sustainability

Review

Exploring Industry-Specific Research Themes on E-Waste: A Literature Review

Hilal Shams [1,*], Altaf Hossain Molla [1], Mohd Nizam Ab Rahman [1], Hawa Hishamuddin [1], Zambri Harun [1] and Nallapaneni Manoj Kumar [2,3,4,*]

1 Department of Mechanical and Manufacturing Engineering, Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia, Bangi 43600, Malaysia; altafhossain1994@gmail.com (A.H.M.); mnizam@ukm.edu.my (M.N.A.R.); hawa7@ukm.edu.my (H.H.); zambri@ukm.edu.my (Z.H.)
2 School of Energy and Environment, City University of Hong Kong, Kowloon, Hong Kong
3 Center for Resource Recovery, HICCER—Hariterde International Council of Circular Economy Research, Palakkad 678631, Kerala, India
4 Swiss School of Business and Management Geneva, Avenue des Morgines 12, 1213 Genève, Switzerland
* Correspondence: hilal_shams7@yahoo.com (H.S.); mnallapan2-c@my.cityu.edu.hk (N.M.K.)

Abstract: The usance of electric and electronic products has become commonplace across the globe. The growing number of customers and the demand for these products are resulting in the manufacturing of new electrical and electronic products into the market, which is ultimately generating a plethora of e-waste. The notion of a circular economy (CE) is attracting more researchers to work in the growing field of e-waste management. Considering e-waste as a prominent menace, the objective of this study was to undertake a comprehensive review of the literature by analyzing the research articles published in the MDPI *Sustainability* journal pertaining to the topic of e-waste in the context of operations and supply chain management (OSCM). This study was addressed via three research questions. A total of 87 selected papers from 2014 to 2023 were analyzed, reviewed, and categorized after data were collected from Web of Science (WOS) and Scopus academic databases with articles only published in the MDPI *Sustainability* journal. This entails identifying prominent research themes, publication trends, research evolution, research clusters, and industries related to e-waste through descriptive analysis. The field of study and methods employed were analyzed by means of content analysis by delving into the main body of the published articles. Further, four major research themes and clusters were identified: (1) closed-loop supply chains; (2) e-waste; (3) sustainable development; and (4) waste electrical and electronic equipment (WEEE). Consequently, this review can be a foundation for subsequent scholarly pursuits toward e-waste management and fresh lines of inquiry for the journal. Finally, in the conclusion section, some future research guidelines are also provided.

Keywords: e-waste; WEEE; sustainability; circular economy; electrical and electronic waste; journal review

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1. Introduction

Electric and electronic equipment (EEE) are a part of everyday life. Their significance is increasing in terms of providing business opportunities, but also as an emerging problem in terms of waste generation, more commonly known as e-waste or WEEE [1]. E-waste or WEEE is the generic short term used for electric and electronic devices either disposed of or discarded, or near their end of life [2]. Electrical and electronic equipment (EEE) include a wide variety of products, such as PCs, laptops, mobile phones, washing machines, televisions, and monitors [3]. The usage of such devices has proliferated as household appliances, in manufacturing, other industries, and services, and simultaneously, the waste related to such products has proportionally increased, which, as a result, is ravaging the environment. Amongst such products, mobile phones and computers comprise the most common form of waste due to their short lifespan, along with their rapid development, replacement, and widespread usage. This brings in the notion of the overconsumption of raw materials, making it a global concern. Moreover, such indulgence of overconsumption results in waste generation. Such wastes have intrinsic noxious and toxic properties, which are pernicious in nature. This is evident as e-waste has an abundance of diverse compounds, presenting opportunities in terms of materials and product reutilizations; however, concurrently, challenges and risks are associated with it in terms of possible contaminations and harmful contents. Furthermore, in terms of e-waste, there is a clear composition differentiation regarding other forms of waste, like industrial or municipal wastes, containing valuable and toxic materials, which have severe and detrimental effects on the environment and humans if not properly taken care of [4–6].

Due to the growing subtle and apparent concern about such wastes, the CE has a vital role in waste recycling and resource efficiency by encouraging circular practices and closed-loop systems to be a sustainable business model [7]. Certain CE activities, such as recycling, reuse, remanufacturing, and refurbishment, play a significant role in e-waste life extension and recovering precious materials from it [8,9]. Such roles and activities of CE are instrumental in sustainable development [10] and e-waste management [3] by maintaining utility and value for such products [11]. Therefore, the adoption of such circular practices is imperative for e-waste management due to its increasing generation of 3–5% per annum [12]. Hence, the core objective of CE is the promotion of sustainable practices to safeguard the environment within its natural domain and ensure the healthy life of living beings.

1.1. Research Motivation

Research regarding e-waste has been growing over the past decades, where researchers play a significant role in journal publications and conferences. Each journal contributes its role in minimizing the menace of e-waste and how to circulate the materials and products associated with it in terms of research through the theoretical framework, results and discussions, and practical implementations. Recent review studies about e-waste [3,13–15] present the growing interests of the research community through their studies on the different aspects of e-waste management.

The purpose of a literature review aims to map and evaluate the extant literature [16] to identify research gaps [17] and to analyze their contribution to the respective research field. Therefore, the research objective of this study is to focus on and gather the extant literature and studies based on the aforementioned *Sustainability* journal. As Govindan and Soleimani [16] as well as Nita [17] suggest, some reviews are limited to certain databases or specific journals to meet the research objectives. Therefore, we have limited this study only to *Sustainability*. The notion of focusing only on *Sustainability* to analyze its role in e-waste research is a promising one. This journal is working on and publishing research related to e-waste management. The aim of reviewing a particular publisher and its specific journal is to steer toward exposing and uncovering the fields and areas where major or minor research is needed. This is based on the proposition proposed by Webster and Watson in their article [18]. Therefore, we can draw out more insights by delving into the publications; and so, in a way, this study will categorize and analyze research themes and trends published in *Sustainability*. To our best knowledge, this is the first study to primarily focus on the said publisher while reviewing the literature and research on e-waste. This was acknowledged while a search was conducted in the month of December on the MDPI website using the exact keywords as presented in Figure 1, along with analyzing the spreadsheets obtained from WOS and Scopus databases. Furthermore, the approach is to analyze the ongoing research patterns for academics and the management team of the publisher, along with the overall research community, whilst focusing on one particular field under a journal. This will provide a thorough overview by presenting the overall research trends and themes while concentrating on the specific journal and presenting insightful information and directions for future research. This study contributes to synthesizing past and extant research findings in the e-waste category, along with presenting a knowledge gap that will pave the way for researchers whilst the journal team can focus on critical areas for revision and improvement.

