Chapter

Urban Mining of e-Waste and the Role of Consumers

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Abstract

This chapter adds to the body of literature on the Circular Economy (CE), urban mining, and their intersection with consumer behaviour, by first providing a review of existing and emergent EU regulations aimed towards enhancing the collection rate of household WEEE. The fast growth of the EEE waste stream and its potential for Urban Mining as well as the inability of WEEE collection to keep up with the growth of the EEE industry is showcased with statistical data. The final section critically analyses the literature the intersection between consumer behaviour and closed-loop supply chains for EEE, identified through a systematic keyword search to ensure replicability. The findings point at a lack of theoretical, methodological and product-case heterogeneity among the identified sources, with most of them employing the Theory of Planned Behaviour and survey methods and focusing on mobile phones or general WEEE. While the literature suggests important behavioural differences across EEE categories, this was not representatively explored. The final section contributes to filling this gap by developing a taxonomy of EEE categories based on characteristics that may predispose consumer behaviour. The identified dimensions are: size, involvement, long-term reliability expectations, value type, internet access, multifunctionality, the quality of being outdated and social meaning.

Keywords: circular economy, urban mining, consumer behaviour, waste electrical and electronic equipment (WEEE), e-waste, electrical and electronic equipment (EEE), EU regulation

1. Introduction

As an increasing number of countries is focusing on CE [1–4], so too does the treatment of WEEE get more attention in academics [4–8]. A topic that has seen little attention is the role of consumers, and specifically consumer behaviour, in the retrieval of household WEEE from anthropogenic stocks, a process called urban mining. This chapter will first provide a short background as to why the proper retrieval of WEEE is important, followed by an overview of the state-of-the-art in WEEE regulations and collection. The main focus of this chapter will be on consumer behaviour in Closed Loop Supply Chains for Electrical and Electronic Equipment (*e*CLSC) to better understand issues with household WEEE collection.

WEEE that is not properly collected and treated often gets dumped or finds its way into the informal sector where it is processed with methods bad for the environment and human health [9]. Informal WEEE dumping grounds and processing

sites are known to contaminate soils, air, and water, including major rivers [10]. This is the result from using unsafe processing methods such as mechanical treatment (leading to a lot of hazardous dust), open burning (releasing toxic fumes), and leaching processes (with waste acid then dumped and toxic fumes being released), having significant effects to the environment and on human health. Health effects especially affect children that are often forced to labour on informal WEEE processing sites, developing changes in typhoid function, a lower forced vital capacity, changes in cellular expression, changes in behaviour and temperament [11], furthermore, exposure to WEEE can later lead to reduced virility, stillbirths, spontaneous abortions, premature births, reduced birth lengths, reduced birthweights and other birth defects showing that improper WEEE handling can damage more than one generation of people at exposure. WEEE is also known to damage DNA and lower educational outcomes.

The urban mining of EEE, which can be defined as a process to retrieve (raw) materials and energy from urban areas, specifically from anthropogenic stocks of WEEE, has only recently started to garner attention in academics [12]. Urban mining is seen as a must to achieve ambitious circular economy targets and an effective method to reduce supply risks of critical raw materials, such as rare earth metals in the EEE industry, as well as for base metals, such as copper (of which an estimate stock in the EU of 82 Megatons exists) [13]. The urban mining of WEEE has the potential to be an industry worth 57 billion USD a year [4]. Besides the economic potential, urban mining is typically better for the environment as compared to the traditional mining of natural resources [14]. The procurement of sufficient volumes of WEEE is currently a prohibiting factor for urban mining. Improvements in the collection rates of household WEEE from consumers are deemed essential to develop the WEEE recycling industry and curb the problems with the rapidly growing EEE waste stream [15]. The growth of the WEEE waste stream is further evidenced in **Table 1**. In 2019, at the global scale, only 17.4% of WEEE got properly collected, with an estimated 44.3 megaton of WEEE likely to be dumped and/or illegally traded to be recycled in a non-environmentally and health damaging way on the informal market, a growth of 7.4 megaton when compared to the 36.9 megaton that saw its way into the informal market or was illegally dumped in 2014 [9].

In this chapter we aim to contribute to the growing body of literature on household WEEE collection and urban mining in the EU and the role of consumers in *e*CLSCs. **Section 2** provides an overview of regulations and directives relevant to the collection of WEEE from consumers in the EU, as well as recent trends in the amount of household EEE put to market in the EU and the amount of household WEEE collected in the EU. **Section 3** provides an in-depth study of the role of consumers in *e*CLSCs. **Section 4** provides a discussion of our findings. **Section 5** presents concluding remarks pertaining to this chapter.

2. WEEE regulation developments in the EU

The EU was one of the first major economic blocks to implement far reaching regulations to curb the growth of WEEE. The first big steps were taken by the EU with the WEEE Directive that set collection, recycling, and recovery targets for WEEE from 2003 onwards, and the RoHS directive that set limitations on the use of hazardous substances from 2004 and onwards. Since then, the body of regulations concerning WEEE has grown considerably and is still being expanded upon, most recently because of aims set out in the European Green Deal and Circular Economy Action Plans. The EU is seen as having the most advanced and progressive

Household WEEE collection compared to Household EEE put to market			
	2011	**2017**	**Delta**
Household EEE put to market per capita in the EU.	17.36 kg	20.27 kg	2.91 kg
Household WEEE collected per capita in the EU.	5.88 kg	7.37 kg	1.49 kg
Percentage of household WEEE collected relative to the amount of household EEE put to market in the same year in the EU.	29%	36%	7%
Household WEEE per capita that remains uncollected in the EU.	11.48 kg	12.9 kg	1.42 kg
	2014	**2019**	**Delta**
Household EEE put to market per capita globally.	6.4 kg	7.3 kg	0.9 kg
Household WEEE collected per capita globally.	1.1 kg	1.3 kg	0.2 kg
Percentage of household WEEE collected relative to the amount of household EEE put to market in the same year globally.	17%	17.4%	0.4%
Household WEEE per capita that remains uncollected globally.	5.3 kg	6 kg	0.7 kg

Table 1.
Both the amount of household EEE put to market and the amount of household WEEE collected is rising in the EU27, as well as the relative amount of household WEEE when put to the amount of household EEE put to market in the same year. However, the uptake in household WEEE collected is lower than the uptake in household EEE put to market, causing a growing amount of uncollected WEEE based on data retrieved from the Eurostat env_waselee database on WEEE (http://ec.europa.eu/eurostat/product?code = env_waselee&language = en). A similar trend is seen on the global level where WEEE collection cannot keep up with the growth of the EEE industry based on Data from the Global e-Waste Monitor 2020 [9].

regulations in the world and its regulations are often followed by other countries in the world [4]. In this section, a background is provided on existing and proposed EU regulations that directly or indirectly affect the role of consumers in *e*CLSCs, so as to provide the state-of-the-art and future scenarios for WEEE regulation. Furthermore, recent trends in household WEEE collection in the EU are presented and compared to the global trend.

2.1 WEEE Directive

The EU's WEEE Directive, which first came into force in 2003, caused a paradigm shift by placing the responsibility for WEEE on the producers and distributors, instead of solely on municipalities, the so-called Extended Producer Responsibility (EPR) [16, 17]. At its first implementation, besides shifting responsibility to producers, the EU also set WEEE collection targets for its member states [18]. At first the collection target for member states was set at 4 kg of household WEEE per capita or the same weight as the average of collected WEEE in the previous three years by a member state, whichever is higher. In later revisions of the WEEE directive [19], the target collection rates were increased to 45% of EEE put to market (taking the average in the three preceding years) for 2016 till 2018. Since 2019, either 65% of EEE put on the market must be collected or 85% of the WEEE generated within a member state. Furthermore, for each category of household WEEE, separate recycle and reuse target rates are given by the WEEE directive, putting extra pressure to facilitate collection on for example large household appliances or gas discharge lamps.

