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Constraints leading to system-level lock-ins—the case of electronic waste management in the circular economy

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ABSTRACT

This study aims to systematically go through the various factors that prevent the implementation and diffusion of new closed-loop solutions and, thus, the transformation towards a circular economy. These factors are studied in the context of waste electrical and electronic equipment (WEEE) management. WEEE management offers an interesting context to study this, as technologies and political pressures, as well as a business potential for more efficient material recovery, exist. The study follows an embedded single case design based on interviews with actors in the WEEE management system. While the individual constraints may hinder the uptake of advanced recycling solutions, the interactions between these constraints seem to have an enforcing effect and lead to the formation of system-level lock-ins. This study identified three system-level lock-ins, the national extended producer responsibility scheme, techno-economic issues, and tensions in the supply chain, which impede the adoptation of innovations and the consequent transformation of the WEEE management system. Understanding how these constraints interact is essential for any effort to unlock the system and support the circular economy transformation.

1. Introduction

A circular economy (CE) is suggested as a concept to overcome the sustainability challenges of the current linear economy. The benefits of a CE are relatively well understood, and the CE has the potential to achieve a more sustainable society and economic growth (Blomsma and Brennan, 2017). However, while we have achieved advances in some aspects of the CE, certain factors still hinder or even prevent implementing a CE (Geissdoerfer et al., 2017; Tura et al., 2019). Implementing a CE would require a systemic change; the co-evolution of technologies, firms, institutions, and society as a whole (Cecere et al., 2014).

A better understanding of what hinders the transformation towards a CE in different contexts and how to overcome them is needed. To study this, we mobilise the concepts of constraints and lock-ins. From the definitions point of view of, the literature is not always consistent in its terminology. Still, this study defines constraints as individual factors that can hinder or slow down the transformation. At the same time, *lock-ins* are seen as coevolved factors that eventually prevent the transformation of a socio-technical system in the near future. The rationale behind a lock-in is that industrial economies have been locked into traditional systems through a process of technological and institutional co-evolution driven by path-dependent increasing returns to scale (Unruh, 2000). Lock-ins result from the efficient convergence of established ways of seeing and doing and can inhibit the diffusion and implementation of new technological solutions despite their apparent environmental and economic advantages (Svingstedt and Corvellec, 2018; Unruh, 2000). Although its obvious relevance, we still know only a little how different individual constraints coevolve to form lock-ins.

This study investigates individual constraints and how they form system-level lock-ins in the context of waste electrical and electronic equipment (WEEE) management. WEEE represents the widest and fastest-growing waste stream, as ca. 45 million tons of WEEE are disposed globally every year, with an annual growth rate of 3–5% (Bressanelli et al., 2020). Regarding a CE, the WEEE industry has substantial economic potential: the overall value of the secondary raw materials in WEEE is estimated to be 55 Billion Euros (Baldé et al., 2017). Indeed, recovering rare earth elements and other critical raw materials (CRMs) from WEEE is at the heart of a CE and essential in mitigating the anticipated shortage of resources (Corsini et al., 2015). However, there is still a significant challenge in achieving the potential environmental, social, and economic gains linked to a CE within the WEEE industry (Bressanelli et al., 2020).

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This study aims *to develop an in-depth understanding of constraints and their role in the formation of system-level lock-ins that prevent the uptake of new technological innovations designed to improve the material efficiency of a WEEE management system. The aim is also to show the theoretical and practical relevance of understanding the lock-ins in this context.* The research questions of this study are: (RQ1) What factors in the WEEE management system constrain the implementation and diffusion of technological innovations? (RQ2) How do these constraints interact and contribute to the formation of system-level lock-ins within the socio-technical system of WEEE management?

The study applies an embedded single case design of the WEEE management system in Finland and contributes to understanding what hinders the transformation towards a CE. The previous empirical literature has emphasised that the relative significance of the individual constraints is highly context-specific (Tura et al., 2019; Aminoff and Pihlajamaa, 2020), and more knowledge is needed in different contexts. Notably, a better understanding of how system-level lock-ins that hinder the implementation of CE principles are formed would provide theoretical and practical assistance in overcoming them. WEEE management offers an interesting context to study this phenomenon, as technologies, political pressures, and business potential exist for improving WEEE recycling for improved recovery of CRMs and other materials. However, uptake of these solutions is still slow. The WEEE industry is gaining primary importance within a CE context (Bressanelli et al., 2020). Also, the WEEE industry would benefit from adopting the CE perspective as there is a lack of a sector-specific approach to CE implementation within the WEEE industry –the literature is still generic in the context of manufacturing companies (Tura et al., 2019; Bressanelli et al., 2020)

2. Literature review

2.1. Challenges of WEEE management system

Rapid technological innovations and increased purchasing power have fuelled the consumption of electrical and electronic equipment (EEE) (Islam and Huda, 2018). The complex composition of electronic appliances makes waste management challenging (Cucchiella et al., 2015). WEEE must be considered as a dangerous waste stream, which, if not treated properly, can cause severe environmental and human health damage (Corsini et al., 2015; Mazahir et al., 2019). Most End-of-Life (EoL) electronic equipment is recycled, as recycling is a low-cost solution that enables compliance with environmental regulations. The recycling process includes collection, disassembly, shredding, separation, and compression of residuals (Cucchiella et al., 2015).

WEEE recycling would provide an opportunity to recover valuable metals and rare natural elements, which is essential, as an increasing number of CRMs are being used in electronic equipment (Boundy, 2020; Corsini et al., 2015). However, recycling practices have not followed the development towards more complex electronic products (Ylä-Mella and Pongrácz, 2016). Many valuable metals are often present in low concentrations and cannot be recovered in conventional WEEE processing facilities utilising only destructive technologies (Ylä-Mella and Pongrácz, 2016; Kumar and Dixit, 2018). Presently, most recycling facilities use technologies that allow efficient separation of steel and aluminium (Tanskanen, 2013) but fail to recover critical metals (Cole et al., 2019a). Thus, from the perceptive of a CE, the resource efficiency of WEEE recycling needs to be radically improved. Better technologies exist, but the uptake of these has been slow.

In the EU, the WEEE Directive, along with the updated circular economy action plan, are the key policy instruments to support the transition to a CE in the EEE sector (Zacho et al., 2018). The WEEE directive was first introduced in 2003, and it was amended in 2012 to better address rapidly expanding EEE markets and shortening innovation cycles (European Commission, 2012). The directive follows the waste hierarchy principle and prioritises prevention of WEEE, followed by the reuse, recycling, and other types of recovery of WEEE (European Commission, 2012). The WEEE Directive introduced the producer responsibility principle, making producers financially responsible for the collection and treatment of WEEE (Corsini et al., 2015). One of the founding philosophies of the extended producer responsibility (EPR) is to link the manufacturing and EoL management of products to encourage reuse and efficient recycling (Corsini et al., 2015; Parajuly and Wenzel, 2017a). The recent update of the European circular economy action plan also addresses the need for extending product lifetimes of certain electronic devices by better eco-design (European Commission, 2020).

