of the ELV sector, specifically in the sedan segment for the entire country. The methodology for this estimation is detailed in the following sections.

2.2. Present State of ELVs Sector in Morocco

To understand the dynamics of the informal ELVs sector in Morocco, this study combined primary field investigations and a review of relevant literature. By analyzing the material flow and stakeholders globally, a preliminary outline of the Moroccan market's informal ELV supply chain was

developed. This framework served as a baseline for quantitatively assessing the ELVs sector's potential as a source of secondary resource materials. Additionally, a Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis was conducted to highlight key aspects of the sector based on literature and field observations.

2.3. Sedan Vehicles' Potential for Recycling and Recoverable Materials

The efficiency of managing ELVs was assessed in terms of the process's potential to generate recyclable and recoverable materials. Mass characterization of sample components used the mass balance approach, based on the law of conservation of mass. Since vehicles experience wear and tear, the mass balance concept estimated the recyclability and recoverability potential of an ELV. As the informal sector lacks standard operating procedures, the method from AIS-219[13], following ISO 22628, was applied to estimate the rates of recyclability (R_{cyc}) and recoverability (R_{cov}). AIS-129 is the primary reference for the Indian ELVs sector, established through consultations by a committee under the Ministry of Road Transport and Highways, Government of India. The study adopted AIS-129 for quantitative estimations, aligning with recent research highlighting its significance in guiding ELV collection and dismantling by authorized centers in India[14]. This choice is particularly relevant for Morocco, where detailed data is currently unavailable.

Equations (1) and (2) express R_{cyc} and R_{cov} as percentages of mass in the samples, respectively:

$$R_{cyc} = \frac{(m_i + m_D + m_M + m_{Rr}) \times 100}{m_V} \quad (1)$$

$$R_{cov} = \frac{(m_i + m_D + m_M + m_{Rr} + m_{Er}) \times 100}{m_V} \quad (2)$$

Here, m_i represents the mass before treatment, m_D is the mass after dismantling, m_M is the mass of metal separation (hulk mass), m_{Rr} is the mass of recyclable material from non-metallic residue, m_{Er} is the mass of energy recovery material from non-metallic residue, and m_V is the weight of the entire vehicle (ELV mass) at the start of the process.

2.4. Assessing Sedans for Secondary Resource Material Potential

Analyzing the quantity and quality of materials in end-of-life passenger vehicles can provide valuable insights into the potential of this sector as a source of secondary resource materials. It also aids in formulating effective waste management strategies for handling the waste generated by the automotive sector, specifically focusing on ELVs. Regularly updating estimates based on the number of ELVs each year allows for constant monitoring of the sector's potential to supply recycled materials, reducing the strain on existing resources.

For instance, a typical sedan car is predominantly composed of various metals, with steel constituting around 60% of its mass[15]. Extrapolating data from this case study to the national level, we estimated the potential of sedan passenger vehicles as a source of iron and aluminum over an 8-year period (2022–2030). The Central Pollution Control Board's benchmark of obsolescence, defined by the number of years a vehicle can be used before being considered an ELV, guided the estimation of ELVs in Morocco[12].

Assuming a 15-year lifetime for passenger vehicles, we identified the year when a vehicle would become an ELV by adding 15 years to its registration year. This study, based on the annual number of registered sedan vehicles between 2003 and 2018, aims to emphasize the potential of the automobile sector as a consistent source of secondary resource materials. Efficient management of these materials can contribute to addressing Morocco's resource scarcity challenges.

Table 1 outlines the assumptions used in estimating the secondary resource material potential from sedan passenger vehicles in Morocco (Data obtained from field research).

The Equation (3) was employed to estimate the mass of the material (iron or aluminum) obtained in the year when sedan passenger vehicles become ELVs.

$$R_{yi} = \sum_{a=1}^{y} u_a r_i \quad (3)$$

In the given equation, R_{yi} represents the amount of secondary resource material (SRM) produced in year y of type i, where i can be iron or aluminum, and y is calculated as a + 15, corresponding to the year when the vehicle becomes an ELV. The variables include u_x , which denotes the number of registered sedan passenger vehicles in year x, and r_i, representing the weight of iron or aluminum in a typical

Table 1. Mass Conversion Factors Used to Estimate the Potential of the ELV Sector in Morocco as a Source of Iron and Aluminum.

