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Understanding Consumer E-Waste Recycling Behavior: Introducing a New Economic Incentive to Increase the Collection Rates

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Abstract: Consumer electronics are made of a wide range of materials, including precious metals and critical minerals with limited global reserves. Ensuring the recycling of these materials is essential for future use, especially since many renewable energy solutions are based on them. In addition, improper end-of-life treatments of these products cause harm to the environment and human health. This study explores the incentives that have been used to increase consumer collection rates for end-of-life electrical and electronic equipment (EoL EEE). Based on extensive global literature reviews, we propose an alternative to existing consumer incentives. The research suggests that implementing an economic incentive based on the electronic bonus card system (EBCS) has several benefits compared to existing incentives. It compensates the consumers for the transaction costs of proper collection and satisfies the consumer perception of EoL EEE as having a residual value. However, application of the EBCS motivation technology will require the cooperation of various stakeholders, including electronics producers and national and international authorities.

Keywords: pro-circular behavior; consumer behavior; reuse; recycling; e-waste; separate collection; motivation; economic incentives; electrical and electronic equipment

1. Introduction

The current way of producing and consuming products presents severe challenges to sustainability in the form of negative environmental impacts, social injustice, and poverty. Many policies have been developed globally to fight these challenges, including the United Nations Sustainable Development Goals [1]. European environment policy has several strategic benchmarks, including "waste prevention and recycling", "sustainable use of resources", "integrated product policy", and "sustainable consumption and production" that, to varying degrees, are reflected in the new General Union Environment Action Programme to 2020 "Living well, within the limits of our planet" [2]. The Programme outlines the issue of moving towards a 'circular economy' as a distinct way of consumption, as well as an economic model. Circular economy is a tool for the operationalization of the concept of sustainable development as highlighted by Murray and colleagues [3]. EU action plan for the circular economy deals with the entire lifecycle and covers production, consumption, secondary raw materials, and waste management [4].

The accelerated transition to a circular economy model requires a corresponding policy that reflects the continuous building-up of material and product circularity potential as well as the fullest use of the available potential based on the priorities of preserving the value of materials, substances, products, modules, and details in the economic system as long as possible [5,6]. Consumer behavior is crucial for preserving the material and product value in the value chain. Consumers determine the demand for various products, use and maintain them, and decide whether to return products to the reuse/recycling system at products' end-of-life (EoL). In this article, we examine consumer e-waste recycling behavior as a distinct activity towards circular economy performance. Our aim is to provide an overview of the determinants of recycling behavior as a theoretical background to justify current incentives aimed at increasing EoL EEE collection rates. This research provides insight into how incentives work and proposes an alternative incentive to support the pro-circular activity of consumers in terms of proper collection. We have chosen e-waste or EoL EEE as a stream of waste, as it is important to retain materials from these products in the technogenic cycle, owing to limited global reserves and substantial negative impacts on the environment and human health when handled improperly. The theoretical background of the study is Ajzen's theory of planned behavior [7] and the ABC model derived from psychological literature [8,9].

2. Background

2.1. Challenges with E-Waste

Current estimates indicate that around 44.7 to 50 Mt of e-waste are produced worldwide per year [10,11]. This equals approximately 6.1 kg per inhabitant [11]. E-waste represents 1–3% of global municipal waste production [12] but is increasing by approximately 3–5% per year [13,14]. By 2021, e-waste is expected to grow to 52.2 Mt, or 6.8 kg per inhabitant [11].

There are more than 900 types of EEE in the developed world [10]. Demand for information and communication technologies and rapid product obsolescence [15] lead to a proportional generation of this waste. According to the United Nations [14], the volume of old computers will increase by 500% in India by 2020. In addition, the amount of used mobile phones will be about 7 times higher in China and 18 times higher in India, compared to 2007 levels [14]. High rates of production and low levels of recycling lead to the accumulation of waste electrical and electronic equipment (WEEE) in the environment, increasing pollution.

WEEE is one of the most problematic waste streams in terms of recycling and potential pollution [16] because of its complex composition that frequently contains hazardous and non-biodegradable materials. WEEE contains more than 1000 different substances (up to 60 elements from the periodic table [17]), many of which are toxic to human health and the environment, such as lead, mercury, arsenic, chromium, cadmium, and plastics [18]. In the USA, 70% of the mercury and cadmium in landfills originates from e-waste [19]. Because of specific types of e-waste contain hazardous material and substances, they need to be managed in order to minimize significant adverse effects.

Recovering materials from e-waste is especially important, as they include valuable recyclable components that are in limited supply such as platinum, palladium, and silver [20,21]. Many of these minerals are essential raw materials in renewable energy products. Overall, UNU [11] estimates the value of secondary e-waste materials at €55 billion.

Review by Bakhiyi et al. [22] showed that there are several challenges related to the management of e-waste. These include lack of harmonization of e-waste definitions, remaining toxic potential of already prohibited or restricted hazardous components (e.g., heavy metals, persistent, and bio-accumulative organic compounds), continuous growth in e-waste volumes, problematic e-recycling procedures, damaging informal e-recycling systems combined with complex and unforeseeable patterns of illicit e-waste trade, and the fragility of the formal e-recycling sector [22]. Similarly, Tansel [23] argued that although the markets for recycled materials are gradually increasing, there are still major challenges in managing e-waste, such as the lack of infrastructure for collection and separation of e-waste, lack of accounting mechanisms for cross-boundary transport, and lack of awareness and training for the safe handling and processing of materials during their recovery at uncontrolled recycling operations.

It is difficult to track the volume of e-waste transported from the richer Global North to the poorer Global South [11]. According to Perkins et al. [24], only 25% of global e-waste is accounted for and recycled by official means, and the remainder is lost in the unreported e-waste trade. By another source [11], only 8.9 Mt (20%) of all e-waste generated is documented to be collected and recycled, and 35.8 Mt or 80% is going undocumented. From the latter share, approximately 4% or 1.7 Mt of e-waste in the higher income countries is thrown into the residual waste, and the fate of 76% (34.1 Mt) of e-waste is unknown [11]. The U.S., U.K., and the EU are the major exporters of e-waste to developing countries such as China, India, and Nigeria [11,25] benefiting from low-cost labor and 'disposal'.

