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Circular economy practices in the waste electrical and electronic equipment (WEEE) industry: A systematic review and future research agendas

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ABSTRACT

Circular economy is a sustainable economic development model. It replaces the traditional economic development model that relies heavily on resource consumption and waste generation. Circular economy is particularly important to the waste electrical and electronic equipment industry as e-waste contains toxic substances and precious metals. While previous review studies focused on specific aspects of the WEEE industry (e.g., "4R" circular economy strategies), these studies offer little details on how circular economy practices affect the development of the environment and economy in the waste electrical and electronic equipment industry. This study examines "10R" circular economy strategies to advance knowledge of the existing literature that focuses on "4R" circular economy strategies. To improve the methodology used in the previous review studies that apply subjective methods (e.g., content analysis), this paper conducts a systematic literature review on 208 studies and uses citation network analysis to examine specific circular economy practices in the waste electrical and electronic equipment industry. The citation network analysis identified five major research domains (i.e., "e-waste management systems and practices", "e-waste legislation and its components", "extended producer responsibility schemes", "recycling critical materials from e-waste", "circular economy strategies for the waste electrical and electronic equipment industry"). Based on these results, this study conducts a main path analysis to reveal ten major topics (i.e., e-waste recycling system; exploring untapped e-waste; compliance assurance of stakeholders; e-waste reverse logistics; reward and punishment mechanisms in extended producer responsibility system; verifying the rationality of product classification; recycling critical materials from urban mines; setting a specific target for preparation for reuse; "10R" strategies applied in the smart factory; consumer attitude toward remanufactured/refurbished/repurposed strategies and the resultant products) in the identified research domain. Finally, this paper proposes future research directions and provides managerial and policy implications for researchers and practitioners.

1. Introduction

With technological innovation and the growing penetration of electronics, a number of electronics will be phased out, which will lead to unprecedented volumes of waste electric and electronic equipment (WEEE). WEEE (also known as e-waste) is defined as the waste from electrical and electronic equipment (EEE) for any EEE (e.g., mobile phones, home appliances, and computers) that is discarded as waste (Widmer et al., 2005). This paper focused on the Circular Economy (CE) activities in which the EEE became WEEE. The activities include 1) useful application of materials, such as recycling and recovery of e-waste and its components; 2) extended the lifespan of e-waste and its components through reuse, repair, refurbishing, remanufacturing, and repurposing; 3) smart use of e-waste and manufacture via refuse, rethink, reduce. The world generated 53.6 million metric tons (Mt) of e-waste in 2019 (Forti et al., 2020), which is an increase from the 41.8 Mt reported in 2014 (Baldé et al., 2015). The WEEE industry is dealing with different types of e-waste generated from the electronics industry (Bressanelli et al., 2020), which contain many toxic additives and hazardous substances (e.g., lead, cadmium). These pose a significant threat to the environment and human health (Bressanelli et al., 2020). E-waste also contains precious metals (e.g., platinum, silver) and critical raw material (e.g., palladium, indium), which are valuable for economic and environmental sustainability purposes. However, only 17.4% of e-waste

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was collected and properly recycled in 2019. This suggests that 44.3 Mt of e-waste was not properly treated and disposed into landfills or introduced into illicit trade (WEEE Forum, 2020b).

In light of the discussed challenges and opportunities, CE is considered to be an appropriate solution for e-waste management because the concept aims to close the product life cycle, minimize pollutant emissions, and maintain the highest utility and value of products (Geissdoerfer et al., 2017b). The application of CE strategies (e.g., recycle, recover) in the WEEE industry has greatly promoted the sustainable development of the environment and economy (Lieder and Rashid, 2016). The value of raw materials recovered from e-waste is roughly equivalent to US$57 billion in 2019, whereas the amount of aluminum, iron, and copper recycled has reduced 15 Mt of CO2 emissions (Forti et al., 2020). This situation shows that CE is gaining paramount importance in the WEEE industry (Bressanelli et al., 2020). Studies of the WEEE industry within the CE context has started in 2003 with a focus on reducing e-waste disposal and preventing the production of more e-waste. However, emerging technologies (e.g., 5G technology, virtual reality) are accelerating the rate of electronics obsolescence and generating new e-waste streams. (Shittu et al., 2020). In anticipation that the global generation of e-waste will increase to 74.7 Mt by 2030 (Forti et al., 2020), it is how timely to examine the development of CE in the WEEE industry to mitigate the environmental impacts and obtain financial gain from e-waste.

This paper contributes to the research agenda by addressing the following research gaps. Previously review studies have examined CE practices in the WEEE industry from the perspectives of “WEEE management systems”, “WEEE legislations”, “Extended producer responsibility (EPR)”, and “4R CE strategies” (i.e., reduce, reuse, remanufacture, and recycle), etc. However, these aspects failed to provide insights into how the specific CE practices affect environmental or economic development in the WEEE industry. For example, although Cesaro et al. (2018) discussed specific CE practices (e.g., the recycling process), they failed to provide how the practices impact ecological or economic development in the WEEE industry. Similarly, previous review articles focused on “4R” CE strategies in the WEEE industry. To the best knowledge, “10R” CE strategies are receiving growing attention in the literature as they cover a wide scope of practices that help mitigate the environmental impacts (e.g., reduce, recycle) and boost economic development (e.g., reuse, remanufacture) (Kirchherr et al., 2017). Therefore, the discussion of other “R” is limited in the previous studies. For example, reuse, repair, refurbish, remanufacture, and repurpose are strategies for product lifecycle extension (Kirchherr et al., 2017). However, previous review articles mostly focused on remanufacturing, which cannot provide a general view of the CE practices in the WEEE industry. In sum, these prior studies offered a limited view of the CE concept applied in the WEEE industry and an unclear future research direction for other scholars. Therefore, this study will examine the specific CE practices applied in the WEEE industry and focus on the “10R” strategies (i.e., refuse, rethink, reduce, reuse, repair, refurbish, remanufacture, repurpose, recycle and recover) to provide a more comprehensive view of the development of CE practices in the WEEE industry compared to those in previous studies. The findings will help researchers to gain a better understanding of the research domains and emerging issues in this industry.

Moreover, previous review articles on CE and WEEE are limited in their use of the subjective analysis method (e.g., content analysis) and classified the research domains, and determined the knowledge structure. They have therefore neglected to provide an objective and systematic analysis to identify the main research domains and guide future research directions. This study conducts citation network analysis (CNA) to objectively map the research domains, track the developments, and disseminate the knowledge. This approach facilitates the selection of core sets of studies in the field to assess their linkages, and produce visual maps of their relationships (Zhao and Strotmann, 2015), thus enabling the identification of the emerging research directions. In the end, this paper proposed five research directions based on each research domain.

To address the research gaps, this paper is guided by the following research questions: 1) what are the main research domains in the WEEE industry within the context of CE? 2) what are the major topics addressed in each main research domain? 3) how are the CE “10R” strategies applied in the WEEE industry to tackle e-waste problems? and 4) what are the future research directions for CE practices in the WEEE industry?

2. Methodology

This study followed a three-stage systematic review method proposed by Tranfield et al. (2003), which includes: 1) planning the review; 2) conducting the review; 3) reporting and disseminating the results. This study systematically gathers, synthesizes, and evaluates the findings of previous studies to minimize bias as discussed follows.

2.1. Planning the review

To ensure that the selected articles are relevant, two criteria were: 1) reference is made to the keywords from the previous studies in the research area of CE and WEEE; 2) the synonyms of the two terms “CE” and “WEEE” (see Appendix A) are identified to avoid missing target papers and ensuring integrity and comprehensiveness of the literature search. Based on these criteria, this paper referred to the synonyms in the CE and WEEE literature, the keywords included: 1) circular economy: “sustainability”, “cradle to cradle”, “green economy”, “bio-economy”, “eco-efficiency”, “resource loops”, “closed-loop system”, “regenerative manufacturing”, “recycling”, “reuse”, “remanufacturing”, “refurbishment”, “cleaner production”, “zero waste”, “circular business models”, “extended producer responsibility”, “material recovery”, “repurposing”, “resource conservation”, “product lifetime extension”; 2) WEEE: “waste electrical and electronic equipment”, “EEE”, “electrical and electronic equipment”, and “appliance”, “metal extraction”, “critical materials”, “rare earth elements”.