Attribute	Estimate
Sedan Proportion Among Total Passenger Vehicles in Morocco	50%
Average Mass of a Single Sedan Passenger Car (kg) in Morocco	1200
Average Iron (Fe) Composition in a Single Sedan Passenger Car (kg) in Morocco (wFe)	
Average % composition of Iron (Fe) in 1 sedan Passenger Car in Morocco (wFe)	76%
Average Aluminum (Al) Composition in a Single Sedan Passenger Car (kg) in Morocco (wAl)	84
Average % Composition of Aluminum (Al) in a Single Sedan Passenger Car in Morocco (wAl)	7%

sedan passenger vehicle determined through mass-balance analysis of four samples used in the present case study.

To extend the projections up to 2030, it was assumed that the mass composition of sedans manufactured in 2003 and in 2018 remains constant. Despite global efforts by car manufacturers to reduce vehicle weight for improved fuel efficiency over the last two decades, this assumption considers that materials like aluminum alloys, plastic, and modified organic natural materials have not significantly replaced iron in the mass composition.

3. Results and Discussion

3.1. Overview of Unregulated ELVs Sector in Morocco: Insights from Salmia Scrap Market Processing Units in Casablanca

Focusing on processing units in the Salmia market. This sector operates without regulation, organization, and formality, functioning as a perfectly competitive. The handling of ELVs in Morocco is limited to basic dismantling using crude methods due to the absence of a specialized and scientific framework for sustainable management. Understanding the holistic management scenario in Morocco requires analyzing the interconnections among two independent domains within the ELV sector, as depicted in **Figure 2**.

A vehicle designated as ELV by its last owner undergoes a specific process in Salmia. Initially, a preprocessing is applied, involving the removal of fuel, liquids, and the battery. Due to its informal sector status, no dedicated depollution measures are implemented. Instead, the vehicle is subjected to repeated hammering and chiseling to break it into smaller parts. ELV markets, such as the one in Casablanca, like Salmia, include numerous traders categorized as first-level, second-level, or third-level traders. These traders manage the parts based on their expected economic benefits.

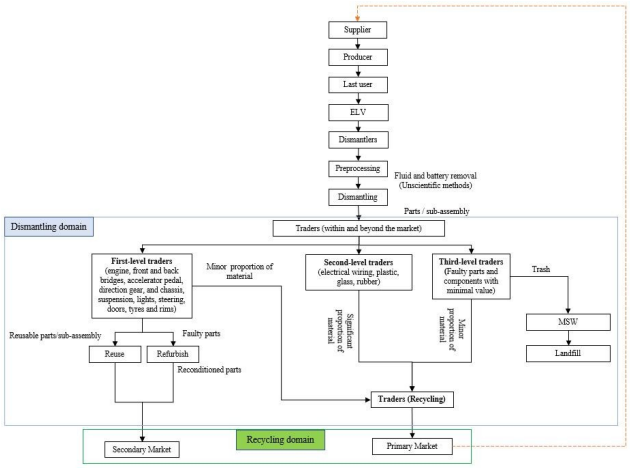

Figure 2. Overview of Informal Recycling and Dismantling Practices for Automobiles in Morocco's Informal Sector: Insights from Salmia Market.

First-level traders handle the important components like the engine, front and back bridges, accelerator pedal, direction gear, chassis, suspension, lights, steering, doors, tyres and rims, etc. They often refurbish or reuse the majority of parts from ELVs to maximize economic returns. Second-level traders focus on recyclable materials like glass and rubber, which are economically less significant. A substantial portion of retrieved materials is directly recycled through these traders. Third-level traders deal with materials having lower economic returns, such as seat foams, materials, broken polymers, and elastomers. Even these low-value parts enter the material chain through recycling traders. The small, unusable fraction of materials not of interest to even third-level traders ends up in landfills as part of municipal solid waste (MSW).

Parts available with recycling traders and first-level traders enter the second segment of the processing cycle, the recycling domain. Parts bought by first-level traders also enter the market for pre-owned or second-hand vehicles. Second-level and third-level parts enter the materials market, processed for secondary-material markets like low-

grade plastics and rubbers. The recycling domain involves inter-market trade between traders dealing in second-hand vehicles and those handling parts of such vehicles.

