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**A Bibliometric Analysis of End-of-Life Vehicles Related Research: Exploring a Path to Environmental Sustainability**

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**Abstract:** Considering rapid economic development and continuously increasing environmental concerns, end-of-life vehicles (ELVs) have significant socioeconomic value as a crucial waste stream. The research relating to ELVs has rapidly evolved over the last few years. However, existing review studies focus on specific research themes, and thus, fail to present a complete picture. Hence, this research intends to explain the current research scenario relating to ELVs by reviewing the critical published studies of the last 22 years. A total of 1405 research publications were extracted from the Scopus database covering the period from 2000 to 2021. Mainly employing bibliometric analysis techniques, this research analyzes the quantity of literature, researchers, institutions, countries, and research themes to understand the current status and future trends in ELV recycling and management. The results revealed a considerable rise in the number of articles published in the last five years. The key producers of influential ELV research are listed as the United States, China, and the United Kingdom. Globally, Chinese universities have the most ELV-related articles published. Similarly, Serbian researcher Vladimir Simic authored the most ELV-related articles during the research period. This article also identifies various research themes: management and recycling, resource recovery and components, life cycle evaluation, and socioeconomic effects. The results also reveal a strong association between distinct ELV research clusters.

**Keywords:** end-of-life vehicles; recycling; waste management; waste recovery; lifecycle assessment

**1. Introduction**

Consumption patterns have substantially changed around the globe due to continuous improvements in technology. Meanwhile, the past few decades have witnessed a rapid rate of development, causing significant pressures on limited natural resources. This has led authorities to look for ways to efficiently utilize valuable supply sources [1,2]. Due to these rapid advancements, demand for new electronic products and vehicles continuously increases over time, which ultimately results in a large quantity of waste products [3]. Unsustainable consumption trends based on the linear economic model of “make-take-use-dispose” cause major societal and environmental problems. Hence, the circular economy concept that emphasizes reusing and recycling is being widely adopted. Still, this requires efficiently managing end-of-life products to restore their values [4,5]. In turn, increasing environmental awareness and recognizing valuable resources in waste products have raised...
serious concerns regarding the management of end-of-life products [6,7]. Specifically, end-
of-life vehicles (ELVs) are considered a significant waste stream with serious discrepancies in waste management performance [8,9]. However, it is strongly believed that ELVs have a relatively high potential for resource recovery and recycling, which could also provide valuable material to related industries [10,11].

Over the last few decades, vehicle ownership has drastically increased globally, which has also resulted in an increasing number of ELVs containing valuable secondary resources [12,13]. Literature indicates that even after the COVID-19 pandemic, approximately 26 million vehicles were produced in the year 2021 [14]. In addition, each year, car technology is continuously upgrading, which leads owners to change their vehicles before their expiry; thus, ultimately resulting in an increased quantity of ELVs [15]. ELVs generally comprise 20 to 30 thousand various parts made of precious materials such as platinum, aluminum, lead, zinc, copper, iron, glass, rubber, textile, wires, plastic, and many others [16]. In addition to precious materials, ELVs also contain many harmful components such as transmission oils, fuels, refrigerants, brominated flame retardants, and acid batteries, which can damage both the environment and human health if improperly dealt with. The proper management and reuse of ELV components can be highly profitable depending on the ELV’s condition. Therefore, it is crucial for the recyclers or dismantlers to understand ELV’s composition and identify the parts that could be remanufactured and reused [17].

On the other hand, ELVs are considered as one of the largest hazardous waste categories, which involves complicated processing because of their complex structure and composition [18]. The poor management of ELVs is the primary reason behind various environmental issues. Mainly, groundwater pollution and heavy metal soil pollution are the common problems caused by improper ELV handling [19,20]. Except for some developed economies, the majority of the countries around the globe lack efficient strategies and recycling systems to deal with increasing number of ELVs [13]. Due to adverse economic circumstances, recycling and the problem of ELVs is a matter of more concern in the developing countries, which are trailing behind in establishing regulation and other practical strategies [21]. Therefore, it has become crucial for global authorities to devise effective policies for sustainable ELV management to achieve sustainability in the context of both the environment and resource efficiency.

Managing ELVs involves efficiently handling all activities relating to the material, finance, and flow of information among the different parties involved; therefore, it is strongly associated with the legislation and processes relating to recycling. Literature indicates that ELVs are one of the fastest-growing waste streams, which is estimated to grow by approximately 80 million vehicles per annum [18]. Considering this growth rate of ELVs, there is a strong motivation to understand the ELVs and related recycling systems to improve and effectively manage the related processes. Specifically, the proper management of ELVs has become a significant sustainability concern that necessitates the use of sophisticated decision-making processes to maximize resource efficiency and economic productivity. ELV management is in some ways similar to other types of waste stream treatment, and previous studies have been conducted to analyze waste management strategies and situations [4]. However, most of the previous studies presenting review analysis regarding ELVs have focused on specific components within the broader system of ELV recycling and management [7,22]. To fill this gap, there is a strong need to conduct a detailed review analysis and present a holistic picture of the previously published work relating to the entire ELV recycling and management system.