2.2. Conducting the review

In this study, there are three steps for conducting the review:1) set the search criteria; 2) generate target papers, assess paper’s quality, and filter out the irrelevant articles; 3) perform the analysis.

2.2.1. Search criteria

Journals. To ensure relevance, this study referred to journals in the fields of “Business”, “Operation Research & Management Science”, “Environment Studies”, “Environment Science”, and “Management” with an impact factor (IF) higher than or equal to 3 (IF $\geq$ 3). The rationale for dropping out the published articles in journals with an IF $\leq$ 3 is shown in Appendix B. Finally, 253 journals were shortlisted.

Time Periods. To obtain historical and comprehensive perspectives, this paper set the time window of the literature review from 1970 to 2020. This is because the concept of CE has been gaining momentum since the 1970s (Geissdoerfer et al., 2017a), and WEEE-related initiatives have emerged in 1989, such as the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes (Widmer et al., 2005). Moreover, technological innovations have led to e-waste problems in the present day at the time of the writing of this paper.

2.2.2. Literature search, quality assessment and screening

In this study, the Web of Science is selected as the database (see Appendix C). This paper developed a search string (see Fig. 1) based on the research topic and after processing, created a sample of 246 papers. This paper referred to previous studies and then set the inclusion and exclusion criteria. In the inclusion process, the authors selected articles that: 1) included at least one CE or WEEE keyword in their title or

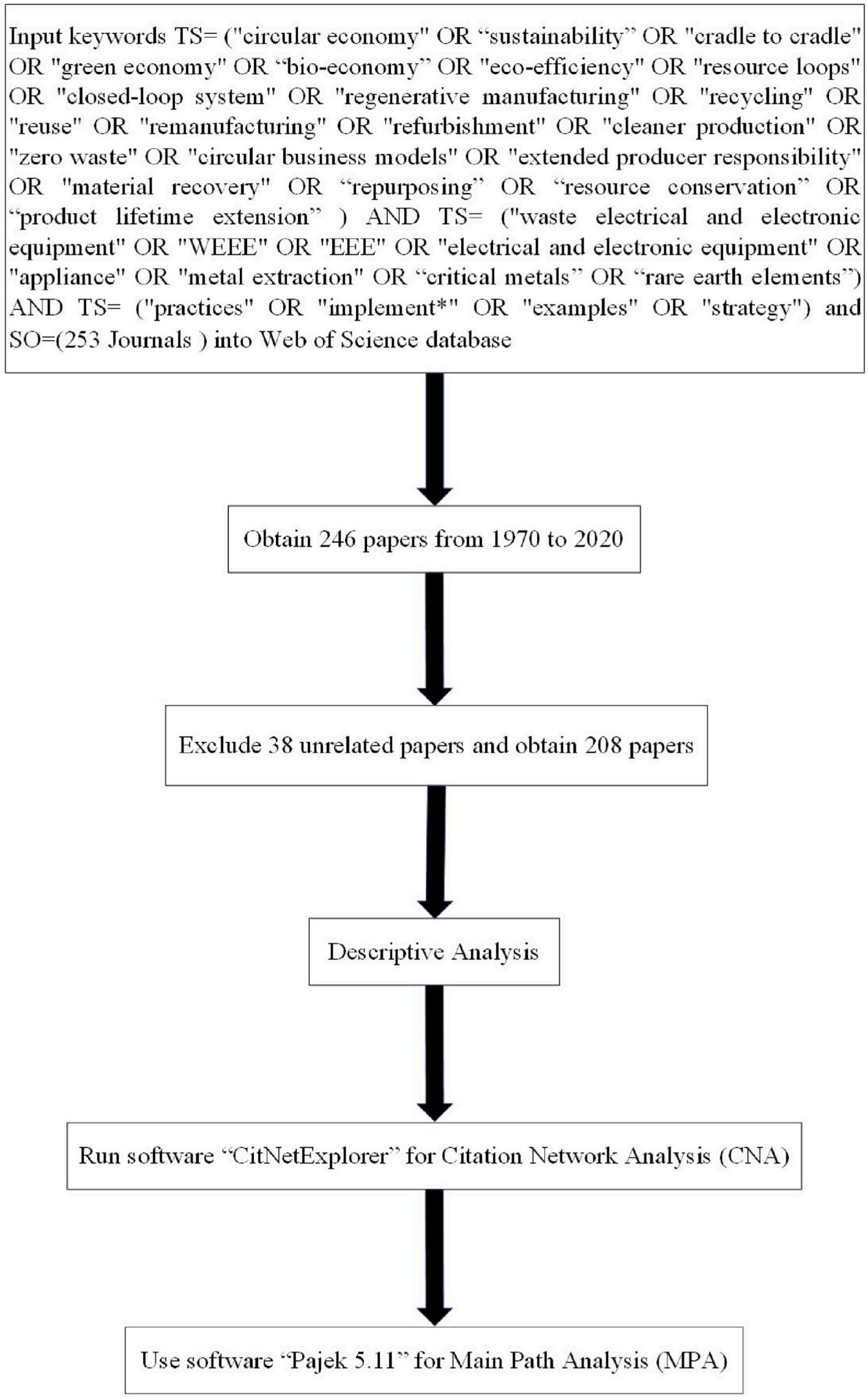

Fig. 1. Flow chart of data collection and data analysis process.

abstract to ensure relevance; 2) contained CE practices in the WEEE industry, such as eco-design; 3) are published in peer-reviewed journals. In the exclusion process, the authors read the title, abstract and full text of 246 articles in the sample to screen out the non-relevant articles that do not discuss the CE practices in the WEEE industry. For example, articles in other industries were excluded. Finally, this study reduced the number of articles to 208 articles for analysis.

2.2.3. Data synthesis and analysis

This paper synthesized 208 articles by conducting a CNA, which resulted in five research domains (see Section 4). Based on the clustering results, the authors reviewed these articles in each research domain to identify common topics and assigned a theme to each cluster. After that, the authors conducted a Main Path Analysis (MPA) to capture the significant paths from the complex citation networks and trace the development trajectories of each research domain (Liu and Lu, 2012).

3. Results

This section presents the results of descriptive analysis, classification of the research domains, and main path analysis.

3.1. Descriptive analysis

As shown in Table 1, most review papers focus on CE and WEEE using subjective analysis methods (e.g., content analysis). Although “R” strategies are emphasized in these articles, a limited body of papers focused on “10R” strategies. Only 50% of the ten review articles explored critical materials and WEEE plastics. In view of these limitations in the existing literature, this study fills these gaps by conducting an extensive and objective review of the CE and WEEE.

Table 2 shows the number of articles distributed by year of publication, research area, journals, and country of origin of the study. For the year of publication, 2005, 2012, and 2015 are the three turning points for the development of the WEEE industry within the context of CE. The researchers started to focus on the WEEE issues in 2005, which may be due to the enactment of the WEEE Directive 2002/96/EC. The number of papers has greatly increased after 2012, for instance, between 2012 and 2013, the increase was from 3 to 12, likely because the recasting of the WEEE Directive recategorized the electronic devices and increased the targeted collection rate of e-waste. In 2015, the adoption of the “European Union (EU) Action Plan for the Circular Economy” and the proposal of “17 Sustainable Development Goals” largely contributed to academic interest in the WEEE industry. The number of publications increased to 34 in 2020, the highest number of publications for all years of interest in this study. The top ten countries of origins of the study are distributed in different regions, including Europe, Asia, North America, and Oceania. Europe and Asia have published the highest number of CE and WEEE articles. The CE and WEEE studies were predominantly done in Europe, probably because the EU countries focused on sustainable development in the WEEE industry in the 2000s (Bressanelli et al., 2020). WEEE management has been highly prioritized in the EU (Ongondo et al., 2011). For example, the EU framed and implemented e-waste related legislations, such as the Restriction of Hazardous Substances in Electrical and Electronic Equipment (RoHS) Directive 2002/95/EC and WEEE Directive 2002/96/EC, to help prevent e-waste generation and improve environmental performance, especially the recasting of the WEEE Directive which set high targets in recycling and collection for the EU member states (Shittu et al., 2020). Following next with the most number of studies is Asia. Due to rapid economic development globally, the volume of WEEE in Asian countries has increased as they are the recipient of the majority of the e-waste worldwide. Among the Asian countries, China has published the most papers probably because it is the largest recipient country of e-waste (Ongondo et al., 2011) and needs to deal with issues related to e-waste. For example, China drafted three e-waste-related legislations between 2002 and 2004 (Ongondo et al., 2011), and enacted the “Circular Economy Promotion Law of the People’s Republic of China” in 2008. However, the discussion of CE and WEEE in other regions is limited. Therefore, more research on CE and WEEE should be conducted beyond Europe and Asia.

