LogForum
> Scientific Journal of Logistics <
2024, 20 (1), 81-95
http://doi.org/10.17270/J.LOG.000973
http://www.logforum.net p-ISSN 1895-2038 e-ISSN 1734-459X
ORIGINAL PAPER

STIMULATORS OF THE TRANSITION TO CIRCULAR SUPPLY CHAINS – EXPLORATORY STUDIES IN THE ELECTRICAL AND ELECTRONIC EQUIPMENT INDUSTRY

Karolina Werner-Lewandowska, Paulina Golińska-Dawson, Piotr Cyplik

Faculty of Engineering Management, Poznan University of Technology, **Poland**

ABSTRACT. Background: Circular supply chains (CSCs) are one of the cornerstones of the circular economy (CE). Previous research has shown that closing the materials loop helps recover value in a supply chain. The aim of the study is to identify factors that stimulate the transition to a circular supply chain. We focus our research on Electrical and Electronic Equipment (EEE), as according to European Commission guidelines, this sector has high potential for circularity and is therefore one of the priority areas for CSC implementation.

Methods: This exploratory study identifies the main factors enabling the transition to CSCs in the EEE industry. We search for the answers to three research questions: 1) What factors are influencing the transition to circular-supply-chain (W)EEE? 2) What factors can be categorized as key stimulators of the transition to circular-supply-chain (W)EEE? 3) How impactful are the stimulators of the transition to a circular (W)EEE supply chain? We used an expert survey with a Likert scale to assess the relevance of stimulators. The results of the expert survey were subjected to statistical analysis to determine the consensus of expert opinion.

Results: Six groups of factors were investigated, related to: legislation, collection (take-back) systems, technology, economy, products, and customers. In total, 30 factors were identified, and were assessed by experts for their impact on three recovery scenarios, namely recycling, remanufacturing and repairs. Based on the research, it can be concluded that the factors driving the development of circular supply chains are primarily related to the organization of the (W)EEE collection system. Legal aspects are perceived as neutral by experts. Product-related factors are key to the further development of EEE remanufacturing and repairs, and technological factors are crucial to the development of WEEE recycling. The shift in consumption from linear sales to Product-as-a-Service (PaaS) models is also supporting the transition towards CSCs.

Conclusions: The transition to circular supply chains is complex, and a number of simulators were identified in this study. The importance of particular factors is related to the (W)EEE recovery scenario under consideration.

Keywords: circular supply chain, circular economy, recovery scenarios, Electrical and Electronic Equipment

INTRODUCTION

Previous research has shown that the circular economy (CE) as a strategy can help companies make the transition from using a traditional (linear) economic model to implementing a circular system (Merli et al., 2018; Shekarian, 2020, Ayati et al., 2022). The CE concept has been studied in various fields (e.g., Ravindra et al., 2015; Annarelli et al., 2016; Tukker, 2015, Zhu et al., 2010; Linder and Williander, 2017). The conclusions of these studies indicate that this economic system is superior to the linear system. Ayati et al. (2022) showed that only a few studies have analyzed how to implement CE for supply chain operations. Previous research on the development of supply chain management (SCM) theory has led to concepts such as sustainable supply chain management (SSCM) (Seuring and Müller, 2008), green supply chain management (GSCM), and the closed-loop supply chain (CLSC) (Shekarian, 2020), which are mainly related to sustainability aspects rather than to CE assumptions. A new paradigm,

Citation: *Werner-Lewandowska K., Golińska-Dawson P., Cyplik P., 2024. Stimulators of transition toward circular supply chain - Exploratory studies in Electrical and Electronic Equipment industry. LogForum 20 (1), 81-95*, http://doi.org/10.17270/J.LOG.000973
Received: 30.11.2023, Accepted: 09.01.2024, on-line: 14.03.2024

circular supply chains (CSC), bridges the gap by integrating CE with SCM (Chen and Tan, 2021).

The goal of CSC is to expand the circulation of resources according to supply chain requirements. It integrates CE and SCM by extending the closed loop boundary and recovers value from primary and secondary supply chains (Farooque et al., 2019). Furthermore, CSC goes beyond the boundaries of SSCM and GSCM and includes resources within supply chain systems to reduce the use of virgin materials (Genovese et al., 2017). It enables CSC to achieve zero waste and facilitates end-of-life (EoL) or end-of-use (EoU) recovery, even for unwanted waste (Aminoff and Kettunen, 2016; Farooque et al., 2019). Batista et al. (2018) showed that CSCs are stimulating growth in remediation in business ecosystems. CSC is one of the reasons for the growing interest in linking the supply chain with CE (Aminoff and Kettunen, 2016). Despite these benefits, Lahane et al. (2020) noted that in this context, there is still room to identify bottlenecks and barriers to achieving a better version of CSC. To advance the CSC concept, it is also necessary to know the drivers of the transition to the circular model. For the successful development of this strategy, measures are needed to remove barriers and strengthen drivers.

In our research, we focus on identifying stimulators for the transition from SC to CSC for electrical and electronic equipment (EEE). This is due to increased awareness of WEEE issues. The increased production and use of EEE in recent years due to technological innovations and new applications has led to a surge in model proliferation. The result is WEEE, which is the largest and fastest growing source of global waste worldwide (Bressanelli et al., 2020). Globally, 45 million tons of WEEE are discarded each year, with an annual growth rate of 3–5% (Baldé et al., 2017).

Bressanelli et al. (2020) point out that the WEEE industry is gaining prime importance in the context of the circular economy (CE). CE not only encourages the closing of product, component, and material cycles through cumulative improvements in EEE design, but also drives business models such as Product-as-a-Service (PaaS), leasing, and sharing (Bressanelli et al., 2019; Rosa et al., 2019).

ON THE WAY TO CSC IN THE ELECTRICAL AND ELECTRONIC EQUIPMENT SECTOR

With growing concerns about sustainability, closed-loop supply chain (CSC) management has been recognized as an important path to achieving the Sustainable Development Goals (Li et al. 2023). In the business environment, when it comes to environmental and ecological aspects, there are, unfortunately, signs of a lack of morality and bending the rules of fairness, such as generating additional pollution, producing additional packaging, dumping waste in unauthorized places, and encouraging excessive and uncontrolled consumption (Lamenta and Grzybowska 2023). The ‘take-produce-use-throw away’ linear model of resource consumption does not appear to be sustainable, as it pollutes the environment and depletes natural resources. CE aims to replace the linear model with closed (circular) loops of material flows by combining many different operations, such as maintenance, repair, reuse, refurbishment, remanufacturing, and recycling (Mishra et al. 2018). Recovering the value of physical goods through shorter cycles of reuse and renewal, as opposed to recycling and energy recovery, is consequently a fundamental principle of CE (Tura et al. 2019) .