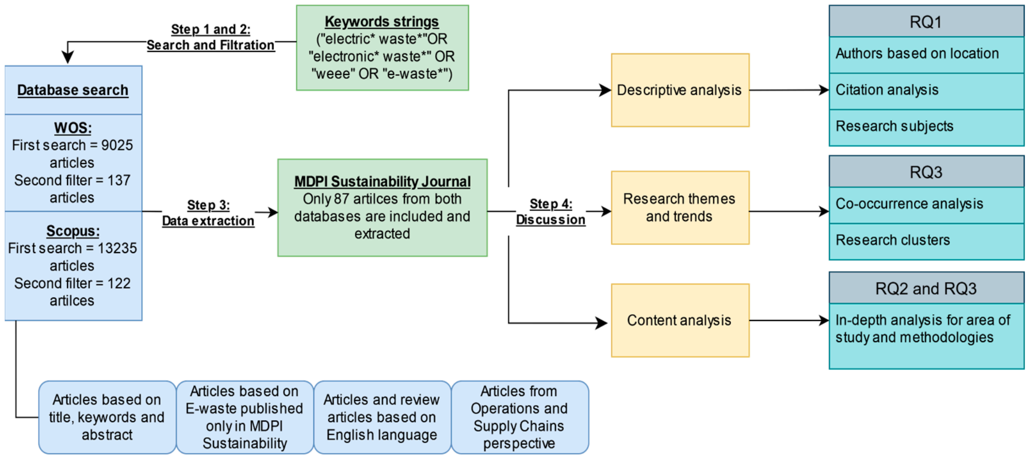

Figure 1. Flowchart of research framework and design.

1.2. Research Objectives

The main objectives of this study within the purview of the selected journal pertaining to e-waste management in the context of OSCM are as follows:

1. To examine the extent and magnitude of the extant published research.
2. To explore the key findings, publication trends, themes and topics covered, and advancements.
3. To find out the area of study and key methodologies employed by authors whilst pursuing their research.
4. To answer the research question: What are potential areas for future research?

For this purpose, three research questions were proposed to conduct this study under such pretext.

RQ1: How has the research field of e-waste evolved under *Sustainability*?

RQ2: What is the currently ongoing research on e-waste in *Sustainability*?

RQ3: What are the current underlying research themes and trends?

The obtained results illustrate that Sustainability has played a substantial role in covering the research in the field of e-waste, which is discussed in detail. For this purpose, the rest of the article is based on the following sections: a brief overview of the past literature is discussed in Section 2, while methodology is presented in Section 3; and Section 4 covers content analysis, which is discussed in several parts based on methodologies different authors have adopted in their studies.

2. Literature Review

The literature review is beneficial in providing a general overview of disparate and interconnected research fields. The existing literature provides excellent review papers covering e-waste from several aspects. Cucchiella et al. [19] perform an economic assessment of WEEE recycling based on descriptive and predictive disposed volumes in Europe. They analyze the economic assessment of 14 e-products. They mention that new products and technologies and the export of used products to developing countries from developed countries are prominent forms through which e-wastes are generated. Kiddee et al. [20] emphasize combining several e-waste management tools instead of using a single technique. For this purpose, they conducted a study by combining four e-waste management techniques, Life Cycle Assessment (LCA), Material Flow Analysis (MFA), Multicriteria Analysis (MCA), and Extended Producer Responsibility (EPR). All four tools are thoroughly discussed in their respective sections. Kumar et al. [14] conducted a correlation study concerning the United States, China, and India based on three variables: e-waste generation, gross domestic product (GDP), and population. Their results show that GDP directly correlates with the amount of e-waste generation, while the population has no significant impact. One of their crucial identification concerns the shorter life span of specific small electronic devices, like mobile phones, laptops, and tablets, indicating them as a significant source of waste generation.

Bressanelli et al. [3] systematically review the WEEE industry under the lens of CE based on four aspects, reviewing previous studies, the geographical location of focus studies, materials' life cycle phases, and 4R strategies of CE. They identify that little attention is given to the design of the practical solution; Europe is focusing on the WEEE industry mainly from a geographical perspective, and there is a lack of attention to the supply chain actors and life cycle phases. In contrast, from the CE lens, the main focus is on reducing and recycling strategies, whereas little attention has been given to the remanufacturing and reusing strategies. Bressanelli et al. [21] study 115 articles to identify CE enablers, levers, and benefits in the EEE supply chain (SC). For this purpose, they develop a framework for categorization, where enablers, levers, and benefits are discussed in detail in the findings section. In a recent review paper, Al-Saleem et al. [15] analyze the implementation process of the CE way of e-waste management based in Kuwait as a case study. Islam et al. [22] review the sustainable approaches for recovering metals from printed circuit boards of e-waste. Shittu et al.'s [23] review concentrates on the global situation regarding policies, legislation making, and WEEE generation. Europe is found to be leading in WEEE management, while the legislation trend is increasing in China, India, and Latin America. The authors identify four concern areas for further improvement; for example, WEEE management needs a formal system at the global level, and the ownership and production of EEE are rising on a global scale, which tends to generate more waste but no implementation of regulations. Furthermore, they suggest some measures for improving WEEE management on a global scale.

In a more recent paper, Ismail and Hanafiah [24] assessed four approaches for managing e-waste in Malaysia based on LCA and MFA. They proposed that energy recovery could be the ideal way to manage e-waste. Ismail and Hanafiah [25] review the present and future perspectives on sustainable e-waste generation. They perform descriptive analysis regarding worldwide e-waste generation and distribution and publication trends, research practices, and applications adopted in articles through content analysis. They study the current practices and research applications adapted for e-waste management thus far. For this purpose, the focus was on the current practices and research applications. They segment the scope and boundary and methodology of the current practices, where scope and boundary are defined through the level of analysis on the macro level and research areas. In contrast, the methodology is split into data sources, whereas the section on research application is mainly related to management practices. Also, in their previous study, Ismail and Hanafiah [26] reviewed the opportunities and challenges regarding the Malaysian recycling system related to e-waste. Their findings suggest that implementing laws on household e-waste management is still lacking. Gollakota et al. [27] review is related to studying inconsistencies in correspondence to e-waste management in developing countries. In such regard, their research identifies ten shortcomings impeding effective e-waste management pertaining to developing nations. They also analyze the micro, meso, and macro levels of e-waste management. The study analyzes the approach for recovering valuable materials from e-waste on the micro level. For addressing meso-level problems, material compatibility, its use, and reclamation are addressed along with LCA, MFA, and MCA, while the macro level is related to the role of government, consumers, and EPR. Furthermore, they have discussed the disproportion in developed and developing countries for e-waste management.