Hence, this research systematically analyzes the existing research within the area of ELV management and recycling. The primary aim is to present a detailed content analysis of the quality research produced in the period from 2000 to 2021. Specifically, bibliometric analysis is performed to analyze the existing literature trends and answer following research questions:

RQ1: How has the field of ELV-related research evolved over the time?
RQ2: What are the essential research themes and trend found in the ELV research?
Bibliometric analysis is considered a valuable method to explore a research field by investigating a large quantity of published literature. It helps to explore citations dynamics involving various authors within the knowledge structure of a research area. Similarly, the bibliometric method also investigates the collaboration between authors, institutions, and countries regarding the research field. Studies are analyzed based on the years, authors, institutions, citations, and countries. A holistic view is presented concerning various perspectives relating to ELV management and the recycling research area. Literature gaps are ultimately identified to suggest valuable future research opportunities.

The rest of this paper is organized in the following manner: The second section describes the research methods adopted in this study. Next, Sections 3 and 4 present the results and discussion from the literature review. Finally, Section 5 presents concluding remarks and insightful recommendations.

2. Research Methodology

In order to examine the existing literature relating to ELVs management and recycling, this research employed a mixed-method approach that included both quantitative and qualitative analyses, as described in this section. Specifically, the following sub-sections present detail regarding the search strategy, data collection, and data analysis techniques adopted in this study.

2.1. Search Strategy and Selection Criteria

This research focuses on ELV-related studies; therefore, “end-of-life vehicles” was used as a keyword to search and select relevant studies. Likewise, this study also used different terms to explore related published work, e.g., ELVs, ELV recycling, ELV management.

In terms of chronology, this research was performed in January 2022 to extract peer-reviewed journal articles published in the period from 2001 to 2021. Specifically, this research restricted its search criteria to the journal articles published in the English language. However, this research focuses on the global literature irrespective of any region or country. Overall, this research aimed to understand the development of literature relating to ELVs and identify potential future research trends.

2.2. Data Collection and Refinement

The database was selected to ensure a quality assessment of the literature. Hence, the Scopus database, being one of the most reliable sources of scientific publications, was chosen for data collection in this study to ensure adequate coverage of the related literature. It is worth noting that the Scopus database is particularly suitable for finding quality research articles for the review purposes. It was assumed that Scopus database contains most of the quality literature providing significant contribution to the ELV-related research. The sample data was extracted and refined before conducting the analysis. This study also used alternative synonyms while searching for the related articles.

Additionally, the writing styles of the keywords were unified, and the singular and plural forms of the keywords were used. To ensure the quality of the analyses, the researchers excluded keywords such as “non-human” and “animal” that had no direct relevance for this study from the dataset. The filter criteria are shown in Figure 1 below. Hence, a total of 1405 research papers were extracted as the final sample for the review analysis.

2.3. Data Processing and Analysis

Following the research methodology presented in Figure 2 below, this research employed three major data analysis techniques along with statistical analysis to analyze the development of the research field relating to ELV recycling and management. These methods include bibliometric, text mining, and content analyses.
Mainly, this study employs a bibliometric analysis technique that uses mathematical tools to explore research perspectives in terms of research trends and sources [23]. Statistical investigation of previous studies, authors, institutions, and countries plays a crucial role in quickly understanding literature development. Likewise, analysis of citations can uncover crucial details about influential literature and researchers, which helps to grasp the growth of research contributions in the specific field [24]. Researchers can use bibliometric analysis to detect internal relationships within literature and analyze core citations and key knowledge groups. Hence, this study reviewed the literature on ELVs management and recycling using bibliometric analysis to explore the characteristics of the literature in more detail, evaluate research trends, and provide innovative perspectives from the literature.

Text mining analysis is an important technique that is widely used in the literature to analyze research trends and themes. Hence, text mining analysis is also employed in this study to extract crucial information from many collected articles. Specifically, text mining analysis is useful in exploring text patterns and semantic structures that best explain complex data. This research performed a text mining analysis based on the term co-occurrence algorithm on the specific phrases contained in the dataset. As a result, latent research themes, underlying structures, and trends in the ELV-related research were discovered.

Next, this research also included a content analysis as a complementary qualitative method to provide additional in-depth insights into the quantitative findings. In this regard, the extracted articles were classified based on the common clusters, and content analysis was performed to identify the most influential published works within the research field to uncover theoretical orientations.