According to the guidelines of the European Commission, the EEE sector has high potential for circularity and is therefore one of the priority areas for the implementation of CSCs. Waste electrical and electronic equipment (WEEE) is one of the fastest-growing waste streams in the world; 53 million tons are generated per year (Forti et al. 2020, Shittu et al., 2021). WEEE is expected to continue to grow due to the rapid and leapfrogging digital economy as a result of the COVID-19 pandemic (Shittu et al. 2021a). Growth in the volume of WEEE and EEE (W(EEE) for short) is also occurring as a result of the emergence of new technologies related to artificial intelligence, biomedical engineering, renewable energy, space travel, e-textiles and smart agriculture

(Shittu et al. 2021). Much (W)EEE now consists of consumer electronics such as laptops, cell phones and televisions, and electric batteries. About 20% of the WEEE generated worldwide is recycled, but the fate of most WEEE is undocumented (Baldé et al. 2017, World Economic Forum 2019, Forti et al. 2020). Tracking W(EEE) flows is therefore difficult (Shittu et al. 2021a).

Increasing WEEE waste generation is a global concern (Zhang et al. 2019). Research on the reuse of (W)EEE is thematically broad and covers issues including poor health and environmental impacts, poorly managed flows of (W)EEE, and global recycling practices.

In this research, we separate the terms WEEE and EEE. The term WEEE refers here to waste electrical and electronic equipment, that is, equipment that has reached the ‘End of Life’ stage of the product life cycle (EoL), cannot be restored to working conditions for technical, technological reasons, or cannot be restored in a cost-effective manner. EEE includes electrical and electronic equipment that has reached the ‘End of Use’ (EoU) stage in the product life cycle. Despite the fact that such EEE is still functioning, the consumer has stopped using it, for example, due to obsolete technology or functionality. EEE also includes equipment that a consumer stops using because it does not work properly, although it is technologically feasible and economically justifiable to repair or remanufacture it. Like Pierron et al. (2021), in this paper we refer to (W)EEE instead of WEEE to emphasize the uncertainty about the status of some electrical and electronic equipment. An unwanted device in working condition may not trigger the same end-of-life decision as a broken device.

W(EEE) collection initiates the circular supply chain (CSC). The continued success of the implementation of reuse processes depends on the efficiency of activities at this stage. The flow of goods in a closed supply chain does not end after the use stage. In a CSC, used goods are transferred back to their manufacturer (or another company) for recovery (Sosnowski and Cyplik, 2022). In Figure 1, we present a general overview of CSC.

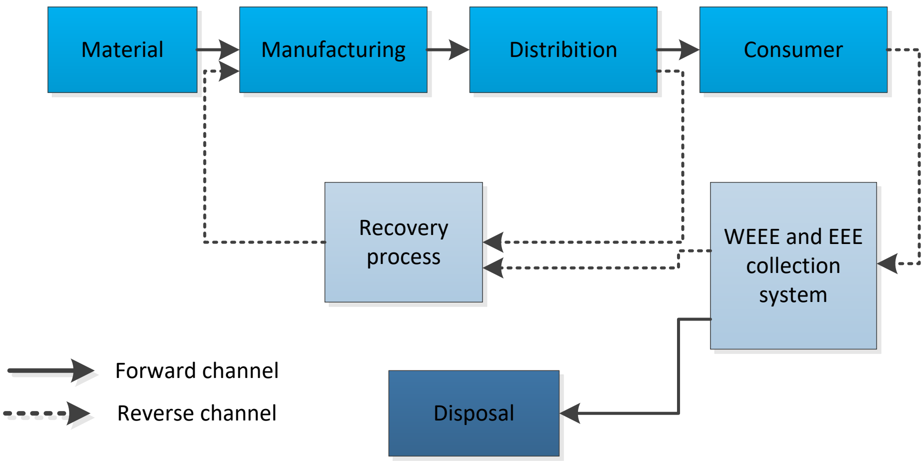

Fig. 1. Circular supply chain – CSC Source: own work

Used goods can be reused, repaired, refurbished, remanufactured or recycled (Golinska-Dawson et.al., 2021). By effectively managing the flow of (W)EEE, products and materials can be recovered without being sent to landfill (Sari, 2020). In this way, human health can be protected and both environmental conditions and the bottom line can be improved (Flygansvær et al. 2018).

MATERIALS AND METHODS

We based our research on a conceptual model (Figure 2), and we addressed the following research questions:

RQ1: What factors are influencing the transition to circular supply chain (W)EEE?

RQ2: What factors can be categorized as key stimulators of the transition to circular supply chain (W)EEE?

RQ3: How impactful are the stimulators of the transition to a circular (W)EEE supply chain?

We assumed that certain factors influence the transition to a closed (W)EEE supply chain.

To answer the research questions posed, we adopted a research methodology (Figure 3).