In addition to the policies and legislation, WEEE generation is one of the rationales that arouses research interest which is reflected by the number of papers published in different times and regions. The volume of global e-waste has been steadily rising since 2010, increasing 23.6 Mt from 2010 to 2020 (Forti et al., 2020). Similarly, there has been a general upward trend in the number of papers since 2010. The number of papers increased by 29 from 2010 to 2020. Concerning the regions, e-waste generation could explain that Europe and Asia published the highest number of studies. In 2019, Europe and Asia generated 12 Mt and 24.9 Mt (Forti et al., 2020), respectively, an increase of 0.4 Mt and 8.9 Mt from 2014 (Baldé et al., 2015). China is the highest e-waste generating country in Asia, which produced 10.1 Mt of e-waste in 2019 (Forti et al., 2020). The quantity of e-waste increased 4.1 Mt e-waste from 2014 to 2019 (Baldé et al., 2015; Forti et al., 2020). Thus, the number of papers published in Europe and Asia is predominant. The foregoing facts indicated that the WEEE generation might influence the number of articles published at different times and regions. Specifically, WEEE generation leads to environmental pollution that drives policymakers to formulate and promulgate e-waste related policies and legislations, motivating researchers to conduct research and publish papers in the related area.

In terms of the research area, previous studies focused on “Environmental Sciences Ecology,” “Engineering,” or “Science Technology Other Topics.” Among the top ten journals, the studies on CE and WEEE

Table 1
Comparison of related review papers.

Aspect	References										
	Widmer et al. (2005)	He et al. (2006)	Sepulveda et al. (2010)	Ongondo et al. (2011)	Li et al. (2013)	Pérez-Belis et al. (2015)	Cesaro et al. (2018)	Islam and Huda (2018)	Bressanelli et al. (2020)	Shittu et al. (2020)	This study
“10R” CE strategies used in WEEE Industry											✓
Environmental and economic aspects	✓	✓		✓		✓	✓	✓	✓	✓	✓
WEEE generation	✓	✓		✓		✓	✓			✓	✓
WEEE legislation	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
WEEE management practices	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Extended producer responsibility	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Critical materials	✓	✓		✓		✓	✓			✓	✓
WEEE plastics	✓	✓		✓		✓				✓	✓
System Literature Review									✓		✓
Citation Network Analysis											✓
Main Path Analysis											✓
Research domains						✓					✓
Emerging topics of each research domain											✓
Future directions for each research domain											✓

Table 2
Descriptive analysis of the literature on CE practices in the WEEE industry.

Year of Publication	No. of articles	Research Areas	No. of articles
2003	1	Environmental Sciences Ecology	203
2005	6	Engineering	166
2006	2	Science Technology Other Topics	73
2007	6	Business Economics	5
2008	6	Operations Research Management Science	3
2009	4	Chemistry	2
2010	5	Toxicology	1
2011	4		
2012	3		
2013	12		
2014	8		
2015	12		
2016	16		
2017	31		
2018	28		
2019	30		
2020	34		
TOP 10 Journals		**TOP 10 Countries**	
Journal of Cleaner Production	55	China	41
Waste Management	42	USA	26
Resource Conservation and Recycling	41	England	19
Journal of Industrial Ecology	16	Germany	17
Environmental Science and Pollution Research	12	Australia	16
Journal of Environmental Management	6	Italy	16
Science of the Total Environment	5	Brazil	14
Environmental Impact Assessment Review	4	Belgium	10
Environmental Science Technology	3	India	10
Frontiers of Environmental Science Engineering	3	Sweden	10

Source: data synthesized from the Web of Science Database

were mostly published in the "Journal of Cleaner Production", "Waste Management", and "Resource Conservation and Recycling", which concern sustainability and environmental issues. This suggests that more academic research could be conducted on the research areas and journals with fewer published related articles.

3.2. Classification of research domains

This paper clustered 208 articles (see Appendix D) in the sample by using CitNetExplorer software. The clustering was conducted according to the citation relations of the publications (Van Eck and Waltman, 2014). Publications that are assigned to the same cluster are prone to be closely linked with each other in a citation network, and thus a cluster could be considered as representing a research topic in the scientific literature (Van Eck and Waltman, 2014). The clustering technique used in CitNetExplorer adopts a variant of modularity-based clustering that has been widely used in previous studies (Van Eck and Waltman, 2014). To identify better modularity optima, the CitNetExplorer clustered publications by using a smart local moving algorithm to maximize (Van Eck and Waltman, 2014)

$$C(S_1,..S_n)=\sum_{i=1}^{n}\sum_{j=1}^{n}\delta(S_i,S_j)(\beta_{ij}-\frac{r}{2n})$$

where n is the number of publications in the citation network; S_i is the cluster where publication i is assigned; the function $\delta(S_i,S_j)$ equals 1 if $S_i=S_j$ and 0 otherwise; r is the resolution parameter, where a higher r-value means more clusters and, consequently, results in a more detailed classification system (Van Eck and Waltman, 2014). This study refers to the default value 1 as the resolution parameter during the clustering process. β_{ij} presents the relatedness between publications i and j, which given by $\beta_{ij}=\frac{b_{ij}}{\sum_{t=1}^{n}b_{it}}$ equals to 1 when publication i refers to publication j. Otherwise, b_{ij} equals to 0 (Van Eck and Waltman, 2014).

Using the clustering technique in CitNetExplorer, this paper identified five clusters and 29 publications that do not belong to any of the five clusters (see Table 3). The "E-waste management systems and practices" cluster is the largest and most popular research domain with 109 papers (52.4%). This cluster of studies investigated WEEE management from the perspective of WEEE recycling systems (Ismail and Hanafiah, 2019), WEEE reverse logistics (Islam and Huda, 2018), policies for stakeholder engagement (Wiesmeth, 2020), environmental impacts (Sepulveda et al., 2010), ecological and economic values of e-waste recycling (Alghazo et al., 2019), and closed-loop supply chain (Islam and Huda, 2018). "E-waste legislations and its components" is the next largest cluster with 25 papers (12%), which discuss research practices on WEEE components with the development of WEEE-related legislations. For example, the study on material flow analysis is carried out on the polybrominated diphenyl ethers of plastics (PBDEs) with the implementation of the RoHS Directive (Babayemi et al., 2015). The third cluster focuses on "EPR schemes" with 16 articles (7.7%) that examine four areas: economic (Mayers et al., 2013), environmental (Jaunich et al., 2020), political (Alev et al., 2020), and operational (Alev et al., 2019) aspects. The fourth cluster includes 16 articles (7.7%) that mainly focus on "Recycling critical materials from e-waste," such as copper, gold, and cobalt. The investigation of critical materials recycling is from the perspective of benefits (Nelen et al., 2014), potentials and barriers (Ueberschaar et al., 2017), and strategic evaluation (Zuo et al., 2019a, 2019b). The fifth cluster is "CE strategies for the WEEE industry", which has the fewest number of publications with only 13 articles (6.25%). The principles of reuse (Kuah and Wang, 2020), remanufacture (Rau et al., 2019), repurpose (Coughlan et al., 2018) are mainly investigated by researchers in this cluster. These results indicate that "E-waste management systems and practices" are studied by many scholars. Therefore, future researchers should turn their research attention to the other four research domains.