2.4. Tools

This research used multiple tools to conduct data analyses. For instance, Bibexcel was used to perform a fundamental bibliometric analysis of the data extracted from the Scopus database. Similarly, VOS viewer, CiteSpace, and Gephi were used for further analysis involving data visualization. Specifically, VOS viewer was used to create maps based on various data classifications. Compared with other visualization applications, its key benefit is that the graphical display is rich and distinct, making bibliometric analysis results simpler to explain.
3. Results and Analysis

3.1. Development of the Literature over Time

This research explores current literature by analyzing published articles from influential authors, representative countries, and popular journals. The development of the number of published articles between the years 2000 and 2021 is presented in Figure 3 and Table 1 below. The results indicate a significant growth in the recent five years, accounting for more than 50% of the published articles. From the observed trend, it can be anticipated that the research field of ELV recycling and management will continue to thrive in the future, thus, suggesting that a greater number of researchers will be interested in the waste recycling system. While explaining the development of literature, this study mainly identifies influential authors, journals, institutions, and countries, which have played a key role in ELV recycling and management.
Table 1 presents citation analysis for the previous twenty-two years. The results indicate that the largest number of articles were published in the year 2021 (212), followed by 2020 (162), 2019 (151), and 2018 (106). However, their number of citations is still relatively small compared with articles from other years. It can be seen in Figure 2 that papers from...
the year 2016 have the highest number of citations in the entire selected period. A total of 102 articles from the year 2016 have been cited 3020 times in the literature. Likewise, 70 articles from 2015 and 32 articles from 2006 have the second (2978) and third (2559) highest number of citations in the previous literature. It can also be observed in Figure 4 that the citation trend was positive from the year 2010 to 2016, whereas it significantly decreased in the most recent five years. Nevertheless, a growing number of articles in the last five years indicates that researchers’ attention toward ELV-related issues is expected to increase significantly with time.

Figure 4. Citations trend from 2000 to 2021.

3.2. Influential Researchers

Figure 5 highlights the 15 most influential researchers who have produced quality articles in the last twenty-two years. In the field of ELV recycling and management, Vladimir Simic from the University of Belgrade is found to be the most influential researcher with twelve Scopus indexed publications in the period 2000–2021. Similarly, Dzuraidah Abd Wahab, based at Universiti Kebangsaan Malaysia, also published twelve articles in the same period. Hence, both Vladimir Simic and Dzuraidah Abd Wahab are identified as top researchers in the field of ELV recycling. They are then followed by Nakajima and Van Mierlo in second place, with ten articles each. Then, Matsubae has the third highest number of publications in the related ELV recycling and management field.

3.3. Influential Institutions

This research also identified the top fifteen influential institutions based on the first author’s affiliation data. The top fifteen most influential institutions are listed in Figure 6 below. Tsinghua University from China is identified as the most influential institution, where nineteen articles have been published with primary authors. Likewise, Shanghai Jiao Tong University in China is ranked as the second most influential institution with eighteen articles relating to ELV research. In the third place, the researchers at Centre National de la Recherche Scientifique and Tohoku University have produced seventeen articles each. In addition, the remaining eleven institutions, out of the top fifteen, have also substantially contributed to the ELV-related research by delivering more than eleven articles each. Interestingly, the top fifteen institutions came from ten different countries, which published a
large quantity of ELV-related articles. Out of fifteen institutions, four are from the Peoples Republic of China, whereas three came from Japan. This indicates the high concern in China and Japan for this research area. Besides these two countries, the remaining top fifteen institutions are in France, the UK, USA, Malaysia, Belgium, Netherlands, Serbia, and Norway. Overall, it was found that the top fifteen institutions published two hundred and fourteen research articles targeting ELVs and their management.

3.4. Influential Countries

From 2000 to 2021, 77 different countries were identified publishing articles relating to ELVs. Table 2 presents results concerning the top fifteen countries and the number of published articles. It can be seen that the USA and China hold the top two positions with 270 and 175 articles, respectively. Similarly, the UK ranks third with 120 published articles during the targeted period. A total of 10 countries have produced more than 50 articles. The results also reveal that most of the top 10 countries, such as Japan, Germany, the USA, China, Korea, etc., have highly developed automobile industries. Further, results also indicate that 29 articles in the sample have an undefined country affiliation.

This research also studied the literature coupling of different countries, as presented in Figure 7 below. A total of 102 countries contributed publications with a minimum of five out of 45 keywords to meet the threshold for inclusion. The number of research publications determines the node’s size, and the width of the line indicates the strength of the relationship between countries. The color shades of the nodes from dark to light show the time when the research was initiated. It can be seen that the highest number of publications are from the USA, China, and the UK. Similarly, China’s node is placed in the center of the figure, with a more substantial level of research collaborations, indicating that China is a relatively active country. Additionally, thick lines show that China has solid academic cooperation with countries such as Japan, the USA, and the UK. Further, it is also shown that countries such as the USA and UK were the first to initiate the research relating to ELVs. Although China produced the second-highest number of scholarly articles,
the results indicate that Chinese scholars have emphasized this research domain more in recent years.