2.2. Theoretical foundations: Factors hindering the socio-technical transformation of a WEEE management system

The study investigates WEEE management as a socio-technical system. *Socio-technical systems* evolve gradually to fulfil certain societal functions and constitute of a complex set of technologies, institutions, networks, norms, preferences, knowledge, and rules, making them relatively stable and resistant to change (Geels, 2004; Rip and Kemp, 1998). While WEEE management forms a good example of a complex socio-technical system, this approach is only scarcely applied in this context or waste management in general (Andersson, 2019). The notable exception is Zacho et al. (2018), who investigated the constraints for increasing the reuse of EEE. They emphasised that the existing waste treatment has minimised the direct environmental impacts, reducing the pressure to implement more sustainable solutions, such as reuse or advanced recycling technologies. However, taking the socio-technical perspective would be important as several factors can create inertia within existing socio-technical systems that may resist or hinder further system transformation and implementation of alternative technologies despite demonstrated improvements to the existing system.

The *concept of lock-in* has its origins in economic studies of the diffusion of technological innovations. The concept was first introduced by Arthur (1989), who discovered that a system could be locked into inferior technologies that become dominant, preventing superior technologies from being adopted. Later Unruh (2000) introduced a more systemic approach and described technological change as a co-evolutionary process that involves not only technologies but also governing institutions and is driven by path-dependent increasing returns to scale. Technological, political and social factors coevolve, forming a socio-technical system around specific technologies and may prevent the diffusion of environmentally benign technologies (Unruh, 2000, 2002; Unruh and Carrillo-hermosilla, 2006). The actors or alliances that benefit from the current system are likely to resist any change; it is difficult to challenge established standards (Corvellec et al., 2013). In the context of WEEE management, recycling with destructive technologies has become the dominant standard (Cole et al., 2019a), which might lead to incremental rather than fundamental changes and lock-in to the established socio-technical system (cf. van den Bergh et al., 2011).

In the literature on CE and WEEE management, sources of inertia have been often labelled under the concepts of constraints and barriers. In contrast, the concept of lock-in has not received attention. These constraints and barriers present individual factors that hinder the transformation of the WEEE management system. One of the main factors identified are the *lack of economic incentives*. The current system is economically efficient in satisfying the market demand for recycled materials and ensuring compliance with environmental regulations (Parajuly and Wenzel, 2017a). Furthermore, *existing infrastructures* can hinder transformation, especially when building the infrastructure requires heavy investment, as is the case of waste management and energy systems (Arthur, 1989; Bolton and Foxon, 2015; Svingstedt and Corvellec, 2018; Unruh, 2002).

Technological or technical factors that hinder the transformation of socio-technical systems may involve existing technological solutions, including dominant design, standard technological architectures and components (Corvellec et al., 2013; Unruh, 2002). Additionally, technology interrelatedness, which occurs when adopting technology fosters the development of complementary technologies, may hinder adopting the technologies (Klitkou et al., 2015). Current EEE product design creates several problems for efficient recycling: first, it makes disassembly and material separation difficult; second, versatile product design and extremely low concentrations of materials in final products reduce recycling potential and hamper the development of economically viable recycling processes (Parajuly and Wenzel, 2017b). The recent trend of smaller and lighter appliances also hinders the economic viability of recycling because achieving sufficient volumes for recycling becomes even more challenging (Kumar et al., 2017). For low-value waste materials, the ability to recycle scrap in an economically viable way can be inhibited by the transportation costs associated with collecting a sufficient amount of material (Boundy, 2020). Furthermore, destructive and unselective technologies in the collection and pre-treatment stages reduce the quality of recovered materials and recycling profits (Ylä-Mella et al., 2014a).

Organisational inertia, caused by established routines and procedures, departmentalisation, and existing customer-supplier relations, is seen as a significant source of lock-ins within organisations (Cecere et al., 2014; Unruh, 2002). For example, municipalities that do not 'own' the EoL products lack the motivation to improve the collection system (Ylä-Mella and Pongrácz, 2016; Zacho et al., 2018), and accordingly, the producers do not have an economic incentive to develop the system (Ylä-Mella et al., 2014a).

Social and cultural factors, such as system socialisation, implementation of preferences, expectations, norms and codes of behaviour contribute to path-dependency and lock-ins (Corvellec et al., 2013; Unruh, 2002). In the existing socio-technical system, EoL products are regarded as waste and are handled in the same fashion as any other type of waste at the collection site. A general approach, particularly in small recycling plants, is to handle the mixed WEEE, regardless of product type and physical or functional condition (Parajuly et al., 2017). Moreover, a considerable portion of WEEE does not circulate and remains in the drawers of consumers (Ylä-Mella et al., 2014b; Ylä-Mella and Pongrácz, 2016).

Several political and institutional factors, such as legal frameworks, political agreements, ambiguity and lack of coordination between policies, existing networks and coalitions may hinder the transformation of socio-technical systems (Cecere et al., 2014; Cole et al., 2019a; Foxon 2002). For example, the existing compliance schemes of the EU directive on WEEE are designed for material collection and recycling instead of manufacturing-centred take-back. Most WEEE is collected by waste management companies and recycled (Parajuly and Wenzel, 2017a). Even though the current WEEE directive aims to reduce the environmental impact and has led to increased recycling within the EU, it has not encouraged actors to reduce material consumption and waste volumes or provided any incentive for reuse (Cole et al., 2019b).

From the critical materials point of view, current recycling policies put too much focus on maximising recycling rates (Cole et al., 2019b). There is no regulatory pressure to increase the recovery of CRMs. Another challenge are the relatively low collection rates via official channels. It has been estimated that only half of the annually generated WEEE was separately collected and appropriately managed under EU compliance schemes in 2010 (Ylä-Mella et al., 2014b). Several studies show that the more inconvenient the recycling schemes, the lower the participation and recovery rates. The rest of WEEE is collected informally by unregistered enterprises, illegally exported abroad or discarded as mixed waste into landfills.

Different impeding factors can emerge and coevolve simultaneously within a socio-technical system, as presented above in the context of WEEE management. The impact of these simultaneous factors is further intensified by network externalities, which emerge from systemic interactions (Unruh, 2000). The term *systemic lock-in* has been proposed in the literature for these interlinked factors that co-occur (Narula, 2002; Wesseling and Van der Vooren, 2017). Wesseling and Van der Vooren (2017, p.116) have further developed the concept and defined systemic lock-in as 'a set of systemic problems that sustain or reinforce each other in one or more closed feedback cycles of interdependent systemic problems'. While lock-ins are often assumed to be systemic, the interactions and mechanisms between these simultaneous hindering factors are less studied in the literature, except in the field of innovation system studies (e.g. Narula, 2002; Wesseling and Van der Vooren, 2017).

Previous CE literature has identified several barriers or constraints that impede the transformation (for example, Tura et al., 2019; Kirchherr et al., 2018; Grafström and Aasama, 2021). Notably, Tura et al. (2019) developed 'an integrated framework' of barriers and drivers to unlocking the CE based on an extensive literature review. They identified eight categories of barriers: Economic, Social, Institutional, Technological and informational, Supply Chains and Organizational. Zhuravleva and Aminoff (2021)- further elaborated this framework in the context of textile recycling. Grafström and Aasama (2021), also based on a literature review, summarised that inconsistent policies and high up-front costs are among the most prevalent barriers. However, the previous empirical literature has emphasised that the significance of individual constraints is *highly context-specific* (Tura et al., 2019). Therefore, CE concepts cannot be copied from one context to another and understanding the constraints in different contexts is needed. WEEE presents an interesting context for this purpose.