3.3. Main path analysis

This paper use Pajek 5.11 for the following reasons: First, Pajek is a visualization tool that has been widely used by researchers in such areas as biomedical/genomics research, chemistry, and social network analysis (Batagelj and Mrvar, 2004). Pajek supports abstraction by recursive decomposing a large network into several smaller networks (Batagelj and Mrvar, 2004). It helps implement selecting the efficient algorithm for large network analysis (Batagelj and Mrvar, 2004). MPA is the type of network analysis technique in the Pajek 5.11 program, in which networks can be weighted based on the importance of network nodes

Table 3
Distribution of papers by research domain.

Cluster	Research Domain	No. of articles
1	E-waste management systems and practices	109
2	E-waste legislations and its components	25
3	EPR scheme	16
4	Recycling critical materials from e-waste	16
5	CE strategies for the WEEE industry	13
Scattered article cluster		29
Total		208

and thus identify the most representative subnets (Barbieri et al., 2016). MPA helps identify the most related articles at different times, highlights the papers based on previous studies, acts as authoritative references for later works, and obtains the critical junctures of the historical development of research domains (Colicchia and Strozzi, 2012). Therefore, this study employed the Pajek 5.11 program to perform MPA to define the knowledge stream for developing CE practices in the WEEE industry.

Figs. 2–6 show a series of important historical events of each research domain in the WEEE industry within the context of CE. However, it should be noted that some articles which do not have citation relations with the main publications will not show up in the main path (Colicchia and Strozzi, 2012).

3.3.1. E-waste management systems and practices

"E-waste management systems and practices" is identified as the largest cluster. As shown in Fig. 2 and Table 4 (see Appendix E), the article's span is from 2005 to 2020, which is the most significant historical route of publication in this research domain. Two areas of knowledge are discussed in this main path: 1) e-waste management practices in developing and developed countries, and 2) the methods and tools applied to WEEE management.

WEEE legislation plays an important role in different countries and regions (Ismail and Hanafiah, 2020). However, the pace for drafting and formulating e-waste legislation seems lacking or slow except in Europe (Ongondo et al., 2011). The WEEE-related legislation covers 78 countries until 2019 (Shittu et al., 2020). Some developed countries, such as U.S. and Canada, still lack national legislation on e-waste management (Shittu et al., 2020). However, the major challenge is the comprehensiveness of the legislation (Ongondo et al., 2011). For instance, the WEEE directive 2012/19/EU classifies a variety of electronics into six categories. Still, only two categories of EEE (i.e., screens, monitors, and equipment with surface screens greater than 100 cm^2 and small IT and telecommunication equipment) were included in the Australia National Television and Computer Recycling Scheme (Islam and Huda, 2020). To address this issue, researchers have started to explore untapped e-waste products outside the scope of this scheme to improve environmental performance in Australia (Islam and Huda, 2020).

Similarly, WEEE legislation is particularly important in developing countries. Because informal recycling system is mainly adopted in developing countries, and the e-waste processing methods (e.g., manual sorting, open burning) in the system have detrimental impacts on the environment and human health, especially people who work and live

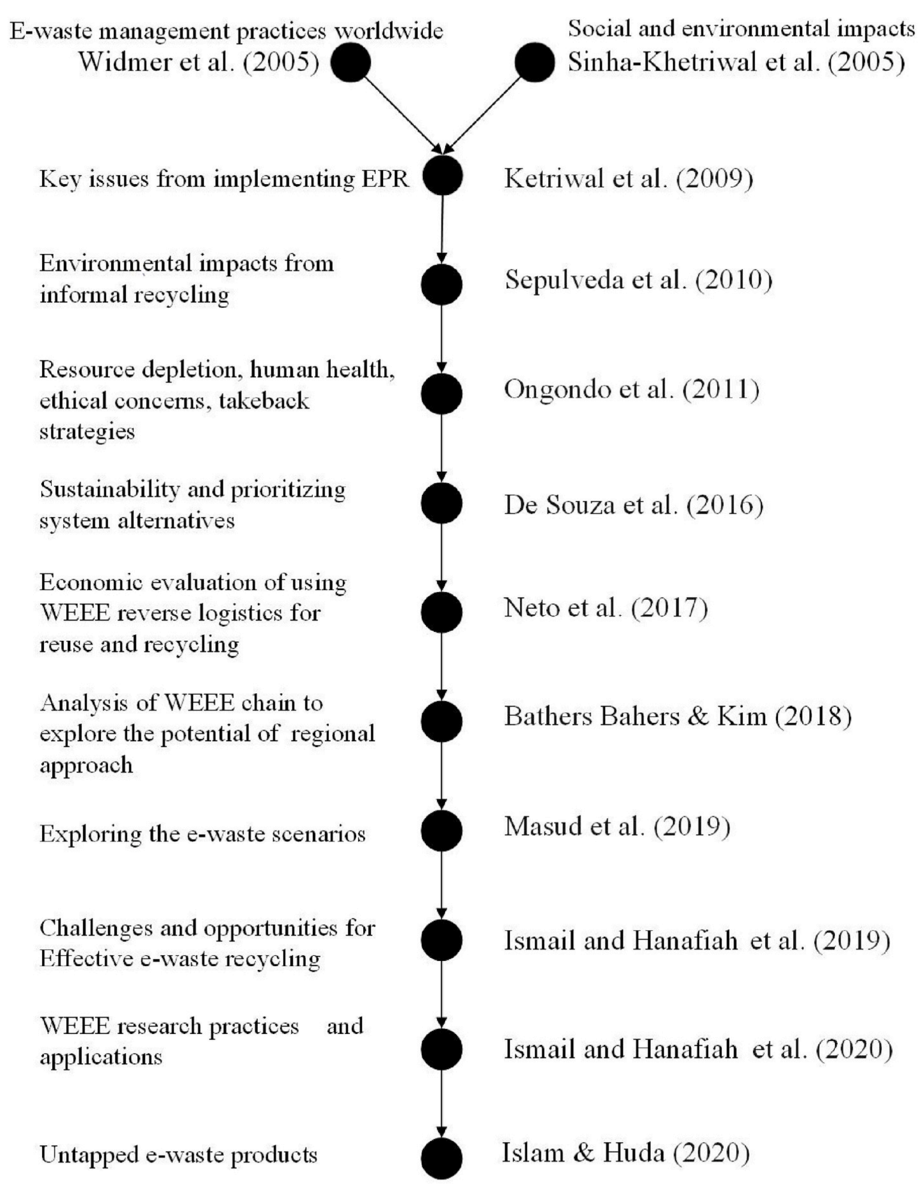

Fig. 2. Main path of e-waste management systems and practices.

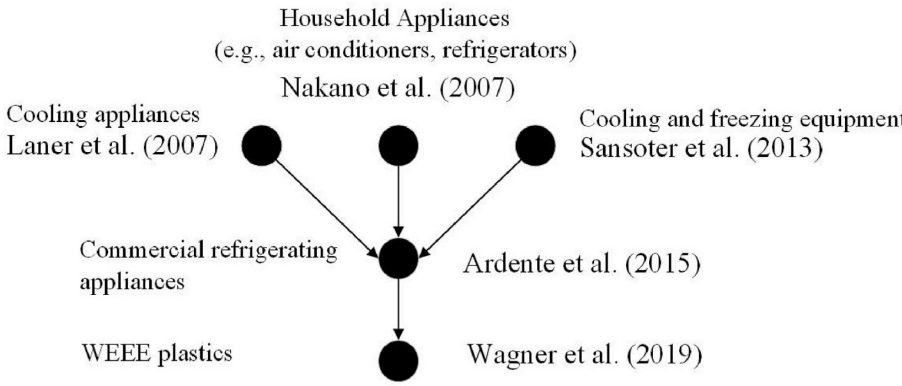

Fig. 3. Main path of e-waste legislations and its components.