![Figure 6. Influential institutions.](image)

**Table 2. Publications by countries.**

| S. No | COUNTRY/TERRITORY          | Articles |
|-------|----------------------------|----------|
| 1     | United States              | 270      |
| 2     | China                      | 175      |
| 3     | United Kingdom             | 120      |
| 4     | India                      | 87       |
| 5     | Italy                      | 84       |
| 6     | Canada                     | 83       |
| 7     | Germany                    | 76       |
| 8     | Japan                      | 76       |
| 9     | France                     | 61       |
| 10    | South Korea                | 60       |
| 11    | Sweden                     | 46       |
| 12    | Spain                      | 45       |
| 13    | Malaysia                   | 43       |
| 14    | Australia                  | 39       |
| 15    | Netherlands                | 37       |
|       | **Other Countries**        | **508**  |
3.5. Analyzing Research Areas

Finally, this research identified various domains within ELV-related research by analyzing keywords clusters. The primary information contained in an article can be mainly represented by keywords, allowing us to comprehend the domain of the research topic through keyword analysis. This research specifically used VOSviewer to examine the author’s keywords. The original data were preprocessed, and comparable keywords were merged to make the data more understandable. Because most terms appeared only once, the top keywords were chosen based on a threshold of five occurrences. Hence, a total of 12,596 keywords were used; out of these, 881 keywords met the threshold with a minimum of five occurrences.

The results mapped in Figure 8 show that six different keyword clusters can be identified in the literature. The significant clusters relating to ELV research can be identified as technology enabled vehicles and management, recycling and reprocessing, resource recovery, automobile parts, life cycle assessment, and social aspects. The results also show strong interdependence among various ELV research clusters. As displayed in Figure 8, the green cluster represents the ELV recycling and reprocessing system that includes keywords such as recycling, solid wastes, ELVs, scrap metal reprocessing, closed-loop supply chain, etc. It is evident that most of the literature in this cluster involves articles targeting various issues relating to recycling and reprocessing. The second cluster shown in red mainly includes keywords such as vehicles, decision making, supply chain, reverse supply chain, transportation, internet of things, artificial intelligence, digital networks, etc. These keywords represent the category of technology enabled ELVs and their management that involves articles with topics relating to various management processes and the role of technologies.

Moreover, the dark blue cluster can be named as resource recovery as it includes the keywords involving the names of the precious metals and resources found in the ELVs. These keywords include energy recovery, chemical composition, car, procedures, rubber, plastic, lead, gas, unclassified drugs, organic pollutants, air pollutants, hazardous wastes, etc. Likewise, the purple cluster includes keywords including the names of several automobile parts such as secondary batteries, electric batteries, electric energy storage, battery pack, photovoltaic cells, etc.
The last two clusters basically represent socioeconomic aspects of the field. For instance, the yellow cluster primarily includes keywords relating to ELVs’ life cycle assessment and their environmental impacts, such as global warming potential, emissions, greenhouse gases, natural gases, hydrogen fuel, etc. In a similar manner, the light blue cluster represents literature covering the social side of the research. This cluster includes articles covering traffic accidents, moralities, human-specific factors, sleep disorder breathing, and positive end-expiratory pressure. Hence, these clusters cover ELV life cycle assessment, including their related socioeconomic problems. The results also indicate that the socioeconomic impacts have received more research attention in recent years.

Furthermore, Figure 9 explains the timeline of various research themes over the last twenty-two years. It is observed that ELV-related research has mostly gained popularity in the last decade. At the start, studies focused on ELV composition, useful automobile parts, and the socioeconomic consequences of vehicle waste. Then, after the year 2010, global authorities expediated their efforts to resolve environmental problems by strengthening the waste management system. In this regard, ELV-related research also focused on the effective treatment of ELVs to ensure efficient utilization of vehicle waste. Literature pertaining to ELV treatment, electric vehicles, and their environmental impacts are found from 2010 to 2015. Similarly, during this period, researchers also began investigating environmental issues such as greenhouse emissions, pollutants, supply chain processes, and ELV lifecycle assessments to improve waste management operations.