3. Methods

This study aims to develop an in-depth understanding of constraints and lock-ins that prevent the implementation and diffusion of new closed-loop innovations and the transformation of the WEEE management system. In this study, we opt for an embedded single case design (Yin, 2014), the case being the WEEE management system in Finland with its different actors as embedded cases. The single case approach is suitable for studying the phenomenon in-depth, as rich data is collected from several informants, allowing us to gain sufficient depth of understanding of different actors' perceptions and make sense of those perceptions (Yin, 2014).

The WEEE management system in Finland was considered to be a good case as the different organisations put a lot of effort to develop the system, and there are several research and development projects going on. Indeed, this case is information-rich (Piekkari et al., 2010) and provides relevant data to answer our research questions.

3.1. Case description: the WEEE management system in Finland

As an EU member state, Finland is obliged to operate a WEEE recovery system to meet the targets set by the EU WEEE directive. The amount of WEEE collected in Finland is moderate: 66,683 tonnes were collected in 2018. The majority of waste was treated in Finland and less than 6% was shipped to another EU member state for treatment (EUROSTAT, 2021). Over 86% of collected waste was recycled as materials, 5% was recovered as energy and 3% was reused. Despite having functioning national recovery systems, the total collection rate is only slightly above the minimum required by the EU directive (European Commission, 2012). However, the recovery rate of collected WEEE is high at 95% and the reuse and recycling rate stands at 90% (EUROSTAT, 2021). The majority of EEE entering markets is imported. As the EU directive on WEEE requires extended producer responsibility (EPR), most of the representatives of producers have fulfilled their responsibilities through compliance schemes and transferred responsibility to several producer associations that organise collection, transportation and recycling. Depending upon the material content and quality of waste, several different disposition alternatives are available, recycling and recovery as materials are the primary mode. Hazardous substances are removed and sent to hazardous waste treatment plants for processing. Metals, plastic and glass parts are sorted, and further processed as materials at recycling companies, smelters or sent to incinerators for energy recovery. Non-recoverable material is disposed of in a landfill. Usually, the WEEE is pre-processed mechanically using destructive methods combined with different sorting techniques, and the resulting fractions are processed in high-standard refineries. This paper focuses on the EoL stages, including WEEE collection, processing and recovery. Reuse is beyond the scope of this study.

3.2. Data collection

The basic assumption behind this study is that WEEE management could be made more efficient by using novel technological solutions. In this study, an advanced WEEE recycling concept was used as a *as a frame of reference* to study factors that hinder the uptake of technologies. This frame allowed us to explore the underlying perceptions of such a transformation in a systematic way. This specific WEEE recycling concept was developed in a joint research and development project (VTT, 2016). This advanced concept integrates material recovery with energy recovery by combining mechanical, thermal and hydrometallurgical unit processes. The technological concept aims to improve the efficiency of WEEE recycling and enable the recovery of valuable materials, including CRMs (VTT, 2016). Transforming WEEE recovery according to an integrated energy-material recovery concept would require changes in the whole WEEE management system.

We used purposive sampling (Patton, 2014) to select the case organisations. We selected the organisations that (1) play an important role in the WEEE recycling system in Finland, (2) present different roles in it, and (3) would potentially be affected by the transformation of the WEEE management system. We first selected the organisations that were part of the research and development project (VTT, 2016), as they have made efforts to understand what is needed for change and thus, can provide in-depth insights into the constraints. Based on the advice of these informants (i.e. snowballing), we contacted for one additional organisation, producer responsibility organisation, that could provide complementing insights. Table 1 presents the selected case organisations and informants in more detail. To acquire a comprehensive understanding of the lock-ins, various data sources were used (Table 1), which also enabled triangulation of the data.

Table 1
Case organisations and data collection details. Persons interviewed twice are marked with an asterisk.

Name	Organisation	Informant	Data collection method: interview (I), workshop (W)
Recyc1	Recycling company 1	R&D manager *	I
		Development engineer *	I
		CSR Manager	I
Recyc2	Recycling company 2	CEO	I
		Marketing manager *	I, W
Recyc3	Recycling company 3	EHSS Manager	I
		Technical manager	I
TechDev1	Technology development company 1	Technology manager	I
TechDev2	Technology development company 2	CEO	W
PRO1	Producer responsibility organization 1	COO	I
PRO2	Producer responsibility organization 2	CEO	I
IA	Industry association	Expert	I
RTO	Research and technology organization	Principal scientist	W
		Senior scientist 1	W
		Senior scientist 2	W
		Senior scientist 3	W
TechCon	Technology consultancy	CEO	W
		Senior advisor	W

The primary data collection method included semi-structured interviews. The informants were responsible for developing recycling and waste management or were leading experts of the topic. In the small organisations, we interviewed the CEOs. The interviews followed a general thematic guide, which was slightly modified based on the organisations' role in the system. The general focus was on understanding the prerequisites and constraints for the implementation and diffusion of an advanced WEEE recycling process and management system, i.e. the above-mentioned material-energy recovery concept used as a frame. The guide included the following general topics: performance of the existing WEEE management system, and prerequisites and constraints for the implementation of a new recovery concept. The results from interviews were further elaborated on in a participatory workshop. This workshop also contributed to the validation of preliminary findings.

3.3. Data coding and analyses

The transcribed data were coded by two researchers using NVivo qualitative data analysis software. The coding and analysis processes were iterative with discussions between the two researchers and returns to the literature.

In the first step, the coding started with getting to know the data through initial coding (Saldaña, 2013), i.e. breaking down the data into parts, examining and comparing similarities and differences, and by writing memos related to connections between different observations. Different secondary data sources were complementary in building a rich picture of the WEEE management system. This initial coding produced an inventory of topics and connections between them that guided us in the next steps. This process also inspired a literature search to identify theoretical insights that might aid in categorising the emerging observations. We went back to the literature on lock-ins and socio-technical systems and searched for feasible frameworks for coding (cf. Dubois and Gadde, 2002).

In the second cycle of coding (Saldaña, 2013), the authors focused on the constraints and re-coded the dataset. Both theoretical coding, which uses higher-level literature themes, and open descriptive coding (Saldaña, 2013), which uses lower-level codes, were used to develop the categories of constraints (cf. Corbin and Strauss, 1990). These lower-level codes were regularly compared to higher-level codes (codes from the literature). During this analysis and generation of categorisations, constant comparisons were made to identify similarities and differences, to achieve precision and consistency as suggested by Corbin and Strauss (1990). As part of this process, the authors conducted rounds of individual coding followed by joint discussions to understand the reasoning behind the categorisations. This process was repeated until agreement and saturation was reached on the final categories of constraints, as presented in Section 4.

In the third step, we analysed how the constraints interacted with each other with the help of mind maps and by reducing the data into matrix displays, i.e. combining the vast array of material into an 'at-a-glance' format that enables reflection, verification, and conclusion drawing (Miles et al., 2013).

The quality of the research was improved by involving two to three researchers in the data collection and analysis and by using multiple data sources (Yin, 2013) as part of the data triangulation. The results were presented in multiple workshops (3) and sent to the interviewees in a report format to ensure the validity of the findings (Yin, 2013).

Table 2
Constraints on the implementation and diffusion of an advanced recycling process and transformation of the WEEE management system.