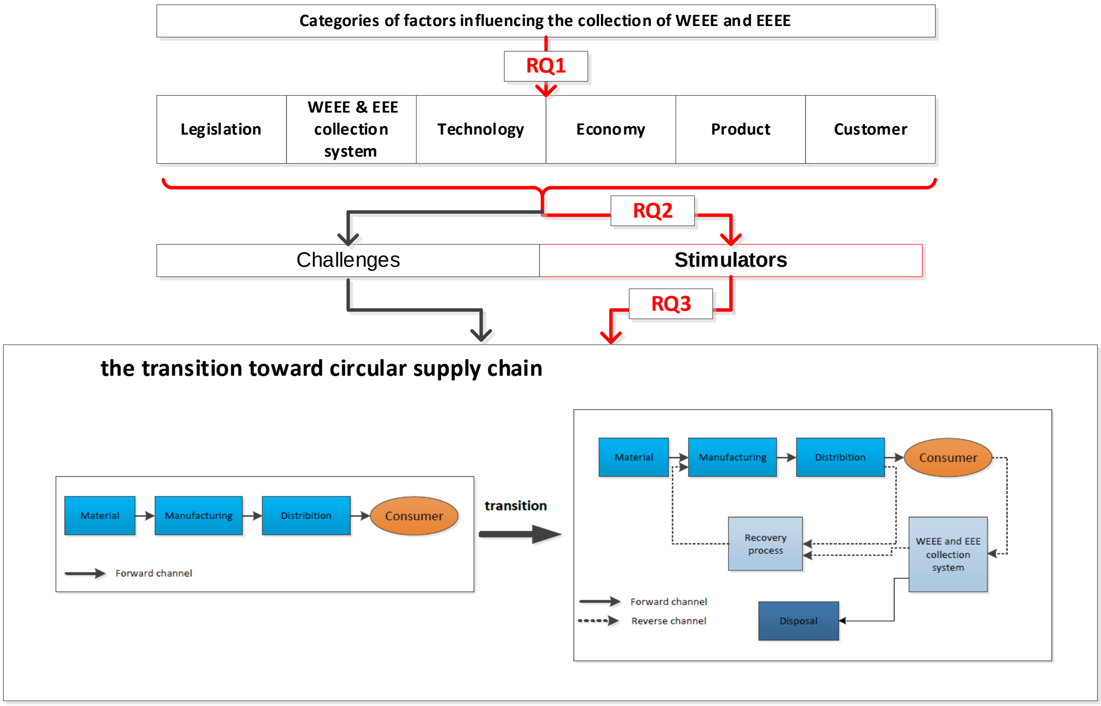

Fig. 2. Conceptual model Source: own work

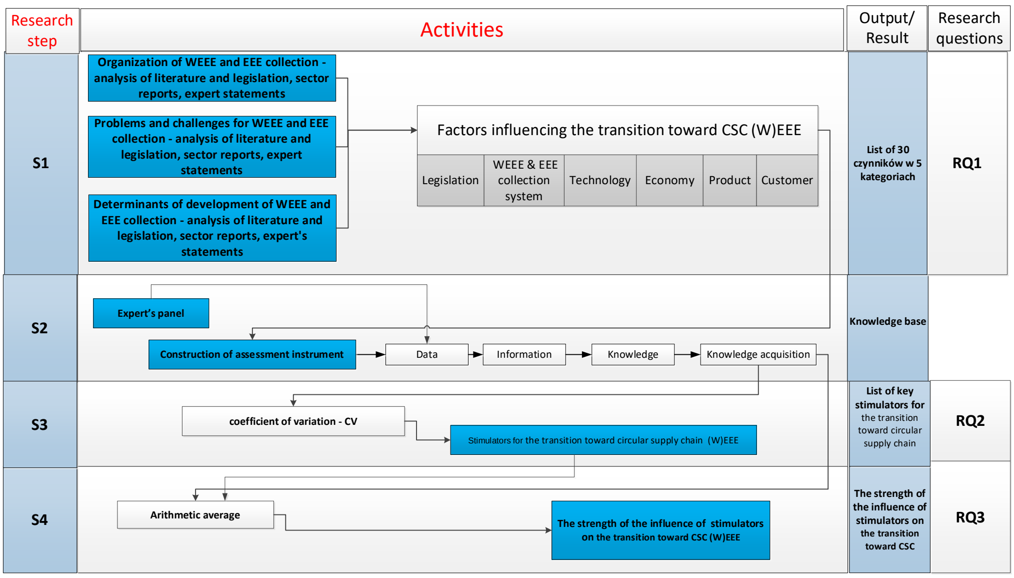

Fig. 3. Research methodology Source: own work

Based on an analysis of the literature, existing legislation, industry reports, and media monitoring, we compiled a list of 30 factors affecting the transition to CSC (W)EEE. The factors were assigned to 6 groups (Table 1).

Table 1. Factors influencing the collection of WEEE and EEEE

ID Factor	*ID name*	*Characteristics*	*Sample References*
Group 1: Legislation – L			
L1	WEEE Directive	Requires the separate collection and proper treatment of WEEE and sets targets for its collection as well as its recovery and recycling.	Svensson-Hoglund et al. 2021
L2:	Regulations on reporting in the WEEE collection system	Reports related to the weight of WEEE products collected and the weight of new EE products introduced to the market. These data are the basis for calculating the return rate.	The WEEE Directive; Andersen et al. 2020
L3	Extended Producer Responsibility (EPR)	A producer's responsibility is extended to the post-consumer stage of a product's life cycle. Producers are to take into account environmental considerations when designing their products.	Cole et al.. 2014;
L4	Ecodesign Directive (Directive 2009/125/EC)	Establishes a framework to set mandatory ecological requirements for energy efficiency of EEE sold in EU (more than 40 different product groups), which is responsible for around 40% of all EU greenhouse gas emissions.	Rudolf et al. 2022; Waite et al. 2015; Bundgaard & Huulgaard, 2023
L5	Right to Repair Initiative	Published on March 22, 2023, by the EU Commission. The proposal would introduce a new 'right to repair' for consumers, both within and beyond the legal guarantee.	Rudolf et al. 2022, European Parliament resolution on the right to repair (2022/2515(RSP))
Group 2: WEEE &EEE collection system – RL			
RL1	Bulk collection of WEEE	At present, the collection of WEEE and EEE at the end of its life or use is carried out without distinction according to the type or condition of a product.	The WEEE Directive; Cole et al. 2009; Kosacka-Olejnik & Werner-Lewandowska, 2020
RL2	Transportation of various categories and types of WEEE together (mixed) at collection sites	At present, all types of WEEE and EEE are transported together from the collection points to the reuse points, with the result that both WEEE and EEE of different sizes are contained in one vehicle.	Dimitrakakis et al. 2009
RL3	Sorting (e.g., by different types, brands) of WEEE and EEE at the collection site.	At present, the WEEE and EEE collection system does not provide for their segregation.	The WEEE Directive; Cole et al. 2009
RL4	Visual inspection of WEEE and EEE at the logistics hub	At present, the collection point for WEEE and EEE does not assess their technical condition, resulting in every piece of EEE donated by the consumer being treated as WEEE. Consumers often throw away working EEE because they have decided to stop using it. Failure to assess the technical condition of EEE at the collection point results in it not being sent for remanufacturing or repair so it can be put back on the market. It is most often recycled, as it is classified as WEEE.	Gonda et al. 2019
RL5	Multiple disposal options for users	A consumer has many options for disposing of WEEE and EEE. This results in more convenient disposal for customers but also causes a dispersion of input volumes for further recycling and value retention processes.	The WEEE Directive; Cole et al. 2015; Kawa & Golinska, 2010
Group 3: Technology -T			
T1	Dedicated technological solutions for WEEE and EEE for dismantling machines, equipment and tools	At present, there are few ready technological solutions available, such as automated lines for performing operations in WEEE recycling, remanufacturing and EEE repair processes. This results in many steps being performed manually by humans, which prolongs the process time and increases the cost of the entire recovery process.	Kuo et al. 2020; dÁlvarez-de-los-Mozos et al. 2020
T2	Dedicated technological solutions available for shredding/grinding WEEE/ regeneration/ repair of EEE		dÁlvarez-de-los-Mozos et al. 2020; Kuo et al. 2020; Rudolf et al. 2022; Cole et al. 2014; Dindarian et al. 2012
T3	Dedicated technological solutions available for WEEE separation/ to assess the technical condition of WEEE and EEE		dÁlvarez-de-los-Mozos et al. 2020; Coughlan et al. 2020; Dindarian et al. 2012; Rudolf et al. 2022
T4	Dedicated technological solutions available for WEEE sorting/ access to EEE software solutions		dÁlvarez-de-los-Mozos et al. 2020; Svensson-Hoglund et al. 2021;Wiens, 2015
T5	Availability of qualified employees	At present, there is a perceived shortage of workers skilled in EEE repair and remanufacturing.	Pérez-Belis et al. 2017; Raihanian Mashhadi et al. 2016; Sabbaghi et al. 2017