Overall, it is observed that the trend of ELV-related research gained substantial popularity in the last five years. Several articles are found examining problems relating to ELVs and their solutions toward enhancing resource efficiency and reducing environmental concerns. Due to environmental concerns, the sustainable management of end-of-life vehicles (ELVs) has become a global issue. One of the potential solutions to the ELV problem is recycling and reusing materials. The circular economy concept, also emerging in the last five years, is related to the circularity of the resource use and focuses on strengthening the waste management system and increasing resource efficiency. With the emergence of the circular economy, researchers also emphasized ELV recycling and remanufacturing processes to improve ELV handling and efficient resource utilization. Recently, researchers have shown significant concern regarding the role of emerging modern technologies in ELV recycling and management. Specifically, various modern technologies are being adopted...
to enhance ELV recycling performance and resource to energy efficiency. Likewise, recent literature analyzing optimal decision-making to maximize profitability in the ELV recycling industry was also found. Mainly, researchers are developing efficient models to make decisions about optimal recycling and processing to maximize ELV recycling performance.

Figure 9. Timeline of various research areas.

4. Discussion
4.1. Overview of the Literature
Currently, global authorities face a tactical threat of diminishing natural resources and increasing waste generation. Therefore, many researchers emphasize material analysis, effective waste management, controlling pollution, efficient recycling, and waste-to-resource recovery [25]. Initially, ELVs were treated only as a major source of environmental problems; hence, researchers were looking to find effective ways for efficiently handling ELVs [26]. Later on, researchers’ focus expanded to several other aspects of ELV-related issues such as increasing volume [27], infrastructure [28,29], legislation [30], reverse logistics [7], sustainability [31], modern technology applications [32,33], environmental performance [34], recycling technologies [35], plastic recycling [36], financial policies [37], hybrid and electric vehicles [38], socioeconomic consequences [39], decomposition [40], and dismantling technologies [41]. Similarly, the literature also further addressed various other aspects such as the business potential for reusing ELV components [42], ELV processing and treatment centers [43], optimization of remanufacturing business [44], and effective decision making in ELV recycling [45].

When determining the influence of different factors on ELV recycling and energy recovery, the literature suggests employing dynamic modeling, non-linear optimization models, and simulation approaches [46,47]. Some authors have also used interval linear programming models to examine ELV recycling [48,49]. The literature suggests that recycling technology innovation can play a crucial role in driving technology transition in the vehicle industry [50]. Notably, the concept of Industry 4 technologies has helped in developing smart systems for monitoring and dismantling procedures in recycling facilities [51–53]. It is also observed that previous studies have mainly focused on resolving
local ELV-related issues; therefore, it has become crucial to conduct comprehensive research to develop concrete solutions considering global perspectives [18,25].

In addition, the materials used in car manufacturing are constantly evolving. As a result, the various components of ELV waste, such as glass, plastic, tires, and oil, should be considered further because of their significant role in environmental conditions and resource recovery [54]. For instance, it is crucial to consider plastic components as ELVs contribute 5% of the total plastic waste. Moreover, complex and time-consuming processes make plastic recycling more challenging than other components. According to Petronijevic et al. [25], ELVs generate around ten million tons of plastic waste, and this amount of plastic waste generated globally has the potential to affect the environment and society adversely. Likewise, other components such as tires, glass, and oils also have a crucial impact on the environment; thus, their disposal has become a matter of great concern for the authorities [55]. Hence, suitable technologies and procedures should be adopted for dismantling and recycling the ELV components. Literature suggests that the best way is to deal with tires first, then recycle other components such as oil and plastic [56].

The existing literature also indicates that promoting resource recovery and material collection from the ELVs is the best strategy to minimize environmental adversities [15]. In this regard, Vermeulen et al. [57] argue that the energy recovery process does not require any complex treatment; therefore, it is considered low-cost recycling. Mainly, ELV tires are used to recover energy in different facilities such as cement plants and paper factories. Moreover, existing literature lacks sufficient information regarding ELV recycling processes and ways to recover essential resources from the ELV waste stream [25]. With the newly evolving regulatory concept of extended producer responsibility, it has become obligatory for manufacturers to take complete responsibility for the entire life span of their products, from manufacturing new vehicles to ELVs’ recycling and remanufacturing [45]. Therefore, vehicle manufacturers continuously strive to develop effective strategies to enhance ELVs’ management and recycling systems.

As far as review articles are concerned, it is essential to mention existing critical studies here to justify the need for this research. Bari et al. [58] and Kindzierski et al. [59] critically reviewed previous studies relating to ELV problems in 2011 and 2013, respectively. Simic [60] reviewed a wide range of articles relating to environmental issues of ELV recycling. Similarly, in 2014, Gan and He [61] provided a brief review of reverse logistics within ELV management. Cin and Kusakci [62] also surveyed previous studies involving ELV-related reverse logistics. Hiratsuka et al. [63] reviewed Japan’s recycling system development. Next, Li et al. [64] mainly investigated the practices of ELV management in the case of China. In contrast, Sakai et al. [15] conducted a comparative investigation of ELV management across various world economies. Zhang and Chen [65] reviewed regulations relating to ELVs and investigated technologies for plastic recycling in the case of several countries, including China, Japan, Korea, the European Union, and the USA.

