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Systematic literature review of reverse logistics for e-waste: overview, analysis, and future research agenda

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ABSTRACT
If the waste of electrical and electronic equipment (WEEE or e-waste) is not appropriately disposed of, it can endanger both human health and the environment by contaminating the air, water, and soil. The purpose of e-waste reverse logistics (RL) is to collect, disassemble, remanufacture, recycle and dispose of end-of-life (EOL) electrical and electronic products to mitigate the risk of environmental damage and maximise the extraction of economic value. In this systematic literature review, we conducted a content analysis of 162 papers written in English from 1998 to 2021 and identified six main research themes on e-waste RL: 1) e-waste legislation and policy, 2) barriers, critical success factors, and solutions, 3) e-waste RL network design decisions, 4) e-waste RL system evaluations and frameworks, 5) consumer e-waste return behaviour, 6) technology-based e-waste RL initiatives. By synthesising these research themes, a conceptual framework of reverse logistics for e-waste is constructed. The review then discusses the limitations and research gaps of each theme and concludes by proposing a detailed future research agenda across 13 specific research topics.

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E-waste; reverse logistics; waste of electrical and electronic equipment; systematic literature review; research agenda

1. Introduction

Rapid technological innovation, together with the lowering of large-scale production costs, has dramatically increased people's access to electrical and electronic equipment (EEE), including both plug-in and battery-powered devices. Although the increased use of EEE has had many benefits, it has also caused the ballooning of e-waste globally. E-waste is a term used to cover items of all types of electrical and electronic equipment (EEE) and its parts that have been discarded by the owner as waste without the intention of re-use(STEP 2014). If handling inappropriately, the harmful materials contained in e-waste such as mercury, lead, cadmium, etc. will endanger people's health by contaminating the soil, water, and air (Tsai and Hung 2009). Around 53.6 million metric tons (Mt) of e-waste (excluding PV panels) was generated, or 7.3 kg per capita. Meanwhile, the formal documented collection and recycling was about 9.3 Mt, accounting for 17.4% compared to e-waste generated. The majority of the e-waste destination is unclear and most likely dumped in the environment directly (Forti et al. 2020).

E-waste contains a variety of hazardous materials, including mercury, lead, and cadmium, etc. Thus, when treated inappropriately, it can endanger both human health and the environment by contaminating the air, water, and soil. Such waste also contains valuable elements such as gold,

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silver, copper, and other residual materials. When such resources are not recovered, additional raw materials must be extracted and processed to make new products, resulting in avoidable environmental damage due to mining, manufacturing, transportation, and energy consumption (Ongondo, Williams, and Cherrett 2011).

Since the beginning of this century, reverse logistics (RL) has received increased attention as an e-waste management strategy from researchers and practitioners. RL refers to the process of planning, implementing, and controlling an efficient, cost-effective flow of raw materials, work-in-process inventory, finished goods, and related information from the point of consumption to the point of origin to recapture value or proper disposal (Rogers and Tibben-Lembke 1998). RL operations process e-waste by utilising the valuable components and disposing of the harmful ones. This approach complies with sustainable development objectives and is economically, environmentally, and socially sustainable (Elkington 1998).

Unlike other EOL products RL, e-waste RL has its unique features. Most of the e-waste contain toxic materials such as printed circular board, fluorescent, freon refrigerant, etc. which require environmentally benign treatments to comply with regulations in RL activities. Furthermore, comparing with other waste, as a high-value waste category, depending on e-waste characteristics, various recovery options such as reuse, remanufacture, and recycle might apply to extract residual value from it. The e-waste RL is more extensive and complex that involves consumers, collectors, repairers, disassemblers, recyclers, EEE producers or remanufacturers, and disposers than other waste RL systems (Cao et al. 2016).

As illustrated in Figure 1, traditionally, raw materials are first supplied to EEE manufacturers frow where finish goods are made and distributed to consumers. When EEE is at end of use but still functional, they may enter the resale or secondary market. The flow of EEE from the supply of raw materials to the secondary market is known as forward logistics (FL). FL is focussed on EEE that is functional. When EEE does not function well, some may either be repaired by replacement of defective components to enable it to be reused, or refurbished and resale in the secondary market, others are discarded by the consumer as e-waste, which is collected, disassembled, recycled, and disposition by different RL operators. The flow of e-waste from the consumer transforming into valuable materials to the manufacturer is known as e-waste RL. Depending on e-waste characteristics, it may be sequentially collected, disassembled, recycled, or disposed of on the end. Collecting involves the efficient consolidation of e-waste from different consumers including households, companies, and governments. While disassembling involves the separation of high-value components(mostly are sub-assemblies), which are restored to their original condition and remanufactured, low-value components, which are recovered as raw materials for lower-tier recyclers. Meanwhile, harmful materials are properly collected in the disassembling process. Recycling consists of hazard-free treatment of harmful materials and recycling basic materials mainly plastics and metals which are supplied as virgin materials in FL. Finally, after remanufacturing and recycling, the residual e-waste materials without any value are disposed of in landfills or incinerated (Stuart et al. 1998).

Many developed and developing countries have introduced legislation to enforce the proper management of e-waste. These laws seek to enforce legal responsibility for all e-waste management stakeholders, as well as supporting sustainable development. However, the prevalence of poor e-waste collection and treatment practices casts doubt on the effectiveness of such legislation. For example, according to WEEE compliance promotion exercise final report (EC 2017), 9 of the 28 EU member states (i.e. 32%) did not achieve the EU's 4 kg/inhabitant e-waste collection target in 2014. Besides, 13 member states did not consider their available e-waste treatment capacity, and the difference between estimated e-waste volume and the sum of different treatment approaches varied from 0 to 68%, indicating large differences in treatment capabilities among the member states. There is limited systemic data on the effectiveness of e-waste management in Brazil and China, as well as other developing countries, because e-waste collection and the implementation of RL are still in their infancy (Sthiannopkao and Wong 2013).

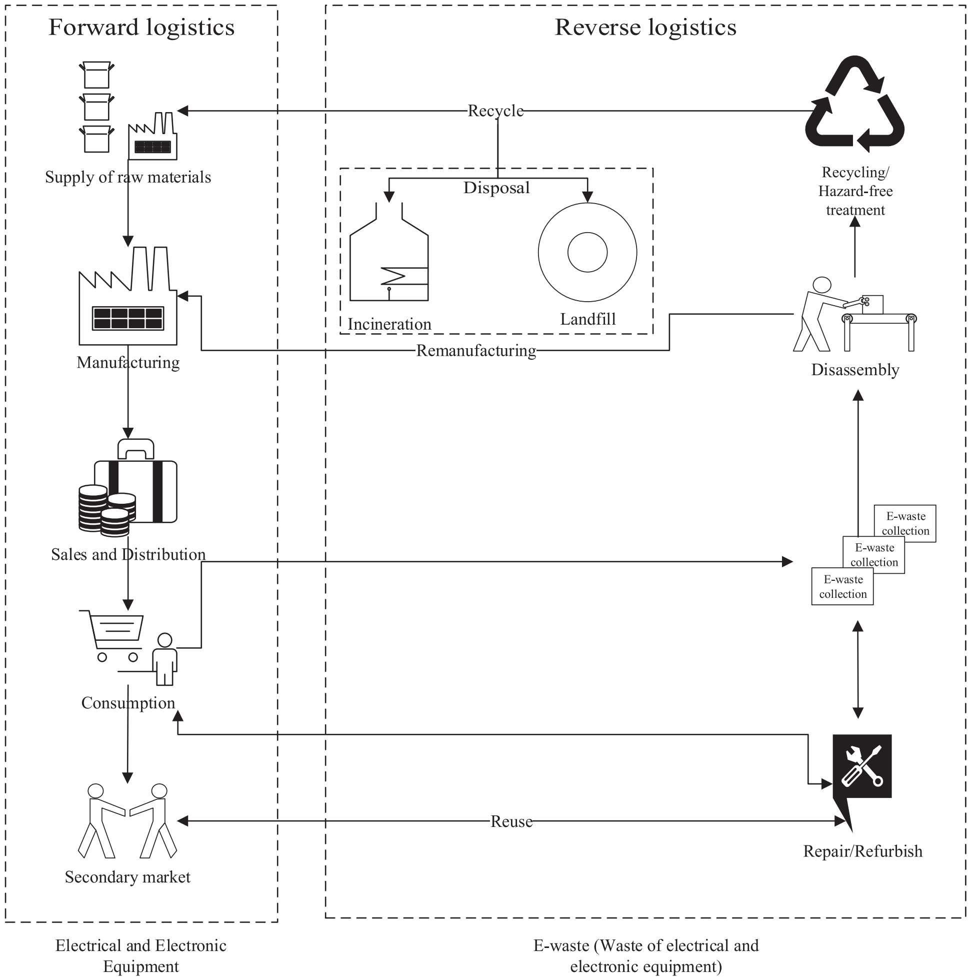

Figure 1. Flows of electrical and electronic equipment in forward and reverse logistics, modified from (Zeng et al. 2013).

To effectively investigate e-waste RL, it is critical to understand the main research themes, contributions, and limitations of existing studies, as well as the results of real-world implementation and future trends in the field. Although there has been increased research interest in e-waste RL in recent years, only a few researchers have considered RL holistically on e-waste.

Islam and Huda (2018) conducted a review of the existing literature on e-waste RL and closed-loop supply chains and identified four research streams: the design and planning of reverse distribution, decision-making and performance evaluation, the creation of conceptual frameworks, and qualitative studies. The authors developed a high-level theoretical framework for e-waste RL, as well as decision-making models to support network design. However, they did not adopt a holistic approach that focus on e-waste RL research from different stakeholders' perspectives or various RL processes perspectives.

To the best of our knowledge, Islam and Huda (2018) paper is the only extant review of the e-waste RL literature. In light of this, the main goal of this study was to undertake an updated, systematic, and well-structured review of e-waste RL. The key objectives of the work were to 1) construct a comprehensive framework of findings, common themes, and issues arising from e-waste RL research and 2) identify the current research theme gaps and propose a future research agenda.

To achieve these objectives, we conducted a systematic literature review, analysing 162 papers written in English from 1998 to 2021. The findings of the papers were formulated into research themes and synthesised into a research framework, providing an in-depth view of both individual elements of e-waste RL and the process of e-waste RL as a whole.