Group 4: Economy – E			
E1	The linear business model of EEE producers	This is based on the simple Buy-Use-Dispose rule, and it is the opposite of a circular business model.	Shittu et al., 2021; Rudolf et al. 2016; Svensson-Hoglund et al. 2021
E2	The demand for WEEE exceeding its availability on the market	The supply exceeding demand, as end-users are hoarding especially small EEE at home, instead of disposing of it at collection points.	https://weee-forum.org/ws_news/international-e-waste-day-2021/
E3	The increase in demand for secondary raw materials	This is due to the move toward a circular supply chain model.	Krook et al. 2012; Burlakovs et al. 2017, https://weee-forum.org/ws_news/international-e-waste-day-2021/
E4	Existing industry business requirements (financial, organizational)	The requirements are described as high. This results in little or no competition in the industry (recyclers, repair services) or even a lack thereof (remanufacturing, refreshing).	The WEEE Directive
E5	The consumption model of the EEE user	At present, this is based on the desire to own the product. CE assumptions propose a model based on usage – PaaS, leasing, rentals, subscriptions, sharing.	Shittu et al. 2021
Group 5: Product -P			
P1	The design for R	This allows the implementation of a cascade business model (recycling, remanufacturing, reuse, repair) or other models related to circular supply chains.	Rudolf et al. 2022; Svensson-Hoglund et al. 2021
P2	The existing availability of information about product structure (e.g. Digital Product Passport)	Information about EEE, such as its composition, sources of origin, environmental impact, as well as information about the product's life cycle – including recycling and disposal – allows the development of a cascade business model.	Jensen et al., 2023 Berger et al., 2023
P3	The existing availability of disassembly information	This allows EEE to be remanufactured/refurbished or repaired.	Westkämper, 2023 Ketzenberg et al., 2023
P4	The availability of spare parts and increased reparability of products	This allows EEE to be remanufactured/refurbished or repaired.	Zhang and X, 2016; Ongondo et al. 2011
P5	The design of products with extended durability	This allows the customer to extend the life of EEE. EEE later goes into circulation as WEEE.	Rivera and Lallmahomed 2016‘ Svensson-Hoglund et al. 2021; Maitre-Ekern and Dalhammar 2016
Group 6: Customer – C			
C1	The short time of use of the product by the customer (end of use of the product even though technically sound)	Speed of technological innovation makes used EEE less attractive for customers (e.g., less energy/water efficient). Consumers want to own modern, technologically advanced equipment. Therefore, consumers dispose of working EEE that could be reintroduced to the consumer market.	Cox et al. 2013; Ongondo et al. 2015; Pierron et al. 2017; Rivera and Lallmahomed 2016; Jaeger-Erben et al. 2020; Mccollough 2010b
C2	The acceptance by the customer of products from re-use or remanufacture	Despite the public's growing awareness of CE, consumers are reluctant to choose products from value retention processes. This is due to little knowledge and fear that such products are of inferior quality or functionality.	Jaeger-Erben et al. 2020; Pérez-Belis et al. 2017;
C3	Easy access to repair or remanufacture services	Even if customers are willing to purchase remanufactured or refurbished EEE, the lack of availability of such services is still a problem.	Rudolf et al. 2022; Svensson-Hoglund et al. 2021; Pérez-Belis et al. 2017; Raihanian Mashhadi et al .2016 ; Sabbaghi et al. 2017;
C4	Easy access to new EEE	Lack of access to repair or remanufacturing services in comparison to the unlimited opportunities to purchase new EEE.	Rainsberger,2023
C5	The total cost of ownership to the client (purchase + servicing, repair)	At present, customers prefer to purchase new EEE instead of having it repaired, mainly due to the cost of this service, which can exceed the cost of buying a new item.	Svensson-Hoglund et al. 2021; McCollough 2009; McCollough 2007, Kerschbamer and Sutter 2017

Source: own work

This study applied the method of a structured face-to-face expert survey. The survey sheet developed for the study consists of 3 parts referring to the cascade model of recovery (I – WEEE recycling, II – EEE remanufacturing, III – repairs). In each part, the experts evaluated the roles of 30 impact factors (Table 1) in the collection of (W)EEE. We used a 7-point Likert scale, where: 1 – the factor is a barrier to a very large extent to the development of the recovery process, 2 – a barrier to a large extent, 3 – a barrier to a small extent, 4 – the factor is neutral, 5 – the factor supports the development of the recovery process to a small extent, 6 – the factor supports the development to a large extent, 7 –

the factor supports the development of one of the 3 reuse scenarios to a very large extent. Eight (8) experts participated in the survey: 3 practitioners, 3 researchers, and 2 lobbyists.

We calculated the coefficient of variation, CV, based on the expert evaluations. The coefficient of variation is the quotient of the standard deviation of a trait and its arithmetic mean. A high value of the coefficient means there is high variation of the trait and indicates heterogeneity of opinions in the studied population; a low value indicates low variation of the trait and homogeneity of the studied population. In our study, we adopted the following rules: CV≤ 25% – low variability, CV ϵ (25%; 45%> – average variability, CV ϵ (45%; 100%> – strong variability, CV > 100%– very strong variability (Bedeian, 1988).

RESULTS

In our research, based on a review of the literature, industry reports, expert opinions, and media monitoring, we identified 30 factors that have an influence on the transition to CSC (W)EEE in the European Union (Table 1). Then, based on the expert assessment, we determined which of the 30 factors the experts considered to be the drivers. For this purpose, we used the coefficient of variation – CV. For further analysis, we used only those factors for which CV≤ 0.25 (Table 2, highlighted in red). In this way, we identified the list of key drivers for the development of recovery processes for the transition to a circular supply chain.

Table 2. Value of CV of expert evaluations

ID Factor	*L1*	*L2*	*L3*	*L4*	*L5*	*RL1*	*RL2*	*RL3*	*RL4*	*RL5*	*T1*	*T2*	*T3*	*T4*	*T5*
Rec	**0,21**	**0,23**	0,30	0,28	0,36	0,31	0,31	**0,23**	0,28	**0,16**	**0,16**	**0,16**	**0,16**	**0,17**	0,63
Rem	**0,25**	**0,13**	**0,16**	**0,16**	0,52	0,37	0,37	**0,23**	**0,18**	**0,19**	**0,25**	0,26	0,26	0,31	0,7
Rep	**0,28**	**0,20**	**0,14**	**0,19**	0,42	0,40	0,34	**0,21**	**0,13**	**0,17**	**0,23**	0,28	0,30	**0,23**	0,67
ID Factor	*E1*	*E2*	*E3*	*E4*	*E5*	*P1*	*P2*	*P3*	*P4*	*P4*	*C1*	*C2*	*C3*	*C4*	*C5*
Rec	0,50	0,30	0,39	0,48	**0,18**	0,30	0,50	0,56	0,44	0,51	**0,18**	0,43	0,46	**0,21**	**0,20**
Rem	0,68	0,44	0,51	0,44	**0,21**	0,29	0,36	0,37	0,30	0,56	0,46	0,28	0,30	0,50	0,32
Rep	0,73	0,46	0,51	0,41	**0,18**	**0,17**	**0,23**	**0,19**	**0,11**	0,37	0,40	**0,11**	**0,24**	0,47	0,35

Source: own work

Based on the results, we obtained a set of 21 key factors that experts unanimously considered to be stimulators for the development of CSC (W)EEE or neutral factors. The set of factors is not the same for all 3 recovery scenarios. The strength and character of their impact also varies (Figure 4).