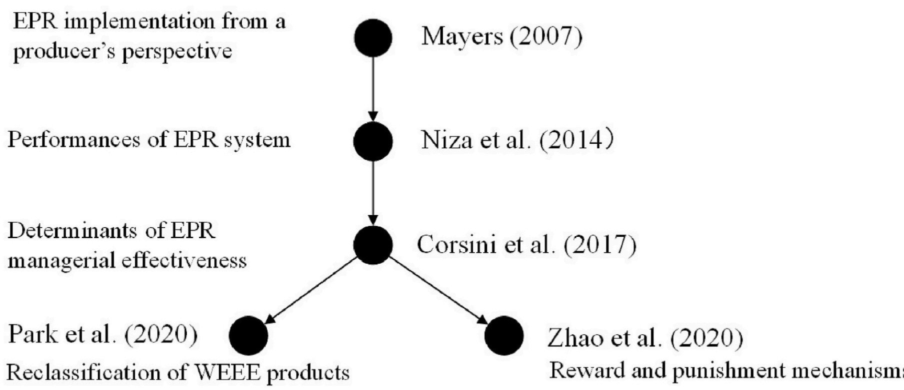

Fig. 4. Main path of the EPR scheme.

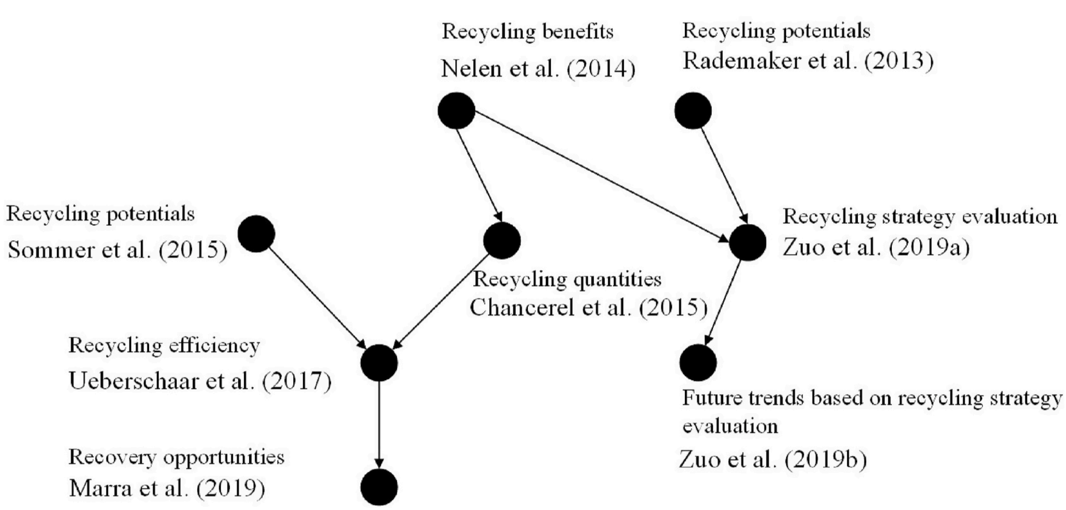

Fig. 5. Main path of recycling critical materials from e-waste.

near the informal recycling sites (Sepulveda et al., 2010). To improve environmental efficiency, some developing countries (e.g., China, India) have established formal recycling systems, but the informal recycling system still dominates e-waste collection (Masud et al., 2019). Substantial evidence demonstrates that informal recycling leads to ineffective e-waste management (Ismail and Hanafiah, 2019). Since e-waste management is in the initial stage in some developing countries, and the proposed e-waste regulations are far from finished (Ismail and Hanafiah, 2019). Masud et al. (2019) proposed an inverted pyramid hierarchy for effective WEEE management in Bangladesh. They found public awareness, budgets, and policies are the key factors for effective e-waste management. In addition, although Neto et al. (2017) found reverse logistics for e-waste recycling could reduce environmental impacts and gain economic benefits in Brazil, the main obstacle to using reverse logistics is technique limitations. However, developed countries mainly adopted formal recycling system, which requires advanced facilities to process e-waste, and have better control over human health and environmental protection (Bahers and Kim, 2018). Although the system has better control over environmental pollution, the lack of engagement of consumers and authorities, and the low recycling rate would result in

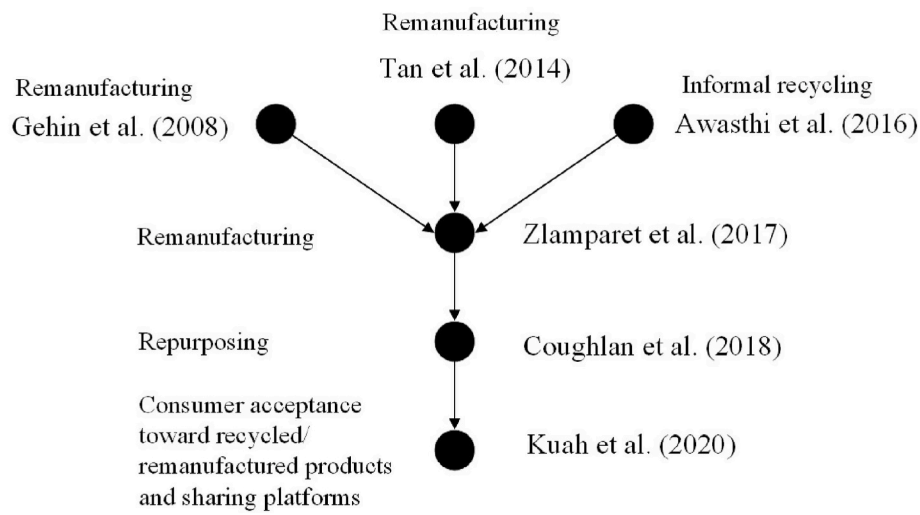

Fig. 6. Main path of CE strategies for the WEEE industry.

the dysfunction of the e-waste management system (Bahers and Kim, 2018). The difference in e-waste management between developing and developed countries is due to the market demand, job demand, environmental regulation, and system operation cost (Chi et al., 2011).

Some developed countries (e.g., Switzerland and Finland) have enacted e-waste legislation based on EPR (Widmer et al., 2005). Although developing countries (e.g., India, Malaysia) introduced EPR in their legislations, the roles of EPR are not well defined (Salhofer et al., 2016). For example, Switzerland ensured producers were responsible for their EoL electronics, but China didn't have designed roles for e-waste collection between retailers and municipalities (Salhofer et al., 2016). In addition, consumers in Switzerland are required by the law to return their e-waste to a designed place (Sinha-Khetriwal et al., 2005). However, informal recyclers provide door-to-door collection services, and consumers can receive an additional fee for selling their e-waste in China (Salhofer et al., 2016). The difference is probably because of the lack of an appropriate legislative framework for EPR or government regulation (Ongondo et al., 2011).

However, the greater challenge in managing e-waste is ensuring the compliance of stakeholders since their compliance and the target of WEEE collection are closely related (WEEE Forum, 2020a). Some key issues should be considered, such as free-riding problems, uncooperative retailers, consumer inaction, and rogue recyclers, which are identified as the destructive forces of WEEE management (Khetriwal et al., 2009). To obtain a higher level of compliance, peer group pressure, implementing and enacting relevant legislation, increasing the awareness of stakeholders, and the transparency of the value chain are needed (Khetriwal et al., 2009). However, the essential element is to enlist the support of all of the stakeholders (Khetriwal et al., 2009).

To verify the environmental or economic valuation of WEEE management, researchers have used several assessment methods and tools. For example, a combination of multicriteria decision analysis, life cycle assessment, and qualitative evaluation to assess the sustainability and prioritization of WEEE management schemes (de Souza et al., 2016); using material flow analysis to analyze WEEE chain and flows and explore the potential of regional approach (Bahers and Kim, 2018); integration of Delphi method and analytical hierarchy process to investigate untapped e-waste products (Islam and Huda, 2020).

3.3.2. E-waste legislations and its components

Due to the dramatic growth of e-waste, WEEE-related legislations have emerged with time. The main path depicted in Fig. 3 and Table 5 (see Appendix E) shows how the implementation of WEEE-related legislation has contributed to the development of academic research on e-waste composition. Cooling and freezing appliances have been the most popular object of research in this main path.