The aforementioned articles provide an overview in terms of covering various aspects of the overall research conducted on e-waste management. In addition, findings of past research are synthesized to elaborate the trends and themes. Moreover, such categorization paves the way for future research. However, this traditional approach is quite broad and comprehensive in synthesizing publications, research findings, and areas. As observed, the existing review works on e-waste in the *Sustainability* journal were lacking. Therefore, the present study was intended to fill and close this gap by gathering and reviewing current research articles published in the said journal. This will explore the existing publications on e-waste whilst providing an overview of topical research progress along with recommendations for future research to fill in gaps and limitations after identification. For this purpose, 87 articles are selected and analyzed, and the discussion is presented in detail.

3. Materials and Methods

The research objective of this study is to focus on and gather the extant literature and studies based on the *Sustainability* journal. A review is based on specific steps determined to address the diversity of knowledge for particular research inquiries [28] by formulating a research topic, data collection, and analysis [29]. This led us to adopt the methodology based on the working of [16,17,30] with some adaptations. The methodology part is divided into three sections, material collection, material filtration, and discussion; each is discussed briefly in Sections 3.1–3.3, respectively, along with a detailed discussion in Section 4. Figure 1 depicts the overall flow of this study.

3.1. Material Collection

The material was collected in three stages. First, databases were selected. In the second stage, data were filtered and exported into a suitable format for analysis. In the last step, data were cleaned to remove any discrepancies and duplication for overall analysis.

WOS and Scopus are leading database sources of information for scientific research [31,32]. Therefore, both WOS and Scopus platforms were selected to search relevant research articles based on specific keywords. For this study, the first search was conducted in December 2022 on both databases. The second and final search was conducted on 11 January 2023. As suggested by Suering and Muller [33], material delimitation and unit characterization is an important decision for conducting analysis. Under this approach, relevant publications were selected from both databases while focusing on e-waste. For this purpose, data were collected in a four-step approach:

- Step 1: A search based on Boolean operators was conducted to search relevant articles based on the following combination of strings: ("electric* waste*" OR "electronic* waste*" OR "weee" OR "e-waste*"). Keywords were limited to topics covering their titles, keywords, and abstract only.
- Step 2a: First search: Specific keywords were applied on both WOS and Scopus databases.
- Step 2b: Results were filtered and limited to: (a) *Sustainability* journal issued by MDPI, (b) articles and review articles based on the English language, and (c) articles only focusing on e-waste.
- Step 3: Relevant articles were extracted for data analysis.
- Step 4: Only articles with the above criteria were analyzed in the final list in both WOS and Scopus databases.

3.2. Material Filtration

The first search was conducted on 21 December 2022. The initial search resulted in 8977 and 13,128 articles from WOS and Scopus, respectively. A second search was made on 11 January 2023, resulting in 9025 and 13,235 articles from WOS and Scopus, respectively. The material filtration was performed in two phases. In the first phase, the WOS data were filtered and cleansed. Only articles and review papers based on the English language published in *Sustainability* were included, limiting the result to 137 publications from 2014 to 2023 for WOS. This limitation was performed as publications that were not related to the domain of this study based on the analysis of keywords and abstract; therefore, they were removed from the study, reducing the final list.

Afterward, the same method was applied to data obtained from the Scopus database, limiting the final result to 122 articles from 2016 to 2023. Also, there were no papers from

2014 and from 2015 on the Scopus database, but the time frame was set from 2014 to 2023, so both databases have the same time frame per analysis regarding time frame. The process is presented in Figure 1 for visualization.

In the second phase, duplication was removed, and overall results were analyzed. Moreover, articles were limited to 87 papers, mainly based on the authors working in the area of OSCM. The whole process was conducted and analyzed on structured datasheets in a spreadsheet. By following step 4, in Section 3.1, the final list of the selected 87 articles was analyzed in detail for this study.

3.3. Content Analysis

Out of 87 papers, only highly cited papers are discussed in Section 4.3; the top 30 papers are presented in Section 4.1.2, based on citations and average citations per year from both databases. The content of selected articles is analyzed in terms of the study's scope, methodology, subject area of research, their discussion, and results.

4. Discussion

This section is divided into two sub-sections. First, we have discussed the descriptive analysis followed by the content analysis of selected papers in detail. Descriptive analysis is regarding publications and citation trends, authors' affiliations based on location, and research subjects in Section 4.1, which will focus on RQ1. Section 4.2, on the other hand, is about research trends and themes, and Section 4.3 is regarding -content analysis, where we have described and analyzed selected publications concerning RQ2 and RQ3.

4.1. Descriptive Analysis

The overall trend suggests that research on e-waste is gaining momentum among the scientific community. For this purpose, descriptive analysis shows the publication and citation trend based on data collected from WOS and Scopus databases. The yearly publication and citation trends are presented in Table 1. The total number of articles published on WOS is 137, with a total citation of 1175. Table 1 illustrates the year 2014, which has only one article published on WOS, while no article was published in 2015. The year 2016 had only five publications, but it gradually started to increase after 2018, with the year 2022 having top publications of 41 articles. Also, it is evident that citations gradually increased after 2018 as well, with a significant portion of citations occurring from 2019 to 2022 (1093 out of 1175), indicating that citation tendency accounts for 93% of total citations alone in these four years. The h-index is 20. This indicates the inclination and growing interests of researchers.

Table 1. Publications and citations from WOS and Scopus (11 January 2023).

Year	WOS		Scopus	
	Publications	Citations	Publications	Citations
2014	1	3	0	0
2015	0	3	0	0
2016	5	3	5	1
2017	7	21	7	10
2018	13	46	8	49
2019	16	94	15	99
2020	24	208	21	242
2021	30	369	28	341
2022	41	422	38	488

Table 1. *Cont.*

Year	WOS		Scopus	
	Publications	Citations	Publications	Citations
2023	0	6	0	13
Total	137	1175	122	1263
h-index	20	-	21	-

On the other hand, data obtained from Scopus almost show the same trend. However, the years 2014 and 2015 account for no publications, where the contribution of publications started from the year 2016 with five publications, which gradually increased with time progression, and the year 2022 having 38 publications. The citation trends tend to be the same with a slight hovering above citations based on the WOS dataset. The h-index for the Scopus dataset is 21.

4.1.1. Authors Based on Locations

All authors' regional affiliations or geographical dispersion based on selected papers are presented in Table 2 in descending order. This selection is only based on authors' affiliations per research paper. It is evident from Table 2 that China is highly contributing, with 18.8% of the total 106 in such regard, followed by Italy at 8.4%, the USA at 4.71%, and Germany at 4.71%. In Asia, China is the main most significant contributor with 20 authors against a total of 41 in all of Asia, while in Europe, it is Italy with 9 affiliations against a total of 45. The publications are primarily divided globally, with countries from Asia and Europe playing a significant role in publications and research. Asia corresponds to 41, Europe to 45, North America to 9, South America to 6, Africa to 3, and Oceania to 2 articles.