As previously mentioned, under the directive the producers or distributors of EEE are responsible for the collection of resulting WEEE. This includes a right of consumers to return WEEE, free of charge, to where they originally bought a product [19]. EEE producers and distributors often opt to join a collaborative take-back system to which they pay a fee, based on the average processing costs of a

product group, which will handle the management of WEEE for companies [3, 20]. EPR policy is often badly implemented, and municipalities still play an important and costly role in the collection of WEEE, in part because consumers are often not knowledgeable in the options available to them [21].

2.2 RoHS & REACH

The EU's RoHS Directive was the first directive to restrict the use of specific hazardous substances in EEE for many types of products, including most consumer products, and is often seen as a supplement to the WEEE Directive, first instuted in 2004 [22]. The directive has later been updated to provide clarity [23], and to add new substances to the list of restrictions [24]. More additions are currently being considered, such as brominated flame retardants, chlorinated flame retardants, and PVC. Other countries have since followed with similar regulations. Sometimes, as is the case with the China RoHS, the regulation does not prohibit the listed hazardous substances but require products to be marked for having none or minimal amounts of certain hazardous substances. Furthermore, because of the size of the EU's market, products offered globally are often compliant with the EU's RoHS regulation, even if offered outside of the EU. Products exported from the EU also have to comply with RoHS regulation.

The EU's REACH regulation also limits to use of hazardous substances but extends beyond the EEE sector, covering 209 different substances [25]. While similar to the RoHS directive, its implementation differs a lot. Besides covering all products imported or produced in the EU and not just EEE products, being a regulation instead of a directive means the law is the same across every member state. Furthermore, while the RoHS directive specifically lists the substances to which it pertains, the REACH regulation refers to an external list that is easier to update, the substance of very high concern list maintained by the European Chemicals Agency. When listed, authorization is required to include said substance in a product on the EU market, customers and consumers also have the right to request a safety data sheet and to be provided information regarding the safe use and disposal of the product.

2.3 Battery Directive

The EU's Battery Directive affects both batteries and accumulators, which are seen as separate from EEE in regulations but are often included in EEE. It limits the use of specific chemicals, requires proper waste management pertaining to the recycling and collection of batteries and accumulators, sets collection targets for batteries and assigns financial responsibility. As of this moment the annual collection target for batteries is 45% of annual battery sales.

In December 2020 the European Commission proposed a new batteries regulation to replace the old Battery Directive and would come into effect in 2025 if accepted [26]. The proposed regulation aims to make batteries and accumulators used more sustainable. The repurposing of used batteries is heavily encouraged, a new collection target of 65-70% is proposed for portable batteries, a new reporting system for electric vehicle and industrial with a new collection target (yet to be set) would come into effect, lead-acid and li-ion batteries would get a new recycling efficiency target as well as new material recovery rates for cobalt, nickel, lithium, copper, and lead, a carbon footprint declaration is to be provided, minimal performance and durability requirements are set, non-rechargeable batteries are to be phased out, clear EPR specifications are to be developed, more obligations on removability are given for the product design phase, an electronic information

exchange system and product passport scheme must be implemented, and a mandatory supply chain due diligence must come into effect. As of now, EU member states are still debating the approval of the proposed regulation[1].

2.4 Eco-design Directive, energy labelling regulation, and the EU ecolabel

The EU's Eco-design Directive is different from most directives in that it is a framework directive, it does net set any standards in itself but provides a framework for regulations that now cover over 30 product groups, mostly within in the EEE sector[2,3] [27]. While most legislations under the Eco-design Directive are mandatory, some are voluntary agreements. Most of the requirements stemming from these legislations regard the sustainability of products and can cover a wide range of rules, such as material requirements, ease of disassembly, the availability of service manuals and spare parts, cleaner production processes, and (further) rules on EPR.

The EU's Energy Labelling Regulation, which came into force this year and replaced Directive 2010/30/EU, requires products from certain product groups to carry energy labels on their packaging [28]. The label assigns an energy class to products so consumers can easily compare products on their energy consumption as well as some other product-group specific information. Labels also carry a QR code so consumers can easily find more information regarding a product in the European Product Registry for Energy Labelling database.

The EU's Ecolabel Regulation, most recently updated in 2009, provides a voluntary scheme so producers can market their products as best of class [29]. Ecolabel requirements are set up for specific product groups and aim to identify the top 10% most sustainable products within a product group. The Ecolabel certification of a product often involves performing a life cycle assessment and life cycle costing analysis. The development of requirements is an ongoing process performed by the European Commission's Product Bureau[4].

The eco-design, energy labelling, and Ecolabel regulations often set high voluntary standards. These standards provide a way for producers to differentiate their products. Furthermore, they are often used as requirements in green public procurement within the EU in addition to other product group specific criteria[5]. As public procurement forms 14% of the EU's market purchases, green public procurement has become a key policy instrument for the European Green Deal and the EU's Circular Economy Action Plans [2, 28, 29].

2.5 WEEE collection trends in the EU

As of 2017, only 2 EU countries managed to reach the 65% household WEEE collection target, of which one country (Bulgaria) only achieved it by using a different definition in their reporting according to the Eurostat env_waselee

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[1] https://www.euractiv.com/section/batteries/news/brussels-in-balancing-act-to-gain-eu-support-for-battery-regulation/

[2] https://ec.europa.eu/energy/topics/energy-efficiency/energy-efficient-products/list-regulations-product-groups-energy-efficient-products_en

[3] https://ec.europa.eu/info/energy-climate-change-environment/standards-tools-and-labels/products-labelling-rules-and-requirements/energy-label-and-ecodesign/energy-efficient-products/voluntary-agreements-under-eco-design-legislation_en

[4] https://susproc.jrc.ec.europa.eu/product-bureau/product-groups

[5] https://ec.europa.eu/environment/gpp/eu_gpp_criteria_en.htm

database on WEEE[6]. 18 out of the EU27 countries, as well as the UK, did reach the 45% collection rate target that was at that time still the requirement. Over time, the amount of household WEEE collected per capita, within the EU27, has gone up from 5.88 kg in 2011 to 7.37 kg per capita in 2017 according to Eurostat estimates, a total increase of 1.49 kg, as is shown in **Table 1**. While this means a higher amount of household EEE put to market has been collected as WEEE, the total amount of household WEEE that is not collected has also increased. In 2011, 17.36 kg of household EEE was put to market, while in 2017 20.27 kg of household EEE was put to market, an increase of 2.91 kg, nearly double amount of the WEEE that was additionally collected in 2017 over 2011, as is shown in **Table 1**. Thus, the amount of uncollected WEEE in the EU is still rising year on year. Take note that for the collection targets under the WEEE directive, the rate of household WEEE collected in a year is set against the average amount of EEE in the preceding three years, as the amount of EEE put to market is rising this results in a lower percentage in our calculations compared to those used by the EU. Nonetheless, globally Europe performs as the best region in WEEE collection, both in absolute and relative metrics [9]. Globally, the amount of WEEE generated has grown from 44.4 Megaton in 2014 to 53.6 Megaton in 2019 and is expected to grow to 74.7 Megaton in 2030, meanwhile the amount WEEE collected has only grown from 7.5 Megaton (17%) in 2014 to 9.3 Megaton (17.4%) in 2019, meaning that currently 44.3 Megaton (82.6%) of household WEEE globally ends up dumped or in the informal recycling sector [9].