In 1987, The Montreal Protocol on Substances that Deplete the Ozone Layer was signed, and its nine revisions had phased out hazardous substances, such as Chlorofluorocarbons (CFCs) and Hydrochlorofluorocarbons (HCFCs), that are responsible for the ozone depletion (Ardente et al., 2015). Cooling and freezing appliances contain CFCs and HCFCs, which are released into the atmosphere and lead to ozone depletion, thus increasing the greenhouse effect (Sansotera et al., 2013). In this case, it is necessary to find alternative refrigerants. The Montreal Protocol requires that alternative refrigerants should consider five aspects: 1) environment; 2) economy, such as technology cost; 3) human health and safety; 4) technical feasibility, commercial availability, and performance; 5) country-specific conditions and local expertise (UNEP, 2020). In addition, the safety characteristics should also be considered. ISO 817:2014 and EN3 378–1:2008 stipulate levels classification of flammability and toxicity of refrigerants. In addition, the characteristics of pressure, availability, and familiarity should be considered in the alternative refrigerants (UNEP, 2014). Therefore, volatile organic compounds (VOCs), such as isobutane, have been used as alternative refrigerants in cooling and freezing appliances since 1997 due to their lower global warming potential (Laner and Rechberger, 2007).

However, most of the appliances that arrive at the treatment facilities contain CFCs, although VOCs are used in Austria (Laner and Rechberger, 2007). In 2003, the EU issued the first WEEE Directive that stipulated a minimum recycling rate of cooling appliances is 75% (Laner and Rechberger, 2007). In response to the changes, Laner and Rechberger (2007) explored whether a minimum recycling rate will result in optimum treatment practices. They compared the basic types of treatment for cooling and freezing appliances that contain CFCs and VOCs. They found that defining a minimum recycling rate is futile since it does not consider the material composition that could be recycled or recovered (Laner and Rechberger, 2007). Sansotera et al. (2013) investigated treatment practices of CFC removal from EoL cooling and freezing appliances after the WEEE directive was implemented in Italy. The research interest then shifted from treatment practices to quantifying the global warming effect as a result of house appliance recycling (e.g., air conditioners, refrigerators). Nakano et al. (2007) found Home Appliance Recycling Law in Japan has significantly contributed to reducing greenhouse gas emissions.

Unlike household appliances, commercial refrigerating appliances (CRAs) are business-to-business products with large dimensions, customized designs, and complex materials/components (Ardente et al., 2015). Research on the EoL CRAs has emerged after CRAs were included in the WEEE Directive (2012/19/EU) and Ecodesign Directive of the EU (Ardente et al., 2015). Ardente et al. (2015) investigated the potential synergies between products and waste policies by using CRAs. The results stated that product and processing requirements defined in the regulations need to be ensured that they are consistent with each other (Ardente et al., 2015).

Recycling WEEE plastics is imperative since they contain harmful substances, such as polybrominated biphenyl (PBB), which are banned by the RoHS Directive. Wagner et al. (2019b) used a strengths, weaknesses, opportunities, and threats (SWOT) analysis to analyze the recycling process based on dismantling by using WEEE plastics of televisions (TVs). They proposed six new recycling strategies that support the physical recycling of housing plastics that have higher economic potential (Wagner et al., 2019b). Although recycling WEEE plastics has been ongoing over the years, the recycling rate of WEEE plastics remains low (Wagner et al., 2019b). This is because attention has been mostly focused on common plastics. Special plastics, such as those used in the engineering field, are neglected (Wagner et al., 2019b).

3.3.3. Extended producer responsibility scheme

EPR is a CE practice that can be traced back to the 1990s (Mayers, 2007). It is defined as an environmental policy instrument that requires producers to extend their responsibility to the post-consumer stage of a product life cycle (OECD, 2003). In addition to transferring responsibility (physical or economical) from municipalities to producers, it is also important that EPR schemes encourage producers to consider environmental issues in the design phase of their products (OECD, 2003).

Fig. 4 and Table 6 (see Appendix E) show the main path of research for the "EPR scheme" from 2005 to 2020, which has two streams: investigating the effect of implementing EPR (2007) and establishing an effective EPR system (2014–2020).

In the first stream, one of the assumptions is that producer responsibility will create economic incentives that encourage producers to exclude the characteristics of products that are harmful to the environment (Niza et al., 2014). However, producers would not use an eco-design strategy in their products under producer responsibility if based on the mass-based targets set in the WEEE directive (Mayers et al., 2005).To find the possible causes for the foregoing issues, Mayers (2007) explored EPR from the perspective of the producer, and identified four barriers: 1) lack of appropriate treatment processes and infrastructures; 2) failure to fully implement future waste requirements; 3) collective financing models offers few design incentives; and 4) lack of treatment methods and specific requirements (Mayers, 2007).

In the second stream, four main research aspects are identified: performance of the EPR system (Niza et al., 2014), determinants of managerial effectiveness around EPR (Corsini et al., 2017), reward and punishment mechanisms (Zhao et al., 2020), and reclassification of WEEE products (Park et al., 2020). The first step in building an effective EPR system is to improve its performance. Three policy instruments have been proposed: 1) administrative instruments, such as increasing the rate of collection, reuse, and recycling targets; 2) economic instruments, such as landfill taxes; 3) informative instruments, such as providing information to recyclers/consumers (Niza et al., 2014). Three potential barriers that affect the performance of EPR systems are identified: 1) lack of guidelines for implementation of EPR schemes; 2) lack of integration of the application of EPR regulations with other waste norms/instruments; 3) few appropriate technical solutions to promote the CE of e-wastes (Corsini et al., 2017).

Zhao et al. (2020) found that the validity of penalty and bonus mechanisms is the most important enabler for producers to implement an EPR scheme. They found that lower reward and punishment mechanisms by the government result in lower pursuit of the recovery rate by producers (Zhao et al., 2020). In this instance, the producers will choose a third-party recycling channel and vice versa (Zhao et al., 2020). It appears that penalty and bonus mechanisms are a good means of encouraging producers to design environmentally-friendly products, build reverse logistic supply chains and improve the efficiency of resource reusability (Zhao et al., 2020). Besides, a study that verifies the rationality of official product classification by analyzing the recycling, recovering, and transport process conditions of e-wastes was conducted by Park et al. (2020).

3.3.4. Recycling critical materials from e-waste

As virgin materials that are used for basic products shrink in number, the critical materials in e-waste are regarded as part of the important source of secondary raw materials (Sommer et al., 2015). Some scholars have explored the critical metals and elements from the perspective of recycling benefits, recycling potential, recycling quantities, recycling efficiency, recovery opportunities, and recycling strategic evaluation. Fig. 5 and Table 7 (see Appendix E) show the main path of studies on "Recycling critical materials from e-waste" from 2013 to 2019.

A comprehensive and operational indicator set was proposed by Nelen et al. (2014) to demonstrate the benefits of recycling valuable metals and assess the performance of the recycling process. Some precious materials, such as rare earth elements (REEs) are found in batteries, but the recycling rate is low (Sommer et al., 2015). A study that evaluates the potential recycling yield of NdFeB Magnet showed that the immature processing and the technical limitations would reduce the recycling potential (Rademaker et al., 2013). Similarly, another study on the assessment of the recycling potential of REEs from e-waste batteries demonstrated that a lack of technical capacity would lead to the low recycling rate of REEs and REE loss (Sommer et al., 2015). Sommer et al. (2015) suggested the most crucial step is increasing the collection rate to tap into the potential raw materials in e-waste. Yet, increasing the recycling rate cannot be achieved by only investigating a few critical materials. As such, Chancerel et al. (2015) estimated the quantities of valuable metals and metal families (e.g., indium, gold) from consumer equipment, such as laptops and smartphones, which have been identified to contain a significant portion of target metals. Besides, the economic incentive is also playing a pivotal role in recycling practices since the expected revenues from manufacturing secondary metals cannot cover the processing cost (Chancerel et al., 2015).

For e-waste management, preprocessing is an essential step since it influences the recycling efficiency and the quality of the recycled materials (Ueberschaar et al., 2017). A study has developed an appropriate methodology for e-waste preprocessing to improve the recycling efficiency of critical elements (e.g., cobalt) (Ueberschaar et al., 2017). For instance, an established extended set of methods (e.g., materials flow analysis, sorting analysis) helps to identify the location of critical metals and elements in e-waste and enable their recovery (Ueberschaar et al., 2017). However, Marra et al. (2019) focused on the recovery opportunities to extract critical metals and elements (e.g., REEs) from shredding dust during the process of industrial treatment of e-waste, which contributes to waste (e.g., e-waste shredding dust) reduction in landfills and decrease the consumption of raw materials.