Table 2. Authors' affiliations are based on countries.

Continent	Countries	Authors' Affiliations	Total Authors	Percentage of Total
Asia	China	20	20	18.8%
	Taiwan, Indonesia	4,4	8	7.5%
	Malaysia	3	3	2.8%
	UAE	2	2	1.8%
	Saudi Arabia, Singapore, Philippines, Iran, South Korea, India, Vietnam, Japan	1,1,1,1, 1,1,1,1	8	7.5%
Total			**41**	**38.6%**
Europe	Italy	9	9	8.5%
	Germany	5	5	4.7%
	Norway, UK	4,4	8	7.5%
	Romania, Poland, Ireland, Finland, Denmark, Sweden	2,2,2,2,2,2	12	11.3%
	Austria, Lithuania, Belgium, Croatia, Ukraine, Serbia, Greece, Spain, Slovakia, Malta, EU	1,1,1,1,1, 1,1,1,1,1, 1	11	10.3%
Total			**45**	**42.4%**
North America	USA	5	5	4.7%
	Mexico, Canada	2,2	4	3.8%
Total			**9**	**8.5%**
South America	Brazil	5	5	4.7%
	Colombia	1	1	0.9%
Total			**6**	**5.6%**

Table 2. *Cont.*

Continent	Countries	Authors' Affiliations	Total Authors	Percentage of Total
Africa	South Africa Nigeria	2 1	2 1	1.8% 0.9%
Total			**3**	**2.8%**
Oceania	Australia New Zealand	1 1	1 1	0.9% 0.9%
Total			**2**	**1.8%**
Grand Total			**106**	**100%**

4.1.2. Citation Analysis

Table 3 presents the details of citations and average citations per year based on the two academic databases, WOS and Scopus. This table is presented under the notion of citation reports, which is utilitarian in terms of assessing the impact and influence of publications as research papers are considered crucial research criteria.

Table 3. Author(s) and citations report on WOS and Scopus (11 January 2023).

Row	Author(s)	WOS		Scopus	
		Citations	Average Citations	Citations	Average Citations
1	Nduneseokwu et al. [34]	58	8.29	67	9.57
2	Sverko Grdic et al. [35]	54	13.5	65	16.25
3	Rocca et al. [36]	54	13.5	65	16.25
4	Thi Thu Nguyen et al. [37]	53	10.6	58	11.6
5	Isernia et al. [38]	36	7.2	45	9
6	Popa et al. [39]	34	4.86	45	6.42
7	Shevchenko et al. [40]	31	6.2	39	7.8
8	Cruz-Sotelo et al. [41]	29	4.14	32	4.57
9	Miner et al. [42]	28	7	30	7.5
10	Parajuly and Wenzel [43]	26	3.71	30	4.28
11	Vermesan et al. [44]	25	5	26	5.2
12	Cordova-Pizzaro et al. [45]	25	5	26	5.2
13	Abalansa et al. [46]	23	7.67	26	8.66
14	D'Adamo et al. [47]	23	2.88	30	3.75
15	Delcea et al. [48]	20	5	20	5
16	Yu and Solvang [49]	19	2.38	36	4.5
17	Wang et al. [50]	17	2.83	21	3.5
18	Cao et al. [51]	17	2.83	21	3.5
19	Vieira et al. [52]	16	4	17	4.25
20	Barletta et al. [53]	14	1.75	14	1.75
21	Murthy and Ramakrishna [54]	13	6.5	22	11
22	Corsini et al. [55]	13	3.25	13	3.25
23	Andersson et al. [56]	13	2.6	14	2.8
24	Magrini et al. [57]	10	2	14	2.8
25	Tu et al. [58]	12	2	12	2
26	Maheswari et al. [59]	10	2	14	2.8
27	Liu et al. [60]	10	1.67	15	2.5
28	Sari et al. [61]	9	3	11	3.6
29	Parajuly and Fitzpatrick [62]	8	2	10	2.5
30	Wang et al. [63]	8	2	12	3

The data presented in Table 3 are based on the search provided on 11 January 2023. Data are presented in descending order only of the top 30 articles; however, citation data are listed in WOS data order, which the authors initially studied for this study. The highly cited article was published by the authors of [34] with a total of 58 citations and an average citation of 8.29 on WOS, and a total of 67 citations and an average citations per year of 9.57 on the Scopus database.

4.1.3. Research Subjects

Figure 2 presents the categorizations of all 87 papers based on research subjects and methodologies adopted by authors. The survey-based methodology is the most prominent one adopted by most authors, with 21 papers, followed by mathematical modeling papers, with 9 papers. Reviews, evaluation studies, and game theory are found in seven papers. Interestingly, the authors of all seven game-theory-model papers [60,64–69] are based in China.

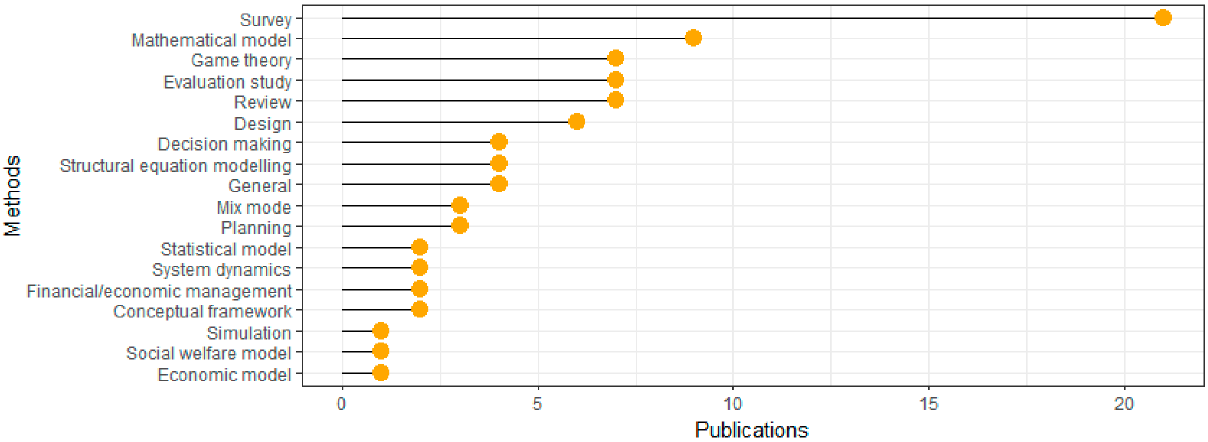

Figure 2. Methodologies and publications.