2.2. E-Waste Legislation and the Extended Producer Responsibility (EPR) Principle

In response to the e-waste problem, policies and legislations are gradually being developed to address the proper handling of EoL EEE. National e-waste management laws cover currently about 66% of the global population [11]. EU legislation [26] contributes to sustainable production and consumption by enforcing a waste hierarchy that focuses on preventing WEEE, followed by re-use, recycling, and other forms of recovery. The WEEE Directive has been adopted by all EU member states and includes a variety of regulations related to WEEE take-back compliance, with a variety of definitions, obligations, and agreements [27]. The e-waste problem is complex, therefore most countries have many laws related to e-waste. For instance, China recently enacted three laws for WEEE: the Cleaner Production Promotion Law, the Solid Waste Pollution Prevention Law (Amendment), and the Circular Economy Promotion Law. Based on these laws, the appropriate agencies have enacted 12 laws and regulations to manage the recycling and treatment of e-waste [28].

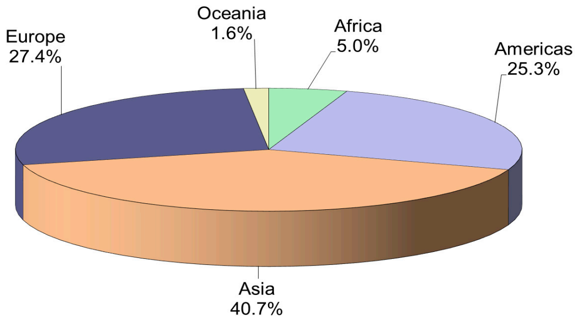
When developing a new e-waste collection and recycling system, it is important to consider who will retain overall control and responsibility for the effective operation of the system [11]. Each state is free to allocate this responsibility in different ways, either assigning them to local governments or exploiting more complex schemes, which may include partnerships between producers and central authorities [29]. The main idea of Extended Producer Responsibility (EPR) is to provide incentives for producers to design products in a way that minimizes waste management costs inasmuch as they are financially responsible for this process. To date, there are five types of EPR: financial, physical, compensation, informational responsibility, and property rights [16].

In general, the implementation of responsibility means that the manufacturer retains the right to own a product when it enters the waste category. The consumer has a special role in the operationalization of EPR principle because they act as a customer, user, and e-waste holder. Increasing consumer participation in e-waste collection schemes requires the identification of determinants that influence consumer recycling behavior.

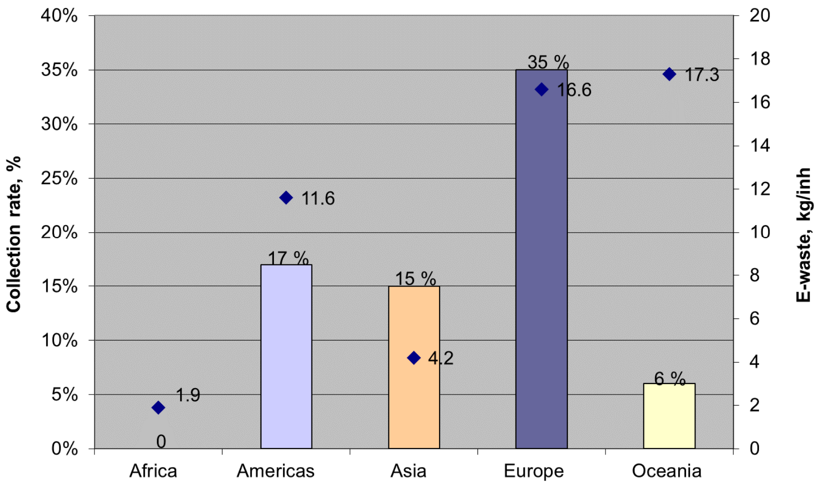
2.3. E-Waste Collection Rates: From Global to Local

The collection rates of e-waste vary by countries [11,12]. Figure 1 shows the global structure of e-waste generation and collection rates by continents. According to Baldé et al. [11], Asia generates approximately 40.7% of global e-waste, but only collects 15%. This high share of waste generation is partly due to the import of e-waste from other continents. Europe and the Americas produce similar amounts of e-waste at 27.4% and 25.3%, respectively (Figure 1a). However, the 35% collection rate in Europe is almost twice as high as in the Americas. The U.S. is the largest e-waste producer in the Americas, at more than 5 Mt per year, which is about one-tenth of the global e-waste generation. Only 0.004 Mt of e-waste is collected and recycled annually in African countries [11]. African countries also have the lowest volume of e-waste generation per inhabitant (Figure 1b).

Approximately 4.3 Mt of e-waste was collected and appropriately managed by Europe's 40 countries in 2016 and this is about one-third from 12.3 Mt e-waste generated [11]. Figure 2 shows that the rate of e-waste recycling of 28 EU countries increased during the period 2010–2015. At the same time, there was an increase in volume of EEE placed on the market during 2014–2016.



(**a**)



(**b**)

Figure 1. E-waste generation structure and collection rates by continents (source: Baldé et al. [11]). (**a**) E-waste generation global structure; (**b**) E-waste generation per inhabitant and collection rates by continents.

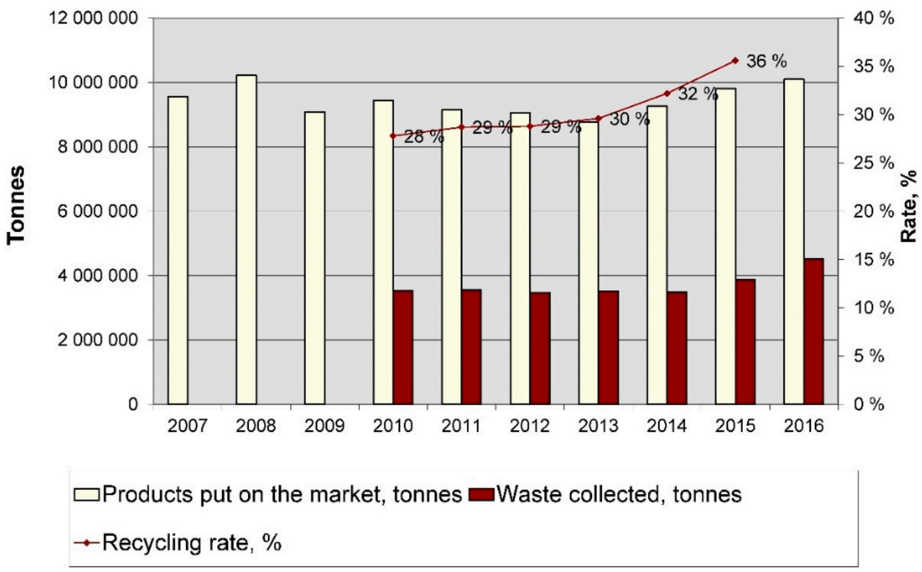


Figure 2. Dynamics of the indicators of the EEE placed on the market, e-waste collected, recycling rates by EU 28 countries during the period 2007–2016 (source: Eurostat official site data [30]).