Urban mine refers to a stockpile of critical metals and materials in the e-waste of society, focusing on urban mines is another way to improve the recycling rate of high-tech metals (Zuo et al., 2019a). Zuo et al. (2019a) identified three clusters of urban mines and proposed relevant management strategies by using a strategic evaluation model (i.e., resource, technology, and environmental index) in China. They found technique limitations are one of the challenges to recycling critical metals. Similarly, Zuo et al. (2019b) used the same model to track the future directions of the high-tech metals recycled from urban mines from 2015 to 2050 in China. The evaluation results showed that cellphones, batteries, computers, etc., should be the priority for collection since they have been the primary source of valuable secondary metals for a long period (Zuo et al., 2019b).

3.3.5. Circular economy strategies for the waste electrical and electronic equipment industry

Fig. 6 and Table 8 (see Appendix E) show the main path of “CE strategies for the WEEE industry” from 2008 to 2020.

In response to the ever-demanding requirements of WEEE legislations of EU, producers have adopted CE strategies. Recycling is the most commonly adopted strategy and the basis of CE (Gehin et al., 2008). Awasthi et al. (2016) found that recycling is an effective method for e-waste management when the most suitable technologies and practices are used together. However, merely recycling is a long way from meeting the goals of sustainable development because recycling is the only minimum effort (e.g., sorting, recovering) and the added value of the products is lost during recycling (Gehin et al., 2008).

Preparation for reuse (PfR) plays a crucial role in the concept of reuse (Lu et al., 2018), which is a type of recovery operation that includes inspection, cleaning, repair, and recovery (Eustat, 2011). After these operations, e-waste and its components are prepared to reuse without other pre-processing operations (Eustat, 2011). The new WEEE directive, Annex V Part 3, stipulates targets for PfR and recycling of six categories of WEEE. For example, 80% of EoL temperature exchange equipment shall be PfR and recycled (Seyring et al., 2015). However, the legislative framework does not support reuse and PfR since the are no specific targets for PfR (Seyring et al., 2015). In addition, other obstacles also hinder the development of PfR activities, such as producer resistance, and restrictions on transboundary shipments (Johnson et al., 2015). Under these circumstances, Seyring et al. (2015) explored the feasibility of setting a separate target for PfR, while Bovea et al. (2016) proposed a methodology (i.e., visual inspection/safety test and reuse protocols) to assess the potential for PfR of small e-waste to improve the rate of reuse.

Remanufacturing is an industrial process to recover/restore used or worn-out products to “as-new” conditions, and it provides an equally functional warranty as that of newly manufactured products (Coughlan et al., 2018). Although remanufacturing improves the environmental and economic performances in the WEEE industry, the positive effects on the environment and economy still need to be supported with evidence since this strategy is immature from the perspective of industrialization (Gehin et al., 2008). Gehin et al. (2008) suggested remanufacturing cannot be considered as a single strategy and should be used along with reusing and recycling for maximum effect in the product development phase. Besides, the life cycle eco-efficiency for e-waste remanufacturing is not always higher than traditional manufacturing when consumers are willing to pay (Tan et al., 2014). Since this situation depends on the quality of recycled products, and the time interval between new products launching and their remanufacturing in the post-consumer stage (Tan et al., 2014). In Europe, the remanufacturing strategy is linked with the production lines related to remanufactured products (Zlamparet et al., 2017). However, in the UK, “the Trade Description Act” stipulates that selling already sold products is illegal, including newly manufactured products that contain remanufactured components (Gehin et al., 2008). The U.S. considers that remanufacturing should be adopted to boost employment rates, and companies (e.g., outsourced companies) can help to assist and contribute to the process of remanufacturing (Zlamparet et al., 2017). In Asian countries, such as China, the concept of remanufacturing has been developing in other sectors except for electronics, even though remanufacturing technology is feasible (Zlamparet et al., 2017). Regulation systems, technology innovations, consumers’ knowledge, and tools and techniques are the four barriers that inhibit the implementation of remanufacturing strategies in China (Tan et al., 2014).

Repurposing is described as using discarded products and their components in a new product that offers different functions (Kirchherr et al., 2017). Sometimes, repurposing is known as adaptive reuse (Coughlan et al., 2015). Coughlan et al. (2018) explored the opportunities to repurpose EoL laptops as thin client computers. They proved the potential of reusing and repurposing e-waste, especially e-waste from the business-to-business channel. E-waste that is still useable could be reused and repurposed, which also acts as a supply of components for repair (Coughlan et al., 2018). The concept of refurbishment is similar to repairing, namely, recovering a product so that it can be used like a new one (Coughlan et al., 2018). Refurbishment can also be a part of repurposing in certain conditions. For instance, repurposing smartphones as parking meters is considered a more environmentally friendly strategy than refurbishing (Coughlan et al., 2018).

Based on previous studies, Kuah and Wang (2020) examined customer’s attitudes toward shared platforms. This aspect is related to rethink strategy, which means making product use more intensive (Kirchherr et al., 2017). They showed that some consumers are willing to use shared platforms but are concerned that they would be cheated or exploited. Besides, consumers’ attitudes toward remanufactured/recycled products are also examined. The result showed that consumers might be willing to purchase remanufactured/recycled products in the future due to increased environmental awareness, but they feel that such products as unreliable or low in quality (Kuah and Wang, 2020). The influencing factors (e.g., trust, cost-saving) will affect the purchase intention of customers (Kuah and Wang, 2020). However, these factors for recycled products are more salient compared to remanufactured products (Kuah and Wang, 2020).

Although previous studies verify the applicability and feasibility of the “10R” CE strategies applied in the WEEE industry, using “R” strategies with traditional management methods fails to deal with e-waste effectively (Wang and Wang, 2019). For example, the remanufacturers need to master a considerable amount of e-waste knowledge and data before being repaired and remanufactured, but the data of product lifecycle information is missing in production or interrupted by the end-users. Under this circumstance, remanufactures need to recreate the product lifecycle information, which results in the data suspension (Wang and Wang, 2019). In addition, the uncertainty of distributed location, e-waste category, and the volume of recycled e-waste will hinder the application of the “10R” strategy used in the WEEE industry (Wang and Wang, 2019). The foregoing facts are partly because lack of a smart system or method to record and update the product information (Wang and Wang, 2019). The smart factory is an excellent solution to manage e-waste since it connects the physical and digital world to monitor the entire manufacturing process of remanufactured/refurbished/repurposed/repaired products (TULP, 2021). Besides, it is a highly digital shop floor that combines modern technologies (e.g., big data analytics) to collect and share data through connected machines, devices, and manufacturing systems (TULP, 2021). The application of smart factories in the WEEE industry, especially the technologies in industry 4.0, will contribute to data collecting on e-waste, optimizing efficacy and productivity, and decreasing costs and minimizing waste (Wang and Wang, 2019). For example, a digital twin-based system that supports remanufacturing/recovery/recycling operations throughout the product’s lifecycle (Wang and Wang, 2019). Yang et al. (2018) found that increased digitalization (e.g., smart factory/services) could reduce the transformation cost of remanufacturing. Therefore, connecting “10R” CE strategies with the smart factory is imperative.

4. Discussion

This paper discussed the details of CE practices (i.e., “10R” CE strategies) applied in the WEEE industry. Recycle, reduce, reuse, repair, refurbish, remanufacture, repurpose, recover, and rethink principles are addressed in the CE and WEEE literature, but refuse is rarely mentioned in the literature. However, the main ideas of refuse are throughout the CE and WEEE literature. Specifically, refuse is discussed from the perspective of consumers and producers (Reike et al., 2018). Regarding consumers, the choice to buy or use less, which aims to prevent waste generation; concerning producers, refuse means that product designers can refuse the use of certain harmful substances and avoid wastage and reduce consumption of any virgin material during the design production process (Reike et al., 2018) (see Section 3.3.3). The following parts will propose future research directions in each research domain.