Section 2 of the paper describes the methodology used in this review, while section 3 provides a descriptive analysis of selected attributes of the papers that were analysed. Section 4 describes the six main research themes that we identified and synthesise a research framework. Section 5 discusses each of the themes in greater depth. Section 6 identifies the gaps in the existing research and proposes a forward research agenda of specific 13 research topics related to e-waste RL, while section 7 summarises and concludes the paper.

2. Methodology

In this study, we undertook a systematic literature review to analyse the existing research on e-waste RL. Systematic literature reviews were first applied in the field of medical science but are now seen as valuable tools of inquiry across all fields; they seek to synthesise research findings in a holistic, transparent, and reproducible way (Davis et al. 2014). Systematic reviews focus on a particular research question and consist of the identification, selection, and critical appraisal of the relevant research, as well as the collection and analysis of data from the relevant studies (Moher et al. 2009). Identifying and analysing all the empirical evidence that fits the review's eligibility criteria enables the minimisation of bias and the production of reliable findings from which conclusions can be drawn.

Certain procedural steps must be followed to ensure a literature review is accurate, precise, and trustworthy (Snyder 2019). The most widely accepted approach to a systematic literature review consists of three stages: 1) planning the review, 2) conducting the review, 3) reporting on and disseminating the review (Tranfield, Denyer, and Smart 2003). This review process is illustrated in greater detail in Figure 2.

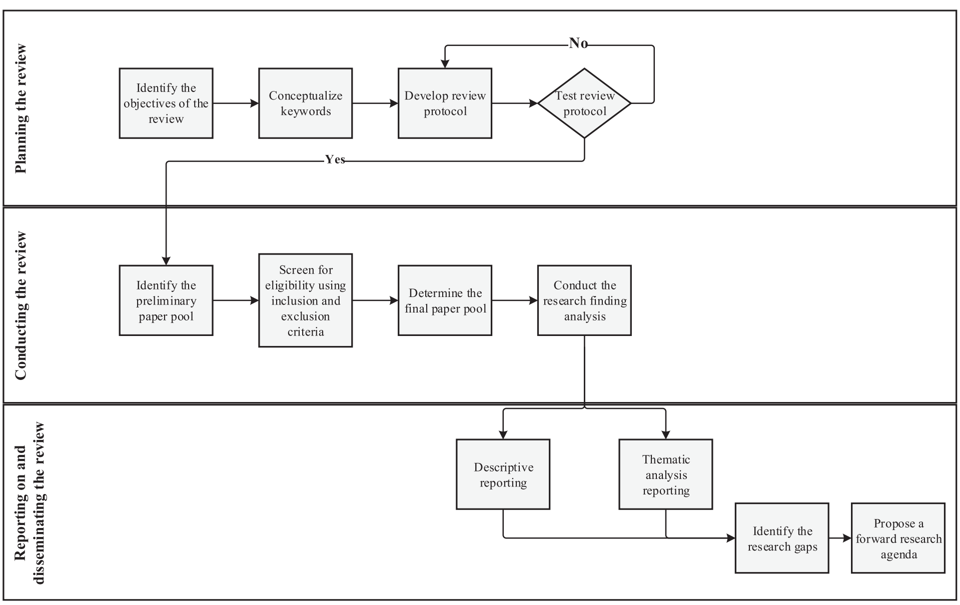

Figure 2. Stages of the systematic literature review process.

2.1. Planning the review

Snyder (2019) reported it is preferred to use two reviewers to select articles to ensure the quality and reliability of the search protocol when reviewing is conducted. In the first stage of the review, we formed a review panel consisting of two researchers to avoid individual bias. Next, the panel agreed on four keywords for the review: reverse logistics, waste of electrical and electronic equipment, WEEE, and e-waste. Thirdly, the panel used these keywords to develop an initial review protocol and conduct a pilot search of two well-known citation databases, Scopus and Web of Science. The search was limited to articles and reviews written in English but did not include any limit on the publication date. Finally, the panel evaluated the relevance of the search results by reviewing the abstracts of the papers and adjusting the keywords accordingly. Given that there was an overlap of approximately 65% across the results from Scopus and Web of Science, with Web of Science providing fewer searching results, the panel selected Scopus as the database for the final review. After conducting three pilot searches, validating the search results, and adjusting the review protocol, the panel finalised the protocol, as shown in Table 1.

2.2. Conducting the review

In December 2020, the panel searched Scopus using the final review protocol and identified an initial pool of 181 papers, including journal articles, book chapters, and trade journal news articles. As discussed in section 2.1, the search did not include any limit on the date, and the publication dates of the results ranged from 1998 to 2021.

Next, the panel reviewed the titles, abstracts, and keywords of the results based on the inclusion and exclusion criteria, as shown in Table 1. Eighteen papers were immediately excluded from the review on this basis. Another two papers required further examination due to a difference of opinion between the panel members. After reviewing the full text of these papers, the panel decided to include

Table 1. Systematic review protocol.

Keywords	Search terms	Period	Inclusion criteria	Exclusion criteria	Type of source	Language	Database
Reverse logistics	(TITLE-ABS-KEY ('reverse logistic*') AND TITLE-ABS-KEY ('electr*') AND TITLE-ABS-KEY ('waste')) AND DOCTYPE (ar OR re) AND (LIMIT-TO (LANGUAGE, 'English'))	No limit	Reverse logistics network design	Industrial symbiosis	Articles	English	Scopus
Waste of electrical and electronic equipment			Tools and models to support decision-making	Reverse logistics for non-EEE materials	Reviews		
WEEE			Consumer intention of returns	Battery technology upgrades or applications			
E-waste			Theoretical framework for e-waste reverse logistics	Purchasing or rental decision making			
			Policy and legislation concerning e-waste management	Production system analysis			
			Innovation in e-waste reverse logistics	Individual firm news in a trade journal			
			Barriers and solutions in e-waste reverse logistics				

one, an empirical study of barriers to lithium battery RL, and exclude another, which described an entity's novel sustainable business model and logistics system but did not mention e-waste.

Ultimately, 162 papers were included in the final pool for review. Figure 3 illustrates the classical Preferred Reporting Items of Systematic and Meta-analysis (PRISMA) screening flow that was used to develop the final paper pool (Moher et al. 2009).

To synthesise the findings of the final pool and develop a holistic overview, the panel reviewed the full text of each paper and identified the research questions and contributions of each paper, then identified common themes.

This review also included an analysis of the characteristics of the pool as a whole, including the number of papers published in each year, the most prolific authors and their affiliations, the most active journals in this area, and the geographic coverage of the papers. The last characteristic is particularly relevant given that e-waste RL legislation, implementation, and practice vary significantly between countries.

The paper-level analysis focused on the objectives, methods, contributions, limitations, and target audience of each work. This information was coded according to the '5W1H' principle (i.e. Who, What, When, Where, How, and Why). Building on this principle, the review considered *why* the research was conducted (i.e. the research motivations), *what* problems is sought to resolve,

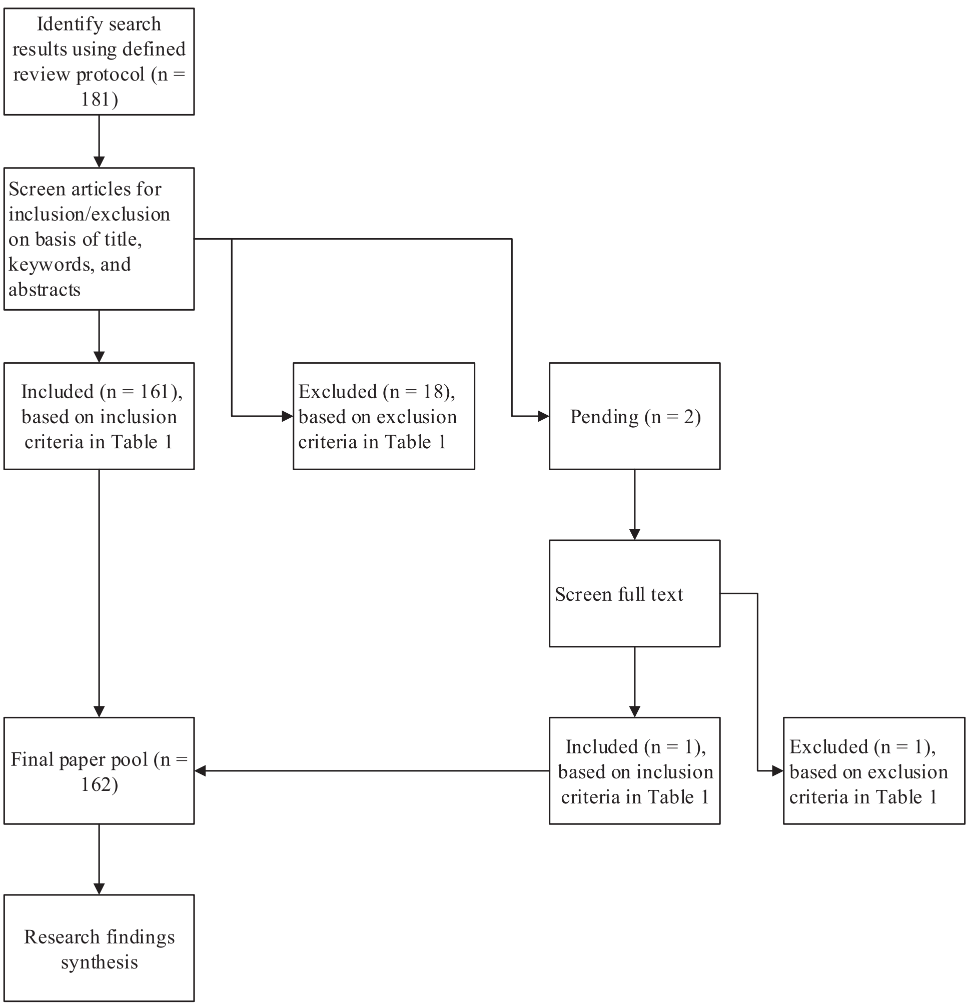

Figure 3. PRISMA screening flow chart.

who the audience and potential beneficiaries of the research were, *when* and *where* the research was conducted, *what* the implications or contributions of the research were, and *how* the research was conducted (i.e. its methodology). After this analysis, the reviewers formulated the overarching research themes and developed a framework to categorise this body of research.