Table 2 and Figure 4 present the summary of the expert assessments. The experts reached a consensus in identifying the stimulators of the transition toward CSC (W)EEE. They identified RL5 – Multiple disposal options for users and RL4 – Visual inspection of WEEE and EEE (in a logistics hub) for remanufacturing and repair as strong drivers. They also considered RL3 – Sorting (e.g., by different types, brands) of WEEE and EEE at the collection site, to be a factor that stimulates the development of three recovery processes to a small extent. These three factors, RL3, RL4 and RL5, are directly related to the flow of materials within W(EEE) supply chains and the reverse logistics system. They have been recognized as drivers for the development of W(EEE) reuse scenarios, indicating that sorting, visual inspection of (W)EEE at the logistics center, W(EEE) collection points and multiple ways for consumers to dispose of (W)EEE should be further developed. In our view, classification through visual inspection could contribute to the strong development of circular supply chains. This is especially relevant for the development of remanufacturing and EEE repair processes.

Factor E5 – Experts found that the EEE users' consumption model stimulates the remanufacturing and repair process to a small extent, whilst the impact of the recycling process was assessed as neutral.

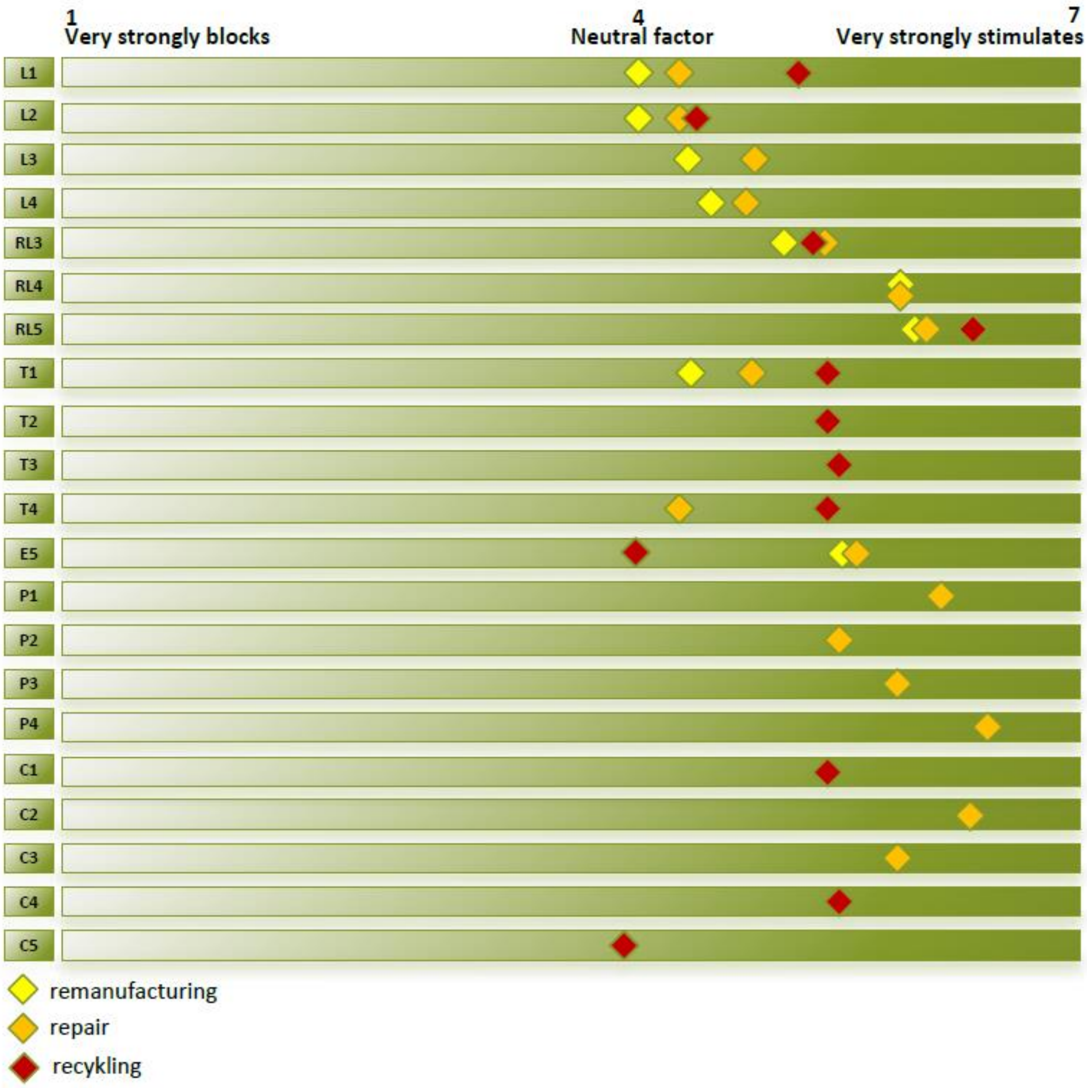

Fig. 4. Drivers and inhibitors of (W)EEE recovery processes Source: own work

DISCUSSION

It can be concluded that to further develop remanufacturing and repair processes, usage-based models – e.g., PaaS, leasing, renting, subscriptions, sharing – should be promoted among consumers.

For the recycling process, experts also considered factors related to technology (T1–T4) to be stimulators but of relatively low importance. This is probably due to the fact that there are currently few ready-made and dedicated technological solutions available, such as automated lines for recycling of (W)EEE. However, their further development could support the scaling up of the recycling process.

The experts identified Factors C1 and C4 as factors that drive the development of recycling to a small extent. Factor C1 – The short time of use of the product by the customer (end of use of the product even though technically sound), unequivocally supports the development of recycling. The sooner a product is considered WEEE by the consumer, the sooner it becomes an input product to the recycling process. In the case of C4 – Easy access to new EEE, the development of WEEE recycling is further possible because it is easier for clients to purchase a new EEE than to repair or remanufacture it. This is due to the lack of access to repair or remanufacturing services compared to the unlimited opportunities to purchase new EEE.

Consequently, for the EEE repair process, experts unanimously considered the factors assigned to the P – Product (P1–P4) group, as well as C2 and C3, to be strong drivers. Factors such as P1 – The design for R; P2 – The existing availability of information about the structure of the product; P3 – The existing availability of disassembly information; P4 – The availability of spare parts, and the increased repairability of the products are factors that should be improved for the growth of the EEE repairs. Similarly, an increase in factor C2 – Acceptance by the customer of products from re-use or remanufacture, and C3 – Easier access to repair or remanufacture services may positively influence the development of circular EEE supply chains.