Category	Subcategory	1st order constraint	Description	Sources
Organisational	Attitudes and corporate culture	WEEE perceived as waste	WEEE is perceived as waste instead of a material containing valuable and rare metals. The primary goal is waste treatment, not the recovery of valuable materials.	PRO1, Recyc2
		Lack of strategic fit	Investing in advanced raw material extraction processes is not part of recycling companies' existing strategies.	PRO1, workshop
		Feels too complex	The topic is perceived to be complicated and difficult to understand.	Recyc1
Supply chains	Existing supply chains	Efficient existing supply chains	The existing WEEE supply chains, including smelters, are seen to function effectively. Basic and valuable metals can be recovered sufficiently using existing operating models.	Recyc1, Recyc2, PRO1
		WEEE operators are seen to be too small to change the system	Existing WEEE operators and other actors are considered too small, not having enough power to change existing supply chains and the system.	Recyc1
	Lack of collaboration	Lack of collaboration with EEE producers	National recycling companies are not in direct contact with global producers of electronics. The connection to producers is getting weaker due to re-structuring of sales organisations from the national to the European/Nordic level.	Recyc1, Recyc2, PRO1
		Tensions in the supply chain	There is strong competition between the operators of the WEEE supply chain. In addition, there are tensions and a lack of trust between producer organisations and processors, which seem to hinder collaboration within the supply chains.	Recyc1, Recyc2, PRO1
	Governance models	Challenges in triadic contracts	Contracts to treat WEEE are triadic: between a recycling operator, importer/producer and a producer association. Challenges in cost and revenue sharing in the agreements.	Recyc2, PRO1 Workshop
		Compliance with existing EPR schemes with minimum costs for producer organisations	Contracts are short term and based on a tendering process, which favours minimum costs for the producer organisation. The existing model does not encourage recycling companies to make long-term investments in infrastructure, as there is no guarantee of WEEE volumes after the relatively short contract period.	Recyc1, Recyc2, Workshop
Economic and market related	Cost efficiency	Existing processes are seen to be sufficiently efficient	Existing processes have been optimised to be cost efficient for individual companies. New process steps that would enable more efficient value recovery are seen to add costs.	Recyc1, Recyc2, PRO1
		High collection costs	Distance between the places where waste is generated, collected and treated has to be relatively short to avoid high logistics costs. Finland is a relatively sparsely populated country with long distances.	Workshop
	Material value and availability	The material value of WEEE is decreasing	Volumes of valuable metals decrease while plastics are increasing in WEEE.	Recyc1, Recyc2, TechDev1
		Competition for WEEE	New recovery systems would compete with other treatment options for the same (limited) WEEE flow.	Recyc2
		Insufficient national WEEE supply for a new treatment process	One of the major challenges is the sufficiency of WEEE supply and quality of the material in Finland. These have a clear impact on the feasibility of the process. Securing sufficient flows to a new treatment process would require WEEE imports. Significant amounts of WEEE disappear from national markets due to inefficient household sorting and recycling and unofficial exports.	Recyc1, Recyc2
	Demand and markets for material	Price volatility of metals	Volatility of global metal prices and uncertainty of future price development.	Recyc2
Infrastructure and technological	Product design	Limited recyclability of EEE	The recyclability of electronic appliances is challenging as the products are not necessarily designed to be recycled. There is a lack of eco-design and circular economy product design approaches.	Recyc1
		Fast technological development in electronics	The pace of technological development and convergence has been increasing. This raises uncertainties for recycling operators about the quality of future WEEE supply.	Recyc1
	Existing infrastructure	WEEE treatment infrastructure and technologies	From companies' perspective, the national WEEE supply is treated efficiently in existing processes and technologies.	Recyc1, PRO1
		Pre-sorting system is inadequate for advanced material recovery	The current collection and pre-sorting system does not support more efficient sorting needed for more advanced recycling and recovery processes.	Recyc2, PRO1
		Large MSW incineration capacity	Finland has a large capacity for incineration of mixed solid waste. However, incineration of WEEE rejects is not favoured in existing facilities.	Recyc2, workshop
Institutional and political	Regulation	Existing national EPR schemes for WEEE	Implementation and performance of national EPR schemes is sufficient.	Recyc2, PRO1
		Conflicting EU regulation	Increasing plastic waste recycling targets and harmful substances regulation (Persistent organic pollutants (POP) regulation) are not aligned.	PRO1, PRO2
	Policy and politics	Lack of policy measures to improve recyclability of EEE	At the moment, market-based economic incentives are not sufficient to encourage producers to improve the recyclability of EEE. Other types of instruments are needed, including regulatory instruments.	PRO1
		Energy policy and politics	Energy recovery from new processes is seen to be challenging due to existing energy policy measures.	PRO1, PRO2
		Uncertainty about national legislative changes	Difficulties in anticipating national legislative changes.	Recyc2, workshop

4. Results

4.1. Constraints on the transformation of a WEEE management system

In the following, the findings regarding each of the five identified categories of constraints (Organisational, Supply chain, Economic, Infrastructure and technological, and Institutional) are discussed, highlighting the relative relevance of the individual constraints. These findings are summarised in Table 2, where these main categories are further divided into sub-categories and 1st order constraints. The main categories of constraints are recognised in the transition literature as well as in the other CE contexts, but the individual constraints and their relative importance differ.

4.1.1. Organisational constraints

The first category of constraints relates to organisational aspects, which may lead to organisational inertia. The constraint of *attitudes and corporate culture* includes the perception of WEEE as waste that needs to be 'dumped' cheaply and not understood as a resource that contains valuable materials, such as CRMs. Another constraint here is the *lack of strategic fit:* recycling operators perceived that advanced raw material extraction from WEEE was not part of their existing strategies, as one interviewee stated, 'This doesn't belong to us' (Recyc1). In short, the recycling operators argued that this extraction could be conducted by a third party. Some of the interviewees considered *the topic to be complex* and difficult to understand, and thus making it hard for them to take action to contribute to the change.

4.1.2. Supply chain related constraints

This category of constraints relates to supply chain aspects, i.e. relationships between the different actors. First, the *existing supply chains* are perceived as efficient and well established. From the recycling operators' point of view, smelters, who play an important part in the supply chain, are efficient enough and closely located. Base and precious metals are sufficiently recovered by the current processes. One of the interviewees noted: 'I think this system as a whole is excellent, and it works well' (Recyc2). On the other hand, the respondents saw that the *lack of collaboration* in supply chains hinders the adoption and diffusion of innovative closed-loop solutions, including technologies and new modes of operation. First, there is a lack of collaboration between producers of electronic products and recycling operators, which would be required for improved recyclability of EoL products. This is a well-established requirement for a CE (cf. Cole et al., 2019b). Second, the respondents saw that there was both a lack of collaboration and strong competition between the various WEEE recycling operators, as the operators compete for the contracts tendered by producer organisations. In addition, there appears to be *tensions* and a lack of trust between the producer organisations and recycling operators:

There are certain sensitivity factors, and we are reluctant to encroach on the territory of our customers, which is the producer community, to tell them how things should be handled there, so that the most valuable materials may be recovered in a different way than at the moment. We try to stay in our own field. (Recyc2).