Table 4 presents the concentration of research fields pursued by the authors. E-waste management has a significant focus, along with recycling and reverse logistics (RLs). Table 5, on the other hand, presents the focus of the authors industry-wise. This table illustrates that a wide variety of studies are primarily based on e-waste, accounting for 68.96% of total publications, followed by mobile phones at 12.64% of total publications. Various other industrial items, like waste printed circuit boards and e-devices, have two publications each, while the rest comprise one publication each.

Table 4. Research fields.

Research Areas	Publications
E-waste management	[34,39,41–43,45–47,53,54,56,57,70–80]
E-waste	[81–84]
E-waste collection	[51]
Recycling	[35,37,40,44,48,60,63,66,69,69,81,85–99]
Disassembly	[36,100]
Reuse	[101,102]
Disposal	[103–105]
Repair	[106]
Consumer behavior	[55,107–112]
Life cycle assessment and material flow analysis	[113]
Supply chain	[114]
Supply chain: reverse supply chain	[68,115]
Supply chain: closed-loop supply chain	[50,64,67,116,117]
Logistics	[62]
Logistics: reverse logistics	[38,49,52,59,61,65,118]
Location: vehicle routing	[119,120]

Table 5. Focus of industries.

Industries	Publications
E-waste	[34,36–43,46,48–57,60,64–73,75,76,78–81,84,86,87,89,91,92,94–99,103,106,108–111,113,116,118,119]
Various sectors	[35]
Waste printed circuit boards	[44,47]
Mobile phones	[45,58,59,61,63,74,83,85,104,107,120]
Plastic and electronic waste	[62]
Washing machine	[101]
Notebooks	[77,88]
Computers	[102]
Car and refrigerator	[90]
Home appliances	[117]
Televisions and monitors	[114]
RFID	[82]
End-of-life vehicles	[93]
Batteries	[100]
E-devices	[105,112]

4.2. Research Themes and Trends

Based on RQ3, research themes and trends are discussed in terms of co-occurrence and research clusters to identify the topics and areas pursued by researchers.

4.2.1. Hotspot Identification Using Co-Occurrence Analysis

Figure 3 illustrates the hotspots of research using authors' keywords. Co-occurrence analysis was performed based on the authors' keywords to identify the main ideas and the border of research. Using VOSviewer 1.6.18, the minimum number of keyword occurrences was kept at 2, under which 54 hotspots met the threshold out of 509 keywords. E-waste occurrence presented 38 times, WEEE at 21, CE at 18, and recycling at 14, while sustainability showed 12 occurrences as the top five hotspots and most frequent keywords. All these five keywords are connected to each other and result in more publications and keywords as off-shoots. All 54 hotspots are mapped in Figure 3, where larger and thicker spots identify more occurrences. The purple color in the visualization represents the occurrences of the authors' keywords as being that of the year 2019, in contrast to the more recent occurrences represented in yellow found in the years 2021 and onward.

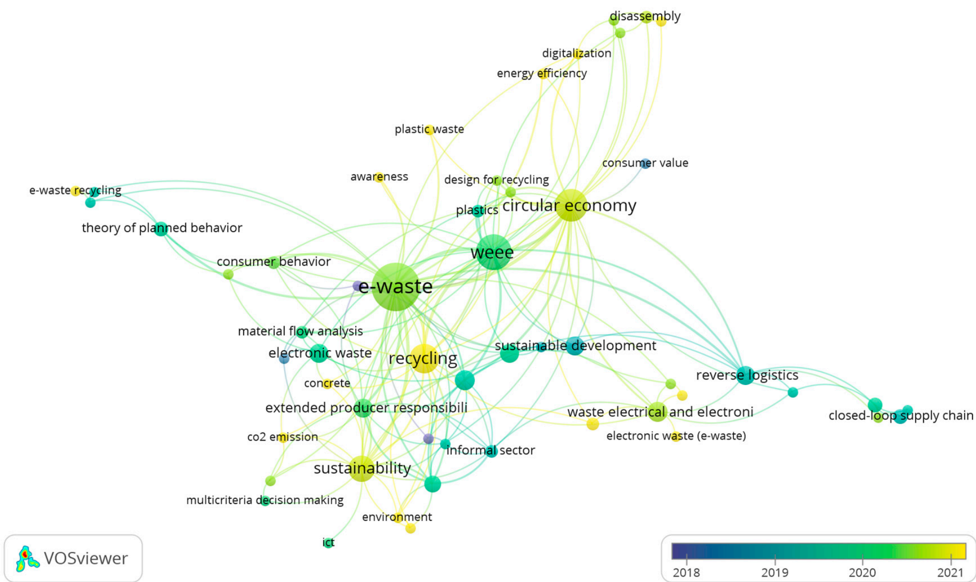

Figure 3. Authors' keywords co-occurrence network.

4.2.2. Research Themes Map by Identifying Clusters

Prominent research clusters and themes are discussed in Table 6 through content analysis. Among such, CLSC, e-waste, sustainable development, and WEEE comprise the more influential and discussed ones; therefore, these four clusters are briefly discussed here.

Table 6. Prominent research clusters.

Cluster	Cluster Category	Terms	Publications
1	Closed-loop supply chain	Closed-loop supply chain, remanufacturing, game theory, Stackelberg game, system dynamics	[50,64,65,67,74,94,117]
2	E-waste	E-waste, WEEE, CE, recycling, sustainability, waste electrical and electronic equipment, extended producer responsibility, reverse logistics, e-waste management, theory of planned behavior, consumer behavior, informal sector, plastics, circularity, design for recycling, design from recycling, end-of-life management, environment, legislation, plastic waste, waste disposal, waste management, repair, industry 4.0, material flow analysis, life cycle assessment, reverse supply chain	[34,38,40,44,46,47,49,51,52,54,55,60–62,70–73,76,77,81,82,85–87,89–91,93,97,99,103,104,109,111,114,116,118]
3	Sustainable development	Sustainable development, environmental sustainability	[35,80,95,107]
4	Waste electrical and electronic equipment (WEEE)	Waste electrical and electronic equipment (WEEE), waste management, repair	[39,56,92,101,102]

E-waste and its handling pose concerning issues to the environment. A recent report estimated that 53.6 million metric tons of e-waste was generated across the globe, and roughly less than 20% is managed under green environment policies [12]. Also, the circular transition is limited in this sector [121]. On the other hand, e-waste also has the economic potential of generating revenues, although it requires meticulous working [47]. Therefore, a systemic support and green eco-design system for restricting the menace of such wastes and acquiring economic gains has the potential for circular transition. The building blocks for such transition and sustainable development are CLSC, RL, health, policies, environmental protection, awareness, government financing, and digitalization. Such blocks work as enablers and levers for implementing CE practices.