4.1. E-waste management systems and practices

First, although previous studies have explored the integration of formal and informal e-waste recycling systems (Yu et al., 2010), the actual effects of implementing an integrated system are unknown. Future research should therefore further examine how integrated recycling systems operate in developing countries and whether the effects of the integrated system excel those of a single recycling system (i.e., formal or informal system). The investigation can be done from the perspective of policies and laws, within a socio-economic or cultural context, based on the manufacturer's responsibility or recycling infrastructure, etc. In doing so, whether this integrated recycling system can be applied to other developing countries that only have an informal recycling system for improving the efficiency of e-waste collection and recycling can be determined.

Second, the behaviors of each stakeholder are the key to e-waste management. Encouraging all stakeholders to engage in a WEEE management system might be a more effective method (WEEE Forum, 2020a). Future research could compare the collection rate of countries (e.g., Switzerland, Italy, Spain) that use all of the stakeholder's methods in practice with those that are not doing so. Then we could learn about the validity of this method in different geographical contexts and whether it will improve the quality of e-waste treatment (WEEE Forum, 2020a).

Third, the research on WEEE reverse logistics mainly discussed environmental and economic dimensions (Islam and Huda, 2018). Future research could focus on the sustainability dimensions (i.e., environment, economy, and society), especially social dimension, the assessment of social impacts, such as public health (Islam and Huda, 2018).

Fourth, the fast technology innovation will create new WEEE streams that may contain harmful substances (Ongondo et al., 2011). For instance, e-cigarettes are considered both electronic and hazardous wastes because they have heavy metals (e.g., lead) and toxic chemicals (e.g., nicotine), which are harmful to the environment and human health (Hendlin, 2018). It remains uncertain whether the e-cigarettes are treated as e-waste or hazardous waste when they reach their EoL (Hendlin, 2018). In addition, there is no standardized way to recycle e-cigarettes in some countries, such as the U.S. (Truth Initiative, 2021). Thus, future research should further explore undefined or untapped e-waste that is not stipulated in the legislation and regulations in different countries to improve the recycling rate and mitigate environmental damage of e-waste.

4.2. E-waste legislations and its components

The WEEE-related legislations play a pivotal role in WEEE management. In this main path, the enforcement of WEEE legislation affects research practices on WEEE components is demonstrated, which range from CFCs/VOCs in cooling and freezing appliances to WEEE plastics of TVs. Previous studies have explored innovative recycling strategies (Wagner et al., 2019b) and recovery systems (Sansotera et al., 2013) of e-waste components, but a limited body of research is found on the systems and strategies that effectively eliminate the toxic substances (e.g., PBB, PBDEs) during the process of recycling, which is a major setback realizing a CE for e-waste recycling (Wagner et al., 2019a).

4.3. Extended producer responsibility scheme

In the EPR system, each stakeholder plays a crucial role and is interlinked with other stakeholders. Previous studies have identified uncooperative roles in the EPR scheme (Khetriwal et al., 2009), but lack an in-depth analysis of each role. Hence, future research could explore each stakeholder who is engaged in the EPR scheme. For instance, analyzing the extent that each stakeholder affects the EPR scheme, the enablers and obstacles that influence the stakeholders in implementing EPR schemes, and whether the drivers and barriers will differ from country to country or region to region. As such, this would give us a good understanding of the underlying causes of the uncooperative stakeholders, and thus policies and regulations can adapt accordingly.

Moreover, previous studies have proposed that the rewards and punishment system is an important driver for manufacturer engagement in the EPR scheme (Zhao et al., 2020). However, little is known about the extent of the reward and punishment mechanism that will encourage manufacturers that produce different categories of products (e.g., air-conditioners, e-cigarettes) to participate in an EPR scheme. The investigation could adopt a perspective from that of product category, product size and weight, recyclable materials or components, etc. In so doing, policymakers would understand how to improve rewards and punishment mechanisms according to different product manufacturer categories and convince more manufacturers to participate in the EPR scheme.

4.4. Recycling critical materials from e-waste

Previous studies have focused on product categories that are mostly medium or large-sized electronic equipment (e.g., laptops and LCD television sets), other small e-waste items also contain critical elements are received less attention in the WEEE streams, such as gas discharged lamps (Richter & Koppejan, 2016). According to Forti et al. (2020), there is a gap between the volume of recycled secondary raw materials and the degree of demand for producing new electronics equipment. Thus, small WEEE is probably the key to increase the recycling rate of critical metals or raw materials/elements. Future research should give more attention to small e-waste in the WEEE streams. Investigation of critical materials could be made in assessing recovery potential or opportunities, estimating recycling quantities, and treatment methods.

Moreover, urban mining is vital for valuable materials recovery and guarantees the ongoing supplies of the manufacturing industry (ProSUM, 2022). Previous study has focused on the recycling strategies and priority of critical metals recovery in urban mine (Zuo et al., 2019b). The discussion of economic benefits from urban mining is limited. Future studies could build an economic model to identify the economic potential of various high-tech metals that are recycled from urban mines (Brunner, 2011). The research can be conducted by comparing the urban mines in different regions.

4.5. Circular economy strategies for the waste electrical and electronic equipment industry

Previous studies have focused on product lifecycle extension (e.g., remanufacturing) (Coughlan et al., 2018) and consumer attitude towards the resultant products and sharing platform (Kuah and Wang, 2020). However, few studies have investigated the attitudes and behaviors of consumers, and the roles they play in the design phase (e.g., eco-design) in the WEEE industry. Future research could examine the relationship between consumers and the design activities in the product development phase. For example, exploring whether consumer attitudes and behaviors encourage firms to adopt eco-designs in the production process or the eco-design activities improve consumer awareness. This will help companies to adjust operation strategies accordingly and address the e-waste problems at the source itself.

Secondly, the characteristics of recycled, remanufactured, repurposed, and refurbished products should be compared and analyzed from the perspective of environmental pollution, customer acceptance (e.g., income, household size, and brand image), market demands, and energy usage (Coughlan et al., 2018), and then the strategies that would be more profitable for companies and cause less environmental issues are evaluated.

5. Conclusion

Ten major topics are identified in the CE and WEEE literature, including 1) e-waste recycling system; 2) exploring untapped e-waste; 3) compliance assurance of stakeholders; 4) e-waste reverse logistics; 5) reward and punishment mechanisms in EPR system; 6) verifying the rationality of product classification; 7) recycling critical materials from urban mines; 8) setting a specific target for PfR; 9) “10R” CE strategy applied in the smart factory; 10) consumer attitude toward remanufactured/refurbished/repurposed strategies and the resultant products.

Although most studies explored e-waste from different dimensions, they ultimately boil down to one point: finding possible ways to reduce environmental pollution, which can be achieved by applying “10R” CE principles with the key point of promoting stakeholders’ compliance. Therefore, the WEEE industry could: 1) establish the coordination body to facilitate communication of each stakeholder, such as knowledge delivery and awareness and behavior changes of each stakeholder; 2) most of the attention focused on recycler for e-waste collection, other important roles such as retailers and service provider of reverse logistics should be paid more attention; 3) strengthen the implementation of e-waste legislation in different regions since stakeholders will do what they are supposed to do (WEEE Forum, 2020). Moreover, technical limitations are obstacles to e-waste management. Government, legislation and fund should be prepared for the technology development of WEEE extraction.

This study contributes to environmentally sustainable practices by identifying the potential issues in the WEEE industry and proposing implications for stakeholders. However, all studies have limitations, and this study is no exception. 1) although cleaner production technologies are critical for reducing environmental impact, the discussion on cleaner production techniques is limited in this paper. Future studies should focus on this aspect; 2) the “Rs” strategies are parts of CE practices, but other CE practices, such as green supply chain management in the WEEE industry, have not been discussed in this paper. Future studies could consider these research directions; 3) even though CNA is regarded as an objective method, the initial process of selecting and identifying target papers is influenced by subjective judgment; 4) CitNetExplorer provides a systematic and objective analysis of the articles, but only applies a single clustering approach, and lacks flexibility in clustering choices. For instance, the program cannot analyze citation networks based on keyword co-occurrence.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jclepro.2022.132671.

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