Collaboration would be important, however, as actors should join forces for development. Also, according to our interviews, individual actors, including recycling operators, *do not have enough power* to change existing supply chains and the socio-technical system, as these companies are small within a national waste management system that also intersects with waste incineration and thus national energy policies. The third sub-category of constraints relates to *governance models.* Here, the interviewees pointed out that *triadic contracts* between a recycling operator, importer/producer and a producer association would be needed, but are challenging in practice. Producers fear that the technology and extra processes needed for improved valorisation would raise the costs they incur for producer responsibility. Some producer representatives raised the problem of 'cherry picking' and argued that many of the recycling operators are interested only in the most valuable materials, making the development of the whole reverse supply chain difficult. This is partly due to limited transparency. A representative of a recycling company commented: 'The pursuit of companies' own interests hampers the development of optimal entities' (Recyc1). The second governance-related issue raised by the respondents was *compliance with EPR schemes* with minimum costs to producer organisations. From the recycling operators' perspective, the EPR system has led not only to short contract periods (1–2 years) with producer associations, but also to the fact that WEEE processing volumes within the contracts are small. The producer associations are non-profit companies aiming for cost efficiency, which is embedded in the existing EPR schemes. The recycling operators considered that this almost kills the possibilities for development and investment. One interviewee from a recycling company commented that 'The new business ideas need approval from the producer associations'.

4.1.3. Economic constraints

This category of constraints relates to the economic factors and incentives for the adoption and diffusion of a new recovery system and includes following components: *Cost efficiency*, W*aste material availability and value, and Demand for recycled metals*. First, related to *cost efficiency,* collection and sorting costs are high. Finland is a relatively sparsely populated country and distances are long, which increases collection costs and makes profitability challenging. One of the in formants noted: 'The role of logistics is significant. If the input is of low value, miscellaneous and rich in plastics, then the high costs of logistics can easily kill the business. (Workshop). Furthermore, existing processes have been developed and optimised to be cost efficient from the perspective of an individual company, thus leading to system-level sub-optimisation and indeed, hindering development. From the recycling operators' perspective, adopting more efficient recovery technology would require new process steps, which would increase processing costs. One significant constraint in the implementation and diffusion of new technologies is that *the material value of WEEE* is decreasing: in electronic products, the amount of plastics is increasing while amount of valuable metals is decreasing, making the investments in more efficient valorisation less profitable. On this topic, one of the informants noted:

The value of materials and especially plastic is very problematic for all actors, and the problem of plastic is that it lowers the value of [discarded electronic] equipment. Of course, there is more and more interest in increasing the lifespan and value of a discarded product and to get more components and perhaps entire products back into use from households as well (Recyc2).

However, regulatory pressures in the EU to solve the plastic problem will increase in coming years, thus driving the change toward a CE for plastics also in WEEE management (European Commission, 2018, 2020). Limited *waste material availability* in Finland was considered an important factor in constraining the adoption and diffusion of new technologies, despite the fact that WEEE flows are growing globally. Respondents considered that both the quality and quantity of the WEEE flows might be insufficient in Finland, as the profitability of valorisation processes is based on economies of scale. The respondents considered that economically feasible valorisation would require WEEE importation. This was explained by one of the informants:

This is a fundamental problem in Finland, our volumes are not enough, and, all the existing material needs be recovered and directed into proper processes and then we might get some more material, maybe, and that might enable more processing (Recyc1).

One factor in waste material availability is the recycling behaviour of consumers, as consumers not only store end-of-life devices in their homes, as noted also by Ylä-Mella and Pongrácz (2016), but also sort and recycle WEEE inefficiently. Importantly, interviewees also pointed out that the implementation of new valorisation technology would increase the competition for WEEE, as the existing processes and supply chains would be competing for the same limited waste fraction. One of the

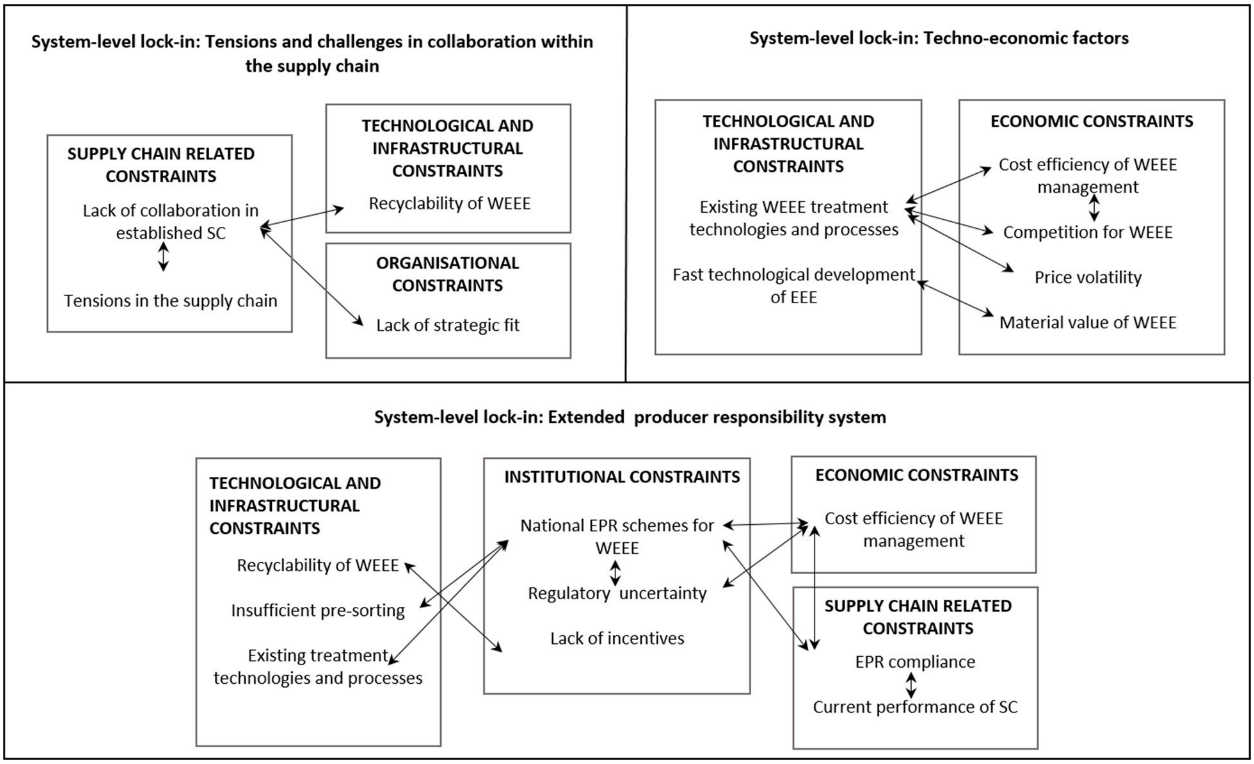

Fig. 1. Interactions and coevolving constraints forming system-level lock-ins.

constraints that the interviewees emphasised relates to metal markets and the price volatility of metals, which is difficult to forecast, making investments in the new technologies risky, and thus, constraining development. One of the informants explained this: 'The price of our products is affected by world market metal prices, yet we must commit to receive and process all the material in the same way, no matter what it is and how it affects our product price. That is a challenge' (Recyc2)

4.1.4. *Infrastructure and technological constraints*

The constraints in this category relate to product design and existing WEEE infrastructure. Limited recyclability is one aspect of *product design,* as products are often not designed to be easily recyclable, which increases recycling costs and makes it more difficult to recover metals. As one of the informants put it: 'The amount of plastic composites, difficult materials, and hybrid materials clearly increases there. Their recyclability will certainly be affected by some market economy factors, in which the recycling operator has no influence' (Recyc1). This is a well recognised constraint both in the CE literature (see for example Tura et al., 2019) and in practice. Furthermore, as the technological development of electrical appliances is fast, the future material value of WEEE is uncertain, thus increasing the risk of investment in more efficient technologies. Interestingly, interviewees also considered technological development of EEE as a driver for the implementation of new recycling and recovery technologies, as the hybrid materials are a challenge to the current destructive recycling technology. Processing WEEE requires capital-intensive infrastructure, so the *existing infrastructure* is a constraint which acts against systemic change. Here, the existing WEEE infrastructure and related processes are perceived to be good enough from a company perspective. This was explained by one of the informants, who stated: 'If you think about electrical and electronic waste, the recycling of metal and precious metal has probably never been any challenge' (Recyc1). Many of the respondents, however, considered that the current pre-sorting system does not support more efficient recycling and recovery processes, thus hindering the adoption of new recovery technologies. In Finland, a large incineration capacity for mixed solid waste treatment has been built, enabling efficient energy recovery, yet limiting materials recovery, especially regarding lower value components or complex components, such as complex hybrid materials and plastics.