2.3. Reporting and disseminating

The main goal of the third stage of the review was to report on and disseminate the findings from stage two. Tranfield, Denyer, and Smart (2003) argued that a two-stage report may be produced, the first is a full 'descriptive analysis' of the field using a simple set of categories, and the other is a 'thematic analysis' derived through an aggregative or interpretative approach. In this paper, the results are reported and disseminated in two sections. Firstly, the reviewer provides a summary of the descriptive statistics of the papers that were analysed. While the second details the thematic analysis of the research findings. As discussed above, the results of our analysis were coded using the '5W1H' principle, then overarching common themes were identified. These themes offer valuable insight into the existing state of e-waste RL literature.

3. Descriptive analysis

3.1. Number of publications trend

The papers analysed in this study included both articles from peer-reviewed journals and published or in-press book chapters. Figure 4 shows the number of publications by date for all the in-scope papers, which illustrates the increase in academic interest in e-waste RL over the past two decades. 2020 saw the largest number of papers being published, at 27. A total of 102 papers, or 63% of the pool, were published in the past five years.

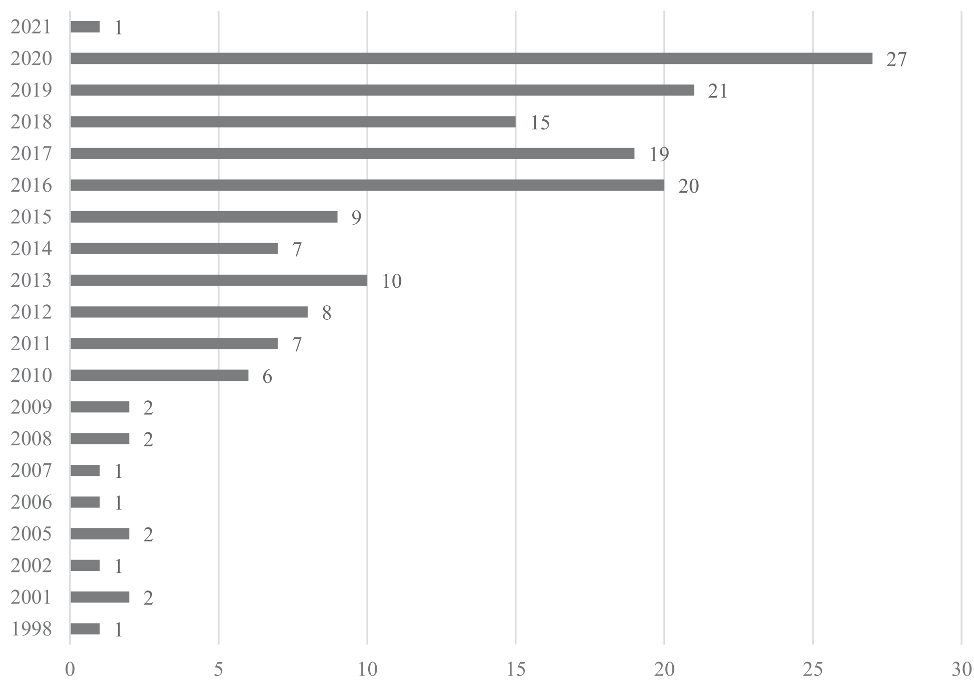

Figure 4. Number of published articles by year (n = 162).

Table 2. First author and affiliation (n = 162).

First author	No. of publications	Affiliation
Mar-Ortiz, J.	3	Universidad Autónoma de Tamaulipas, Tampico, Mexico
Dixit, S.	3	ITM University, Gwalior, Madhya Pradesh, India
Agrawal, S.	3	Delhi Technological University, Delhi, India
Tong, X.	2	Peking University, Beijing, China
Achillas, C.	2	International Hellenic University, Thermi, Greece
Ayvaz, B.	2	Istanbul Commerce University Küçükyali, Istanbul, Turkey
Maheswari, H.	2	Institute Teknologi Bandung, Bandung, Indonesia
Temur, G.T.	2	Bahçeşehir University, Istanbul, Turkey
Prakash, C.	2	Indian Institute of Technology, Roorkee, Uttarakhand, India
Tosarkani, B.M.	2	Ryerson University, Ontario, Canada
Achillas, C.	2	Aristotle University, Thessaloniki, Thessaloniki, Greece
Duman, G.M.	2	University of Bridgeport, Bridgeport, United States
Flygansvær, B.	2	BI Norwegian Business School, Norway
Islam, M.T.	2	Macquarie University, New South Wales, Australia
Other 131 authors	1	Other affiliations

3.2. Most productive authors and journals

Table 2 lists the most productive authors in the pool according to the first author of each paper, as well as their affiliations. Figure 5 shows the most active journals in this research area.

The top three authors (i.e. Mar-Ortiz, of the Universidad Autónoma de Tamaulipas, Dixit, of ITM University, and Agrawal, of Delhi Technological University) each published three papers over the past two decades. The most active journals (i.e. *The Journal of Cleaner Production*, *Resources, Conservation and Recycling*, and *Waste Management*) accounted for 51 papers or 31% of the total pool. Each of the top journals had an impact factor of > 5.0, indicating they are high-quality journals.

To eliminate the possibility of missing papers in top operation management journals(The University of Texas at Dallas list or equivalent), the panel makes another round of searching on INFORMS (The Institute for Operations Research and the Management Sciences) publication online using the same keywords. While the searching result shows only one relevant paper, it investigates a channel competition mechanism under different e-waste recycling standards. This paper speaks for itself is more a general competition management issue focus and not an e-waste RL research.

Figure 5. Journals by number of publications (n = 162).

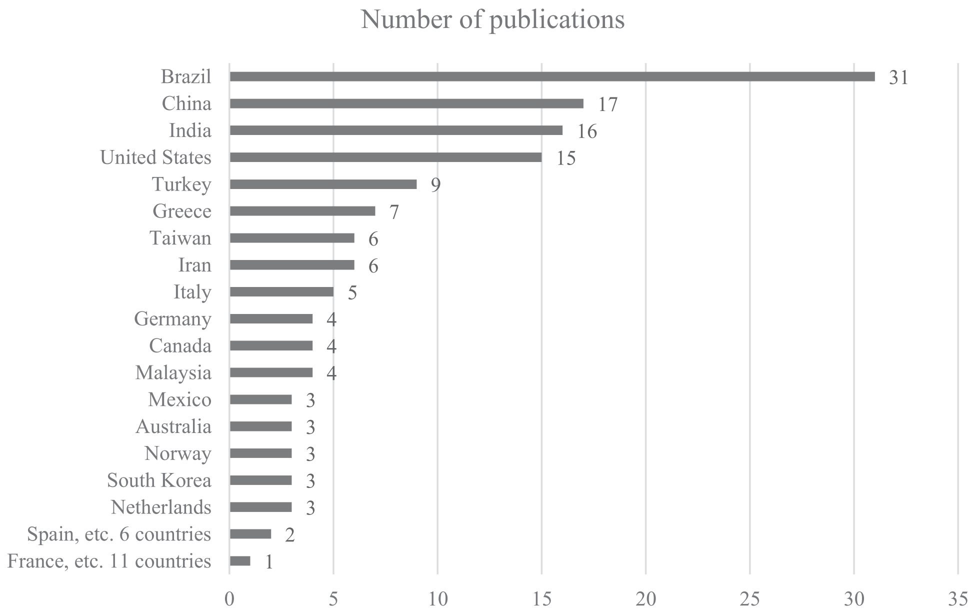

Figure 6. Geographic distribution of publications (n = 162 papers).

3.3. Geographical distribution of research

Developing countries typically face greater challenges with more research interests than developed countries concerning e-waste RL. These challenges include low public awareness of the harmfulness of e-waste, non-existent or ineffective RL networks, a lack of relevant legislation, and an inability to offer economic incentives to recycle. The geographical distribution of research in this study reflected this fact, with Brazil, China, and India producing a total of 64 publications, or 40% of the total number of papers, as shown in Figure 6. Publications in the United States go to fifteen showing more concern on this research topic than other developed countries.

3.4. Research methods adoption

Various research methods are applied in e-waste RL. Among all 162 papers, mathematic modelling, qualitative analysis, survey, case study, and interview are mainly used methods to conduct research. Total 146 papers, or 90% of the paper pool, adopt the five methods, of which mathematic modelling method falls into 70 papers, implying a relatively popular topic on the e-waste RL network design and optimisation. Meanwhile, methods such as the technique for order preference by similarity to ideal solution (TOPSIS), system dynamics, mixed methods, secondary data analysis, etc. which account for the rest 10% of the total publications are also adopted in responding to certain e-waste RL research questions. Figure 7 illustrates research method distribution in more detail.

4. Thematic analysis

4.1. Coding method

The existing literature on e-waste RL is diverse, with a wide variety of topics, perspectives, theoretical frameworks, and decision models. This indicates that this research area is rather fragmented and that it is challenging to develop a holistic picture of e-waste RL research.

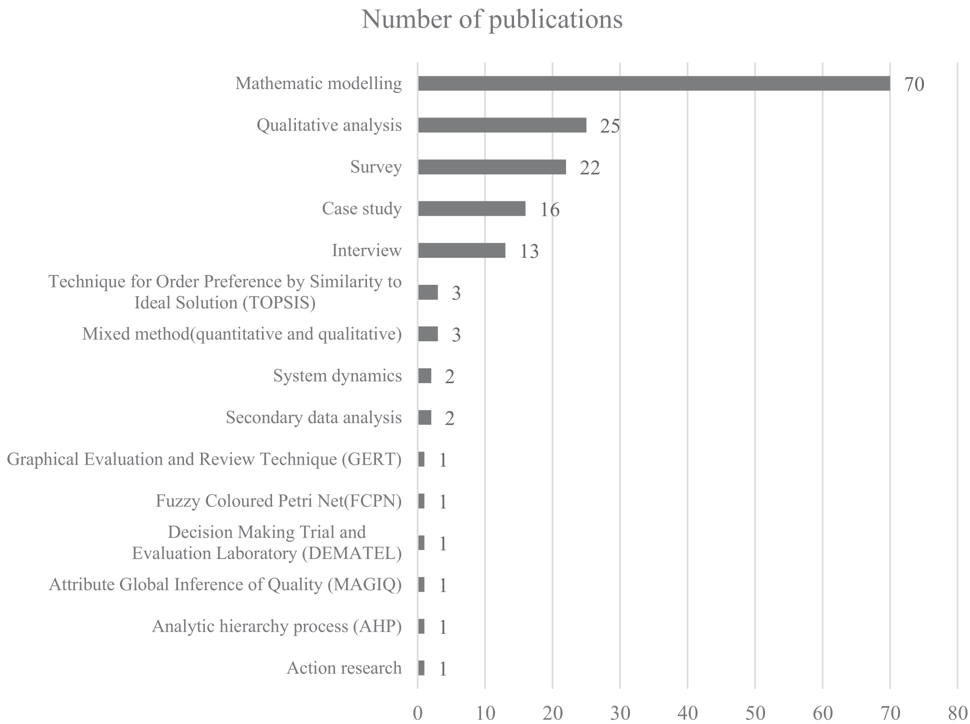

Figure 7. Research method distribution of publications (n = 162 papers).