Components and recycled products that find no immediate use undergo processing to generate low-grade materials or parts suitable for retrofitting other local applications, such as customized motor vehicles.

While efforts are underway, energy recovery from waste is still in its early stages of development in Morocco.

As demonstrated in the process flow, the informal sector involves multiple stakeholders and links, with many intermediaries aiming to maximize monetary gains, making the system less efficient as a whole. Although this informal approach to ELV management has been perceived as unsustainable and harmful to the environment, dismantlers strive to extract the maximum from each ELV, segregating proceeds for reuse or appealing to recycling traders, ultimately reducing overall waste from ELVs. However, due to undefined boundaries and the absence of a legal framework, it is challenging to either support or question these observations, highlighting the need for more scientific evaluations.

In contrast to the current scenario in Morocco, the broken red line in **Figure 2** represents the ideal situation; a direct link between traders and OEMs (Original Equipment Manufacturers), conferring multiple benefits. Despite the total dominance of the informal sector, if a large proportion of secondary resource materials, such as iron and aluminum, goes back to car makers or OEMs, it could contribute significantly to sustainable and environmentally friendly ELV management. The ideal situation presented in the framework in **Figure 2** is also followed in the EU, where ferrous materials retrieved after separation of scraps are directly reintroduced into the automotive supply chain for recycling within the value chain (as input material for foundries).

To address the ongoing debate on the efficiency of informal ELV management, a SWOT analysis was conducted for the Salmia informal ELV sector, detailed in **Table 2**.

Table 2. SWOT Analysis of the Informal ELV Disposal Sector in Salmia, Casablanca.

Strengths	**Weaknesses**
Low capital investment compared to formal setups. Manual dismantling enhances part reuse potential and saves energy. Strong network ensures a balanced supply of ELVs and parts. Affordable labor creates more job opportunities. Specialized traders contribute to high recovery rates for basic materials.	Lack of regulatory framework for ELV management. Slow dismantling pace and lack of formal setups limit capacity. Unscientific methods lead to environmental and health hazards. Occupational hazards pose risks to workers. Involvement in stolen vehicle dismantling threatens stability. Lack of transparency with formal stakeholders.
Opportunities	**Threats**
Collaboration with formal sectors for better resources and regulations. Improved vehicle design for better recovery of rare elements. Government policies on electric vehicles boost recycling. Demand for secondary materials positions the sector as key player. Potential for formalization and increased legitimacy.	Lack of regulatory framework causes instability. Environmental and health risks harm reputation. Involvement in illegal activities risks shutdown. Uncoordinated operations with formal sectors lead to inefficiencies.

The results of the SWOT analysis clearly indicate inefficiencies in the overall ELV management cycle, leading to environmental and occupational challenges. However, a notable outcome underscores the importance of dismantlers in efficiently segregating vehicles and reintegrating materials into the supply chain. It is also highlighted that, due to manual dismantling in the informal sector, the potential for recyclability and recoverability may be relatively higher, with minimal energy consumption, compared to formal ELV setups. Similar findings about an informal ELV sector have been reported[14].

3.2. Evaluating the Recyclability and Recoverability Potential of ELVs Managed in Salmia

The lack of high-quality data and standardized procedures for ELV management has been a persistent challenge in research[16]. This study addresses this issue by providing insights into the recyclability potential of ELVs dismantled in the informal sector in Morocco, representing one of the first in this domain. **Table 3** and **Figure 3** presents estimated recycling (87.9%) and recoverability (90,7%) rates, derived from dismantling four ELVs in the sample. The recycling

rate is notably higher than that observed in countries with more formalized systems. For instance, in Europe, the reuse and recycling rates are required to reach at least 85% of the average weight per vehicle annually, as mandated by Directive 2000/53/EC [17].

The difference can be attributed to Morocco's informal sector's extensive manual dismantling processes, which allow for greater recovery of reusable components and materials, though at the expense of both efficiency and environmental safety.

Table 3. Mass Quantities of Various Components (in Kg) and Recycling/Recovery Rates after Dismantling Four ELVs.