Figure 3 shows the ranking of European countries by the level of e-waste collection in 2016. The EU WEEE directive specifies minimum annual collection rates for member states. These targets are increased periodically. In 2016, the minimum annual collection rate was set to 45% of the average volume of EEE placed on the market over the three preceding years [26]. Most countries achieved this target, including Sweden (55.4%), Norway (49.3%), Ireland (49.5%), Slovakia (50.3%), Portugal (45.8%), Hungary (53.4%), Luxemburg (45.6%), and the Czech Republic (46.1%). In 2016, a few countries achieved the higher minimum rate of 65% set by the Directive [26] for 2019–2020 including Liechtenstein, Bulgaria, Estonia, and Croatia. Among EU member states, Lichtenstein and Bulgaria had the highest e-waste collection rates in 2016 at 111.9% and 105.2%, respectively. In Bulgaria, a robust consumer campaign that included payments to citizens resulted in historic rates of waste return [31]. However, the Bulgarian figure is also likely overestimated due to unregistered EEE from industrial use and imports of used goods [32]. The lowest 2016 collection rates were in Malta (6.2%), Romania (19.4%), Cyprus (23.1%), and Latvia (23.2%). Scandinavian countries, as well as Liechtenstein and Switzerland, are the most progressive EU countries for e-waste collection, with consistently high rates over the last few years [30].

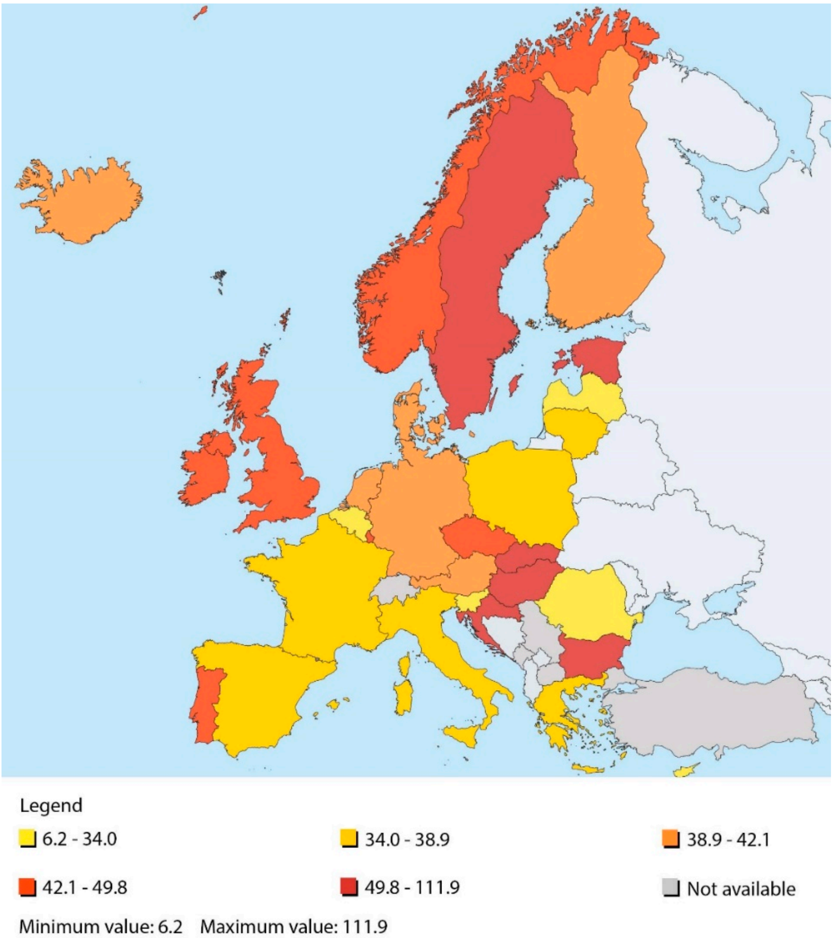


Figure 3. Recycling rate (%) of e-waste by 28 EU countries in 2016 (source: Eurostat official site data [30]).

The volume of e-waste collected by EEE categories in EU countries during 2011–2016 is presented in Figure 4. The share of e-waste from large household appliances increased by 4–5% per year during the last three years. In contrast, the share of e-waste generated by IT and telecommunications equipment has decreased [30]. It seems that the trends in these two categories can be partly explained by the higher focus of member countries on increasing the volume of collected e-waste, instead of the number of units. An additional explanation for this could be that consumer recycling behavior varies between types of products, as it is easier to dispose of smaller items with generic waste.

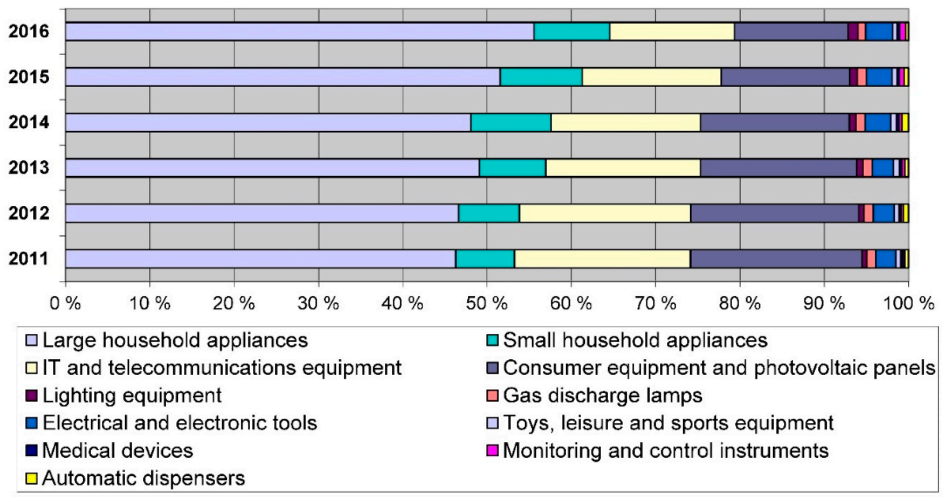


Figure 4. Dynamics of collected e-waste structure by EEE categories for EU countries during the period between 2011–2016 (source: Eurostat official site data [30]).