CONCLUSIONS

In this paper, in order to answer RQ1, we identified a set of 30 factors that have an influence on the transition towards CSC (W)EEE. Based on an expert survey, we developed a list of 18 factors that stimulate at least one of the WEEE or EEE recovery processes (RQ2). The strength of the factors that stimulate the development of a (W)EEE collection system within circular supply chains ranges from weak to very stimulating. None of the factors was rated as very strongly stimulating the development of (W)EEE recovery processes (RQ3). The factor RL5 – Multiple disposal options for users for the recycling and remanufacturing process and P4 – The availability of spare parts and the increased reparability of products for the repair process were identified as the most influential.

In general, the conclusions we established indicate that the development of reverse logistics processes is necessary for the development of circular (W)EEE supply chains. Factors assigned to the L – Legislation group were mostly considered by experts to be neutral. The exception was L1 – WEEE Directive, which was rated as stimulating the development of WEEE recycling at a low level.

In the Economy – E group, experts were not unanimous in their opinions, rating only 1 factor E5 as weakly stimulating the process of remanufacturing and repair and as neutral for the process of recycling.

The limitations of the paper are related to the geographic focus of the study. Conditions typical in the European Union for the management of W(EEE) were taken into consideration. All experts had extensive experience and knowledge of the EU market.

Future research will focus on the development of the decision model with guidelines which allow the stimulators to take effect, and thus empower the transition to circular supply chains in the EEE sector.

ACKNOWLEDGMENTS

This research was supported by the SCANDERE (Scaling up a circular economy business model by new design, leaner remanufacturing, and automated material recycling technologies) project funded by the ERA-MIN3 program under grant number 101003575. Poznan University of Technology is financially supported by NCBR, National Centre for Research and Development, Poland (No. ERA-MIN3/1/SCANDERE/4/2022).

REFERENCES

Álvarez- de-los-Mozos, E., Rentería-Bilbao, A., & Díaz-Martín, F., 2020, WEEE Recycling and Circular Economy Assisted by Collaborative Robots. Applied Sciences, 10(14), 4800. https://doi.org/10.3390/app10144800

Aminoff, A., & Kettunen, O. (2016). Sustainable supply chain management in a circular economy—towards supply circles. In Sustainable Design and Manufacturing 2016 (pp. 61-72). Springer International Publishing, https://doi.org/10.1007/978-3-319-32098-4_6

Andersen, T., Jæger, B., & Mishra, A., 2020, Circularity in Waste Electrical and Electronic Equipment (WEEE) Directive. Comparison of a Manufacturer's Danish and Norwegian Operations. Sustainability, 12(13), 5236. https://doi.org/10.3390/su12135236

Annarelli, A., Battistella, C., & Nonino, F. (2016). Product service system: A conceptual framework from a systematic review. Journal of cleaner production, 139, 1011-1032, https://doi.org/10.1016/j.jclepro.2016.08.061

Ayati S. M., Shekarian E., Majava J., Wæhrens B.V., Toward a circular supply chain: Understanding barriers from the perspective of recovery approaches, Journal of Cleaner Production, Volume 359, 2022, 131775, ISSN 0959-6526, https://doi.org/10.1016/j.jclepro.2022.131775.

Baldé,C.P., Forti,V., Gray,V., Kuehr,R. and Stegmann,P., 2017, The Global E-waste Monitor – 2017, United Nations University (UNU). International Telecommunication Union (ITU) & International Solid Waste Association (ISWA), Bonn/Geneva/Vienna.

Batista, L., Bourlakis, M., Smart, P., & Maull, R. (2018). In search of a circular supply chain archetype–a content-analysis-based literature review. Production Planning & Control, 29(6), 438-451.

Bedeian, A. G., Armenakis, A. A., & Randolph, W. A. (1988). The Significance of Congruence Coefficients: A Comment and Statistical Test. Journal of Management, 14(4), 559-566. https://doi.org/10.1177/014920638801400406

Berger K., Baumgartner R.J., Weinzerl M., Bachler J., Schöggl J. P. (2023), Factors of digital product passport adoption to enable circular information flows along the battery value chain, Procedia CIRP, Volume 116. 528-533, https://doi.org/10.1016/j.procir.2023.02.089.

Bressanelli G., Saccani N., Pigosso D.C.A., Perona M., Circular Economy in the WEEE industry: a systematic literature review and a research agenda, Sustainable Production and Consumption, Volume 23, 2020, Pages 174-188, ISSN 2352-5509, https://doi.org/10.1016/j.spc.2020.05.007.

Bundgaard A.M., Huulgaard R.D. (2023)The role of standards in support of material efficiency requirements under the Ecodesign Directive, Journal of Cleaner Production, Volume 385, https://doi.org/10.1016/j.jclepro.2022.135599.

Burlakovs, J.; Kriipsalu, M.; Klavins, M.; Bhatnagar, A.; Vincevica-Gaile, Z.; Stenis, J.; Jani, Y.; Mykhaylenko, V.; Denafas, G.; Turkadze, T., 2017, Paradigms on landfill mining: From dump site scavenging to ecosystem services revitalization. Resour. Conserv. Recycl. 2017, 123, 73–84, https://doi.org/10.1016/j.resconrec.2016.07.007

Chen Z., Tan A., 2021. Exploring the circular supply chain to reduce plastic waste in Singapore. LogForum 17 (2), 271-286, http://doi.org/10.17270/J.LOG.2021.564

Cole, Agrawal, S., Singh, R.K. & Murtaza, Q., 2015, A literature review and perspectives in reverse logistics. Resources, Conservation and Recycling. 97: 76-92, http://doi.org/10.1016/j.resconrec.2015.02.009

Cole, C., Osmani, M., Quddus, M., Wheatley, A. & Kay, K., 2014, Towards a zero waste strategy for an English local authority. Resources, Conservation and Recycling. 89: 64-75, http://dx.doi.org/10.1016/j.resconrec.2014.05.005

Chancerel, P. & Rotter, S., 2009, Recycling-oriented characterization of small waste electrical and electronic equipment. Waste Management, 29 (8), 2336-2352, https://doi.org/10.1016/j.wasman.2009.04.003

Coughlan D., Fitzpatrick C., 2020, Trialling the preparation for reuse of consumer ICT WEEE in Ireland, Journal of Cleaner Production, Volume 256, 2020, 120512, ISSN 0959-6526, https://doi.org/10.1016/j.jclepro.2020.120512.