4.1.5. *Institutional constraints*

This group of constraints relates to legal frameworks and institutional settings. Regulations and other policy instruments have often been identified as important drivers for more advanced recycling and circularity, which are needed due to a lack of economic incentives. On the other hand, a lack of supporting regulation can become a constraint. First, as part of *regulations*, the *national EPR schemes for WEEE* that are set to implement an EU-level WEEE directive in Finland will create a framework for the development of WEEE management. Although EPR schemes are one of the key instruments in the transformation towards a CE, the respondents saw that certain aspects of the existing EPR scheme hinder the technological change. One of the main reasons is that with the current EPR schemes, Finland is already fulfilling the recycling targets required by the WEEE directive. There are no further institutional incentives to exceed quantitative or qualitative targets. On the other hand, some parts of the EU legislation were considered to be inconsistent. For instance, increasing plastic waste recycling targets and harmful substances regulation are not aligned, creating confusion and uncertainty about the future and thus hindering investment in new technologies. Additionally, the respondents had difficulties anticipating changes in national legislation, which also makes the investment feel more risky.

In the EU and in Finland, various policy measures both drive and hinder development. The respondents perceived is a lack of policy measures to improve the recyclability of products, as today's market-based economic incentives are not sufficient to encourage producers to improve the recyclability of electronic products.

4.2. *Constraints leading to system-level lock-ins*

While the identified individual constraints can impede the implementation of new closed loop solutions, the interactions between coevolved individual factors seem to strengthen individual constraints and lead to *system-level lock-in (*cf. Unruh, 2000, 2002) as explained next.

First, while the *national EPR scheme* falls into the institutional constraint category, the implementation of this instrument is manifested in other categories: in governance models and performance of supply chains, as well as in economic factors and infrastructure (see Fig. 1). The development of the WEEE management system is highly regulation driven. The current national EPR scheme was designed to comply with EU environmental regulation. The supply chains and WEEE treatment technologies and processes have been designed to comply with EPR regulations. The implementation and performance of the EPR scheme for WEEE has been successful and quantitative recycling targets have been achieved. However, it seems that legislative frameworks, especially EU WEEE legislation, can lock companies into minimum standards that prevent innovation. While the EPR system seems to disincentivise companies from investing in new technologies, uncertainty in regulatory changes further strengthens the lock-in.

The second system-level lock-in emerges from several interlinked *techno-economic factors* (Fig. 1). These factors include previous investments in the existing infrastructure, leading to high technological and infrastructural switching costs. As the interviews indicate, the fast technological development of EEE increases uncertainties about the future material value of WEEE and, together with high material price volatility, leads to significant financial risks. Furthermore, the perceived low profitability of CRM recovery does not favour future investments in new technologies. In addition, a novel treatment facility would then have to compete for the same waste streams with the current system. Taken together, these factors appear to create an unfavourable business case for the adoption of new material recovery technologies.

The third key cause of system-level lock-in is found in the *tensions and challenges in collaboration within the supply chain* (Fig. 1). According to respondents, an individual company has limited transformative power to change the existing complex system. Implementation of a new recovery technology would require several changes, not only within an organisation but also throughout the entire supply chain as well as collaboration between actors. Tensions between the producer community and recycling operators regarding short-term contracts and pricing models prevent cooperation, as does tough competition between recycling operators. Such cooperation would be needed to change the system to favour innovation. Furthermore, organisational inertia, including the existing buyer-supplier relations and practices, and a perceived lack of strategic fit for recycling operators, can further strengthen this lock-in.

5. Discussion

The transformation to a CE requires a systemic change. However, established socio-technical systems may resist this change, and understanding the systemic nature of factors that impede the transformation is necessary. As the CE entails the entire economy covering various contexts, research of these constraints is needed in different contexts (Tura et al., 2019). This study started by identifying the various individual constraints (Section 4.1) in the context of WEEE management. Previous studies of WEEE management have focused on individual barriers or constraints but systematic mapping of these has been missing.

The results illustrate the multitude of *individual factors*, in several categories, *constraining the transformation* of the WEEE management system and thus, elaborating on and extending previous studies on barriers to the implementation of CE approaches (cf. Grafström and Asama, 2021; Kichherr et al., 2018; Tura et al., 2019) in the context of WEEE. Many of the identified main constraints categories are also recognised in other CE contexts, but their relative importance and some of the sub-categories differ. As one example, legislative frameworks have also been identified as a constraint in the previous literature (Kichherr et al., 2018; Tura et al., 2019; Zhuravleva and Aminoff, 2021). This empirical evidence from other CE contexts shows that the uncertainty of legislative development and lack of regulatory incentives hinder transformation. The results of this study, on the other hand, emphasise the role of WEEE legislation in locking companies into minimum standards and preventing innovation. This, in fact, contradicts the WEEE directive's target, in which 'producer responsibility is one of the means of encouraging design and production of EEE which take into full account and facilitate its repair, possible upgrading, reuse, disassembly and recycling'. As an other example, regarding technological aspects, the complexity of technology, the high upfront costs, and the lack of know-how among the practitioners of these solutions are also recognised in other CE contexts (Grafström and Asama, 2021; Tura et al., 2019). However, in the context of WEEE, the previous investments in the infrastructure, leading to high technological and infrastructural switching costs, seem to lead to lock-in. From the perspective of supply chains, lack of collaboration has been identified as one of the most important constraints also in other CE contexts (cf. Tura et al., 2019), but in the context of WEEE management, in addition to the lack of collaboration, the tensions in supply chains were emphasised.

Interestingly, although the previous literature has identified existing business models as potential barriers to change (cf. Corvellec et al., 2013), this aspect was not strongly present in the empirical data of this study. However, some elements of the business models are part of various categories of constraints, especially part 'supply chains' and 'economic and market-related' constraints.

This systematic mapping of constraints framed the complex and multifaceted challenge of transforming the well-established socio-technical system of Finnish WEEE management. The study shows that these interrelated constraints may work independently, but they can at times reinforce each other (cf. Corvellec et al., 2013). Importantly, we analysed the emerging patterns and identified how certain constraints interact and *lock the system in*. The study identified the current national EPR scheme, techno-economic issues, and tensions in the supply chain *as lock-ins*. Systematically mapping and analysing the existing constraints and their interactions can point to opportunities to overcome system-level lock-ins (Corvellec et al., 2013).

This study makes an important theoretical contribution as understanding the reasons why a system is locked-in is a critical step towards overcoming the obstacles to innovation and opening up possibilities for the uptake of new closed-loop solutions and transformation towards a CE (cf. Cecere et al., 2014). From a CE perspective, WEEE management offers an interesting context to study this phenomenon, as technologies and political pressures to improve the resource-efficiency of recycling already exist.