In addition, under the CE framework, e-waste management activities can be enhanced for efficient resource usage, recovery, and recycling methods. For this purpose, CLSC activities for e-waste management operating in a CLSC system play a vital role in achieving sustainable goals from manufacturing to customer usage, recycling, and the disposal of such electrical and electronic products and components [122]. In essence, such green initiative reduces overall waste quantities, forming responsible consumption and well-designed processes linking forward and backward streams in an environmentally friendly way. E-waste appears to be one of the leading research themes covering different aspects, whereby the more prominent ones include WEEE, CE, recycling, sustainability, and RL. While the authors of [34] worked on consumers' intention, ref. [38] worked on the reverse supply chain, ref. [40] studied consumer recycling behavior, ref. [44] worked on recovery techniques from waste circuit boards, and ref. [47] identified challenges in the profitability assessment of e-waste. In CLSC research clusters, most studies are based on the game theory approach as well as on system dynamics.

4.3. Content Analysis

Figure 2 presents the various studies adopted by researchers. The 87 studies are related to OSCM. In operations management and a typical SC environment, the supplier, manufacturer, distribution channel, and customers are involved, intertwined, and related in terms of products, their consumption, collection, recycling, remanufacturing, reusing, feedback in terms of information, product delivery in the forward stream, and product flow back in terms of the upstream. Thus, in a way, all of these key stakeholders work together and are dependent on each other for their objectives, be it profit or end product for consumption and usage. Furthermore, under CE principles, CLSC, RL, and waste collection systems play their roles. Table 4 depicts the overall picture for a better understanding.

This review also identified the critical methodologies adopted by researchers and authors, as presented in Figure 2. According to the analysis, 21 out of 87 papers are based on survey methodology, followed by mathematical models with 9 papers, and finally, reviews, evaluation studies, and game theory models with 7 papers each. It is evident from Table 4 that the majority of papers are based on e-waste management (26.43%) and recycling (27.58%) subjects, while the rest are distributed on other aspects, such as: consumer behavior (10.3%); RL (8.04%); CLSC (5.74%); e-waste (4.46%); disposal (3.34%); disassembly, reuse, reverse supply chain, and vehicle routing (each with 2.29%); and e-waste collection, repair, SC, logistics, LCA, and MFA (each with 1%). It can be concluded that most studies are based on the management, SC, and R-framework of CE, like recycling.

On the other hand, Figure 2 illustrates that most of the studies are based on the qualitative type of research compared to quantitative studies. For instance, survey corresponds to 24.13% of studies; mathematical model, 10.34%; review, 8.04%; evaluation study, 8.04%; game theory, 8.04%; design, 6.89%; general, 4.59%; structural equation modeling, 4.59%; decision making, 4.59%; planning, 3.44%; mix mode, 3.44%; conceptual framework, 2.29%; financial/economic management, 2.29%; statistical model, 2.29%; economic model, 1.14%; social welfare model, 1.14%; and simulation, 1.14%. This comparative analysis shows that more research and work are required and are imperative in terms of quantitative studies.

The content analysis of 87 papers is presented below; the papers are categorized based on methodologies and publications based on Figure 1 to answer RQ2 and RQ3.

4.3.1. Survey-Based Studies

A survey gathers information and data from the sample size of people through questionnaires, phone calls, interviews, or using any web-based platform [123]. Some of the critical articles based on the survey are discussed here.

Nduneseokwu et al. [34] developed a theoretical framework based on the theory of planned behavior (TPB) to identify the influencing factors on consumers' intentions to participate in an e-waste collection system through conducting an empirical survey in Nigeria. Through studying customers' intentions for participation, the authors identified that consumer participation is vital for e-waste collection management due to the interrelation of both traits. Their research was limited to one metropolitan city, however, rather than focusing on multiple cities.

Miner et al. [42] surveyed 228 respondents about their awareness level and knowledge of e-waste management based in Nigeria. Their results indicate that cell phones and television sets are prominent devices. Also, open space dumping is the most predominant method for disposing of e-wastes, followed by storing at home and selling it, in that order. The authors only focused on household citizens in a specific city in Nigeria. Cordova-Pizarro et al. [45] analyze the economic and technical situation in Mexico by surveying the e-waste generation of cell phones using MFA. They perform fieldwork to quantify e-waste processing through personal interviews in selected twelve companies. They only address repair and recycling in terms of closing the loop for achieving circularity. Cao et al. [51] present an existing framework based on the survey to identify problems associated with the WEEE collection system in China by conducting an explorative study. They proposed four WEEE collection modes. This study, however, has focused on specific modes while ignoring the economic benefits participants can achieve form recycling systems in such different modes. Magrini et al. [57] studied the application of digital technologies, like IoT and blockchain, for the prevention of WEEE based on interviewing five companies. They performed a survey and presented a framework for enabling and using digital technologies for a better management of electrical and electronic products. Tu et al.'s [58] study analyze the critical factors from a consumer perspective of purchasing smartphones based on the Taiwanese market. They analyze and compare the demographic differences and the associations between such factors. Their study had limitations in terms of uneven demographic online questionnaire distribution, where most respondents were university students under the age of 30 years. Also, the focus of the study was on one specific brand of mobile phone.

Maheswari et al. [59] perform an interview-based study to analyze the Indonesian mobile phone market by engaging with government and intermediary businesses. For this purpose, they employ the sustainable RL theory using the customer value chain as an analysis parameter. They divide mobile phone waste into two categories, (1) household, as an informal group, and (2) industrial, as a formal group. Furthermore, their respondents for interviews consist of international and national waste management companies, whereas dealers, stalls for electronic goods, exporters, local smelters, retailers, and service and repair come under the informal group. They note that those in the informal group mostly ignore safety procedures for RL activities. Sari et al. [61] surveyed smartphone users located in Indonesia. They developed 324 valid questionnaires. They applied the TPB as a base framework, mainly focusing on the consumers as they play the suppliers' role in terms of waste. Therefore, the authors used RL drivers along with facility accessibility to explore consumer intention to participate in programs related to e-waste. Their study shows that the government can drive consumers' intention to participate in e-waste collection, followed by facility accessibility and personal attitudes. The main limitation of their study is the use of only RL as a variable. Blake et al. [70] investigate a case study using an online survey module to analyze households about e-waste management in the Whangarei district of New Zealand. They suggest that e-waste management should be made mandatory for achieving sustainability. Also, their study shows that cost is the main barrier associated with recycling services to perform appropriate disposal. Moreover, their local authorities reported an intention level of up to 26.9% in recycling their e-waste, but the municipal recycling services reported only 1.8% in 2017.