Cox, J., Griffith, S., Georgi, S., and King, G., 2013, Consumer understanding of product lifetimes. Resources, Conservation and Recycling, 79, 21-29 (2013), DOI: 10.1016/j.resconrec.2013.05.003

Dimitrakakis, E., Janz, A., Bilitewski, B. & Gidarakos, E., 2009, Small WEEE: determining recyclables and hazardous substances in plastics. Journal of hazardous materials. 161(2) 913-919, https://doi.org/10.1016/j.jhazmat.2008.04.054

Dindarian, A., Gibson, A.A.P. & Quariguasi-Frota-Neto, J., 2012, Electronic product returns and potential reuse opportunities: a microwave case study, in the United Kingdom. Journal of Cleaner Production. 32: 22-31, https://doi.org/10.1016/j.jclepro.2012.03.015

Directive 2012/19/EU of the European Parliament and of the Council of 4 July 2012 on waste electrical and electronic equipment (WEEE), https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:02012L0019-20180704 access: 25.05.2023

Dowlatshahi, S. (2000). Developing a Theory of Reverse Logistics. Interfaces, 30(3), 143–155. http://www.jstor.org/stable/25062603

European Parliament resolution on the right to repair (2022/2515(RSP)), https://www.europarl.europa.eu/doceo/document/B-9-2022-0175_EN.pdf, accsess :May, 23, 2023

Farooque, M., Zhang, A., Thürer, M., Qu, T., & Huisingh, D. (2019). Circular supply chain management: A definition and structured literature review. Journal of cleaner production, 228, 882-900 https://doi.org/10.1016/j.jclepro.2019.04.303

Flygansvær, B., Dahlstrom, R., & Nygaard, A. (2018). Exploring the pursuit of sustainability in reverse supply chains for electronics. Journal of Cleaner Production, 189, 472-484. https://doi.org/10.1016/j.jclepro.2018.04.014Get rights and content

Forti V., Baldé C.P., Kuehr R., Bel G., 2020, The Global E-waste Monitor 2020: Quantities, flows and the circular economy potential, United Nations University (UNU)/United Nations Institute for Training and Research (UNITAR) – co-hosted SCYCLE Programme, International Telecommunication Union (ITU) & International Solid Waste Association (ISWA), Bonn/Geneva/Rotterdam.

Genovese, A., Acquaye, A. A., Figueroa, A., & Koh, S. L. (2017). Sustainable supply chain management and the transition towards a circular economy: Evidence and some applications. Omega, 66, 344-357, https://doi.org/10.1016/j.omega.2015.05.015

Golinska-Dawson, Paulina, Karolina Werner-Lewandowska, and Monika Kosacka-Olejnik. 2021. "Responsible Resource Management in Remanufacturing—Framework for Qualitative Assessment in Small and Medium-Sized Enterprises" *Resources* 10, no. 2: 19. https://doi.org/10.3390/resources10020019

Gonda L., D'Ans P., Degrez M., 2019, A comparative assessment of WEEE collection in an urban and rural context: Case study on desktop computers in Belgium, Resources, Conservation and Recycling, Volume 142, 2019, Pages 131-142, ISSN 0921-3449, https://doi.org/10.1016/j.resconrec.2018.11.008.

https://weee-forum.org/ws_news/international-e-waste-day-2021/

Jensen S.F., Kristensen J.H., Adamsen, S., Christensen A., Waehrens B.V. (2023). Digital product passports for a circular economy: Data needs for product life cycle decision-making, Sustainable Production and Consumption, Volume 37, 2023, 242-255, https://doi.org/10.1016/j.spc.2023.02.021.

Kawa, A., & Golinska, P. (2010). Supply chain arrangements in recovery network. In Agent and Multi-Agent Systems: Technologies and Applications: 4th KES International Symposium, KES-AMSTA 2010, Gdynia, Poland, June 23-25, 2010, Proceedings. Part II 4 (pp. 292-301). Springer Berlin Heidelberg, https://doi.org/10.1007/978-3-642-13541-5_30

Kerschbamer, R., Sutter, M., 2017, The economics of credence goodsea survey of recent lab and field experiments. CESifo Econ. Stud. 63 (1), 1e23.

Ketzenberg, M. E., Souza, G. C., & Guide, V. D. R. (2003). Mixed Assembly And Disassembly Operations For Remanufacturing. Production and Operations Management, 12(3), 320-335. https://doi.org/10.1111/j.1937-5956.2003.tb00206.x

Kosacka-Olejnik, M., & Werner-Lewandowska, K. (2020). Reverse logistics as a trend of XXI century–state of art. Management Systems in Production Engineering, 28(1), 9-14, https://doi.org/10.2478/mspe-2020-0002

Krook, J.; Svensson, N.; Eklund, M., 2012, Landfill mining: A critical review of two decades of research. Waste Manag. 2012, 32, 513–520, https://doi.org/10.1016/j.wasman.2011.10.015

Kuo, T.C., 2010, The construction of a collaborative-d,esign platform to support waste electrical and electronic equipment recycling. Robot. Comput. Integr. Manuf. 2010, 26, 100–108, https://doi.org/10.3390/su12135236

Lahane, S., Kant, R., & Shankar, R. (2020). Circular supply chain management: A state-of-art review and future opportunities. Journal of Cleaner Production, 258, 120859, https://doi.org/10.1016/j.jclepro.2020.120859

Lamenta Z., Grzybowska K., 2023, Impact of the European Green Deal on Business Operations—Preliminary Benchmarking, Sustainability 2023, 15(10), 7780, https://doi.org/10.3390/su15107780

Li M., Cao G., Cui L., Liu X., Dai J., 2023, Examining how government subsidies influence firms' circular supply chain management: The role of eco-innovation and top management team, International Journal of Production Economics, Volume 261, 2023, 108893, ISSN 0925-5273, https://doi.org/10.1016/j.ijpe.2023.108893

Linder, M., & Williander, M. (2017). Circular business model innovation: inherent uncertainties. Business strategy and the environment, 26(2), 182-196, DOI: 10.1002/bse.1906

Maitre-Ekern, E., Dalhammar, C., 2016, Regulating planned obsolescence: a review of legal approaches to increase product durability and reparability in Europe.Rev. Eur. Community Int. Environ. Law 25 (3), 378e394. https://doi.org/10.1111/reel.12182.

Merli, R., Preziosi, M., & Acampora, A. (2018). How do scholars approach the circular economy? A systematic literature review. Journal of cleaner production, 178, 703-722. https://doi.org/10.1016/j.jclepro.2017.12.112.

Mishra J.T., Hopkinson P.G. & Tidridge G., 2018, Value creation from circular economy-led closed loop supply chains: a case study of fast-moving consumer goods, Production Planning & Control, 29:6, 509-521, https://doi.org/10.1080/09537287.2018.1449245

Ongondo, F.O., Williams, I.D. and Whitlock, G., 2015, Distinct Urban Mines: Exploiting secondary resources in unique anthropogenic spaces. Waste Management, 45, 4-9, https://doi.org/10.1016/j.wasman.2015.05.026

Perez-Belis, V., Braulio-Gonzalo, M., Juan, P., Bovea, M.D., 2017, Consumer attitude towards the repair and the second-hand purchase of small household electrical and electronic equipment. A Spanish case study. J. Clean. Prod. 158, 261e275. https://doi.org/10.1016/j.jclepro.2017.04.143.