The circular diagram presented in Figure 5 shows the amount of uncollected e-waste across European countries. While e-waste recycling rates vary over time, huge amounts of e-waste remain uncollected in some countries.

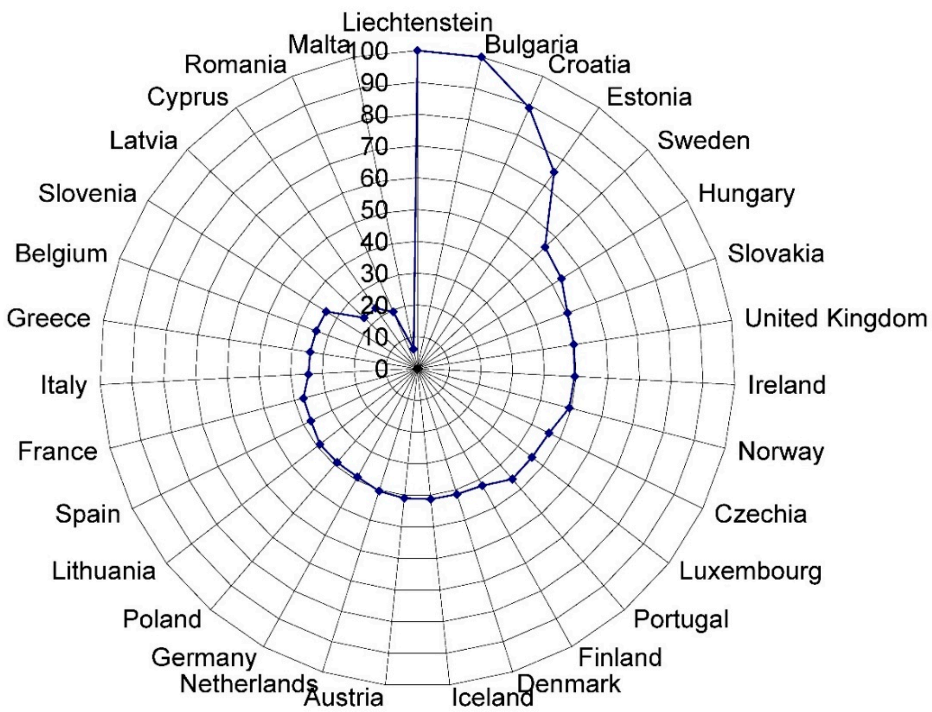


Figure 5. A circular diagram of e-waste recycling rates by EU countries in 2016 (source: Eurostat official site data [30]).

Even though proper collection is the beginning point for reuse and recycling, there are no punitive measures to force consumers to participate in e-waste management systems [15]. Ultimately, consumer behavior does not lie in the area of to 'be obliged' and is determined by an individual attitude to the collection process. The tools and techniques for changing neutral or negative consumer attitudes about collection are still being discussed. Understanding consumer motivations and intentions regarding e-waste collection is crucial for increasing their involvement.

3. Research Methodology

This study was conducted as a literature review to bring together recent articles relevant to consumer recycling behavior. Our aim was to identify key underlying determinants and incentives that increase consumer engagement in EoL EEE collection, thereby creating the pre-requisites for circular economy operationalization. To ensure the review was comprehensive, the search of the initial body of literature was carried out via Scopus, Web of Science, and Google Scholar search engines based on the following keywords: "waste electrical and electronic equipment", "e-waste", "end-of-life products", "recycling behavior", "consumer behavior", "behavior determinants", "behavior factors", "proper collection", "e-waste collection challenges ", "consumers' incentives", "economic incentives", and "e-waste collection incentives". In addition, some papers were discovered from the references of selected articles. Our selection criteria were peer-reviewed journal articles published over the last 15 years in English. We excluded research papers that did not focus on e-waste disposal and did not discuss determinants of consumer recycling behavior. We examined these articles on possible determinants of consumer recycling behavior affiliating to various countries that were selected by the criterions of the popularity in terms of citations and the presence of analysis of a number of determinants. The collection of papers was stopped at about 30 when a data saturation point [33] was found and no more new categories emerged.

4. Consumer Recycling Behavior: Key Determinants in Terms of Theory and Practice

4.1. Perceived Behavioral Control in Consumers' Recycling Behavior

Several theoretical approaches have been used in studies of consumer e-waste disposal behavior. One of the most popular theories is Ajzen's theory of planned behavior (TPB) [7] that states that an individual's behavioral intentions are shaped by their attitude towards behavior, subjective norms, and perceived behavioral control. Based on this theory, the perceived behavioral control that takes place in e-waste recycling reflects an individual's perceived ease or difficulty in performing this behavior. This idea is depicted in the ABC-Model (ABC-Hypothesis) which reveals that if external conditions (C) are unfavorable, then the impact of attitudes (A) on behavior (B) will be weak [8]. In a similar vein, when the C-determinant (techno-organizational factors) has extreme values, the significance of the A-determinant (socio-psychological factors) to the B-determinant (behavior) decreases. In respect of consumer's e-waste recycling behavior [9], if the C-determinant exhibits behavior that enables proper participation, then many will participate, and the attitude (A-determinant) will not be an important factor for behavior (B-determinant). If the C-determinant makes the action very difficult, then few will participate, irrespective of the A-determinant.

As an alternative to causal models or rational choice theories such as TPB, social practice theory focuses on practices that are a part of routine, everyday life and are not fully conscious, rational behaviors. This can partly explain the discrepancies often documented in studies that are called the "value-action gap" [34], "intention-behavior gap" [35], or "knowledge-to-action gap" [36]. Practices consist of elements that are routinely repeated but are also subject to possibilities of constant change [37]. These elements are categorized in various ways by different researchers, but generally include "forms of bodily activities, forms of mental activities, 'things' and their use, background knowledge in the form of understanding, know-how, states of emotion and motivational knowledge" [38] (p. 249). Change can occur when new elements or links are introduced. Practices can be deconstructed and relinked to new behaviors. In our case, the new element is the application of EBCS combined with increased knowledge of environmental or economic advantages of recycling.