3. Consumers in a closed loop supply chain for EEE (*e*CLSC)

Considering the timeliness of understanding consumer behaviour in *e*CLSC, in this section, we aim to contribute to the said literature by (1) providing an overview of the topic, (2) building a holistic conceptualisation of the role of the consumer in *e*CLSC and (3) developing a consumer-behaviour-focused taxonomy of EEE categories.

Consumers are not only the engine that can fuel the success of *e*CLSC through their behaviour and decision making, they are also one of the core receptors of the health, environmental and even ethical benefits that *e*CLSC can help achieve. The case of WEEE magnifies this relationship given the widely observed tendency of consumers to stockpile (i.e. hoard) replaced equipment, even in cases when the products are broken, due to a combination of overvaluing discarded EEE and a lack of WEEE management infrastructure. Given the typical hazardous and toxic elements contained in most EEE, this tendency constitutes an important health risk, directly for them, and an environmental risk to ecological systems and society. As such, it is not surprising that EEE stockpiling has been reported to score among the top urgent and important issues within the context of WEEE management [4].

Addressing this issue can be viewed as an opportunity to progress in other global issues, such the Sustainable Development Goals (SDG), by enhancing proper WEEE recovery and reuse at end-of-use (EoU)[7], particularly on the consumers' side. The latter has also been identified as a key challenge for WEEE management [4] and its connection to SDG highlights the potential environmental and social benefits of improving recovery of discarded EEE from consumers. Moreover, since there is space for improvement in the retrieval of discarded EEE from consumers in Europe,

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[6] http://ec.europa.eu/eurostat/product?code = env_waselee&language = en.

[7] By end-of-use we mean the time when some EEE goes from being in-use, to being out-of-use. Conversely, end-of-life is taken to identify the moment when the EEE in question ceases to function properly, leading to its end-of-use.

the stock of WEEE in urban environments is currently underexploited. Along these lines, urban mining, which relates to the recovery of materials from discarded EEE, could improve significantly if consumer behaviour shifts towards the extension of products', parts' and materials' useful lifetimes.

Stockpiling of EEE by consumers is envisaged to worsen as more appliances become smart and are given internet-access capabilities. These raise data protection considerations which, if not studied and communicated correctly, can pose a further barrier for consumer returns of WEEE due to fear of personal data breaches. Additional ethical considerations are attached to the issue of increasing technical obsolescence, whereby equipment becomes functionally impaired, due to the fast technological advancements and marketing which continuously contributes to the creation of new consumer needs. This leads to the premature replacement of EEE which is also more likely to be overvalued and stockpiled. These examples highlight the fast pace at which consumer behaviour evolves with technological advancement.

Finally, empirical findings suggest that the same theoretical models applied to different EEE categories have substantially different results, e.g. [30, 31]. Despite the important implications of these findings, there are no studies synthesising the characteristics of EEE categories that account for substantial differences in consumer behaviour. Specifically, there is no framework for the systematic differentiation between EEE categories with respect to their physical, functional and symbolic characteristics' influences on consumer behaviour.

Therefore, in this section, we aim to answer the following research question: What EEE characteristics are most significant in pre-conditioning *e*CLSC-relevant consumer behaviour and the processes behind it?

3.1 Materials and methods

3.1.1 Literature review methods

We conducted a keyword search following the PRISMA framework [32] for reporting systematic literature reviews (up to article selection) which is detailed in the *Supplementary Materials* document[8] (see **Appendix**). The identified sources were critically analysed to identify significant research gaps. A first worthy observation is the low number of sources we were able to identify, with only 40 articles being identified after removal of the duplicates from both utilised databases, Scopus and Web of Science. After exclusion of articles based, first, on screening of the abstracts, and second, on the content of the full articles, the final dataset was comprised of 24 studies, based on whether the consumer behavioural role was central or not, to their analyses. Additionally, a second dataset, built under less strict conditions, i.e. including articles whose main focus is not understanding consumer behaviour in *e*CLSC. The latter dataset was comprised of 31 articles. Moreover, the oldest study our search was able to capture was from 2013 [33]. These results alone illustrate well the fact that consumer behaviour in the context of *e*CLSC is still a nascent field.

3.1.2 Taxonomy building methods

Research has found some confusion around the definitions of typology and taxonomy. While the main differences emerge from the approach used, i.e.

[8] The *Supplementary Materials* document is available upon request from the authors.

inductive (empirical-to-conceptual; objects to dimensions/characteristics) vs. deductive (conceptual-to-empirical; theory to dimensions/characteristics), they have often been used interchangeably [34]. We employ the term taxonomy more generally to refer to the classification system, without requiring that it is constructed only inductively or deductively, as it has been suggested in the literature [34]. Specifically, we use the following definition: "A taxonomy T is a set of n dimensions D_i $(i = 1, \ldots, n)$ each consisting of k_i $(k_i \geq 2)$ mutually exclusive and collectively exhaustive characteristics C_{ij} $(j = 1, \ldots, k_i)$ such that each object under consideration has one and only one C_{ij} for each D_i" [34] (p. 340). That is:

$$T_i = \left\{D_i, i = 1, \ldots, n | D_i = \left\{C_{ij}, j = 1, \ldots, k_i; k_i \geq 2\right\}\right\}. \quad (1)$$

In **Section 3.3**, we develop a taxonomy of EEE categories which aims to facilitate the identification of potential EEE-characteristic-related changes in behaviours that are relevant to *e*CLSC. We draw from [34], to employ robust and transparent methods in the construction of the taxonomy. The resulting taxonomy is presented in **Table 2** and discussed in more depth in Section 3.3. We offer a more detailed account of the procedure we applied, which went through five iterations before reaching its final version, in the *Supplementary Materials* file (see **Appendix**).

3.2 Conceptualisation and literature review

3.2.1 The consumer's role in CLSC

While previous research tends to consider consumers' involvement in CLSC in terms of consumption phases (i.e. purchase, use, lifetime extension, dispose etc.) [35], in addition to this, we take a more direct approach to exploring the extant interactions. We begin by considering how consumers' decision making may influence CLSC implementation. This leads to the distinction between direct influences, where consumers decide on whether to engage or not as suppliers of discarded equipment, and indirect influences, where consumers make decisions based on addressing their functional and emotional needs by acquiring some EEE or repairing/upgrading already owned equipment that no longer fulfils the consumers' expectations. In other words, direct-influence behaviours (DIB) have to do with the supply or lack thereof of discarded EEE in initiatives which aim to re-introduce out-of-use equipment back into the economy, a.k.a. *reversing* behaviours, while indirect-influence behaviours (IIB) pertain to choices that affect the sales volumes of outputs from CLSC that aim to create value. We provide a more in-depth description of our conceptualisation in the *Supplementary Materials* (see **Appendix**). For our purposes, we present the resulting classification of behaviours in **Tables 3** and **4**.