As discussed in section 2, to overcome this problem, the panel reviewed the full text of each paper and coded its contents using the 5W1H principle. Using this method, the researchers acquired an in-depth understanding of the purpose, content, audience, timing, location, and methods of the papers, enabling their effective categorisation (Yoshioka et al. 2001). The coding method adopted in this study is described in more detail in Table 3.

4.2. Research framework synthesis

Following by answering the 5W1H questions, the panel synthesised answers and six overarching research themes were identified: 1) e-waste legislation and policy, 2) barriers, critical success factors, and solutions, 3) e-waste RL network design decisions, 4) e-waste RL system evaluations and frameworks, 5) consumer e-waste return behaviour, 6) technology-based e-waste RL initiatives. These

Table 3. Coding based on the 5W1H principle.

5W1H	Configured question	Content Elements	Description
Why	Why was the research conducted?	Motivation	Motivation for the research
What	What objectives/problems did the research seek to resolve?	Research questions	Research questions and objectives of the paper
	What were the contributions of the research?	Contributions	Contributions of the paper, including innovative knowledge, methods, theories, and managerial implications
Who	Who was the intended audience for the research?	Beneficiaries	Target audience of the paper (e.g. government officials, e-waste reverse logistics practitioners, consumers)
When	When was the research conducted?	Time	Time that the research was conducted
Where	Where was the research conducted?	Location	Geographical coverage of the research
How	How was the research conducted?	Methods	Methods adopted to conduct the research.

themes represent a comprehensive overview of the existing e-waste RL research, from government, operator, and consumer perspectives. Each theme also included several subcategories, illustrating the richness and diversity of this research area. Figure 8 illustrates the above themes and subcategories in more detail.

The above six themes represent a comprehensive perspective from the government, producer, e-waste RL operator, and consumer about current e-waste RL research. Besides, the six themes are both independent and interrelated. For example, legislation and policy regulate the disposal of dangerous substances, and e-waste RL operators must obey such laws when designing the disposition capacity and return rate of the RL network. Policies such as government subsidies also enable e-waste RL operators to sustain profitability within the network. Consumer intention and behaviour determine patterns of e-waste returns, which impact RL network design decisions such as disassembling capacity, vehicle routing planning, third-party RL(3PRL) provider selection, and facility location. Evaluation frameworks measure the strengths and weaknesses of RL operators and the effectiveness of e-waste RL deployment, as well as identifying barriers, success factors, and solutions concerning the real-world implementation of e-waste RL. Technical innovations offer new tools to manage complex e-waste RL problems and transform e-waste RL business models. Thus, the six themes provide an essential framework to advance the understanding of e-waste RL research and practice for both scholars and practitioners.

5. Detailed analysis of e-waste RL themes

5.1. E-waste legislation and policy

Legislation and policy play an important role in e-waste RL implementation by, for example, defining the scope of e-waste, allocating management responsibility, and specifying collection channels.

Both developing and developed countries have introduced e-waste management legislation. For example, the European Commission (EC) introduced its first WEEE (e-waste) directive in February 2003, and a revised directive (Directive 2012/19/EU) came into effect on 13 August 2012. The directive was transposed into the national laws of the 28 EU member states on 14 February 2014 (EC 2012). The US enacted the Responsible Electronics Recycling Act (HR2284) in 2011, while Japan introduced its Home Appliance Recycling Law in 2001. In Brazil, the National Policy on Waste Management came into force on 3 August 2010 (Guarnieri, e Silva, and Levino 2016). On 1 January 2011, China adopted the Catalogue of Waste Electrical and Electronic Products for Disposal and Administrative Rules of Collection and Disposal of Waste Electrical Appliances and Electronic Products. Both instruments are administered by the Ministry of Environmental Protection (Zeng et al. 2013). All these laws contribute to the achievement of countries' sustainability goals but vary in their degree of explicitness. The degree of compliance with such laws also varies significantly between developing and developed countries.

Furthermore, government policies such as financial incentives or subsidies have a significant impact on the profitability of RL operators and can influence the type of e-waste that is collected, as well as operators' disassembling and recycling capacity.

Zeng et al. (2013) compared e-waste legislation in the EU and China and found that the EU's WEEE2 Directive (Directive 2012/19/EU) positions EEE producers as the only party responsible for e-waste management. The directive provides that EEE producers should finance the management of waste from their products, including e-waste collection, treatment, recovery, and disposal. According to the directive, individual consumers should be able to return e-waste at no additional cost. On the other hand, China's Administration Regulation for the Collection and Treatment of Waste Electric and Electronic Products (January 2011) imposes shared responsibilities on several different stakeholders. The Regulation encourages producers to recover e-waste either independently or by commissioning a licensed company and notes that e-waste collectors should provide

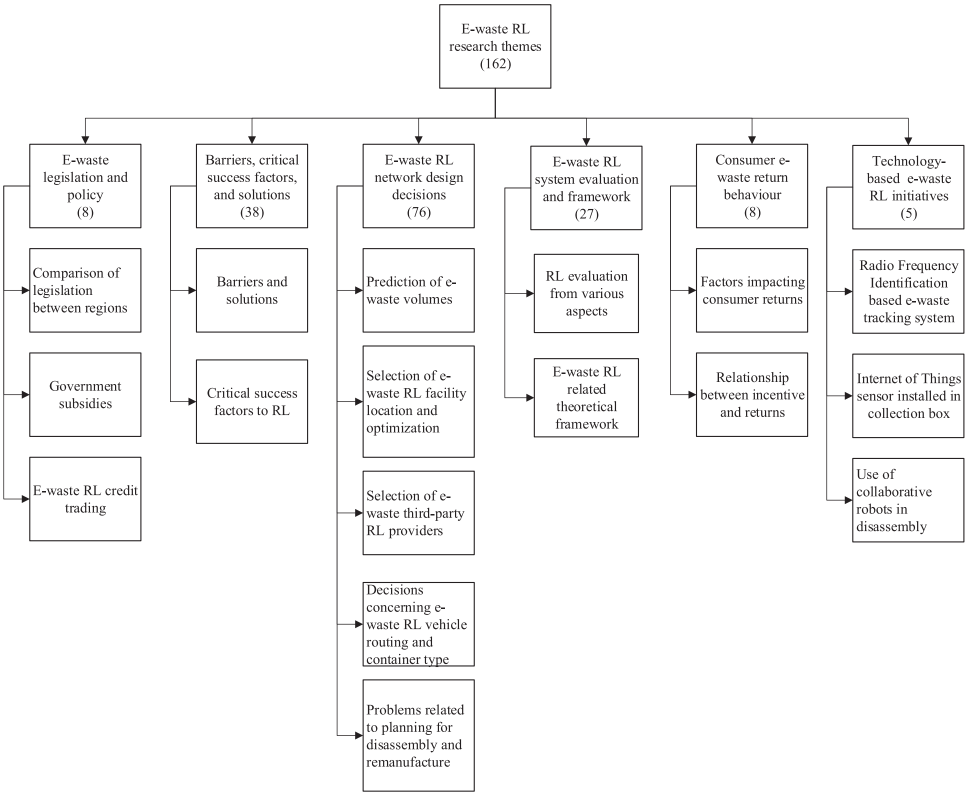

Figure 8. E-waste RL research themes and subcategories.

a convenient service for consumers. Government agencies, organisations, enterprises, and institutions must submit their e-waste to licensed treatment companies, which are required to establish an e-waste database that is submitted to their local environmental protection bureau. The definition of e-waste and enforcement of e-waste management vary between product types and government departments.

Government subsidies for e-waste treatment are a popular way to promote the appropriate disposal of e-waste around the world. In the Chinese context, Liu et al. (2016) proposed the creation of a competitive pricing model for both formal and informal collectors to help the government determine the appropriate level of subsidy and quality threshold for e-waste disposal. The authors suggested that the Chinese government should not impose a high-quality threshold, in order to avoid disadvantaging informal collectors. In many countries, informal collectors represent a large proportion of e-waste collection overall.

Caiado et al. (2017) explored the feasibility of establishing an RL credit market in Brazil. Such a market would enable high-performing RL producers to sell credits to low-performing producers to stimulate RL implementation. Although the authors supported the proposal in principle, they found that Brazil did not have an appropriate regulatory environment to support an RL credit market. There is no existent law stipulating producers must join the RL credit market, thus the proposed RL credit market mechanism is still in the air.

These researches on legislation and policy illustrate the positions and attitudes of various governments on e-waste RL, as well as key policies and tools impacting e-waste RL practice. These legislative and policy frameworks offer insights for researchers seeking to expand their knowledge of e-waste RL.

5.2. Barriers, critical success factors, and solutions

Many researchers around the world have identified weaknesses in the collection, remanufacture, recycling, and disposal of e-waste. For example, around 74% of e-waste is recycled in Japan, while the US average is approximately 12.5% (Sthiannopkao and Wong 2013). A study of the recycling of e-bike batteries in Xuzhou, China, found that the actual number of batteries recycled between 2011–2014 was up to 17.6% lower than the estimated output volume(Chen et al. 2017).