Johnson et al. [101] perform a trial base study to assess the reusing of washing machines in Ireland. They use the terminology "preparation for reuse". They collect data on a business-to-consumer (B2C) basis for re-use trials. Their study accepted 23,129 appliances for inspection, and 1134 machines were selected for the trial study phase. Only 327 washing machines were sold back to the market after successfully converting them through reuse. This is merely 1.5% of the overall reuse rate.

4.3.2. Modeling-Based Studies

Some of the critical papers based on a variety of modeling approaches are discussed here.

Servko Grdic et al. [35] apply an econometric model to determine the relationship between economic development and the circular economy (CE) concept while using GDP and the production and recycling rates of wastes as variables for their statistical analysis. The results showed that the CE concept could pave the way for economic growth.

Rocca et al. [36] perform virtual testing through simulation for a practical demonstration of supporting CE practices through I4.0-based technologies for WEEE management.

Thi Thu Nguyen et al. [37] work on the public perception of e-waste recycling in Da Nang city in Vietnam under TPB by employing structural equation modeling (SEM). Their analysis showed that awareness and attitude about environmental factors toward recycling, pressure from society, laws and regulations, inconvenience, and the cost of e-waste recycling directly contribute to residents' behavioral intentions. Their results showed that the inconvenience of e-waste recycling had a negative impact on their recycling behavior intention. Delcea et al. [48] studied consumer behavior about recycling, the influence of determinants toward e-waste recycling intentions, and behavior in Romania. They gathered data through a survey for which they generated 54 questions, which decreased to 41 questions after validation, and performed structural equation modeling for the analysis.

They observed that consumer intention has a direct positive impact on their behavior toward e-waste recycling. One of the limitations they mention is the sample size, as their respondents were only social media users.

Wang et al. [50] investigated competition between retailers and third-party recyclers in a CLSC model using the principle-agent theory without the government's reward and penalty mechanism (RPM). One assumption they adopted was that new and remanufactured products had no differences between them. Isernia et al. [38] study the RL cycle for WEEE management by focusing on waste collection centers located in Italy on the provincial level. They employ a stochastic matrix model for their analysis to study the correlation between the collection rate of WEEE and collection centers across different provinces using data provided by the Italian national clearinghouse. This study only focuses on the collection part in terms of the WEEE management system rather than the whole treatment process for WEEE. Yu and Solvang [49] developed a model based on stochastic mixed-integer programming to analyze an RL network under uncertainty for WEEE management. Their model for the RL system includes: (1) locations of local and regional collection centers, (2) recycling plants, (3) market, (4) disposal, and (5) hazardous waste management. Stochastic parameters for their model are (1) WEEE generation and (2) the price of recycled products and materials. They adopt and utilize numerical experiments along with sensitivity analyses to support and validate their results.

The most prominent model adopted regarding e-waste research is based on game theory. Hence, some of the critical papers are discussed here. Liu et al. [60] analyze the WEEE disposal fund policy in the Chinese e-waste market to optimize the formal and informal recycling market for recycling fees and subsidies based on the game theory model. First, they construct a game model to study the competition between the formal and informal markets for dismantling and refurbishing processes. They identify the trade-offs between subsidy and its marginal effect and setting up recycling fees. They suggest that the government set up appropriate recycling fees and subsidy levels to have a better social welfare and a balance of disposal funds. Gong et al. [64] analyze the SC actors in terms of manufacturing- and retailer-led scenarios, considering choices and profits for each actor. The results show that a hybrid-led strategy of manufacturer and retailer is more beneficial against large firms regarding the recycling rate of the products and their demand.

D'Adamo et al. [47] analyze challenges in recycling WEEE for waste printed circuit boards (WPCBs). They develop an economic model for identifying profitability in recovering WPCBs as a tool for profitability assessment. They identify critical constituents from waste recoveries like gold, palladium, and copper that play a significant revenue-generation role.

4.3.3. Review-Based Studies

Below is a summarization of critical review articles. The authors performed review papers based on different aspects that are briefly summarized and discussed.

Shevchenko et al. [40] perform a literature review of extant articles studying consumer behavior regarding e-waste recycling. They suggest that an electronic bonus card system (EBCS) based as an economic incentive is beneficial for consumers in terms of: (1) compensating the cost for e-waste collection and (2) satisfying consumer perception that value can be generated from e-waste at their end of life and that this is a valuable resource. They identify that consumer recycling behavior varies between countries. For instance, the causal factor in western European countries is an increased level of awareness and knowledge, while American consumers prefer convenience, for which convenient infrastructure is developed. On the other hand, Asian and African countries are facing challenges, mainly due to financial attributions. Vermesan et al. [44] focus on recycling techniques such as disassembly, treatment, and refinement for waste printed circuit boards. They identify some critical problems related to the recycling process, such as: (1) the aggregation of waste items, (2) transportation, and (3) the heterogeneous nature of such wastes. They propose that one way to achieve CE through recycling techniques is by adopting chemical and electrochemical processes. Murthy and Ramakrishna [54] perform a review based on global e-waste management to highlight key factors, such as policies, technology requirements, and social awareness. Corsini et al. [55] explore and analyze consumer behavior related to (1) purchasing, (2) life extension, (3) recycling, and (4) the take-back participation of EoL electrical and electronic equipment by conducting a review. They adopt the TPB as a base theory.

4.3.4. Designing

Two papers primarily focused on designing a new waste collection system and consumer participation in an online recycling platform, respectively, and both of which are summarized.

Popa et al. [39] designed an IoT-based cloud platform for waste collection systems intending to develop and implement a smart system to identify and collect wastes like plastics, glass, aluminum, WEEEs, papers, cans, batteries, etc. They also propose further research in terms of virtual modeling and simulation. Wang et al. [63] perform two experiments to analyze how green information can influence the respondents participating in online recycling websites. Their study is based on the situational experiment method; however, a real-environment scenario can yield far different results, considering the seriousness level and subjects' understanding related to the experiment.

4.3.5. Frameworks

Some authors attempt to develop, adopt, and approach framework-based studies concerning an issue to pursue a solution for the said challenge. Two such approaches are discussed here.

Parajuly and Wenzel [43] propose a conceptual framework to alleviate the challenges posed by the diversity of e-waste. They investigate the quantities and management of electric and electronic products (e-products), product and material flow in the overall recovery chain, information exchange, and characteristics of e-products. They identify three aspects for improvements in the recovery chain: (1) "improved collection system", (2) "presorting and testing platform", and (3) "family-centric processing of EoL products". Andersen and Jager's [116] study is about manufacturers' ability to make their products more circular. Their findings suggest that they must explicitly bear the responsibility of all stakeholders in their product networking, from its conception up to its disposal, by creating a circular system for handling the products and their components. The authors focused on the technical parts of their model. However, encouraging actors for information sharing can be focused on through incentives and regulations.