Ease or difficulty in the performance of the proper e-waste recycling behavior is perceived by the individual, based on the so-called consumer's transaction costs that accompany the process of participation. Wagner [39] and Dixit and Vaish [40] proceed from the criterion of minimizing all possible consumer efforts in terms of transaction costs in determining the essence of 'convenience' of the proper discard from the EoL product process. Dixit and Vaish [40] noted that consumers spend personal resources (e.g., effort, time, and money) while returning e-waste. In the case of household waste, Best et al. [41] argued that average behavioral costs are lower for a curbside recycling scheme than for a drop-off system. To examine post-consumer collection efforts, Wagner [39] identified five major categories of convenience–knowledge requirements (minimum time in determining requirements), proximity to a collection site (minimum distance that must be travelled), opportunity to drop-off materials (maximum days and times of accepting materials), the draw of the collection site (the more services offered at a drop-off site), and the simplicity of the process. Wagner proposed a matrix of convenience criteria and ranked the various factors of convenience within each of these categories; according to this matrix, there are high, medium, and low levels of convenience for consumer collection of e-waste [39]. Six types of transaction costs have been identified by Posselt and Gensler (2002): time costs, information cost, planning costs, transportation costs, psychological costs, and inventory costs [42].

4.2. Prevalent Determinants of Consumers' Recycling Behavior across Various Countries

To achieve high recycling rates, the most important issue to be considered is how to ensure the consumers' fullest participation in a proper collection. Undoubtedly, in this respect, various determinants affect consumer recycling behavior, including demographic and socio-economic factors, environmental knowledge, current habits, convenience, and motivations [9,43]. According to Colesca et al. [43], this is why some studies report contradictory results and demonstrate that the peculiarities of each country have different influences on how people are engaged in e-waste collection and recycling.

The analysis and systematization of recent and relevant research papers revealed that some countries have their own current prevalent determinant of consumers' e-waste recycling behavior. Table 1 presents the findings grouped by the study content affiliation to European, American, Asian, and African countries.

We suggest that the dominant determinant of European consumer behavior is the level of awareness and knowledge of e-waste recycling, especially for western European countries. All studies stated that raising awareness and knowledge should be the utmost priority at the moment [9,44,45].

Analogous research results show that convenience is also a prevalent determinant of rational consumer e-waste recycling behavior for American consumers, such that municipalities in the U.S. try to create convenient infrastructure [39,46,47]. In Asian countries, e-waste management initiatives are especially challenging because financial attributions largely determine consumer e-waste disposal behavior in contrast to European or American consumers, who believe that they are mitigating environmental degradation by engaging in recycling activities [12,40]. Since economic incentives in Asia are dominating determinants for consumer recycling behavior as well as lack of legislative norms, the informal e-waste collection sector is gaining momentum in these countries. A similar situation is observed in a few African countries [48].

Although modern programs for EOL EEE collection are aimed at minimizing consumer efforts and transaction costs and conducting awareness-raising measures, there are other determinants that restrain proper collection process. In this regard, Tanskanen argued that the success of consumer e-waste collection programs is also based on longevity because it can take years to establish a recycling habit [19]. However, e-waste recycling analytics in European countries reveal competing habits, such as the tendency to store some EEE at home [19,44,49].

Table 1. Consumer's recycling behaviour determinants grouped by the study affiliation. Blue color is used to highlight similarities within continents.

Study Affiliation	**Europe**												**Americas**						**Asia**							**Africa**	
Consumer's Recycling Behaviour Determinants	**Bovea et al., 2018 [44]**	**Perez-Belis et al., 2015 [45]**	**Miliute-Plepiene et al. 2016 [9]**	**Gurauskiene, 2008 [15]**	**Colesca et al., 2014 [43]**	**Ylä-Mella et al., 2015 [49]**	**Tanskanen, 2013 [19]**	**Ongondo and Williams, 2011 [50]**	**Bezzina and Dimech, 2011 [51]**	**Darby and Obara, 2005 [52]**	**Tonglet et al., 2004 [53]**	**Vicente and Reis, 2008 [54]**	**Bakhiyi et al., 2018 [22]**	**Tansel, 2017 [23]**	**Milovantseva and Saphores, 2013 [46]**	**Wagner, 2013 [40]**	**Saphores et al., 2006 [55]**	**Echegaray and Hansstein, 2016 [35]**	**Chi et al., 2014 [56]**	**Orlins and Guan, 2016 [57]**	**Manomaivibool and Vassanadumrongdee, 2012 [58]**	**Borthakur and Govin, 2016 [12]**	**Dixit and Vaish, 2015 [40]**	**Li et al., 2012 [59]**	**Yin et al., 2014 [28]**	**Nduneseokwu et al., 2017 [60]**	**Nnorom et al., 2009 [61]**
Economic incentives						*		*	*	*		*			*				*	*	*	*	*	*	*	*	
Conveniences			*			*	*	*	*	*	*		*	*	*	*	*	*	*	*	*	*	*			*	*
Current habits				*		*	*			*																	
Mentality, attitude											*	*							*	*		*					
Income										*												*			*		*
Awareness level, knowledge	*	*	*	*	*	*	*	*	*	*	*	*	*	*		*		*	*	*		*	*	*			*
Education level		*		*	*				*			*					*	*							*		*
Gender									*	*					*		*	*				*					
Age									*						*							*					*
Legislative norms					*																						
Trustworthiness																					*		*				
Category of e-waste																											
All categories e-waste				*									*	*			*	*	*	*	*	*				*	
Specific category of e-waste	*	*				*	*	*		*					*								*	*	*		*
All types of waste including e-waste			*						*							*											

According to Borthakur and Govind [12], "waste" is considered valuable in developing countries. However, developed countries do not view discarded products as having intrinsic value. In contrast, Ylä-Mella et al. [49] argued that some e-waste categories (for instance, IT and telecommunication equipment) are perceived as having residual value in developed countries, therefore, consumers tend to store a few categories of EoL EEE at home. Probably, consumer motivation to return EoL EEE depends on economic incentives, irrespective of whether the country is developed or not, as the high price of EEE increases the perception of residual value. Moreover, the majority of EEE refers to the "up-to-date" products according to the product topology based on product lifetime preferences proposed by Cox et al. [62]. These products are often discarded due to fashion trends, or to keep up with technological advances before they have reached the end of their functional life. Furthermore, in developed countries, the recycling industry is developed and is therefore profitable. Hence, the consumer will perceive waste as valuable rather than useless.