This paper also makes some *managerial and societal contributions.* WEEE represents a valuable source for secondary raw materials, which should be better utilised due to the scarcity of many critical raw materials. New advanced recycling technologies that would enable the recovery of more metals and other materials exist, but their uptake has been slow due to well established socio-economic system. In this context, a key to unlocking the system is to reform the current producer responsibility system; instead of just meeting weight-based recycling targets, it would also consider the quality of recycled materials, including the recovery of critical raw materials. This could encourage innovation and uptake of technologies that improve the resource efficiency of material recovery. Furthermore, the regulation should incentivise producers to make their EEE more easily recyclable. Our results show that policymakers, authorities, and company managers have to work on an array of interrelated factors to overcome a lock-in, as lock-ins are a matter of co-evolution as also suggested by Unruh (2000).

6. Conclusions

The case of the WEEE management system in Finland shows how the various constraints interact to build lock-ins that inhibit the uptake of advanced recycling technologies and transformation of WEEE management towards a CE. These constraints are grouped into five categories:

organisational, supply chain, economic and market related, institutional and infrastructure and technological. While these identified individual constraints may hinder the implementation of closed loop solutions, the interactions between them seem to strengthen the constraints, leading to *system-level lock-in.* This study identified the current national EPR scheme, techno-economic issues and tensions in the supply chain as lock-ins.

This study has *limitations that point to opportunities for future research*. First, the study investigates constraints and locks-ins in a specific CE context: WEEE management with a focus on materials recovery, which has special contextual characteristics and is strongly driven by EPR schemes. In future research, the constraints should be studied in other contexts, for instance in the textile recycling industry, to see how contextual factors influence lock-ins. Additional quantitative research in this field would likely produce valuable insights regarding the significance of the different constraints and their interactions. It would be interesting to better understand this context-specificity of constraints and adapt the contingency approach (see for example Sousa and Voss, 2008).

Furthermore, as this inquiry follows a qualitative research approach, no claims are made regarding the generalisability of the identified constraints in different contexts. This study only touched upon the possibilities to break down the lock-ins. This provides an important future research avenue. In this avenue, interesting aspects include entrepreneurship and business model perspectives of WEEE management. Despite the importance, reuse and remanufacturing of EEE were beyond the scope of this study.

CRediT authorship contribution statement

Anna Aminoff: Conceptualization, Methodology, Formal analysis, Investigation, Validation, Writing – original draft, Writing – review & editing, Project administration. **Henna Sundqvist-Andberg:** Conceptualization, Formal analysis, Investigation, Validation, Writing – original draft, Writing – review & editing, Visualization.

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.

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References

Aminoff, A., Pihlajamaa, M., 2020. Business experimentation for a circular economy - learning in the front end of innovation. J. Clean. Prod. 275, 124051. https://doi.org/10.1016/j.jclepro.2020.124051.

Andersson, M., 2019. Adoption of Systemic and Socio-Technical Perspectives in Waste Management , WEEE and ELV Research. https://doi.org/10.3390/su11061677.

Arthur, W.B., 1989. Competing technologies, increasing returns, and lock-in by historical events. Econ. J. 99 (394), 116. https://doi.org/10.2307/2234208.

Baldé, C.P., Forti, V., Gray, V., Kuehr, R., Stegmann, P., 2017. The Global E-Waste Monitor 2017. United Nations University.

Blomsma, F., Brennan, G., 2017. The emergence of circular economy: a new framing around prolonging resource productivity. J. Ind. Ecol. 21 (3), 603–614. https://doi.org/10.1111/jiec.12603.

Bolton, R., Foxon, T.J., 2015. Infrastructure transformation as a socio-technical process — implications for the governance of energy distribution networks in the UK. Technol. Forecast. Soc. Change 90, 538–550. https://doi.org/10.1016/J.TECHFORE.2014.02.017.

Boundy, T., 2020. How much material can a recycling facility source? A business-incentive based model for secondary material sourcing applied to waste LCD screen material. Resour. Conserv. Recycl. 152 https://doi.org/10.1016/j.resconrec.2019.104528.

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

Cecere, G., Corrocher, N., Gossart, C., Ozman, M., 2014. Lock-in and path dependence: an evolutionary approach to eco-innovations. Journal of Evolutionary Economics. https://doi.org/10.1007/s00191-014-0381-5, 24, 5, 1037-1065.

Cole, C., Gnanapragasam, A., Cooper, T., Singh, J., 2019a. An assessment of achievements of the WEEE Directive in promoting movement up the waste hierarchy: experiences in the UK. Waste Manag. 87, 417–427. https://doi.org/10.1016/J.WASMAN.2019.01.046.

Cole, C., Gnanapragasam, A., Cooper, T., Singh, J., 2019b. Assessing barriers to reuse of electrical and electronic equipment , a UK perspective. Resour. Conserv. Recycl. 1, 100004. https://doi.org/10.1016/j.rcrx.2019.100004.

Corbin & Strauss, 1990. Grounded theory research: procedures, canons, and evaluative criteria. Qual. Sociol. 13 (1), 3–21.

Corsini, F., Rizzi, F., Gusmerotti, N.M., Frey, M., 2015. Extended producer responsibility and the evolution of sustainable specialisations: evidences from the e-waste sector. Bus. Strat. Environ. 24 (6), 466–476. https://doi.org/10.1002/bse.1831.

Corvellec, H., Campos, M.J.Z., Zapata, P., 2013. Infrastructures, lock-in, and sustainable urban development: the case of waste incineration in the Göteborg Metropolitan Area. J. Clean. Prod. 50, 32–39. https://doi.org/10.1016/j.jclepro.2012.12.009.

Cucchiella, F., D'Adamo, I., Lenny Koh, S.C., Rosa, P., 2015. Recycling of WEEEs: an economic assessment of present and future e-waste streams. Renew. Sustain. Energy Rev. 51, 263–272. https://doi.org/10.1016/J.RSER.2015.06.010.

Dubois, A., Gadde, L.-E., 2002. Systematic combining: an abductive approach to case research. J. Bus. Res. 55 (7), 553–560. https://doi.org/10.1016/S0148-2963(00)00195-8.

European Commission, 2012. Directive 2012/19/EU of the European Parliament and of the Council of 4 July 2012 on Waste Electrical and Electronic Equipment (WEEE). Off. J, vol. 197. the Eur. Union, pp. 38–71. July.

European Commission, 2018. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. A European Strategy for Plastics in a Circular Economy COM/2018/028 Final.

European Commission, 2020. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. A New Circular Economy Action Plan. COM/2020/098 final.

EUROSTAT, 2021. Waste Electrical and Electronic Equipment (WEEE) by Waste Management [Data file]. Retrieved from. https://ec.europa.eu/eurostat/databrowser/view/ENV_WASELEE_custom_563461/default/table?lang=en.

Foxon, T.J., 2002a. Technological and institutional 'lock-in'as a barrier to sustainable innovation. In: Imperial College Centre for Policy and Technology Working Paper.

Foxon, T.J., 2002b. Technological and institutional ' lock-in ' as a barrier to sustainable innovation. In: ICCEPT Working Paper. November 2.

Grafström, J., Aasma, S., 2021. Breaking circular economy barriers. J. Clean. Prod. 126002.