Furthermore, Rosa and Terzi [66] conducted a structured literature review to assess ELV and WEEE waste streams from various viewpoints, highlighting present disparities and possible commonalities. Cucchiella et al. [67] conducted a brief overview of the subject of vehicle electronics recycling. De Almeida and Borsato [22] conducted a bibliometric review of the existing treatments for end-of-life products. Recently, He et al. [7] also conducted a detailed review of the ELV-related reverse logistics sector, whereas Karagoz et al. [18] presented a critical review of ELV management in general. Overall, it is found that the majority of the existing review articles only targeted specific fields within ELV management for particular countries or regions, hence, leaving a gap in the detailed analysis relating to the broader field of ELV recycling and management.

Moreover, several recent studies have examined the recycling process and production relating to ELVs. For instance, Zhang and Chen [65] have compared different dismantling scenarios using the analytic hierarchy process (AHP) method. Khodier et al. [68] have analyzed issues relating to disposal and processing of automotive shredder residue (ASR) in the case of the UK. Some of the previous articles also focused on improving reverse
logistics operations of ELVs concerning the circular economy transition [69]. Previous studies have proposed several methods to analyze various ELV recycling processes. These methods include a population balance model to predict ELV generation [13], a downcycling assessment approach for evaluating material lost in recycling [70], a processing framework to utilize ELV waste in the construction sector [34], a system dynamic simulation method to evaluate the economic performance of ELV recovery [66], an analytic hierarchy process for better management of ELVs [71], and a system dynamic model to assess informal ELV dismantling [28].

Considering sustainability issues, the literature also developed evaluation methods to assess the benefits of ELV recycling to reduce carbon emissions and energy consumption [72]. The literature also states that efficient ELV reverse logistics help optimize resource consumption [73]. Similarly, literature also developed various survey methods to investigate the environmental and economic consequences of ELV recycling [74] and to estimate the content of valuable substances [75]. Additionally, methods such as systematic index systems exist to determine sustainable ELV management practices [26]. Various researchers have used the lifecycle assessment method to investigate the environmental sustainability of ELVs and further compared alternative methods and technologies to determine effective outcomes [76,77]. Rovinaru et al. [78] has analyzed the economic effect of ELV dismantling activities. However, the environmental consequences associated with the ELV recycling process are still not well understood, making it challenging to develop effective procedures for minimizing the ecological problems related to ELV recovery and recycling [7].

Recently, Khan et al. [45] developed an optimum model for ELV recycling and remanufacturing business profitability. On the other hand, it is observed that previous studies mostly overlooked the management of hazardous waste generated from ELV recycling procedures [18]. Yi and Lee [79] suggested authorities prioritize their support towards ELV dismantling as it is the primary element in ELV recycling. Petronijevic et al. [25] has attempted to develop an integrated approach to address energy recovery via ELV recycling. Furthermore, Modoi and Mihai [3] stated that ELVs are a fast-growing waste stream requiring detailed analysis to devise effective collection and treatment solutions to minimize environmental problems and resource depletion. Various other gaps are also identified in the existing literature, which must be investigated in the future. According to Jang et al. [17], the circular economy and the ELVs’ sustainable resource management have become global concerns. Therefore, understanding ELV recycling and flow is critical due to the possibility of resource recovery and the environmental implications of dangerous substances.

4.2. Factors Influencing ELV Management and Recycling

Generally, ELVs are those vehicles that are damaged, defective, or too old to be used by consumers. Hence, authorities struggle to reduce ELV waste and try to promote ELV recycling to recover and utilize valuable resources [3]. Usually, about 95% parts of an ELV are recoverable and considered as useful potential resources [80]. With the increasing growth in automobile industries, the management of ELVs has become crucial for environmental quality and sustainable development. Hence, the major stakeholders such as producers and consumers are considered more responsible for resource recovery in the circular economy model [18]. Basically, the concept of ELV management and recycling is based on the principle of extended producer responsibility (EPR), which holds manufacturers responsible for their goods. It requires manufacturers to take over their end-of-life products and encourage consumers to deliver their used goods to the authorized recyclers [3]. However, the principle of EPR also requires systematic management of ELVs involving activities such as collection, reporting, reverse flow, and recycling etc.

The previous literature has mainly demonstrated various factors that could strengthen the ELV management and recycling system. The literature indicates that the adoption of circular economy practices within ELV management would play a crucial role in achieving sustainability [72]. The circular economy models facilitate various activities within ELV management and recycling systems to protect the environment and enhance resource
efficiency [8]. Zhou et al. [35] state that ELV management and recycling is affected by several factors across different levels, such as consumers, industrial organizations, and authorities.