Many studies have sought to understand and address the barriers to the effective deployment of e-waste RL. Bouzon et al. (2016) reported that economic barriers are the most significant; for example, the financial burden of tax and general economic uncertainty are major obstacles to RL implementation in Brazil. Bakhiyi et al. (2018) argued upstream e-waste solutions should focus on reducing the use of potentially toxic compounds. Specifically, the authors advocated taking pragmatic action to progressively reduce the illegal e-waste trade, particularly through international cooperation. They also recommended better enforcement and monitoring of domestic laws, as well as the supervised integration of the informal sector into the formal recycling system and the global expansion of formal e-waste collection and recycling. In Thailand, Sirisawat and Kiatcharoenpol (2018) identified eight types of barriers to effective e-waste RL, including management barriers, organisational barriers, product barriers, legal barriers, infrastructure barriers, financial barriers, technical barriers, and engagement barriers. The authors also offered twelve proposals to resolve these barriers. Using a combination of fuzzy analytic hierarchy process(AHP) and technique for order performance by similarity to ideal solution(TOPSIS), they found that increasing management awareness of and support for e-waste RL is the most effective solution. Finally, in Brazil, one study identified the low residual value of cores, low volumes, high transportation costs, lax regulation by original equipment manufacturers, and low participation in take-back initiatives as key barriers (Quariguasi Frota Neto and Van Wassenhove 2013).

Several studies have also investigated the critical success factors for e-waste RL operators. Agrawal, Singh, and Murtaza (2018) reviewed 12 critical success factors from the literature and identified awareness among senior management, resource management, economic factors, and the terms and conditions of supplier contracts as the most important factors in the Indian electronics industry. A Dutch study found that voluntary pro-environment attitudes toward product return, rather than commercial considerations or legislative pressures, led to the successful implementation of e-waste RL (Marić and Opazo-Basáez 2019). Motivating formal recyclers to accept e-waste from informal collectors was identified as an opportunity to enhance RL practice in China, because the final destination of e-waste gathered by informal collectors is currently unknown (Cao et al. 2016).

5.3. E-waste RL network design decisions

Papers on RL network design formed the bulk of the e-waste RL research that was reviewed in this study. A total of 76 papers, or 47% of the pool, focused on this issue. Decision-makers are motivated to meet the Sustainable Development Goals based on economic, environmental, and social factors(Rosati and Faria 2019). One element of this is the planning and implementation of a cost-effective, environmentally friendly, and socially beneficial e-waste RL network for both commercial product recovery and legislative compliance. The key decisions related to RL network design include the location of facilities, storage space, capacity planning, and service level (Yu and Solvang 2016).

The general theme of RL network design can be divided into several decision-making sub-categories: 1) the prediction of e-waste volumes, 2) the selection of e-waste RL facility location, 3) the selection of 3PRL providers, 4) decisions concerning e-waste RL vehicle routing and container type; 5) problems related to planning for disassembly and remanufacture.

5.3.1. Prediction of e-waste volumes

The expected volume of e-waste is the first question to be answered in RL network design. For example, Chung, Lau, and Zhang (2011) estimated that Hong Kong generates no more than 80,443 tons (11.5 kg/capita) of waste per year. Using Robinson's approach, they concluded that only 15–17% of discarded televisions, washing machines, air-conditioners, refrigerators, and computers (TWARC) are disposed of as waste. Machado Santos, Cabral Neto, and Mendonça Silva (2019) proposed a forecasting model for lead generation from lead-acid battery scrap based on time series modelling of data regarding the after-market of batteries, as well as the production of new batteries. Temur and Bolat (2017) tested two models that used regulatory and non-regulatory constraints to predict the rate of e-waste returns using mixed-integer linear programming (MILP) and an Artificial Neural Network (ANN) system. Such comparative methodologies provide insights to support facility selection, contributing to sustainable industrial development and enabling governments to review their regulatory initiatives in terms of expected returns.

5.3.2. Selection of e-waste RL facility location

The selection of the location of facilities is another key decision for RL network design. The locations of centres for collection, sorting and remanufacturing, recycling, and disposal have a significant impact on the efficiency and effectiveness of an RL network. Most studies in this area involved modelling (i.e. the construction of a mathematical model to solve the location problems in a heuristic or near-optimal way).

Most research on facility locations seeks to apply models that minimise the costs or maximise the revenues of such facilities while considering various constraints. Sodhi and Reimer (2001) proposed three models that sought to optimise the operations of a generator, recycler, and smelter, respectively. Ottoni, Dias, and Xavier (2020) conducted an empirical study on e-waste generation, collection, and treatment networks in Rio de Janeiro, Brazil. The authors sought to solve the problem of facility location in challenging areas of collection and recycling, considering waste quantity and distance. Their constraints also took into account the triple bottom line index, including the city's population, GDP, and Human Development Index. Reddy, Kumar, and Ballantyne (2019) developed a MILP model for the design of a reverse logistics network in a multiperiod setting. The model also incorporated the selection of vehicle type and level of carbon emission, as well as providing a three-phase heuristic solution. Dat et al. (2012) determined the optimal facility locations and material flows to maximise profit in an e-waste RL network using a mathematical programming model. Their model considered the costs of collection, treatment, and transportation, as well as sales income, for different proportions of returned products. Ponce-Cueto, Manteca, and Carrasco-Gallego (2011) developed a multiple-criteria decision model to increase or decrease the number of collection points for portable batteries and dynamically optimise battery collection capacity.

5.3.3. Selection of e-waste 3PRL providers

Many EEE producers, in light of increasing regulatory pressure to take responsibility for e-waste RL for their products, often engage 3PRL providers to enable a greater focus on their core business. Selecting the right 3PRL is critical for producers, considering both their regulatory accountability and their need to maintain a positive public image. E-waste is more complex and technically intensive than other forms of municipal waste, and thus its management demands a high degree of specialisation.

Prakash and Barua (2016) defined seven key 3PRL provider selection criteria along with various sub-criteria, drawing on a literature review and panel interviews with RL providers and applying the fuzzy analytical hierarchy process. Their research indicated that capacity is of greater importance than other criteria, whereas geographical location is of lesser importance.

Tosarkani and Amin (2018) ranked five suppliers, six recovery centres, and five remanufacturing plants using three independent frameworks, and identified the top performers in each category based on environmental sustainability. Liu et al. (2019) proposed a novel interval-valued decision-making method for the selection of 3PRLs. The method used Pythagorean, hesitant, fuzzy, best-worst, multicriteria, large group decision-making. The authors applied the method to a real-world test case concerning the selection of a mobile phone 3PRL and concluded that technical factors, as well as the quantity and price of recycled components on EOL and used mobile phones, play an important role in the selection of 3PRLs. This research provided producers with useful decision-making tools to support the selection of 3PRL, which is likely to support their RL practices.

5.3.4. Decisions concerning e-waste RL vehicle routing and container type

Decisions related to vehicle routing and container type are also important parts of network design. Such decisions enable the minimisation of a network's carbon footprint, as well as the reduction of costs.

Mar-Ortiz, González-Velarde, and Adenso-Díaz (2013) developed an integer programming model that used a Greedy Randomised Adaptive Searching Procedure (GRASP) algorithm to solve vehicle routing and scheduling problems. They tested the model using a set of 540 random instances to show the ability of the algorithm to solve problems even under time and collection capacity constraints. Cao, Liao, and Huang (2021) used a hybrid genetic algorithm, together with a large-scale neighbourhood search algorithm, to resolve a vehicle routing model within particular time windows to minimise the total cost. Achillas et al. (2012) presented a multicriteria optimisation model for the selection of multitype e-waste transportation containers. The model sought to minimise the cost, production of emissions, and fuel consumption, taking into account the existing collection point and treatment facility.

5.3.5. Problems related to planning for disassembly and remanufacture

Comparing to other e-waste RL research themes, planning the balance of disassembling and remanufacturing are discussed by only five papers in this review. One output of the product recovery process is that high-quality components disassembled from e-waste are remanufactured into new EEE. Remanufacturers must choose whether to use disassembled components or newly purchased virgin parts. Most research approaches this problem from a material-planning perspective, due to the uncertainty as to the availability and quality of disassembled components.

Farahani, Otieno, and Barah (2019) developed a mixed-integer nonlinear programming (MINLP) model for integrated production planning and inventory control by a third-party remanufacturer to meet secondary market requests. The study found that the quality grading mechanism of the recovered components was a critical factor in profit maximisation.

Balancing e-waste disassembly lines to utilise human and technical resources efficiently is crucial to reducing idle time and minimising costs (Lu et al. 2020). Kannan et al. (2017) proposed a MILP model to integrate disassembly line balancing into the planning of a 3PRL provider's network. The study found that reducing employee idle time and promoting the use of recovered components are key to increasing profit for disassemblers. Sathish et al. (2017) developed a procedure to minimise the cost of disassembly by optimising the scheduling of disassembly machines to reduce e-waste aggregation time. Budak (2020) applied a multi-period multi-objective MINLP model to optimise the (i) quantity of e-waste across facilities and inventories, (ii) number of workstations in disassembly centres, (iii) number of facilities to open, and (iv) task assignments to workstations in disassembly centres.

5.4. E-waste RL system evaluations and frameworks

Evaluating the performance of existing e-waste RL networks and ensuring continuous improvement are topics of great interest to RL operators. Thus, many studies have considered or proposed frameworks and metrics to measure the effectiveness and efficiency of the e-waste RL system.

Nikolaou, Evangelinos, and Allan (2013) proposed a methodological indicator matrix to evaluate the social responsibility of RL, which is of interest to producers. Azevedo et al. (2017) proposed a model to evaluate the sustainability of RL for the recycling of e-waste in the Minas Gerais region, in terms of both mandatory legislative requirements and costs and profitability. The model estimated the operational and transportation costs, as well as the value that RL created in the region. The numerical simulation indicated that the operation was profitable and sustainable.

Tong, Tao, and Lifset (2018) developed a qualitative evaluation framework for a new model of e-waste recycling that incorporated five elements: convenience for consumers, traceability for producers, profitability for recyclers, ability to collect multiple product types, and reliability of the information used by the public. Sellitto, Bittencourt, and Reckziegel (2015) proposed a framework to assess the effectiveness of green supply chain management. Drawing on both theory and empirical evidence, Janse, Schuur, and De Brito (2010) developed a diagnostic tool for determining the RL maturity of a consumer electronics company. The tool assessed RL practice as either immature, naïve mature, semi-mature, and mature across five dimensions. In a study in Indonesia (Maheswari et al. 2020), the authors developed a scorecard to measure the RL sustainability of informal e-waste entities, incorporating 22 parameters across six categories: financial sustainability, value to stakeholders, internal business processes, innovation and growth, environmental sustainability, and social sustainability.