4.3. Main Challenges with E-Waste Collection

4.3.1. Informal Sector Development

In general, the informal sector is considered to be operating in a type of self-governance as well as being beyond the reach of governments and therefore lacks regulation or structure [63]. The informal sector is typical of developing countries [22,63] where e-waste is mostly recycled through substandard or crude methods that cause damage to human health and the environment. Substandard methods include open burning to extract metals and to melt plastics, acid leaching for precious metals, and direct disposal of toxic residuals [11]. Children, teenagers, and older adults may work in the informal sector where they are mainly involved in outdoor activities, including dismantling and open burning [11,12].

In India, 95% of e-waste is recycled through the informal sector [12]. Residents of India refuse to deliver their obsolete EEE without financial incentive, because e-waste is still considered a worthy commodity of commerce [12,64]. According to recent studies [12,65], the informal sector leads to increased collection rates and provides social and economic benefits in India.

In Nigeria, there is no collection system and practically no capacity for e-waste recovery [60]. Furthermore, there is a lack of accounting and practices for e-waste managing. Consequently, these items are recycled using crude methods and unwanted components are discarded in local landfills or water bodies [60,61].

In China, weak enforcement of existing legislation [22] and the "waste as value" mentality [66] drives the informal system. According to Liu et al. [67], 94% of households dispose of e-waste using the informal sector. E-waste collectors usually work door-to-door on bikes and carts to buy e-waste from consumers at home, and then sell it to be refurbished and recycled [68,69]. Following the informal 'rules', the collectors provide consumers with an economic motivator return EoL EEE. In conjunction with the formal system, the informal e-waste system can be kept powerful. For instance, the government launched the "Old-for-New" home appliance trade program in 2009, where consumers received a 10% discount on buying a new appliance in exchange for returning the old one (TVs, refrigerators, washing machines, air conditioners, and computers) [50]. The difference between informal and formal e-waste prices is significant. Formal recyclers still face great challenges in covering the total costs of buying and treating e-wastes because of strong competition from informal recyclers and current consumer habits [56]. The informal sector provides greater economic benefits and convenience for consumers [56,70].

In Romania, the informal system remains functional despite the creation of a formal e-waste system [40] that features 'single day' collection, the 'take-back' system with a discount on new equipment, and collection centers to dispose of WEEE free of charge. According to a survey conducted in Romania, 42% of people dispose of WEEE using the formal system, while 29% of respondents use the informal system [39].

4.3.2. Storing E-Waste at Home

Studies conducted in developed [19,44,49] and developing countries [12,28,58] have revealed that consumers tend to some store EoL EEE at home rather than discard them in a proper manner. When these devices are kept as reserve in developed countries, it indicates that they may still be functional to some degree. According to Packard [71], product obsolescence can be divided between absolute obsolescence, which means that the product has failed and is no longer usable, and to relative obsolescence, which applies to products that are still at least partly functional but are discarded for other reasons. These reasons can be categorized to quality, functionality, psychological reasons (desirability), or new consumer needs [71,72]. Another term for this is moral obsolescence, when the product is still functioning, but it is no longer needed or not in fashion. These devices stored at home as spare are a results of relative obsolescence, and when no longer in active use, result in a vast amount of appliances and devices that are unavailable for reuse and recycling [28,44,49].

In Finland, surveys show that up to 85% of users store their old mobile phones at home until a possible future use, which may never come, despite the proximity and convenience of current waste management systems [49]. Tanskanen [19] underlined that many electronic devices in Finland, particularly smaller ones (e.g., mobile phones, laptops, and entertainment electronics), are no longer in active use but still kept at home as a reserve, for sentimental reasons or because the owners assume that the devices have high residual value and therefore are unwilling to deliver it to reuse or recycling. Ylä-Mella and colleagues highlighted that awareness has not translated to recycling behavior. Thus, the existing waste management system is inadequate in promoting the return of small WEEE. To facilitate re-use, and the highest level of recovery, consumers should deliver EoL electronics to collection centers without delay [49]. Similar storing tendencies have been observed in other countries. In Spain, 73.9% of respondents stored disused small ICT devices at home [44], and in Thailand, more than half of households stored EoL EEEs at home [58]. Survey data indicated that these were stored because they were regarded as having remaining value [58]. In China, only 47.1% of EoL mobile phones were stored at home [28]. This is probably because used phones are usually sold through the informal sector for cash back. An investigation of the consumer recycling patterns in China indicated that 28.5% of consumers are willing to send their phones to sellers through the "Old-for-New" activity, while some consumers prefer to receive a bonus by selling their waste phones [28]. Consumers in India expect financial benefits for discarding their e-waste [12].

These results indicate that economic incentives such as the Deposit Refund System enforce the proper return e-waste, especially of small WEEE.

In summary, besides improper disposal, current EoL EEE recycling programs are faced with the challenges of home storage and the informal sector. These challenges are mainly associated with the lack of economic incentives for the proper return of used EEE, especially for those products that are expensive and quickly become morally obsolete.

4.4. Consumer Incentives to Return E-Waste

For mass and the fullest consumer involvement in a proper e-waste collection, special attention has been paid to economic motivation. Defra's [73] analysis shows that the actual costs of offering a financial incentive are relatively low compared to the actual costs of promotion, monitoring, and evaluation. It is worth noting that the limiting factor in any recycling scheme is minimizing collection and transportation costs.

The following categories of incentives were determined by Dixit and Vaish [40]: (1) financial incentives (cash back and discount coupons); (2) environmental incentives (donation of e-waste to an organization in return for tree planting); and (3) societal charity incentives (donation). The scientists ranked these incentives based on consumer preferences in India. Most consumers favored the "cashback" incentive followed by "donate for planting a tree", "discount in purchase of other product", and "donate for charity" [40].

The “cash back” incentive can be implemented through a deposit-refund system (DRS) that has been successfully used for returning bottles in many countries. Ylä-Mella et al. [49] argued that a monetary deposit system should be considered for valuable electronics such as mobile phones to motivate their return. In Finland, 70% of respondents claimed that a 20-euro deposit would motivate them to return old mobile phones.