Pierron, X., Williams, I., & Shaw, P., 2021, Extending the Theory of Planned Behaviour Using Behavioural Economics to Reduce and Access Small WEEE Anthropogenic Stocks. Volume 14 – March 2021, 14, 54–67. https://doi.org/10.31025/2611-4135/2021.14062

Pierron, X., Williams, I.D., Shaw, P.J. and Cleaver, V., 2017, Using choice architecture to exploit a university Distinct Urban Mine. Waste Management, 68, 547-556, https://doi.org/10.1016/j.wasman.2017.06.034

Raihanian Mashhadi, A., Esmaeilian, B., Cade,W.,Wiens, K., Behdad, S., 2016, Mining consumer experiences of repairing electronics: product design insights and business lessons learned. J. Clean. Prod. 137, 716e727. https://doi.org/10.1016/j.jclepro.2016.07.144.

Rainsberger, L. (2023). The EEE-World. In The Modern Customer–the PHANTOM: Customers on the Run: How Sales must Respond to Radically New Buying Behavior (pp. 1-18). Wiesbaden: Springer Fachmedien Wiesbaden. https://doi.org/10.1007/978-3-658-39196-6_1

Ravindra, K., Kaur, K., & Mor, S. (2015). System analysis of municipal solid waste management in Chandigarh and minimization practices for cleaner emissions. Journal of Cleaner production, 89, 251-256, http://dx.doi.org/10.1016/j.jclepro.2014.10.036

Rivera, J.L., Lallmahomed, A., 2016, Environmental implications of planned obsolescence and product lifetime: a literature review. Int. J. Sustain. Eng. 9 (2), 119e129. https://doi.org/10.1080/19397038.2015.1099757.

Rosa, P., Sassanelli, C., & Terzi, S. (2019). Towards Circular Business Models: A systematic literature review on classification frameworks and archetypes. Journal of cleaner production, 236, 117696, https://doi.org/10.1016/j.jclepro.2019.117696

Rudolf S., Blömeke S., Niemeyer J.F., Lawrenz S., Sharma P., 2022, Hemminghaus, S.; Mennenga, M.; Schmidt, K.; Rausch, A.; Spengler, T.S.; et al. Extending the Life Cycle of EEE—Findings from a Repair Study in Germany: Repair Challenges and Recommendations for Action. Sustainability 2022, 14, 2993. https://doi.org/10.3390/su14052993

Sabbaghi, M., Cade, W., Behdad, S., Bisantz, A.M., 2017, The current status of the consumer electronics repair industry in the U.S.: a survey-based study. Resour. Conserv. Recycl. 116, 137e151. https://doi.org/10.1016/j.resconrec.2016.09.013.

Sari E.B., 2020. Recovery alternatives decision by using fuzzy based preference selection index method. LogForum 16 (1), 171-181, http://doi.org/10.17270/J.LOG.2020.386

Seuring, S., & Müller, M. (2008). From a literature review to a conceptual framework for sustainable supply chain management. Journal of cleaner production, 16(15), 1699-1710, https://doi.org/10.1016/j.jclepro.2008.04.020

Shekarian, E., 2020, A review of factors affecting closed-loop supply chain models. Journal of Cleaner Production, 253, 119823. https://doi.org/10.1016/j.jclepro.2019.119823

Shittu, O. S., Williams, I. D., Shaw, P., Montiero, N., & Creffield, R., 2021, Demonstrating reuse of EEE in a distinct urban mine: a case study. Volume 15 – June 2021, 15, 78–93. https://doi.org/10.31025/2611-4135/2021.15091

Sosnowski P.C., Cyplik P., 2022, Closed loop supply chains and circular economy – the possibilities of interplay. LogForum 18 (4), 413-420, http://doi.org/10.17270/J.LOG.2022.784

Svensson-Hoglund S., Richter J.L., Maitre-Ekern E., Russell J.D., Pihlajarinne T., Dalhammar C.,2021, Barriers, enablers and market governance: A review of the policy landscape for repair of consumer electronics in the EU and the U.S., Journal of Cleaner Production, Volume 288, 2021, 125488, ISSN 0959-6526, https://doi.org/10.1016/j.jclepro.2020.125488

Tukker, A. (2015). Product services for a resource-efficient and circular economy–a review. Journal of cleaner production, 97, 76-91, https://doi.org/10.1016/j.jclepro.2013.11.049

Tura N., Hanski J., Ahola T., Ståhle M., Piiparinen S., Valkokari P., 2019, Unlocking circular business: A framework of barriers and drivers, Journal of Cleaner Production, Volume 212, 2019, Pages 90-98, ISSN 0959-6526, https://doi.org/10.1016/j.jclepro.2018.11.202.

Waite, S., Cox, P. & Tudor, T., 2015, Strategies for local authorities to achieve the EU 2020 50% recycling, reuse and composting target: A case study of England. Resources, Conservation and Recycling, 105: 18-28, http://dx.doi.org/10.1016/j.resconrec.2015.09.017

WEEE Forum 2019, The International e-waste day. (Online) Available at: https://weee-forum.org/iewd-about/ (accessed 4 Oct 2019).

Westkämper E., (2003), Assembly and Disassembly Processes in Product Life Cycle Perspectives, CIRP Annals,Volume 52, Issue 2, 579-588, https://doi.org/10.1016/S0007-8506(07)60205-4.

Wiens, K. ,2015, New high-tech farm equipment is a nightmare for farmers. Wired.

Wilkinson, A. and Williams, I.D., 2020, Why do (W)EEE hoard? The effect of consumer behaviour on the release of (W)EEE from home entertainment products into the circular economy. Detritus (In press), 1-16 https://doi.org/10.31025/2611-135/2020.14004

World Economic Forum, 2019, A new circular vision for electronics. World Economic Forum, 91-93 route de la Capite CH-1223 Cologny/ Geneva Switzerland; www.weforum.org.

Zhang, L. & Xu, Z., 2016, A review of current progress of recycling technologies for metals from waste electrical and electronic equipment. Journal of Cleaner Production. 127, 19-36, https://doi.org/10.1016/j.jclepro.2016.04.004

Zhang, L., Geng, Y., Zhong, Y. et al., 2019, A bibliometric analysis of waste electrical and electronic research. Environmental Science and Pollution Research, 26, 21098–21108 https://doi.org/10.1007/s11356-019-05409-2

Zhu, Q., Geng, Y., & Lai, K. H. (2010). Circular economy practices among Chinese manufacturers varying in environmental-oriented supply chain cooperation and the performance implications. Journal of environmental management, 91(6), 1324-1331, https://doi.org/10.1016/j.jenvman.2010.02.013

Karolina Werner-Lewandowska ORCID ID: https://orcid.org/0000-0002-9549-4511
Faculty of Engineering Management,
Poznan University of Technology, **Poland**
e-mail: karolina.werner@put.poznan.pl

Paulina Golińska-Dawson ORCID ID: https://orcid.org/0000-0002-5821-3805
Faculty of Engineering Management,
Poznan University of Technology, **Poland**
e-mail: paulina.golinska@put.poznan.pl

Piotr Cyplik ORCID ID: https://orcid.org/0000-0002-5775-6760
Faculty of Engineering Management,
Poznan University of Technology, **Poland**
e-mail: piotr.cyplik@put.poznan.pl