Some empirical studies have also evaluated the degree of cost savings and emissions reduction generated by RL recycling practices of e-waste. For example, a Brazilian study compared an existing e-waste RL system with the virgin production of plastic materials such as acrylonitrile–butadiene-styrene (ABS) and high impact polystyrene (HIPS). The authors found that the e-waste RL system consumed 90% less energy compared to the virgin production of ABS and HIPS. It also emitted 84% less carbon dioxide than virgin HIPS, and 87% less than virgin ABS (Mendes Campolina et al. 2017).

5.5. Consumer e-waste return behaviour

Consumers' perceptions and behaviour regarding e-waste determine the actual and economic scale of RL collection. Understanding consumers' reasons for not returning e-waste, as well as identifying strategies to improve their return rate has always been an important focus of e-waste RL implementation and practice.

Alves et al. (2019) conducted action research to implement an e-waste management programme in São João del Rei, Brazil. Although 85.7% of the participants claimed that they knew what e-waste was, only 4.7% accurately identified it. Further, most people (97%) expressed interest in learning how to properly dispose of e-waste. Only 5.2% of the respondents reported that they properly dispose of their e-waste, with 47.1% of respondents leaving their e-waste at home.

Yuan et al. (2016) identified the motivations for consumer electronic product exchange (EPE) through a survey of 250 respondents in China. They found that the most common motivations were pro-environmental values, awareness of consequences failing to exchange products, a feeling of individual responsibility, and personal norms. The authors also noted that the attitude-behaviour gap is moderated by consumer knowledge and neutralisation. Thus, when consumers possess insufficient knowledge or use neutralisation techniques to avoid dissonance, they may not act pro-environmentally.

Pessanha and Morales (2020) defined seven criteria that influence return behaviour for different types of EEE and ranked their priority using AHP. For cell phones, the location of the collection point, the potential for the contamination of the e-waste, and the destination of the e-waste (e.g. whether it will be donated to institutions) are priority criteria. For computers, only collection point location and potential contamination are priorities, while the location of the collection point is also a priority criterion for tablets.

The relationship between incentives and consumer returns is another commonly researched topic. Offering appropriate incentives leads to an increase in the quantity and quality of e-waste returns. In Iran, Jafari, Heydari, and Keramati (2017) surveyed 148 subjects and found that when there was no incentive, only about 58% of the participants showed a willingness to return e-waste. As the incentive increased, more participants became eager to participate in the recycling programme, and when the incentive reached 180,000 Iranian Rial, about 95% of the residents were persuaded to participate.

Agarwal, Barari, and Tiwari (2012) used particle swarm optimisation to propose an optimal consumer incentive policy and e-waste quality and reliability model to maximise RL operators' profit. The authors argued that if producers offer an effective incentive scheme for the disposal and recycling of EEE, they can achieve significant profits. This study disproves the myth that waste management is a financial burden to producers.

5.6. Technology-based e-waste RL initiatives

Advances in information communication technology have enabled innovative RL practices that enhance workers' ability to complete complex, repetitive and tedious work over long periods. For example, radio frequency identification (RFID) tags, the Internet of Things(IoT), online platforms, and collaborative robots have all been found to improve efficiency and productivity in real-life RL practices. Although these technologies are still being tested and developed, their availability enables practitioners to adopt new ways of managing e-waste RL.

Conti and Orcioni (2019) described a system and database structure for the tracing of e-waste using RFID tags. Their system provides a more efficient and cost-effective way of managing the reuse, repair, and recycling phases of products and components compared to the traditional approach.

In an experiment conducted in Korea, IoT sensors were installed in e-waste collection boxes, and the data was used to develop an algorithm to improve collection efficiency and optimise the collection time (Sung, Kim, and Kim 2020).

Wang et al. (2020) developed a recycling system framework for EOL e-bicycle batteries based on 'Internet Plus'. The platform integrated offline RL and online registration to manage e-waste collection in an effective and trackable measure. Consumers can register waste batteries' information in the online platform and trigger offline collection. Once registered, the afterward disassembling, recycling and disposition can be traced in the online platform providing a whole life cycle management in the RL chain.

Alvarez-de-los-Mozos and Renteria (2017) applied new developments in collaborative robotics to optimise the profitability of the recycling process. They developed a collaborative robot application to dismantle components collected by a cell phone recycler. The worker showed the robot where to cut a cable or fix, unscrew or manipulate a component, and where to discard it by gestures. The robot conducted tedious and often dangerous tasks follow the worker's instructions. The application was validated and proved to be both efficient and useful.

6. Gap analysis and future research agenda

Although many studies have investigated e-waste RL across the six themes identified in this review, many research gaps and opportunities for future work remain. In this section, we review each theme, discuss the existing studies and research gaps, and propose a forward research agenda.

6.1. E-waste legislation and policy

Many countries, including the EU, Brazil, and Japan, have adopted the principle of expanded producer responsibility, while others, such as China, have favoured shared responsibility (Baldé et al. 2017).

Zeng et al. (2013) compared e-waste legislation and policy in the EU and China and found a huge variance in both scope and management responsibility. Sthiannopkao and Wong (2013) also identified fundamental differences in e-waste collection between developing and developed countries. In developed countries, e-waste is collected to both recover valuable materials and safely dispose of toxic materials. In developing countries, on the other hand, e-waste is collected principally to recover valuable metals.

Despite this existing research, there is a lack of in-depth comparative analysis of countries' approaches to e-waste RL. For example, Japan has been found to have the world's highest-performing e-waste RL system, in terms of scope and compliance (Sthiannopkao and Wong 2013). Ongondo, Williams, and Cherrett (2011) investigated three major elements of Japan's system: its limited number of target appliances, the fact that consumers pay a recycling fee, and the requirement that manufacturers recycle (in particular, that they have a physical, rather than financial, responsibility). Japanese consumers pay a recycling fee of ¥1,800–1,900 yen (about US$20–50), depending on the type of item (Sthiannopkao and Wong 2013). In many other developing countries, such as Brazil, China, and India, consumers are paid for giving e-waste to collectors. For example, Chinese consumers receive RMB20–80 yuan (about US$4–15) for giving an LCD TV to street peddlers. This difference in approach—pay for disposal or get paid for disposal—indicates deep-rooted differences in the legislation and policy environments of Japan and China. Future research could compare the legislation and policy settings of the country with the highest performing e-waste system, Japan, and the largest developing country, China, as proposed below.

> Future research topic 1: Pay for disposal or get paid for disposal? A comparative study of e-waste RL legislation and policy in Japan and China.

National legislation and policy should establish a workable and fair financial model for e-waste RL (Baldé et al. 2017). Such a financial model should apply to collection sites and logistics, as well as physical recycling. Many governments subsidise the operations of e-waste RL operators, as well as providing tax exemptions to incentivise compliance with regulations. Liu et al. (2016) recommended that subsidies provided to formal recyclers should not negatively impact the informal sector.

However, there is a research gap concerning the appropriate level of subsidy. Under the existing Chinese regulations, the subsidy granted to disassemblers and disposers is much higher than the funding collected from producers. For example, the Chinese government pays RMB85 to disassemblers for each TV disposal, while collecting only RMB15 from each producer (MOF 2012). This high level of subsidy threatens the financial sustainability of the national fund.

To address this research gap, researchers could test the effects of different levels of subsidy to determine the appropriate subsidy, taking the level of subsidy as an independent variable and the waste TV disposal rate as the dependent variable. Further studies could also investigate the appropriate levels of subsidy and investment in disposal capacity in particular e-waste categories.

> Future research topic 2: What is the appropriate level of subsidy as an incentive for waste TV disposal? What effect does this have on RL operators?

6.2. Barriers, critical success factors, and solutions

Many studies have considered the barriers to and critical success factors for the successful deployment of e-waste RL from the perspective of industrial producers (Agrawal, Singh, and Murtaza 2018; Bakhiyi et al. 2018; Bouzon et al. 2016; Quariguasi Frota Neto and Van Wassenhove 2013; Sirisawat and Kiatcharoenpol 2018; Vieira et al. 2020).

However, these studies have largely been high-level overviews; they have not investigated individual e-waste categories in great depth. Different types of e-waste face different barriers and rely on different success factors. The geographic context of e-waste RL deployment also has a significant impact. For example, Sirisawat and Kiatcharoenpol (2018) concluded technological barriers are the most important barriers to the implementation of RL in the Thai electronics industry, while

Bouzon et al. (2016) concluded that economic issues are the most significant barrier in Brazil. Thus, studies that are high-level and not context-specific can have limited utility for RL practitioners in practice.

Additionally, few empirical studies have considered e-waste RL from the perspective of different roles within the system, such as collectors, disassemblers and refurbishers, recyclers, and disposers. Studies that have considered e-waste RL from the perspective of particular roles tend to provide greater insight than more general studies. Geyer and Blass (2010) investigated the reuse and recycling of mobile phones in the UK and US from the perspective of refurbishers and found that such operators can be profitable as long as their collection for reuse rate was over 50%. This indicates that the most critical success factor in mobile phone RL is the quality of collections. Similarly, Wilson et al. (2017) reported that consumers' disposable phone hibernation, which erodes the quality of mobile phone collected, is a barrier to efficient waste recovery.

As mentioned above, the barriers and corresponding solutions concerning e-waste RL vary widely depending on product type. In China, Chen et al. (2017) reported that there are technical barriers to the disposal of lithium batteries as compared to traditional e-bike batteries. Quariguasi Frota Neto and Van Wassenhove (2013) identified low residual value and return volume as major barriers to the return of EOL computers in Brazil. RL barriers and solutions for EOL mobile phones and personal computers have been widely studied (Alves and Farina 2018; Curvelo Santana et al. 2020; Geyer and Blass 2010; Ghisolfi et al. 2017; Quariguasi Frota Neto and Van Wassenhove 2013; Wilson et al. 2017), while there has been limited research on large household appliances such as TVs, washing machines, and refrigerators. Thus, there is an opportunity for future research in this area.

Future research topic 3: Barriers and solutions concerning e-waste RL for large household appliances, a collector/disassembler/recycler/disposer perspective.

6.3. E-waste RL network design decisions

Decisions concerning e-waste RL network design are known for their complexity (Reddy, Kumar, and Ballantyne 2019). Typical challenges include the prediction of e-waste collection volumes, the location selection of collection or disassembly facilities, the selection of 3RLP, transportation routing and toolings, and remanufacturing materials planning. Such problems have been widely modelled and researched, given that studies on e-waste RL network design decisions represent the largest proportion of studies across all six themes.