However, Ylä-Mella et al. [49] highlighted applying a large-scale DRS for EEE is an intricate issue. An attempt to apply the deposit-refund systems is seen in the Thai government initiative “buy back WEEE from households” within the Thai WEEE Strategy draft. Manomaivibool and Vassanadumrongdee [58] commented that this arrangement is a variation of DRS: a front-end product fee (or a ‘deposit’), and a back-end buy-back mechanism (or a ‘refund’). It is obvious that the greater the deposit, the more it motivates consumers to return EoL EEE, but inasmuch EEE have some specificity—in particular, higher price, long useful life, different residual value, etc.—hence it is difficult to justify how DRS can be implemented for EEE and how much should be the sum of deposit on specific types and models of EEE.

Economic incentives such as ‘discount coupons’ or ‘purchase discount’ and similar monetary payments are used in e-waste collection schemes, along with donation to charity and entry into prize draws in European countries [50]. This type of motivational tool certainly encourages the return of EEE; however, it has a drawback as people need to buy new products at the same time. As an alternative to the existing economic incentives, this research justifies the rationale for an electronic bonus card system (EBCS) as a motivation technology for compensating consumer efforts for proper collection and satisfying consumer perceptions of EoL EEE as having a residual value. Unlike purchase discounts, bonus cards allow the accumulation of bonuses to buy a new product without need for additional payments. We suggest that EBCS could counteract at least two failures of e-waste recycling programs: storing e-waste at home, and improperly discarding e-waste with domestic waste.

5. Potential to Implement Electronic Bonus Card System for EoL EEE Collection

Based on the literature review presented above, we propose that applying an EBCS for EoL EEE collection has several benefits, including minimizing consumer transaction costs by providing convenience and economic motivation. This system can be used in the presence of DRS or without it. The consumer’s motivational technologies based on economic incentive are likely to be beneficial for countries that are at the early stage of a recycling system creation as it allows to achieve a high level of consumer involvement in the short-term period. These technologies are not only convenient, but also attractive to consumers who have not yet developed recycling habits or perceive that e-waste has residual value.

The essence of EBCS consists in the accumulation of bonuses onto consumer cards for the return of EoL or obsolete products. The amount of bonuses may be equivalent to the refund value of DRS, or it can correspond to a certain part of the residual value. To simplify the calculation of bonuses amount, we will use a “1 bonus–1 euro” equivalence as an example. While purchasing a new product, the buyer can take advantage of the accumulated bonuses. The list of products that can be covered by bonuses requires justification from the perspective of rational allocation of the benefits among participants involved in the process of EoL EEE collection. EBCS can be implemented into EoL EEE collection system in cities in two ways: (1) the trading network that specializes in the sale of such products; (2) the specialized enterprise (compliance organization) that provides EoL EEE collection service for the consumers.

In the case of EBCS implementation through the trading network, each trade enterprise forms its own infrastructure of EoL EEE collection. The collection point should be equipped with a special device which can identify the EoL product that returns as well as accrues/writes off bonuses for the return of old products or the purchase of new ones, respectively. Figure 6 shows the scheme of the EBCS implementation through a trading network, including waste flows for EEE, portable batteries and accumulators, and light bulbs. The driver for the reverse movement of these products is the trading enterprise. Currently, a few shops already operate with a discount for customers that return the old product and buy a new one. However, the proposed EBCS provides additional benefits for consumers as it does not require the purchase to take place at the same time or at the same store as the return of an old product. In addition, the bonuses can be accumulated and exchanged for a new product without any additional payment.

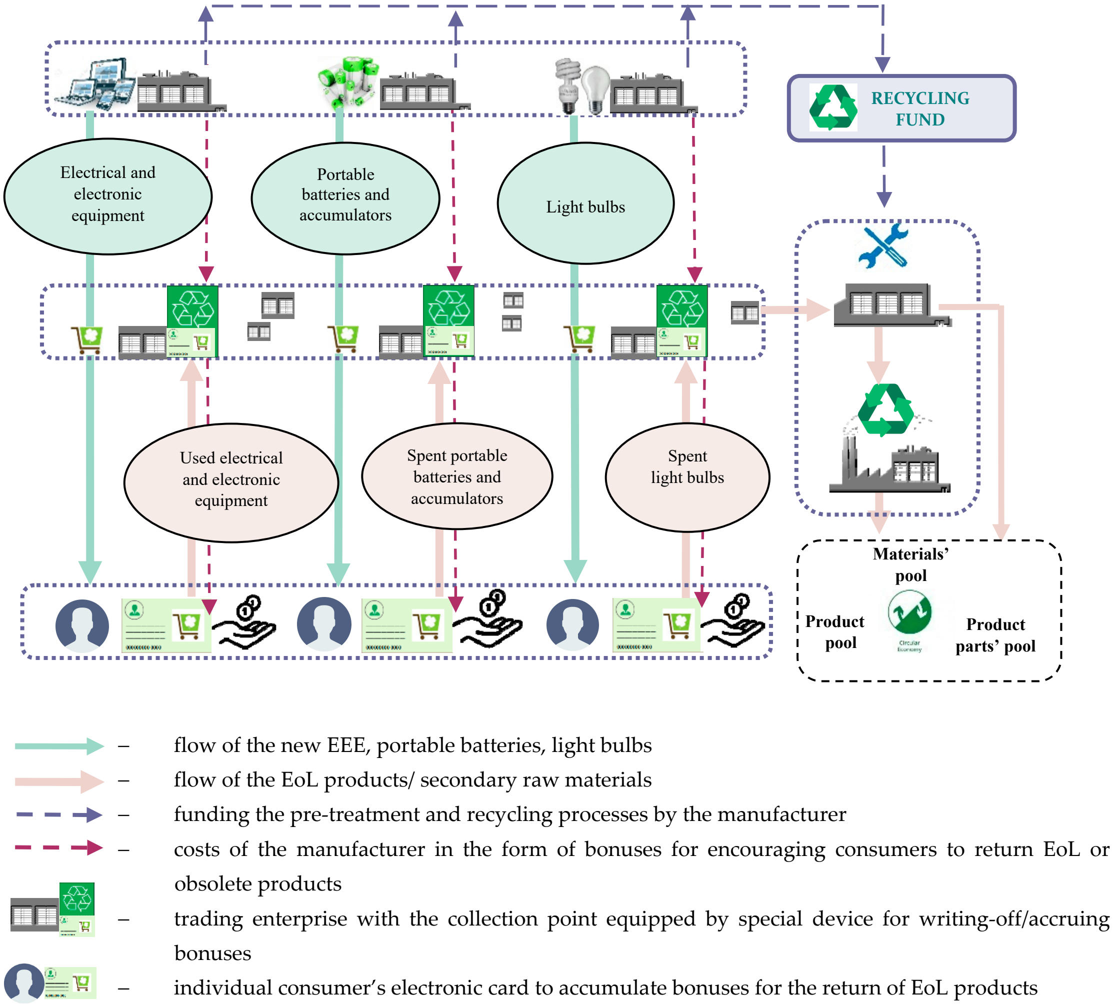


Figure 6. Scheme for EBCS implementation to return e-waste through a trading network.