The tables show three levels (layers) of behaviours with each level breaking down its preceding levels into several other, more concrete, behaviours (as numbering increases). Behaviours within the same level are mutually exclusive, such that adoption of one implies non-adoption of the others (see *Supplementary Materials* and **Appendix**). Therefore, the benefits associated with behaviours within a given level, that are not adopted, form the opportunity cost of the adopted behaviour. The point we aim to highlight is that all these behavioural layers, based on the situations that lead consumers to engage or not with an *e*CLSC, are of interest to consumer research in this area. Some studies may explore more general behaviours, such as discarding [33, 36], or specific behaviours such as the purchase of remanufactured/recycled products, see [35] for an overview. In doing so, results offer more, or less, abstract perspectives on behaviours which may lead to different results. Here, our classification provides a basis for understanding findings on

EEE category	Size				Involvement		Long-term reliability expectations			Value type			Internet access		Multifunctionality			Outdated		Social meaning (status, etc.) identity etc.)		
	S	M	L	XL	L	H	L	M	H	H	M	F	N	Y	L	M	H	N	Y	N	M	HS
Washing machine				X		X			X			X	X		X			X		X		
Coffee machine		X			X			X				X	X		X			X		X		
Mobile phone	X				X			X			X		X			X			X		X	
Smartphones	X					X		X			X			X			X	X				X
LCD-TV			X			X		X			X		X			X		X				X
Hair dryer	X				X		X					X	X		X			X		X		
DVD player		X			X			X		X			X		X				X	X		
Electric shaver	X				X			X				X	X		X			X		X		
Radio receiver		X			X			X		X			X		X				X	X		
Refrigerator				X		X			X			X	X			X		X		X		
Smart TV			X			X		X			X			X			X	X			X	
Electric iron	X				X		X					X	X		X			X		X		
VCR		X			X			X		X			X		X				X	X		
CRT-TV			X		X			X		X			X		X				X	X		
Desktop comp.			X			X			X		X			X			X	X			X	
Laptop		X				X		X			X			X			X	X				X
Flat irons	X				X		X					X	X		X			X		X		
Blender		X			X		X					X	X		X			X		X		
Stereo system			X			X			X	X			X		X			X				X
Printer			X		X			X				X	X		X			X		X		

EEE category	Size				Involvement		Long-term reliability expectations			Value type			Internet access		Multifunctionality			Outdated		Social meaning (status, etc.) identity etc.)		
	S	M	L	XL	L	H	L	M	H	H	M	F	N	Y	L	M	H	N	Y	N	M	HS
MP3/MP4 player	X				X			X		X			X			X			X		X	
Electric fan		X			X		X					X	X		X			X		X		
Smart MP3/MP4	X				X			X			X			X			X	X			X	
Smart printer		X				X		X			X			X		X		X			X	
Lamp		X			X		X					X	X		X			X		X		
Air conditioner			X			X			X			X	X		X			X		X		
Batteries	X				X		X					X	X		X			X		X		
Vacuum cleaner		X				X		X				X	X		X			X		X		
Microwave		X			X		X					X	X		X			X		X		

Table 2.
Taxonomy iteration 5. Size(Small, Medium, Large), Involvement(Low, High), Long-term reliability expectations(Low, Moderate, High), Value type (Hedonic, Mixed, Functional), Internet access(No, Yes), Multifunctionality (Low, Moderate, High), Social meaning (Negligible, Moderate, Highly significant).

Direct-influence behaviours (DIB)		
Layer 1	**Layer 2**	**Layer 3**
Discard	Reuse	Second-hand selling. Donating/Leasing.
	Recycle	Selling as scrap. Return for incentives. Disassembly and reuse of parts. ...
	Disposal in ordinary waste	
Stockpiling (out-of-use storage)		

Table 3.
By direct-influence behaviours (DIB) we refer to those that stem from decisions about whether to dispose of, and how to dispose of, equipment that is no longer in-use. The behaviours in the table are presented in three levels, and behaviours from the same level are mutually exclusive since they represent the options between which consumers may choose. In layer 1, consumers decide to either discard or stockpile. In layer 2, if they choose to discard, they may choose between reversing behaviours (reuse, recycle etc.) or discard in the ordinary waste routes. Finally, layer 3 provides some examples of reuse- and recycle-based reversing behaviours. See Supplementary Materials document, available upon request from the authors.

Indirect-influence behaviours (IIB)		
Layer 1	**Layer 2**	**Layer 3**
Acquisition, previously unowned EEE category	Alternative to new EEE purchase	Second-hand purchasing. Borrowing/leasing/renting. Remanufactured/recycled product purchasing. ...
	New product purchase	
Replacement of already owned	Alternative to new EEE purchase	Second-hand purchasing. Borrowing/leasing/renting. Remanufactured/recycled product purchasing. ...
	New product purchase	
Repair/upgrade		

Table 4.
By indirect-influence behaviours (IIB) we refer to those that stem from decisions about how an underfilled need should be addressed. The behaviours are presented in three levels, and behaviours from the same level are mutually exclusive since they represent the options between which consumers may choose. In layer 1, consumers decide to either acquire some product from a previously unowned EEE category, to replace some EEE they already own or to repair/upgrade some already owned EEE. In layer 2, provided that the consumer chooses one of the two former options, consumers may acquire a new product or engage in some behavioural alternative. Finally, layer 3 provides some examples of behaviours alternative to the purchase of new products. See Supplementary Materials document, available upon request from the authors.

concrete behaviours in relation to their higher-level (abstract) analogues, eventually allowing for between-level comparisons with respect to changes in EEE categories and institutional and cultural contexts.

Additionally, an important gap exists in the literature with respect to explorations into similar mechanisms that may occur in different consumption phases. For example, there are no empirical considerations of whether the emotional reasons for which consumers replace their EEE prematurely, i.e. before its end-of-life (EoL), to which marketing strategies tend to appeal, are partly the same as the reasons behind consumers' attachment to the replaced products, which eventually leads to

overestimation of their value and subsequent stockpiling. Some studies suggest that this may be the case, while some others seem to assume that stockpiling tends to occur for overestimation of future functional needs. Our conceptualisation is better suited to mixed context considerations such as this one, since it groups all behaviours into two unambiguous groups, highlighting the potential interactions between behavioural contexts that may otherwise seem unrelated.

3.2.2 The consumer behaviour perspective: drivers and barriers

Two distinguishable research foci can be identified in the literature: Consumer behaviour regarding the sales volume of secondary and primary EEE, as an engine for the success of *e*CLSC [37–39], and consumer *reversing* and out-of-use storage (stockpiling) behaviours (see **Tables 3** and **4**). Recognising this, a recent systematic literature review [35], aimed to synthesise extant findings from the consumer behaviour literature on determinants of purchase, extension of life and EoU/EoL management of EEE. In contrast, our keyword search was restricted to the CLSC and reverse logistics (RL) literature. Consequently, the studies identified hereby focused primarily on the consumer's role regarding WEEE management, such as recycling and reversing behaviours, as shown in **Tables 5** and **6**. Surprisingly, while [35] identify some additional studies focusing on purchasing and lifetime extension behaviours, our search was able to identify further sources regarding disposal and reversing behaviours. This highlights the need for consumer behaviour research on all the phases of consumption of EEE to align etymologically with research on CLSC, RL and CE, to explicitly account for the importance of all the roles of consumers in relation to *e*CLSC. This result indicates that consumer behaviour research on purchase and lifetime extension of EEE is not fully aware of its importance to the context of *e*CLSC.