The authorities particularly influence ELV management through several actions, such as developing public policies to motivate consumers, implementing the extended producer responsibility principle, and imposing regulations relating to recycling. Similarly, organizations play crucial role by promoting easy recycling and investing in cleaner production [3]. In the context of industrial organizations, the literature also indicates various other factors that could strengthen ELV management and recycling, such as economic cost, remanufacturing, repairing, and dismantling techniques [28,81–83]. Further, the availability of metals and recycling practices also play important role in improving ELVs management [39,84,85]. The literature also indicates several factors relating to the consumers that could also influence ELVs management and recycling systems. These include, for instance, awareness among consumers regarding the importance of ELV recycling and the acceptance of recyclable products in the market [35,86]. In addition, ELV management and recycling is also influenced by distinct regional socioeconomic factors. Particularly, the adoption of advanced technologies could play vital role in ensuring the sustainable use of resources and facilitating recycling operations to achieve sustainability [45,87–89].

4.3. Contribution to the Literature

Overall, ELV management and recycling systems include various activities involving different components of the entire process. The efficient management of ELVs is crucial for maintaining environmental quality, the circular economy, and sustainability. Hence, strengthening the management of ELVs has become a major concern for authorities and researchers. Therefore, researchers have focused on reviewing the relevant studies to understand the dynamics of ELV management and recycling systems. In this regard, a total of 23 review studies are listed in the Table 3 below to justify the contribution of this research. Specifically, Table 3 presents review papers, their target time period, and specific scopes. The studies have been categorized on the basis of their aim and scope within ELV management. It can be observed that most of the existing review studies have targeted only specific components within the field of ELV management and recycling systems such as treatment processes, disassembling, recovery infrastructure, reverse logistics etc. It is evident that there is a lack of review studies targeting the broader field of ELV management and recycling. It has become crucial to review the entire ELV management literature to help future researchers in determining the future directions of research. Hence, this research discusses a holistic view of literature relating to ELV management and recycling by including a wider set of articles published in the period 2000–2021.

Table 3. Summary and scope of existing review studies.

| Previous Studies                  | Scope                        | Target Period | Number of Articles |
|-----------------------------------|------------------------------|---------------|--------------------|
| He et al., (2020) [7]             | Reverse logistics            | 2000–2019     | 299                |
| Cin and Kusakci (2017) [62]       | Automotive electronics       | 2001–2015     | 35                 |
| Gan and He (2014) [61]            | Automotive shredder residue plastics | 1977–2012 | 76                 |
| Karagoz et al., (2020) [18]       | ELV management               | 2000–2019     | 232                |
| Rosa and Terzi (2018) [66]        | Management practices         | 2005–2016     | 23                 |
| Sakai et al., (2014) [15]         | Management plastics          | 1991–2012     | 90                 |
| Zhang and Chen (2014) [65]        | Management practices         | 2005–2012     | 16                 |
| Li et al., (2014) [64]            | Management practices         | 2005–2012     | 16                 |
| Buekens and Zhou (2014) [90]      | Automotive plastics          | 1993–2012     | 63                 |
Table 3. Cont.

| Previous Studies               | Scope                                      | Target Period | Number of Articles |
|--------------------------------|--------------------------------------------|---------------|--------------------|
| Lashlem et al., (2013) [91]    | Environmental engineering issues           | 1995–2012     | 20                 |
| Simic (2013) [60]              |                                            | 2003–2012     | 93                 |
| Kindzierski et al., (2013) [59]| Automotive waste                          | 2012          | 107                |
| Bari et al., (2011) [58]       |                                            | 2010          | 103                |
| Mayyas et al., (2012) [92];    | Sustainability of the automotive industry | 1984–2011     | 90                 |
| Khan et al., (2021) [93]       | Disassembling                              | 1992–2010     | 38                 |
| Go et al., (2011) [94]         | Vehicle recovery infrastructure            | 1995–2012     | 26                 |
| Hiratsuka et al., (2014) [63]  |                                            | 1986–2007     | 73                 |
| Vermeulen et al., (2011) [57]  | Automotive shredder residue treatment      | 1999–2016     | 76                 |
| De Almeida and Borsato (2019) [22]|                                         |               |                    |
| Cossu and Lai (2015) [96]      |                                            | 2005–2014     | 120                |
| Zorpas and Inglezakis (2012) [97]|                                         | 1978–2010     | 110                |
| Vermeulen et al., (2011) [57]  |                                            | 1994–2011     | 150                |
| Nourreddine (2007) [98]        |                                            | 1991–2004     | 26                 |

4.4. Implications: Future Trends and Research Directions

Considering gaps and limitations in the existing literature, this research suggests several future research trends.