4.3.6. Planning

Cruz-Sotelo et al. [41] suggest a planning model for the e-waste supply chain in Mexico. They analyzed actors in the WEEE recovery chain, public policies, legal regulations, existing practices for handling e-waste, opportunities, and challenges regarding waste flow management and proposed a management model. They identified one limitation and future prospective research in terms of applying uncertainty methods.

4.3.7. Decision Making

Decision-making is a fundamental process to maximize a firm's capability, resources, profits, operational capabilities, and optimality [124]. Two articles are summarized below.

Vieira et al. [52] use a multicriteria decision aid approach (MCDA) for small and medium-sized companies' (SMEs) prioritization of barriers for implementing RL for e-waste collection in Brazil. They perform the study in two steps; first, they identify the main barriers through a literature review and then apply MCDA application. The results show that the internal barriers of organizations are the main barrier to RL implementation from the government and SMEs' perspective, while consumers consider the managerial level as the main barrier. One limitation was the non-identification of e-wastes purchased by customers, as such information has the potential to shed light on the intention of reselling or repairing them. Barletta et al. [53] propose a novel methodological framework using several methods, like discrete event simulation, LCA, and stakeholder mapping, to access the sustainability dimension of e-waste management. They test their methodology using a case study.

4.3.8. Evaluation Study

Parajuly and Fitzpatrick [62] use e-waste and plastic waste as case fractions to evaluate the policy impact and assessment regarding transboundary waste movement. They recommend that policymakers should be aware of environmental and socio-economic issues. They also state that public involvement is imperative for improving the validity of any policy, as the public is ultimately one of the significant stakeholders.

4.3.9. Finance/Economic Management

Extended Producer Responsibility (EPR) is a built-in cost function for the protection of the environment as a whole from the manufacturing point of view. The background is related to producers who have to take responsibility for their post-consumer products in terms of environmental protection. For this purpose, a study is discussed here.

Cheng et al. [86] investigate the cost management functions for the recycling fee equation while considering environmental costs. Their study is based on Taiwan's EPR version for WEEE recycling. They suggest that the pricing mechanism for e-waste recycling cost has helped us by considering all perspectives, like labor, administration, and the environment itself. Their study has four players: (1) household communities generate waste, (2) the recycling industry is for processing, (3) municipalities collect e-waste, and (4) the recycling fund is for supporting incentives. They identify that the government is the most concerned authority regarding the recycling system and environmental cost compared to private authorities.

5. Conclusions

The research implications of conducting a review paper for investigating e-waste centering exclusively on a single selected journal are multifaceted and possess substantial value for involved stakeholders. This can be argued from different angles. For instance, this study primarily aimed to provide a comprehensive and confined examination of the extant literature and research activities contained precisely in the MDPI *Sustainability* journal rather than the copious literature from different sources. As a result, it offered insightful information pertaining to the progression of research on e-waste in the said journal discussed through bibliometric and content analysis in Section 4. Moreover, this review can stem from academic contribution in terms of e-waste awareness, existing techniques, approaches, and dominant research methodologies, implied along with research trends and tendencies. Hence, it could act as a reference point for researchers, scholars, and decision-makers of the said journal, sweeping for prospective research paths regarding e-waste management. Furthermore, this study could pave the way for unexplored domains concerning e-waste management within this journal or outside of its premises by stimulating multidisciplinary collaboration among researchers. In addition, such encouragement can work for both theoretical and practical contributions aiming at mitigating economic, societal, and environmental impacts posed by e-waste.

For this purpose, a thorough review is performed in this paper to analyze the selected 87 papers based on the *Sustainability* journal of MDPI in the famous research field of e-waste. Two forms of search were made based on specific keywords on WOS and Scopus databases, the first on 21 December 2022 and the second on 11 January 2023. The final list of 87 papers is examined, reviewed, and categorized based on the proposed research questions. This study aims to aid academics in the field of OSCM in understanding and analyzing the published papers under the prospect of potential future investigation. It will also help the publishers and policymakers of the said journal to assess and evaluate their publications.

Overall, this review paper has certain limitations. Firstly, we could not focus on the overall extant literature regarding e-waste, as the study was confined to MDPI's *Sustainability* journal only. This way, we could not work on the entire breadth of the available literature. This is the trade-off we had to perform in order to confine this study. The second focus was within the purview of OSCM potentially limiting the inclusivity and exhaustive examination. However, prospective researchers can work on other domains for more exploration by incorporating multiple databases and journals.

The review has provided some ideas for future research as well:

- Figure 3 presents a digitalization that was less focused. Future studies and examinations in a digital era with advanced applications can explore strategies for an effective and efficient e-waste management against the challenges and opportunities posited by e-products. E-learning platforms, big data, analytics, and subsequent digital technologies can be exploring strategies.
- Another aspect is that most underdeveloped countries have an informal market in terms of recycling, remanufacturing, and reusing. More studies on e-waste management whilst focusing on informal e-waste management processes, recycling, and remanufacturing facilities is an exploration to ponder and work on. Therefore, in such regard, the social and environmental aspect of CE practice has huge potential.
- Figure 3 illustrates that most papers are related to e-waste management and recycling, whilst other subject areas are less considered. For instance, disposal, disassembly, repair, and CLSC are crucial elements for effective e-waste management as the environmental performance of an SC affects sustainability [125].
- On the other hand, an e-waste collection center plays an essential role in the effectiveness of the SC and logistics network. We can see only one paper adequately dedicated to the collection of e-waste [51]; one paper on collection systems from an RL perspective [118]; and two papers on location problems [119,120]. Therefore, more research is needed from such a perspective, as e-waste management is very much related to collection and location centers for properly and effectively handling e-waste, as it cannot operate independently.
- Another aspect is the role of the consumer in e-waste management, as they act as a network function to supply such products. Consumer behavior and intention are the intangible aspects of sustainability. This study accounts for only 10.3% of papers; hence, more investigation is crucial and imperative.
- Only one article based on CE and I4.0 regarding e-waste, by Rocca et al. [36], and three IoT-related articles by the authors of [39,57,84] are found for this review paper during analysis. Further, this subject area can be considered by researchers for future studies based on the notion that I4.0 is the critical driving force in transforming the linear economy to a more circular method [126], which, as a result, will have profound effects on the production process and the whole SC.
- Table 5 suggests that various electronic items like computer parts, televisions parts, and end-of-life vehicle parts could be a significant future research area. Therefore, such areas need more attention from researchers for future intake.
- Another additional study is in assessing the risk management and operational capacity of such operations in terms of resource sharing and industrial symbiosis, in more generic terms, fostering a better industrial ecological system.
- The process of material and study categorization is another angle to ponder and look upon since this study is mainly focusing on the OSCM side of the research.

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