Despite these differences regarding the sample of articles identified, our findings in terms of theoretical frameworks and behavioural predictors are in coherence with [35]. In particular, as we depict in **Tables 5** and **6**, the identified literature is dominated by theoretical frameworks that are built around the Theory of Planned Behaviour (TPB). While the results support the TPB's utility in understanding the influences of some cognitive factors behind behaviour, they do come with some

Study	Dependent construct	Main predictors
[36][a]	Discharge behaviour	Subjective norms, perceived behavioural control, size of EEE
[40][a]	Willingness to recycle online	Perceived behavioural control, subjective norms, attitudes, economic motivation
[41]	Disposal for reuse	Barriers: attachment and frugality. Drivers: infrequent use and emotional reward.
[42][a]	Intention to recycle	Attitude, perceived behavioural control, subjective norm and individual responsibility. In turn, sense of duty found to predict attitudes.
[43]	Recycling behaviour	Attitudes, moral norms, awareness of consequences, perceived convenience.
[44]	Acceptability of incentive schemes for take-back	Information conditions, education, gender, age, income. Type of product found to influence usage habits

[a]*The study uses (extended) Theory of Planned Behaviour as a theoretical framework.*

Table 5.
Target construct and identified predictors for studies exploring no specific WEEE categories. The "Dependent construct" column contains the construct of interest for each study, be it behavioural, attitudinal or otherwise. The "Main predictors" column contains the main predictors of the dependent construct, identified by each study.

Study	EEE category	Dependent construct	Main predictors
[31][a]	ICT	Reversing behaviour	Attitudes, moral norms, perceived behavioural control, subjective norms.
[30][a]	Mobile phone	Reversing behaviour	Attitudes, moral norms, perceived behavioural control, subjective norms.
[45]	Mobile phone, washing machine, coffee machine	Preferences for collection services	Price, reluctance for incineration, nature of product type
[39]	Smartphone	Recycling behaviour	Incentives, convenience, information security.
[46][a]	Mobile phone	Intention to recycle	Attitude, perceived behavioural control, subjective norm. In turn, perceived benefits and sense of duty found to predict attitudes.
[47][a]	Mobile phone	Returning to companies	Attitude, perceived behavioural control, subjective norm.
[48][a]	Mobile phone	Recycling behaviour	Barriers: lack of proximity and convenience of waste management systems.
[33]	Mobile phone	Post-consumption disposal	Age, gender, income, place of residence.

[a]*The study uses (extended) Theory of Planned Behaviour as a theoretical framework.*

Table 6.
Target construct and identified predictors for studies exploring specific WEEE categories explicitly. The "EEE category" column displays the product category addressed by the study. The "Dependent construct" column contains the construct of interest for each study, be it behavioural, attitudinal or otherwise. The "Main predictors" column contains the main predictors of the dependent construct identified by each study.

limitations. These include the tendency to focus on the formation of intentions under the assumption that these will be strong predictors of actual behaviour, e.g. [42, 46], and the lack of space for the identification of new processes, mechanisms and factors which can be relevant to behavioural outcomes, such as institutional context, personality traits, habitual behaviours or cultural dispositions, among others. The assumption that reported intentions reflect actual behaviour has been identified as an important limitation in the wider sustainable and ethical consumer behaviour literature due to a phenomenon known as the intention-behaviour gap, whereby consumers over-report on their intentions and attitudes when compared to observations of how much they really adopt sustainable-ethical behaviours [49, 50]. Finally, the lack of heterogeneity on theoretical (and methodological) frameworks results in a very good understanding of a very small portion of the plurality of mechanisms, processes and factors that determine consumer behaviour. Therefore, there is a need for theoretical and conceptual innovation regarding consumer behaviour for *e*CLSC, particularly across EEE categories and characteristics as we illustrate in the following sections.

In **Table 5**, we include the articles that do not focus on behaviours regarding no specific EEE category. Conversely, **Table 6** contains the identified studies that explore behaviours focusing on specific EEE categories. In both tables each study is presented with the main construct of interest and the main identified predictors, while in **Table 6**, the EEE categories studied are also specified. A quick inspection of these two tables provides some interesting insights. Specifically, the literature at the intersection between consumer behaviour and *e*CLSC, is dominated by studies on mobile phones specifically (6 studies) and on no specific WEEE category (6 studies). One article was also found to consider ICT equipment more widely [31], another study looked at smartphones more specifically [39], and only one article considered more than one EEE category explicitly [45].

Moreover, in the context of our discussion of different levels of behaviours (see **Tables 3** and **4**), we found most studies to fall within levels 2 and 3 as shown in **Tables 5** and **6**, and only one study considered post-consumption disposal behaviours more generally, but did so by breaking them down into some lower level, less abstract, behaviours [33]. As such, the research literature offers much space for improvement in this sense.

In conclusion, there is a need for innovation regarding the theoretical frameworks employed to enrich academic knowledge on consumer behaviour relevant to *e*CLSC, beyond the constructs hypothesised by TPB and similar frameworks. Moreover, results from studies focusing on the formation of intentions should be interpreted with care due to their susceptibility to biases. There is a need for empirical research to explore consumer behaviours pertaining to a wider variety of behavioural layers and specific EEE categories to establish the fundamental behavioural differences across categories of varying characteristics, the different perspectives that can be achieved through framings of varying abstraction, and the reasons behind them. This is further highlighted below.

3.2.3 EEE characteristics and pre-conditioning of consumer behaviour

Studies have used consumer surveys to profile the purchasing, usage, stockpiling, replacing and discarding of EEE in different national and sub-national settings (e.g. [51, 52]). For instance, [51] conducted a survey, distributed among a representative sample (n = 395) of households in Sao Paolo, Brazil. The study considers all the stages of consumption and, given the large variety of product categories that fall within the scope of EEE, the authors account and collect data for 26 separate EEE categories. Not surprisingly, their results vary significantly from one EEE category to another, as well as in comparison to similar results from different geographical contexts.

When considering in-use EEE, they found that each household had, on average, 17 items, where mobile phones and cathode-ray-tube TVs (CRT-TV) lead the ranking with about 2 per household. However, a closer look at how long the equipment had been owned, revealed that 60% of the mobile phones had been owned for less than 2 years at the time of reporting, while almost 85% of CRT-TVs had been owned for longer than 2 years, and about 25% had been owned for over 10 years. The latter, however, was true only for a negligible percentage of in-use mobile phones. Similar results are obtained by [44] from a sample of Portuguese consumers, where LCD-TVs are found to be typically in use for more than 10 years, while mobile phones were in use typically for 3-5 years. Given that CRT-TVs were found to have been replaced by LCD-TVs, since only 16% of the former were less than 2 years old while this applied to 74% of LCD-TVs [51], the differences and parallels of these studies likely indicate that CRT-TVs had already been replaced a lot earlier in Portugal. As illustrated by these examples, there are significant differences in consumer purchasing and use behaviour between different EEE categories, which persist across social contexts.

When considering out-of-use EEE that was being stored, i.e. stockpiling, the study finds these to represent about 12% of the total amount of EEE that is present in the surveyed households. The authors attribute this finding to the "treasure effect", a phenomenon whereby consumers tend to overvalue out-of-use products, and consequently do not discard them but instead keep them in a drawer or storage room over the belief that at some point in the future it will be needed and used again. This idea was supported by their findings which reveal that more than 50% of the out-of-use EEE was fully functional for the majority of EEE. However, for washing machines, microwave ovens, electric drills and DVD players, over 50% of the out-of-use EEE is functionally damaged. Therefore, their findings, when it comes to stockpiling behaviour, are significantly different for different EEE categories.