The application of Industry-4.0 technologies such as the internet of things, artificial intelligence, and blockchain has produced promising results toward an environment-friendly and sustainable ELV recycling system. In the future, designing smart systems based on Industry-5.0 technologies would provide an auspicious future research direction in the field of ELV-related research.

The recent COVID-19 pandemic has caused severe disruptions in various sectors, resulting in unsustainable consumption practices. Notably, the new trade-offs between health, safety and environmental sustainability have occurred during this unprecedented situation. Such trade-offs need to be thoroughly investigated and resolved in future research. Various researchers have started to discuss new experiences learned during pandemic situations relating to the transition toward sustainable production and consumption system.

With the evolving concept of the circular economy, it is crucial to conduct detailed analysis relating to the reduction of waste and material recyclability. Meanwhile, future studies are also suggested to specifically consider environmental consequences in the ELV recycling processes.

There is a strong need to focus on the triple bottom line approach in the ELV recycling industry in future research. The triple bottom line approach has crucial implications for the transition towards an efficient and productive ELV recycling system; it requires firms to focus on all three sustainability dimensions: social, environmental, and economic consequences.

It is also observed that existing studies generally analyze and suggest solutions for specific country cases, thus, failing to address the global perspectives of ELV recycling. Hence, it is crucial for researchers to address more global and general perspectives in the future.

Next, most of the existing studies target material and economic issues relating to ELV recycling and management, thus leaving a gap in terms of social criteria. Mainly, public perception is critical for the performance of ELV recycling. In this regard, ELV owners must be encouraged to return their ELVs for the purpose of recycling and remanufacturing. Therefore, social awareness and acceptance have become critical issues that need to be addressed for efficient ELV recycling and management.

Though there is plenty of research discussing product design and production planning relating to ELV recycling, this signifies the need to compare different design and planning systems in the future.
Uncertainty is considered the primary element affecting the management of ELVs and their recycling process. However, uncertainty analysis is largely overlooked in the previously available research. Hence, incorporating uncertainty analysis techniques into future modelling frameworks may help in effective decision making.

Considering the element of uncertainty, it is found that current models are incapable of incorporating managers’ risk perspectives. Thus, future studies must incorporate risk assessment techniques into ELV recycling models.

Traditionally, the number of ELVs has been anticipated using a constant percentage of total vehicle ownership, a method which has low predictive accuracy. Thus, in recent years, various prediction processes that use statistical models are being developed. There is a strong need to explore ELV prediction models in future research.

Lastly, there is also a strong need to incorporate both profitability and environmental efficiency into the ELV waste treatment options. In this regard, to achieve the greatest improvements, actual industry practices must also be considered.

5. Conclusions

This research provides a comprehensive bibliometric assessment of the existing literature in the field of ELV-related research. In total, 1405 research publications were extracted from the period 2000 to 2021. The results revealed a considerable rise in the number of articles published in the last five years. The USA, China, and UK were found to be producing most of the influential research relating to ELVs. Among the institutions, Chinese universities were found on the top in publishing the highest number of ELV-related articles around the globe. Likewise, it is also identified that Vladimir Simic of Serbia has produced the highest number of ELV-related articles among individual researchers during the targeted period of research. Overall, this research identifies six major clusters of ELV research, which can be categorized as management, recycling, resource recovery, components, life cycle assessment, and socioeconomic implications. Further, the results also indicate considerable interrelations between distinct ELV research clusters.

It was found that most of the existing studies focused on local scenarios and specific processes within the broader field of ELV recycling and management. Therefore, it has become crucial to conduct detailed analysis incorporating more global and general perspectives relating to ELVs. Similarly, it was observed that the existing literature incorporates only material and economic perspectives in research, whereas social perspectives are also equally important for improved ELV treatment. Particularly, enhancing social awareness would be critical factor in promoting ELV recycling performance. This study also suggests analyzing the element of uncertainty within ELV recycling models. Further, it is also concluded that previously used methods such as environmental designs and lifecycle assessments may be insufficient to further improve ELV recycling systems, and incorporating various socioeconomic factors can provide effective methodology for more promising results.

Limitations

Lastly, this research has some limitations which need to be addressed in similar future studies. First and foremost, this research relied only on the Scopus database for literature extraction. Future studies should use other popular databases such as the Web of Science collection to review a wider set of published articles. Secondly, this study covers research articles published in the last twenty-one years; hence, future studies can target a further longer span of time to obtain a broader picture. Likewise, this research presents a general overview of the literature irrespective of any specific regional case. In this regard, future studies can provide detailed insights in the context of literature targeting specific regional areas.

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