6.3.1. Prediction of e-waste volumes

Companies rely on accurate e-waste volume forecasting to build appropriate RL infrastructure. Such forecasting is becoming even more crucial as the collection, recycling, and disposal of e-waste become more complex and unpredictable (Duman, Kongar, and Gupta 2020). Many e-waste volume prediction models use independent variables such as population density, median household size, median household income, or historical sales numbers as their inputs (Chung, Lau, and Zhang 2011; Duman, Kongar, and Gupta 2019, 2020; Hanafi, Kara, and Kaebernick 2008). Various techniques have been adopted, including the Robinson's approach (Chung, Lau, and Zhang 2011), Fuzzy Coloured Petri Net (Hanafi, Kara, and Kaebernick 2008), the Graphical Evaluation and Review Technique (Agrawal, Singh, and Murtaza 2014), multivariate grey models (Duman, Kongar, and Gupta 2019), and regression and time series modelling (Machado Santos, Cabral Neto, and Mendonça Silva 2019). The latter model integrates surveys or historical data collected by governments to forecast the volume of e-waste that will be generated in a territory or country.

Multiproduct, multiperiod estimation models do enable e-waste forecasting covering a wider type of e-waste and across different periods. However, these models do not consider critical variables such as institutional e-waste generation and imports and exports of e-waste. Ottoni, Dias, and Xavier (2020) used EEE sales figures and lifespan to forecasting e-waste volumes in Brazil. However, such an approach leads to overestimation, because a high portion of e-waste sold in Brazil is exported to other countries. Disregarding such major variables prevents accurate forecasting.

Decision-makers also require predictions of the volume of e-waste collection, rather than generation, to plan their investment of resources in e-waste RL systems. Many studies have considered the e-waste collection rate only at a high level, and some did not adequately explain their methodology. For example, Hanafi, Kara, and Kaebernick (2008) did not elaborate on their calculation of the projected collection amount, while Chung, Lau, and Zhang (2011) used a street survey sample to determine the e-waste collection and disposition rate but did not describe their calculation in detail. Future research should provide robust detail on the calculations and modelling underlying the predicted collection rate.

> Future research topic 4: A comprehensive estimation model for e-waste collection volumes, considering household, institution, and import/export volumes

6.3.2. Selection of e-waste RL facility location

RL networks consist of collection centres that cover particular customer zones, disassembly and recycling plants, and disposal facilities (Reddy, Kumar, and Ballantyne 2019). Thus, the planning of the location, capacity, and transportation routes of such facilities to achieve economic, environmental, and social objectives has been a major research focus.

Most papers considered in this review proposed novel models that considered various constraints and applied algorithms to solve them, providing a meta-angular view of the solutions. The most popular models adopted used MILP models with the objective of minimisation of the overall operational cost of the facilities(Ayvaz, Bolat, and Aydin 2015; Dat et al. 2012; Djikanovic and Vujosević 2016; Kilic, Cebeci, and Ayhan 2015; Shi et al. 2020; Sodhi and Reimer 2001). Some researchers also considered environmental objectives, such as the minimisation of carbon emissions arising from transportation between the facilities, together with the maximisation of profits (Moslehi, Sahebi, and Teymouri 2020; Reddy, Kumar, and Ballantyne 2019; Tosarkani, Amin, and Zolfagharinia 2020; Yu and Solvang 2016).

Given that few models have considered social or regulatory constraints, future research could consider social objectives, including the maximisation of job opportunities in collection, disassembly, and disposal centres, as a constraint. Furthermore, regulatory requirements, such as a minimum quantity or percentage of certain e-waste category for collection and disposal stipulated by the administration, could also be considered. Broadly, future research on facility location models should consider all relevant economic, environmental, and social objectives, as suggested in the research topic below.

> Future research topic 5: A multi-objective e-waste RL facility location decision-making model, taking into account the triple bottom line.

RL network design modelling relies on many assumptions that do not necessarily apply in practice. For example, Yu and Solvang (2016) constructed their objective function by assuming that 1) the number and locations of local collection centres, product markets, material markets, and disposal facilities were known, 2) the potential locations of regional collection centres and recycling plants were known, 3) the fixed costs, unit transportation costs, and unit processing costs were known, and 4) the capacities of new facilities were predetermined. Assavapokee and Wongthatsanekorn (2012) used a MILP model to analyse locations problems in Texas and assumed that all mathematical parameters were given.

Furthermore, the large number of variables and constraints in the existing models limit their real-world application. Tosarkani, Amin, and Zolfagharinia (2020) proposed a scenario-based optimisation model to resolve an RL network design problem in Toronto, Canada based on economic and environmental objectives. However, the model was highly complex; it included 5,321 constraints, 32,108 decision variables, 47 binary variables, and 264,521 non-zero coefficients. Similarly, a multi-objective linear programming model that was developed for application in Central Macedonia, Greece, consisted of 223 continuous variables, 222 integers, 111 binary variables, and 499 constraints (Achillas et al. 2012). It is difficult to accurately define such a large number of variables and apply such complex mathematical models in a real scenario. Additionally, many existing models are static, meaning they do not consider the attributes of existing facilities when creating new nodes in the network.

To overcome the unrealistic assumptions and limitations of static models noted above, future research should incorporate modularised, scenario-based and dynamic modelling. Rather than establishing a new RL network from scratch, modularised scenario optimisation models integrate data on current facilities to support either gradual expansion or elimination. For example, RL operators must choose between establishing a new facility or expanding the capacity of existing facilities, given both service and cost advantages. Researchers could modularise optimisation models to solve this problem. Standardising the input parameters, constraints, and function objectives would enable scenario-based models to be resolved with expected outputs. This would allow RL network optimisation models to be more easily deployed in practice, as well as standardising the models' data requirements.

Future research topic 6: Expanding the RL network by increasing capacity or establishing a new facility, based on both service and economic advantages: a dynamic multiperiod model.

6.3.3. Selection of e-waste 3PRL providers

Under the extended producer responsibility approach that has been adopted in, for example, the EU, manufacturers of EEE are financially responsible for the disposal of e-waste. In reality, many manufacturers outsource the physical disposal to 3PRL providers to maintain their reputation; they often cooperate closely with such providers through long-term contracts. Thus, manufacturers are cautious about selecting an appropriate 3PRL provider.

The selection of a 3PRL provider is a multicriteria decision-making problem (Prakash and Barua 2016). Liu et al. (2019) proposed a novel, interval-valued, Pythagorean, hesitant fuzzy, best-worst, multicriteria, large group decision-making method for the selection of 3PRLs. Another study proposed the innovative application of fuzzy AHP and fuzzy TOPSIS to the selection of 3PRL providers in the Indian EEE industry (Prakash and Barua 2016).

These studies have contributed to improving the 3PRL process and reducing the dependence on subjective judgments. However, the selection of a 3PRL provider cannot be made in isolation from considerations of overall RL network effectiveness and efficiency. Given that they play multiple roles in e-waste RL networks, including collector, disassembler, recycler, and disposer, the 3PRL providers should be selected in a way that integrates overall network modelling with evaluation on economic, environmental, and social objectives. By combining the 3PRL network with data on producers' sales and disposal volume, researchers can develop an integrated model for 3PRL selection based on the lowest operational cost for the overall network.

Future research topic 7: 3PRL provider selection: an integrated RL network design and evaluation approach, considering both producers and providers.

6.3.4. Decisions concerning e-waste RL vehicle routing and container type

Vehicle routing planning (VRP) is one of the most studied problems in the combinatorial optimisation field, as well as in the logistics literature (Mar-Ortiz, González-Velarde, and Adenso-Díaz 2013). Safdar et al. (2020) concluded that transportation costs from initial collection centres to final distribution centres account for 79% of the total cost of the reverse logistics process.

Vehicle routing for e-waste RL is not different from the VRP for forward logistics; it requires a trade-off between transportation cost and response time Cao, Liao, and Huang (2021). Mar-Ortiz, González-Velarde, and Adenso-Díaz (2013) applied MILP modelling to minimise transportation costs and respond to collection requests within a certain time window. Achillas et al. (2012) introduced another parameter, container size selection, to this MILP model to evaluate overall costs and meet carbon emission objectives.

RL VRP and container selection should be considered as part of overall RL network design. The VRP is not only about minimising transportation costs and sustaining service levels but also maintaining the consistent operation of downstream nodes, particularly disassemblers and recyclers. Thus, future studies on vehicle routing and container selection models ought to consider non-economic constraints, including the stable upstream supply of e-waste and the maintenance of rapid collection from consumers, in their modelling.

Future research topic 8: A optimised decision model for e-waste RL vehicle routing, taking into account a quick response to customers and stable upstream supply.

6.3.5. Problems related to planning for disassembly and remanufacture

The majority of modern disassembly facilities consist of a few stations where e-waste is manually disassembled to retrieve the highest-value components or most easily recyclable bulk parts (Altekin, Kandiller, and Ozdemirel 2008). Due to the complexity of different types of e-waste, disassembly is a technical process that requires specific product knowledge. Accordingly, the processing time and capacity vary between different workstations, leading to long idle periods for both machines and employees.

There are also challenges in the utilisation of the disassembled components in remanufacturing centres, including quantity and quality instability (Farahani, Otieno, and Barah 2019). Kannan et al. (2017) and Budak (2020) both constructed MILP models that embedded disassembling line balance (DLB) in their e-waste RL network planning to minimise overall costs. Farahani, Otieno, and Barah (2019) and Lu et al. (2020) proposed sourcing raw materials from recycling centres or external suppliers and embedded such an approach into their RL network design models. Both models were experimentally validated.

Unlike other RL network design problems, disassembly and remanufacturing balance decisions are more relevant to the internal operations of disassemblers and manufacturers, rather than the network as a whole. It may not be wise to integrate such decisions into models for overall RL network design, as this would complicate the modelling and weaken the depth of research on these problems. Again, case-based empirical studies are recommended, as these are problems commonly faced by dissemblers or manufacturers in practice.

Future research topic 9: Optimising disassembling line balance/recycled material remanufacture planning: A case study from a disassembler/manufacturer.