The authors find similar results concerning the acquisition of EEE from different routes (second hand, new …), reasons for acquiring the EEE and disposal routes (reuse, recycling …). Furthermore, [36] conduct a survey in South Korea (n = 2000) where they focus on identifying the current state of adoption of WEEE disposal behaviours and the cognitive factors behind it. The study too finds that products of different characteristics lead to contrasting results and dedicates one section to exploring how their results vary between EEE categories of varying sizes (small, medium and large). Namely, their findings suggest, among other differences, that while take-back initiatives only represent 10.24% of the disposition routes for small and medium sized appliances, it is the leading route for large EEE as it represents 34.5% of the total. However, the authors do not go beyond these characteristics as it is not the focus of their study.

As illustrated by the examples provided above, when considering consumer behaviour, the EEE category under study plays an important role in determining the needs and wants of the consumer, and hence their behaviour. Additionally, very significant differences emerge in similar studies in different national contexts due to important institutional and cultural differences. However, this does not change the fact that there are product characteristics which fundamentally influence consumer perception and behaviour in their decision-making process [45, 53].

Despite that, [36]'s attempt to explicitly assess the behavioural differences among different EEE clusters, namely by size, is one of the only available accounts. Other interesting findings in support of the importance of considering the types of EEE categories include [45]'s article which finds product type to be one of the most critical factors in determining behavioural differences. However, the study fails to unveil what the factors are that differentiate the EEE categories they explore, providing little information on how these EEE characteristics may be operating in leading to different behavioural outcomes. Finally, [30, 31] conduct two studies with the same sample (and dataset) but targeting ICT products in general and mobile phones, respectively (see **Table 4**). Both studies use the TPB to explore the adoption of recycling behaviours for ICT equipment and mobile phones separately. The results change substantially for the behavioural adoption, as intentions are only able to explain about 9% of the variation in the case of mobile phones, in contrast to 15% for ICT in general, while the opposite happens in the case of intentions to recycle, of which about 36% of the variation can be explained for mobile phones, but only 30% is captured in the general case. Additionally, when comparing structural equation modelling results with artificial neural network outcomes, the results agreed in the case of mobile phones, but in the case of general ICT equipment, the two analyses result in differences regarding the predictors' significances relative to one another. This further illustrates the idea that different EEE categories may better fit certain theoretical and methodological frameworks than others.

While all this evidence highlights the importance of developing an understanding of the EEE category characteristics that influence consumer behaviour and the reasons behind these influences, the literature is currently missing a comprehensive framework through which to do so. As [45] conclude, there is a need "[…] for the refinement of EEE classifications used for collection operations to encompass consumers' preferences, and not recycling requirements only". Moreover, we further extend their claim to all consumer-behavioural aspects of *e*CLSC, such as acquiring, using and storing, besides the already mentioned disposal.

3.3 A consumer behaviour focused taxonomy of EEE categories

We begin by stating the intended use of our taxonomy which is the first step in taxonomy building [34]. The intended users of our taxonomy include researchers in

the area of WEEE more generally, as well as more specifically consumer researchers in this area. In particular, while there are increasing accounts of behavioural differences among EEE categories, e.g. [51, 54], there are no frameworks that synthesise the main characteristics that may lead to such differences. Our taxonomy aims to provide a foundation on which to build subsequent knowledge regarding the behavioural differences that arise between EEE categories of differing characteristics and that are critical for *e*CLSC success.

Our taxonomy's dimensions and characteristics (see **Section 3.1.2**) are drawn from empirical and conceptual observations in the literature. However, one of the basic goals of a taxonomy is to be easily extendible [34]. In this sense, we provide hereby a starting point on which to further extend our knowledge regarding the main EEE characteristics that lead to behavioural differences among consumers. To construct the taxonomy, we used an initial pool of 29 EEE categories to test the relevance of the taxonomy. The method and the classification of the initial sample of EEE categories is presented in full detail in the *Supplementary Materials* to this chapter, see **Appendix**. The final taxonomy, which we present in **Table 2**, reads as follows:

T_4 = {*Size* (Small; Medium; Large; Extra-large); *Involvement* (Low; High); *Long-term reliability expectations* (Low; Moderate; High); *Value type* (Hedonic; Mixed; Functional); *Internet access* (No; Yes); *Multifunctionality* (Low; Moderate; High); *Outdated* (No; Yes); *Social meaning* (Negligible; Moderate; Highly significant)}.

Next, we provide an explanation of each dimension and their characteristics together with some of the potential behavioural differences that may be expected.

3.3.1 Size

The *Size* dimension contains three characteristics: small (e.g. mobile phones, smartphones, hair drier, electric shaver …), medium (e.g. coffee machine, DVD player, radio receiver, VCR, laptop …), large (e.g. LCD-TV, desktop computer, stereo system …) and extra-large (e.g. washing machine, refrigerator …). We conceptualise it as having four characteristics since we found the typical *small-medium-large* system to be ambiguous when trying to classify our pool of items at the taxonomy building stage. This has interesting implications for consumer research aiming to elicit attitudinal or other differences in consumer perceptions through self-reports. In particular, through disambiguation, grouping EEE categories in four clusters of size, rather than three, could improve discriminant validity of the studies. In other words, while the relative differences between EEE sizes decrease, less of the EEE categories fall within the "boundaries" of the size characteristics, making clustering more natural for respondents of these studies. Size of the EEE is likely to lead to differences in out-of-use storage, use and discarding behaviours [36, 51, 55] of consumers.

3.3.2 Involvement

The *Involvement* dimension contains two characteristics: low (e.g. batteries, hair drier, electric shaver …) and high (e.g. washing machine, smart TV, air conditioner …). This dimension can be broken down into two intertwined aspects: **price** and **risk**. Hence, low-involvement EEE categories fall within a lower price range and have less risk associated with their purchase, while high-involvement ones fulfil the opposite. As the name suggests, these differences in what we call involvement, invoke different levels of interest and importance, quantity and type of information required to reach decisions for the consumption process at hand, in other words this captures how involved the decision making is expected to be. Less involved decision making tends to be dominated by price and routine considerations, while high-

involvement decision making involve premeditation and information seeking leading to a more conscious sequence of decisions.

3.3.3 Long-term reliability expectations: essentiality of EEE

The *Long-term reliability expectations* dimension contains three characteristics: low (e.g. hair drier, electric iron, blender …), moderate (e.g. coffee machine, mobile phone, DVD player) and high (e.g. washing machine, refrigerator, air conditioner …). We identify differences in the assessed EEE categories regarding how essential or necessary they are to consumers' day-to-day lives. Moreover, some products are more susceptible to considerations regarding the expected longevity of the equipment. Quite clearly, these two considerations are intertwined in the sense that consumers are likely to strongly consider longevity when purchasing items that they expect to need to use very often. However, they are not equal, since some, e.g. high involvement or large EEE, could include strong considerations of longevity for other reasons, i.e. without it being an essential piece of equipment to one's everyday life. As such we conceptualise this dimension which compositely considers the importance of **longevity considerations** when acquiring the EEE and how **essential** the equipment is to consumers' day-to-day life.

There is a trivial effect of this dimension on purchasing and use behaviours, since we aim to differentiate between EEE that invokes more considerations for longevity and is more frequently needed/used, by definition. It is worth mentioning that this is similar to the influence discussed for involvement of EEE. Despite that, the behavioural outcomes of interest here differ substantially since they are restricted to involvement regarding considerations of longevity and necessity, while the previous dimension is more general. Moreover, these differences are particularly relevant to considerations about repair, restoring and second-hand markets. This is because having longevity in mind develops some expectations that the consumer will tend to meet. In turn, this results in better kept equipment that may be fit for further reuse in remanufacturing or even second-hand markets.