Sample	Preprocessing Mass (m_i)	Dismantling Mass (m_D)	Hulk Mass (m_M)	Non-Metallic Residue Treatment Mass (m_{Rr})	Potential Energy Recovery Mass (m_{Er})	Initial Mass of ELV (m_V)	Recyclability Rate (R_{cyc})	Recoverability Rate (R_{cov})
V1	71	530	465	106	33.5	1300	90%	93%
V2	58	423.5	366	96	36	1100	86%	89%
V3	41.5	484	436.5	94	32	1200	88%	91%
V4	53	461	445	92	34	1200	88%	90%
						Average	87.9%	90.7%

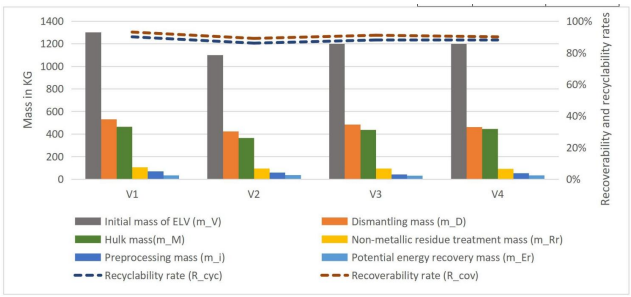

Figure 3. Recycling and Recovery Rates of Various Components from 4 Dismantled ELVs.

Salmia's higher rates can also be attributed to the involvement of multiple stakeholders in the informal setup, as depicted in **Figure 2**, including scrap dealers accepting various ELV parts for profitability. However, the absence of depollution measures, as emphasized by ISO 22628, remains a critical gap that compromises environmental sustainability. Similar environmental concerns have been reported in studies on informal ELV management in developing countries like Nigeria, where hazardous fluids are often improperly disposed of [18].

Unlike Morocco's informal process, more formally managed operations in developed countries generate substantial auto shredder residues. This shredding process breaks vehicles into smaller fragments for sorting, but the complexity and diversity of materials, such as polymers and composites, make effective separation challenging. Furthermore, the process is energy-intensive, with most energy being consumed by mechanical actions, which add little value to the recovery of recyclable resources [19]. To overcome these challenges, advanced technologies for post-shredding material separation, such as AI-driven automated sorting systems, are increasingly being adopted. These technologies utilize machine learning to identify and separate different substrates with greater accuracy than traditional methods [20], offering the potential to enhance material recovery efficiency while reducing waste.

Due to their profit-oriented focus, these vendors prefer purchasing minimally processed dismantled parts. This preference leads dismantlers to distribute the parts to various dealers without concern for the subsequent steps in the chain. Another factor contributing to the higher rates in this study is the contrast between piecemeal processing in informal setups and batch processing in formal setups. Manual dismantling by four individuals using basic tools takes 120 minutes for one car, while a shredding machine can process hundreds of cars in the same timeframe. Despite achieving higher recycling and recovery rates, the informal sector is incapable of managing the substantial number of ELVs in Morocco efficiently.

The government's initiative to encourage electric and hybrid vehicles intensifies the challenges. With these considerations, the informal sector's capacity will be exceeded, prompting the government to establish a formal setup for handling the growing load from the ELV stream.

3.3. Exploring Morocco's Capacity for Recovering Secondary Resource Materials from ELV Sedans

In 2020, Morocco reported a total of around 182,000 registered vehicles, with the majority, approximately 106,200, belonging to the category of passenger vehicles [21].

During the period from 2015 to 2020, the Average Annual Growth Rate of car usage stood at 4%. As of 2022, car production in Morocco contributes significantly, representing 56.5% of the overall automotive production on the African continent[22–24].

The rising number of registered vehicles, particularly passenger vehicles, presents a significant potential for recovering secondary resource materials from ELVs. Despite limited data reliability, this study focuses on the sedan variant of passenger vehicles in Morocco. However, acknowledging the broader scope of the entire motorized vehicle fleet as Secondary Resource Materials (SRM) at their ELV stage, the potential becomes substantially higher.