6.4. E-waste RL system evaluations and frameworks

E-waste RL is usually evaluated from the perspective of producers, with a conceptual framework or matrix being applied to measure effectiveness based on economic, social, and environmental criteria. Nikolaou, Evangelinos, and Allan (2013) developed a framework of social responsibility indicators for producers, whereas Ravi (2012) built a quality assessment framework regarding the RL of end-of-life computer components. Tong, Tao, and Lifset (2018) proposed a qualitative framework to evaluate the recycling business model, while Janse, Schuur, and De Brito (2010) developed a tool to assess producers' RL maturity. These general frameworks provide meaningful insights to producers and RL operators concerning their current position, future goals, and required next steps.

Another stream of evaluation research is empirical studies that report specific achievements (e.g. economic gains, carbon emission reductions, or chemical waste elimination) using real-world case studies. For example, a Brazilian study on the adoption of e-waste RL for alkaline batteries reported the collection of 4,304,465 batteries, resulting in a 176,422 kg reduction in solid and chemical waste. The study provided quantitative criteria to evaluate the effectiveness of the alkaline battery RL (Neto et al. 2018). Similarly, Mendes Campolina et al. (2017) reported an energy saving of about 90% as a result of recycling HIPS and ABS, as well as the emission of 84% less CO2 by recycling HIPS and 87% by recycling ABS. These studies provide clear data demonstrating the economic and sustainability benefits of implementing e-waste RL management.

Due to the diversity of e-waste RL practices around the world, the existing evaluation systems and frameworks have various areas of focus and take various forms. The construction of high-level evaluation frameworks may not directly support the implementation of e-waste RL. However, the collection of empirical data on the advantages of e-waste RL may help to convince stakeholders to adopt such an approach.

The evaluation models developed in previous studies did not consider regional regulatory requirements and, thus, were not comprehensive. Future research should both collect empirical data and consider regional regulations, especially for those developed regions with clear e-waste RL legislation and policy.

Future research topic 10: What's next? An evaluation of the effectiveness of e-waste management in developed countries from a regulatory perspective.

6.5. Consumer e-waste return behaviour

Many studies have analysed consumers' e-waste return intentions and behaviour in different regions. Research from the USA, China, Brazil, and India has identified various determinants of e-waste return behaviour, including consumers' attitudes, awareness of consequences, and personal norms, as well as the convenience of collection and economic considerations (Alves et al. 2019; Dixit and Badgaiyan 2016; Gonul Kochan et al. 2016; Pessanha and Morales 2020; Yuan et al. 2016).

Most studies in this area are static, and apply a survey-based, quantitative analysis to data from a certain period. More insightful conclusions can be obtained using a dynamic approach that considers the interrelationship between factors such as incentives and e-waste returns volume. For example, one study suggested that a return rate of up to 98% could be achieved in Iran if a certain level of incentive were provided (Jafari, Heydari, and Keramati 2017). Agarwal, Barari, and Tiwari (2012) proposed a tool to determine the proper incentive level, taking into account product reliability and quality, to maximise producers' profits.

Consumer return behaviour is constantly changing. Thus, longitudinal research into the changes in return behaviour over time, ie. a five years' study in a developing region, is recommended, in order to understand the critical determinants of consumer intention and behaviour. Such research would enable RL operators and policymakers to strengthen their e-waste RL performance and maximise the effectiveness of regulation. This would support the ultimate goal of e-waste RL: to protect the environment and people's health.

Future research topic 11: What changed consumer e-waste returns? A longitudinal comparison study from developing countries.

Additionally, all prior research in this area has focused on individual e-waste returns, with few studies examing return intention, behaviour, and performance at an institutional level (e.g. companies or not-for-profit organisations). This could be a direction to explore in future research.

Future research topic 12: Toward an improved understanding of e-waste returns: analysis and evidence from institutional e-product users.

6.6. Technology-based e-waste RL initiatives

Initiatives incorporating collaborative robots, RFID tracking systems, online-offline integrated platforms, and IoT have broadened the range of tools available to manage e-waste RL (Alvarez-de-los-Mozos and Renteria 2017; Conti and Orcioni 2019; Sung, Kim, and Kim 2020; Wang et al. 2020).

In one study, the use of collaborative robots enabled close cooperation between humans and robots in a disassembling centre, leaving the complex task of material and component identification to a human while allowing more physically demanding and dangerous tasks to be carried out by a robot (Alvarez-de-los-Mozos and Renteria 2017). However, this approach is process-specific and highly customised, limiting its application.

The e-waste tracing project, which was funded by the European Commission, uses RFID tags during e-waste collection to ensure full traceability. The use of tracing led to a 25% increase in the amount of e-waste legally collected compared to 2009, as well as a 29% reduction in CO2 emissions and a 20–30% reduction in the administrative costs of treatment (Conti and Orcioni 2019). However, given the costs of attaching RFID tags to e-waste, the tracing project is a voluntarily based activity, it would be difficult to scale up this initiative without regulatory intervention.

In another study, an IoT sensor embedded in a collection box provided additional transparency regarding the volume of e-waste. However, again, the additional costs of such an approach may outweigh the benefits of reduced transportation fees (Sung, Kim, and Kim 2020). Wang et al. (2020) developed an implementable approach, which used the Internet Plus platform to register and trace e-bicycle batteries in RL providing unprecedented visualisation of the e-waste RL process.

As discussed above, previous studies have considered technological e-waste initiatives in a diverse range of applications. However, this research has found little quantifiable evidence of the benefits (e.g. improved accuracy, processing efficiency, and cost-saving) of such initiatives in comparison with traditional methods. Demonstrating the value of such methods in either economic gains or improved traceability is critical to convincing e-waste RL operators to adopt the technology. Thus, future research should seek to gather more empirical evidence in this area, including comparing the outcomes before and after the adoption of technology.

> Future research topic 13: Improved e-waste RL management through technological innovation: A case study from the European Union/China/Brazil/India.

This section has described the contributions and limitations of prior research across each theme group are reported. Gaps in the research, as well as 13 future research topics, have also been identified. Table 4 illustrates the future research agenda proposed by this review.

7. Conclusion

In this systematic review of the literature on e-waste RL, 162 papers in English from 1998 to 2021 were reviewed using descriptive and thematic analysis. Six main research themes were identified: 1) legislation and policy, 2) barriers, critical success factors, and solutions, 3) problems related to RL network design decisions, 4) technology-based e-waste RL initiatives, 5) consumer e-waste return behaviour, and 6) RL system evaluations and frameworks. By synthesising the six research themes, a conceptual research framework is constructed. The review then identified the specific limitations and gaps of each theme, as well as proposing a future research agenda with 13 specific research topics. This wide-ranging and specific future research agenda represents a significant opportunity for researchers to contribute to the area of e-waste RL management.

Limitations of this paper lie in that, firstly, we choose paper in English only, while e-waste RL is a highly geographical oriented field varied in economic, social, and regulatory conditions in different countries, we might lose some of the insights of e-waste RL research in those non-English speaking countries. Besides, we searched limited keywords in e-waste RL forming a limited paper pool, which may neglect other products RL relevant papers that might also generally apply to e-waste RL research. Meanwhile, given the complexity of e-waste RL management, expanding a broader

Table 4. E-waste RL gaps and future research topics.

No	Theme group	Gap identified	Future research topic
1	E-waste legislation and policy	Comparative legislative analysis of benchmark countries	Future research topic 1: Pay for disposal or get paid for disposal? A comparative study of e-waste RL legislation and policy in Japan and China.
		Appropriate levels of subsidy for e-waste RL	Future research topic 2: What is the appropriate level of subsidy as an incentive for waste TV disposal? What effect does this have on RL operators?
2	Barriers, critical success factors, and solutions	In-depth empirical study of barriers and solutions for specific products, such as large appliances, and different RL roles	Future research topic 3: Barriers and solutions concerning e-waste RL for large household appliances, a collector/disassembler/recycler/disposer perspective.
3	E-waste RL network design decisions	Lack of consideration of institutional factors and import/export data in e-waste volume forecasting	Future research topic 4: A comprehensive estimation model for e-waste collection volumes, considering household, institution, and import/export volumes
		Comprehensive RL network models considering all economic, environmental, and social aspects	Future research topic 5: A multi-objective e-waste RL facility location decision-making model, taking into account the triple bottom line.
		Dynamic, modularised, scenario-based optimisation modelling for RL networks	Future research topic 6: Expanding the RL network by increasing capacity or establishing a new facility, based on both service and economic advantages: a dynamic multiperiod model.
		Integrated modelling to inform 3PRL selection decisions, including producers and 3PRL suppliers	Future research topic 7: 3PRL provider selection: an integrated RL network design and evaluation approach, considering both producers and providers.
		Integrated Vehicle Route Planning and container RL network design considering upstream supply and downstream response time	Future research topic 8: A optimised decision model for e-waste RL vehicle routing, taking into account a quick response to customers and stable upstream supply.
		Empirical research on disassembling line balance and recycling materials planning from disassembler and remanufacturer perspectives	Future research topic 9: Optimising disassembling line balance/recycled material remanufacture planning: A case study from a disassembler/manufacturer.
4	E-waste RL system evaluation and framework	Empirical research on evaluation of e-waste management from regulatory perspective	Future research topic 10: What's next? An evaluation of the effectiveness of e-waste management in developed countries from a regulatory perspective.
5	Consumer e-waste return behaviour	Longitudinal research on changes in consumer return behaviour	Future research topic 11: What changed in consumer E-waste returns? A longitudinal comparison study from developing countries.
		Institutional consumer return behavior	Future research topic 12: Toward an improved understanding of e-waste returns: analysis and evidence from institutional e-product users.
6	Technology-based e-waste RL initiatives	Comparative analysis of new technologies and existing methods of deployment	Future research topic 13: Improved E-waste RL management through technological innovation: A case study from the European Union/China/Brazil/India.

range of the keywords and beyond RL management such as closed-loop supply chain management (CLSCM) may add further value to the deep and far-reaching e-waste RL literature. Finally, social development is always faster than research publication. Therefore, in addition to the development of 13 research opportunities extracting from existing published papers, more innovative research opportunities can be explored based on instant interaction with practitioners. Investigating current new practices or emerging hot issues of e-waste reverse logistics will be another future research direction. Hence, we call for wider cooperation between researchers and e-waste RL practitioners to advance understanding and research of this important topic in the future.

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