3.3.4 Value type

The *Value type* dimension contains three characteristics: hedonic (e.g. stereo system, DVD player, MP3/MP4 player …), mixed (e.g. laptop, smartphone, smart TV …) and functional (e.g. washing machine, refrigerator, air conditioner …). In other words, our taxonomy distinguishes between EEE in which hedonic value dominates, those in which functional value dominates and those in which they are both comparable. We refer to fun and entertainment value which consumers associate with some EEE category as hedonic, while we refer to utilitarian, service or use value that consumers extract from using some EEE as functional value. Equipment with hedonic value type is more likely to give rise to emotional responses [56] making them more susceptible to premature replacement (i.e. before EoL) and stockpiling, particularly if they are also large. On the other hand, EEE categories with functional value are likely to be replaced at EoL or repaired [54]. Finally, mixed value EEE categories are likely to give rise to more consumer-dependent responses depending on whether they perceive the hedonic or the functional value of the equipment more.

3.3.5 Internet access

The *Internet access* dimension contains three characteristics: no, i.e. no internet access capabilities, (e.g. washing machine, batteries, lamp …) and yes, i.e. with

internet access, (e.g. laptop, smart TV ...). It is becoming increasingly common for EEE to be upgraded into its smart version, i.e. a version with internet access capabilities. This raises concerns for consumers regarding their personal data. Therefore, consumers are more likely to stockpile EEE with internet access, and hence less likely to return for reuse or recycle, in order to avoid facing the additional cost incurred due to concerns and further involvement that may be viewed as unnecessary. Additionally, the smart versions of EEE categories invoke changes in other dimensions considered in our taxonomy when compared to their conventional counterparts, like size (due to optimization of component sizes), involvement (due to increases in price) and multifunctionality – which emerges naturally from internet access.

3.3.6 Multifunctionality

The *Multifunctionality* dimension contains three characteristics: low (e.g. washing machine, coffee machine, hair drier ...), moderate (e.g. mobile phone, LCD-TV ...) and high (e.g. laptop, smartphone ...). We distinguish between three levels of multifunctionality. In particular, multifunctionality refers to the attribute of offering more than one function. While every product can be considered multifunctional provided some creativity is in place, e.g. a washing machine or a refrigerator doubling up as a table and a notice boar, respectively, this is not what our multifunctionality aims to capture. Conversely, it aims to distinguish between EEE whose intended function is very specific, often singular; such as washing machines, lamps or electric shavers; somewhat multifunctional, most often offering a couple of functions; such as classic mobile phones which can serve for communication but also for reproduction of sounds or taking pictures; and highly multifunctional EEE, which is usually designed to offer a large variety of capabilities resulting in both hedonic and functional values; such as laptops and smartphones.

More multifunctional EEE is less likely to be kept unused, since it fulfils many needs, making it likely to be used frequently. Therefore, equipment that is more single-functional offers a greater opportunity for sharing, leasing, and borrowing initiatives. In addition, there may be interesting implications on stockpiling behaviour since more multifunctional equipment is more susceptible to the thought that it may be needed in the future, even more so for moderately multifunctional EEE which is not necessarily being used frequently in the first place. Similarly, since highly multifunctional EEE tends to offer mixed value (see **Section 3.3.4**) it may also turn out to be more susceptible to stockpiling behaviours and premature replacement.

3.3.7 Outdated EEE

The *Outdated* dimension contains three characteristics: no, i.e. not outdated, (e.g. stereo system, DVD player, MP3/MP4 player ...) and yes, i.e. outdated, (e.g. washing machine, refrigerator, air conditioner ...). We regard as outdated EEE categories, those which have been widely replaced by newer, functionally more advanced EEE. A tangible example is that of classic mobile phones vs. smartphones. In other words, outdated EEE displays great losses in sales in the last years and are often discontinued (but not always). Outdated equipment may be stored out-of-use or in-use due to emotional attachment, as a collectable or vintage item. This type of equipment may also be more susceptible to being discarded in conventional waste routes, with all its health and environmental implications. Finally, since often

discontinued, outdated EEE is unlikely to be acquired through the purchase of new EEE but is more likely to enter the second-hand and recycled product markets.

3.3.8 Social meaning (identity and status)

The *Social meaning* dimension contains three characteristics: negligible (e.g. stereo system, DVD player, MP3/MP4 player …), moderate (e.g. laptop, smartphone, smart TV …) and highly significant (e.g. washing machine, refrigerator, air conditioner …). This dimension aims to capture some indication of the level of social meaning typically attached to a given EEE category. Material possessions are often attached to social meaning, in other words, they communicate belonging to a certain social group [57]. For example, cars and houses have been symbols of wealth and success, i.e. social status, for decades. A similar situation can be observed increasingly prominently with EEE, such as mobile phones [54, 58]. It is straightforward to see that this social meaning has little to do with the functionality of the products (see high heels and fast cars, for example), making products that are highly stereotyped and to which a great deal of social meaning is attached, much more susceptible to emotional responses. Such EEE categories are more likely to awake the desire to replace products before their EoL, but also potentially to lead to an overestimation of the replaced equipment [54]. This establishes the level of social meaning attached to a given EEE category as an important indicator of susceptibility to being prematurely replaced and kept out-of-use, hence affecting all consumer behaviour phases.

Not surprisingly, given that the EU's classification system [4] does not consider consumer behaviour but rather operational and material differences, we found their classification to poorly differentiate among EEE categories with respect to consumer behaviour. As shown in **Table 2** in bold, in the last iteration of the taxonomy, we classified items that the EU classification system regards as pertaining to different classes. The classification of these under our taxonomy's dimensions and characteristics revealed that they only differed on three out of the eight proposed dimensions, indicating that with respect to our taxonomy's dimensions and under considerations of consumer behavioural outcomes, the EEE categories were actually very similar. In other words, any behavioural differences could easily be attributed to one of the three dimensions on which they differ, but behavioural differences would be less likely to emerge. This suggests that EU regulation could benefit from the perspective offered by our taxonomy in accounting for the associated differences. Additionally, this supports the utility of our taxonomy as an alternative compass for understanding the differences across EEE categories for consumer behaviour and *e*CLSC research.

4. Discussion

In this chapter, we have provided an overview of the current state of WEEE regulation and collection trends in the EU and analysed and contributed to the consumer behaviour literature in the context of *e*CLSC by building a taxonomy of EEE categories. In this section we offer a discussion of implications, limitations, and avenues for future research.

In Section 2, discussing the EU's household WEEE related regulations, which is considered the state-of-the-art [4], the main implication from our research is that it is not enough. The increase in household WEEE collection falls behind the increase in new EEE put to the market, resulting in an ever-growing stream of WEEE that ends up being dumped or processed in the informal sector. This is not just an issue

in the EU, but a global issue as is evidenced in **Table 1** [9]. Considering that Europe is the region most effective in household WEEE collection, it is a suitable object of study when researching regulation and identifying novel ways of growing the urban mining sector. Bad WEEE collection is not just a missed financial opportunity [13], dumped or ill processed WEEE forms serious environmental and health hazards, hitting developing countries especially hard [10]. Based on these findings, we consider it critical that improvements are made in engaging consumers with proper and responsible WEEE collection and the role of consumers in *e*CLSCs should be well understood.