The critical pre-treatment step, often referred to as depollution according to ISO 22628, is essential in ELV processing. Unfortunately, the informal sector often neglects this step, leading to spillage of liquids like fuel and engine oil on the ground. While the spillage constitutes only about 1.5% of the vehicle's initial mass, it significantly contributes to environmental contamination.

Figure 4 illustrates the average mass distribution of various elements across four cars in the study sample, while **Table 4** provides a detailed breakdown of the mass distribution for each car. Notably, an average sedan weight of 1200 kg reflects the cumulative impact of wear and tear during the operational years of the vehicles.

Table 4. Mass Distribution (In Kg) of Various Elements in The Four Cars Comprising The Study Sample.

SRM Element	V1	V2	V3	V4	Average Mass
Iron	928.5	782.0	837.9	845.7	848.5
Aluminum	62.4	74.7	75.2	61.4	68.4
Polymers	61.6	57.8	55.6	52.0	56.8
Glass	44.4	36.7	40.9	39.2	40.3
Elastomers	42.7	41.6	40.9	37.5	40.7
Others	25.5	23.3	22.9	21.3	23.2
MONM*	9.9	9.9	8.2	6.8	8.7
Lead	8.2	7.1	8.2	6.8	7.6
Copper	3.3	3.5	4.1	3.4	3.6
Fluids	3.3	4.2	4.9	5.1	4.4
Total mass of ELV parts	1189.8	1040.8	1098.6	1079.3	
Initial mass of the vehicle	1300	1100	1200	1200	1200

*Modified Organic Natural Materials.

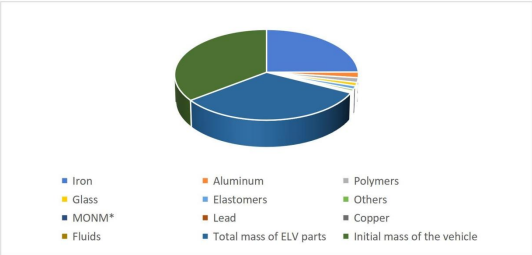

Figure 4. Average Mass Distribution of Various Elements Across Four Cars in the Study Sample.

*Modified Organic Natural Materials.

Iron and Aluminum, the predominant metal components, collectively constitute approximately 76% and 7% of the total mass, respectively, post-processing.

4. Conclusions

The global concern surrounding vehicles reaching the end of their life cycle has intensified over the years, driven by the increasing affordability of automobiles and the shift from car ownership as a status symbol to a fundamental need for today's commuters. This phenomenon is particularly pronounced in developing nations like Morocco, where a surge in automobile ownership has underscored the challenges confronting the ELV) sector. Through on-site investigations and discussions with stakeholders, it has become evident that a standardized operating procedure is notably absent in this sector. Concerns arise from the insufficient investment in eco-design to facilitate end-of-life recycling by simplifying the disassembly of valuable components, as well as the utilization of crude and unscientific dismantling methods in environmentally unfriendly conditions.

Once an automobile transitions into an ELV, it represents a potential source of secondary resource material, contributing to the circular economy by alleviating the de-

mand for virgin material. This study seeks to comprehend the current state of the informal ELV sector and scrutinize the material composition of sedan ELVs in Morocco, with a specific focus on the informal ELV market in Salmia. The findings underscore that Morocco's informal ELV sector not only lacks the capacity to manage the existing load but is also ill-equipped to handle the escalating volume of ELV waste in the country. This poses unprecedented challenges to the waste management system, especially in the absence of a formalized setup. To address these challenges effectively, it is crucial for the informal and formal sectors to join forces, combining their strengths and resources to tackle material scarcity and foster a more sustainable approach to ELV recycling. The comprehensive analysis of ELVs aims to provide insights into the current scenario and guide potential solutions.

Author Contributions

Conceptualization, I.R.; methodology, I.R., M.S.; research, I.R.; writing—original draft preparation, I.R.; writing—review and editing, I.R., F.Z.M., M.S., J.M., M.E.A.; supervision, M.S.; project administration, M.S.; manuscript submission, J.M. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement

This study presents a mathematical model developed to address the absence of a formal ELV recycling infrastructure in Morocco. As no real-world dataset was available, the model's parameters and assumptions are detailed in the article.

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Conflicts of Interest

The authors declare no conflict of interest.

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