Geels, F.W., 2004. From sectoral systems of innovation to socio-technical systems: insights about dynamics and change from sociology and institutional theory. Res. Pol. 33 (6–7), 897–920. https://doi.org/10.1016/J.RESPOL.2004.01.015.

Geissdoerfer, M., Savaget, P., Bocken, N.M., Hultink, E.J., 2017. The Circular Economy–A new sustainability paradigm? J. Clean. Prod. 143, 757–768.

Islam, M.T., Huda, N., 2018. Reverse logistics and closed-loop supply chain of Waste Electrical and Electronic Equipment (WEEE)/E-waste: a comprehensive literature review. Resour. Conserv. Recycl. 137, 48–75.

Kirchherr, J., Piscicelli, L., Bour, R., Kostense-Smit, E., Muller, J., Huibrechtse-Truijens, A., Hekkert, M., 2018. Barriers to the circular economy: evidence from the European union (EU). Ecol. Econ. 150, 264–272.

Klitkou, A., Bolwig, S., Hansen, T., Wessberg, N., 2015. The role of lock-in mechanisms in transition processes: the case of energy for road transport. Environmental Innovation and Societal Transitions 16, 22–37. https://doi.org/10.1016/J.EIST.2015.07.005.

Kumar, Amit, Holuszko, M., Crocce, D., Espinosa, D.C.R., 2017. E-waste : an overview on generation , collection , legislation and recycling practices. Resour. Conserv. Recycl. 122, 32–42. https://doi.org/10.1016/j.resconrec.2017.01.018.

Kumar, Ashwani, Dixit, G., 2018. Evaluating critical barriers to implementation of WEEE management using DEMATEL approach. December 2017 Resour. Conserv. Recycl. 131, 101–121. https://doi.org/10.1016/j.resconrec.2017.12.024.

Mazahir, S., Verter, V., Boyaci, T., Van Wassenhove, L.N., 2019. Did europe move in the right direction on E-waste legislation? Prod. Oper. Manag. 28 (1), 121–139. https://doi.org/10.1111/poms.12894.

Miles, M.B., Huberman, A.M., Saldaña, J., 2013. Qualitative Data Analysis: A Methods Sourcebook. SAGE Publications, Inc, Thousand Oaks, CA.

Narula, R., 2002. Innovation systems and 'inertia' in R&D location: Norwegian firms and the role of systemic lock-in. Res. Pol. 31 (5), 795–816. https://doi.org/10.1016/S0048-7333(01)00148-2.

Parajuly, K., Habib, K., Liu, G., 2017. Waste electrical and electronic equipment (WEEE) in Denmark: flows, quantities and management. Resour. Conserv. Recycl. 123, 85–92. https://doi.org/10.1016/J.RESCONREC.2016.08.004.

Parajuly, K., Wenzel, H., 2017. Potential for circular economy in household WEEE management. J. Clean. Prod. 151, 272–285. https://doi.org/10.1016/j.jclepro.2017.03.045.

Patton, M.Q., 2014. Qualitative Research & Evaluation Methods: Integrating Theory and Practice. Sage publications.

Piekkari, R., Plakoyiannaki, E., Welch, C., 2010. 'Good' case research in industrial marketing: insights from research practice. Case Study Research in Industrial Marketing 39 (1), 109–117. https://doi.org/10.1016/j.indmarman.2008.04.017.
Rip, A., Kemp, R., 1998. Technological change. In: Rayner, E.M.S. (Ed.), Human Choice and Climate Change. Battelle, Columbus, Ohio, pp. 327–399. Retrieved from. https://pdfs.semanticscholar.org/4739/5c4a2d310598d1e945873ee3787535df2844.pdf.
Saldaña, J., 2013. The Coding Manual for Qualitative Researchers. Sage Publications, Inc, London, United Kingdom.
Sousa, R., Voss, C.A., 2008. Contingency research in operations management practices. J. Oper. Manag. 26 (6), 697–713. https://doi.org/10.1016/j.jom.2008.06.001.
Svingstedt, A., Corvellec, H., 2018. When lock-ins impede value co-creation in service. International Journal of Quality and Service Sciences 10 (1), 2–15. https://doi.org/10.1108/IJQSS-10-2016-0072.
Tanskanen, P., 2013. Management and recycling of electronic waste. Acta Mater. 61 (3), 1001–1011. https://doi.org/10.1016/J.ACTAMAT.2012.11.005.
Tura, N., Hanski, J., Ahola, T., Ståhle, M., Piiparinen, S., Valkokari, P., 2019. Unlocking circular business: a framework of barriers and drivers. J. Clean. Prod. 212, 90–98. https://doi.org/10.1016/J.JCLEPRO.2018.11.202.
Unruh, G.C., 2000. Understanding carbon lock-in. March Energy Pol. 28, 817–830.
Unruh, G.C., 2002. Escaping carbon lock-in. Energy Pol. 30 (4), 317–325. https://doi.org/10.1016/S0301-4215(01)00098-2.
Unruh, G.C., Carrillo-hermosilla, J., 2006. Globalising carbon lock-in. Energy Pol. 34 (10), 1185–1197. https://doi.org/10.1016/j.enpol.2004.10.013.
van den Bergh, J., Truffer, B., Kallis, G., 2011. Environmental innovation and societal transitions: introduction and overview. Environmental Innovation and Societal Transitions 1, 1–23.
VTT, 2016. New Ways of Thinking Will Lead to Economic Growth. Bringing Circular Economy into Play. VTT Policy Brief 1/2016. VTT Technical Research Centre of Finland. http://www.vtt.fi/inf/pdf/policybrief/2016/PB1-2016_Eng.pdf.
Wesseling, J.H., Van der Vooren, A., 2017. Lock-in of mature innovation systems: the transformation toward clean concrete in The Netherlands. J. Clean. Prod. 155, 114–124. https://doi.org/10.1016/J.JCLEPRO.2016.08.115.
Yin, R., 2014. Case Study Research: Design and Methods (Applied Social Research Methods), fifth ed. Sage Publications.
Ylä-Mella, J., Poikela, K., Lehtinen, U., Keiski, R.L., Pongrácz, E., 2014a. Implementation of waste electrical and electronic equipment directive in Finland: evaluation of the collection network and challenges of the effective WEEE management. Resour. Conserv. Recycl. 86, 38–46. https://doi.org/10.1016/j.resconrec.2014.02.001.
Ylä-Mella, J., Poikela, K., Lehtinen, U., Tanskanen, P., Román, E., Keiski, R.L., Pongrácz, E., 2014b. Overview of the WEEE directive and its implementation in the nordic countries: national realisations and best practices. Journal of Waste Management 1–18. https://doi.org/10.1155/2014/457372.
Ylä-Mella, J., Pongrácz, E., 2016. Drivers and constraints of critical materials recycling: the case of indium. Resources 5 (4), 34. https://doi.org/10.3390/resources5040034.
Zacho, K.O., Bundgaard, A.M., Mosgaard, M.A., 2018. Constraints and opportunities for integrating preparation for reuse in the Danish WEEE management system. Resour. Conserv. Recycl. 138, 13–23. https://doi.org/10.1016/J.RESCONREC.2018.06.006.
Zhuravleva, A., Aminoff, A., 2021. Emerging partnerships between non-profit organisations and companies in reverse supply chains: enabling valorisation of post-use textile. Int. J. Phys. Distrib. Logist. Manag.