Some limitations of our work are related to the use of systematic keyword search for the consumer behaviour literature on *e*CLSC. In particular, by restricting our search to the context of CLSC, it identified mostly studies about the post-consumption or disposal phase. However, the existence of a recent literature review that identifies studies relating to all phases of consumption [35], reduces the negative impacts of the limitation discussed hereby. This is also supported by the similarity of our findings. Moreover, our search is able to identify a significant number of articles that are not identified by [35], hence offering a complementary view, rather than a biased one. Finally, to reduce potential negative impacts, we employed snowball mapping to identify further studies from the reference lists of the original set of articles.

We conducted a classification of consumer behaviours for *e*CLSC based on the consideration of direct, i.e. pertaining to considerations about equipment that has reached its EoU phase, and indirect, i.e. emerging from considerations about fulfilling some need(s), influences of consumer behaviour on *e*CLSC (see **Tables 3** and **4**). These have highlighted different levels of abstraction with which behaviours may be conceptualised. Future research could consider the concreteness of their conceptualisations to balance between reliability and generalisability of their results. While less concrete conceptualisations may offer less confident real-life predictions on a specific-case basis, results may be applicable to more scenarios. Moreover, abstract conceptualisations of behaviours (e.g. disposal) can be broken down into more concrete ones (e.g. return for incentives, sell second-hand, sell as scrap etc.) based on the objectives of the specific studies. While there are studies employing such techniques, e.g. [33], they do not do so explicitly. We have not encountered studies that also measure the overarching abstract behaviour in addition to its concrete constituents. Therefore, our findings suggest an interesting avenue for future research could be to account for these conceptualisations, of varying levels of abstraction, in order to allow for comparison of the results. In other words, *how do results change between the concrete and the more abstract conceptualisations of behaviours?*

The role of consumer behaviour in *e*CLSC was found to be critical to their success, but poorly understood by the surveyed literature. Specifically, there is a lack of variety concerning theoretical and methodological frameworks resulting in a significant amount of knowledge generation but pertaining to a very specific portion of the many simultaneous factors and processes leading to consumer behaviour. As such, institutional and cross-cultural perspectives, among others, have been overlooked in exchange for repeated applications of frameworks built around the TPB. Moreover, some studies employing this framework tend to assume that findings about behavioural intentions are realistically representative of actual behaviour, which has been widely rejected in the context of sustainable and ethical consumer behaviour. Therefore, we call for careful interpretations of such results.

In relation to methodological and theoretical innovation, we propose that, given the already existing literature on CLSC from a game theoretic perspective,

experimental economics [59] may offer an interesting framework for the empirical testing of extant and future models. Additionally, in this proposed direction, future research could focus on modelling and optimising of consumer decisions, on top of all other nodes in the modelled CLSC network. Moreover, the development of further structural models based on institutional and cultural considerations offers a natural continuation to the set of TPB-based studies.

Our review identified a sector of studies aiming to characterise the waste streams of certain national contexts through household surveys. While these studies offer little empirical explanation for the reasons behind observed behaviours, they do identify significant differences between the concrete behaviours, EEE categories and geographical contexts. This highlights the need for future research to work towards the elucidation of the most significant reasons for behavioural differences to emerge across all the aforementioned domains. To this end, we offer a conceptual starting point as discussed below.

In **Section 3.3** we developed a taxonomy of EEE categories by considering how their characteristics may predispose consumer behaviour towards different directions. While there had been some attempts to consider how EEE categories' characteristics tend to predispose consumers in specific behavioural areas [54], to the best of our knowledge, ours is the first attempt at capturing a large pool of dimensions through which to differentiate among EEE relating to all phases of consumption. The main benefits associated with our methods are those of replicability, extendibility and systematicity. Specifically, by following a fully transparent method and reporting on every iteration and decision made leading up to the final taxonomy [34], see Supplementary Materials document (see **Appendix**), we allow for plasticity and advancement of the taxonomy based, for example, on case-specific applications, theoretical and empirical criticism and extension or modification due to increase in data availability.

The classification of the sample of EEE categories used in the construction of the taxonomy was necessarily carried out *ad hoc* in some instances, due to unavailability of product-specific studies and data leading to potential ambiguity or disagreement among users. Therefore, it should be highlighted that the goal is not to set said classification in stone, but rather to provide a conceptually sound starting point for research to build upon as knowledge is generated. Despite its limitations, however, our taxonomy highlights what we have determined to be the most relevant characteristics that predispose consumers to adopt certain behaviours. We expect this to aid the inclusion of dimensions other than size in future comparisons of behavioural outcomes between EEE categories.

The main implications of our taxonomy can be summarised into the following points: (1) There are many physical, functional and symbolic dimensions and characteristics on which EEE categories may differ, leading to differences in behaviour. (2) There is a lack of research explicitly trying to consider and understand these differences, other than superficial explorations of those related to size and price heterogeneity. (3) Our result calls for further research to use, explore, expand and modify our taxonomy such that its value to researchers can increase. (4) There are interesting interconnections between some of the dimensions, which can be understood as moderation effects, which offer interesting avenues for future research. For example, value type may be able to explain some of the tendency to stockpile, but this may apply more strongly to small EEE categories than the other sizes, i.e. a moderation effect from size on the relationship between value type and stockpiling behaviour. (5) The EU would benefit from complementing extant classifications of EEE categories with our taxonomy's perspective in order to explicitly consider how consumers relate to EEE categories of different characteristics.

5. Conclusion

In this chapter, we first developed an understanding of the current state of household WEEE regulation in the EU. The EU currently has the state of the art in household WEEE regulation and achieves the world's highest collection rates. Nonetheless, the EU, and the rest of the world, cannot cope with the growth of the EEE sector, and WEEE collection falls behind, leading to a vast amount of valuable resources that is removed from the formal economy and instead causes further harm to the environment and human health. Based on these findings, which establish the return of consumer products as one of the most underexploited resources when it comes to the sustainable recirculation of products and materials into the economy, we build an understanding of the role of consumers in *e*CLSC. Our analysis establishes that the intersection between the consumer behaviour and the *e*CLSC literatures is still nascent and offers many interesting routes for research. Finally, we develop a taxonomy of EEE categories based on characteristics, physical, functional and symbolic, that predispose consumers to some behaviours. We identify 8 key dimensions: size, involvement (price and risk), long-term reliability expectations (essentiality and requirement for longevity), value type, internet access, multifunctionality, the quality of being outdated and social meaning. The chapter concludes by discussing limitations, which mostly emerge due to the systematic literature search, and how we addressed them. Additionally, implications and avenues for future research, including the necessary methodological and theoretical innovation beyond the TPB framework and survey methodologies are discussed.

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Conflict of interest

The authors declare no conflict of interest.

Nomenclature

CE	Circular Economy
CLSC	Closed Loop Supply Chain(s)
*e*CLSC	Closed Loop Supply Chain(s) for Electrical and Electronic Equipment
EEE	Electrical and Electronic Equipment
EoL	End of Life
EoU	End of Use
EPR	Extended Producer Responsibility
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals
RL	Reverse Logistics
RoHS	Restriction of Hazardous Substances
WEEE	Waste Electrical and Electronic Equipment

Appendix

Due to space limitations, we wrote a *Supplementary Materials* document that is available upon request from the authors. Its contents can be summarised as follows: First, it provides further insight into our conceptualisation of *e*CLSC-relevant consumer behaviours. Second, it provides complementary details about the literature search and literature identification phase conducted as part of **Section 3** in the chapter. Finally, it offers an in-depth account of our taxonomy development strategy, including explanations for all the decisions and iterations leading to the final taxonomy presented in **Table 2**.

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