Another method of collection is through specialized enterprises that serve individual customers through a network of stationary and mobile collection points (Figure 7). A special pick-up service can be provided to consumers that may require extra help with transport, such as pensioners and people with disabilities.

It is worth noting that EBCS application in EoL EEE collection allows the monitoring of user participation in proper collection and the identification of the product manufacturer. In fact, beyond the motivational function, the EBCS performs a control-fixing function. Hence, it additionally motivates compliance with the rules and instructions for a collection defined by municipal regulations.

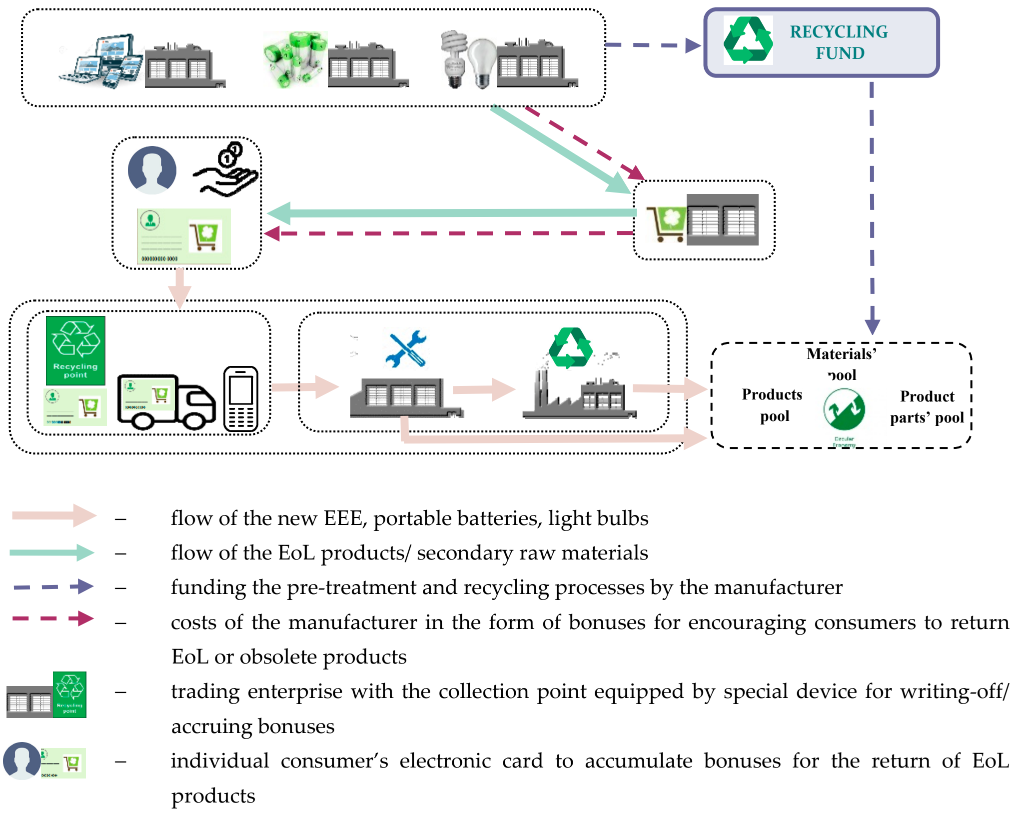


Figure 7. Scheme for EBCS implementation to return e-waste through specialized enterprises.

6. Discussion

For the adoption of EU action plan for the Circular Economy 'Closing the loop' [4], consumer pro-circular recycling behavior is an important component of e-waste management [35,74,75]. Proper return of EoL product ensures the saving of the value of parts and modules, and materials in the economy as long as possible. To increase the e-waste collection rate, economic incentives are used in addition to convenient and adequate collection infrastructure. Economic incentives for the proper return of EoL products do not contrast with less consumption but complement it because the functional parts and modules can be redistributed, hereby enabling reduction in overall consumption based on reuse. The literature review showed that coupons, discounts, prizes, and gifts are used as economic incentives to increase collection rates [40,50]. As an alternative to existing incentives, we propose to introduce an individual accumulative bonus card that acts as an economic incentive. The EBCS seems promising because it provides the opportunity to accumulate bonuses and exchange them for a new planned product without additional charges. However, there are a few unresolved issues regarding the operationalization of EBCS, including responsibility for financing the system, and whether bonuses from different enterprises can be shared.

The most crucial issue to be discussed is who will ultimately pay for the incentive that is created for the end user. One option is to share costs between distributors, manufacturers, and municipalities (as part of taxes) in the same way as recycling costs are shared today, but this would depend on the country in question, and likely vary between developed and developing countries.

The EBCS is of particular interest for developing countries that do not yet have environmental legislation, because it allows ensuring the consumer's rational behavior in a short period with minimal infrastructure costs. In countries with a profitable informal sector, it is difficult to promote formal e-waste recycling through economic incentives, including the EBCS. However, the proposed system may become an instrument for compensating a portion of the residual value to which the residents of these countries are accustomed, although the compensation will obviously be less due to the need to conduct processes within the framework of the regulations that must be adopted. In these countries, legislation is needed to regulate prohibited recycling methods. In this case, the proposed stimulus may become more justified than a discount on the purchase of a new product, for example.

Another issue to consider is the connection between the companies where the products were produced, purchased, and collected. One advantage of EBCS is the possibility to monitor the belonging of the used product to the company that produced it in the past based on identification facility by product serial numbers for those product groups that have individual numbering. Creating a special web platform for the accumulation of such data could be the basis for tracking electronic waste flows with affiliation to the manufacturers and traders.

To achieve the full impact of EBCS, it is important to share accumulated bonuses among trade enterprises. If consumers are requested to return the old products to different enterprises and to use the accumulated bonuses only in a certain enterprise or only by the place of returning, it would probably reduce the incentives brought by the system.

Furthermore, the idea of accumulating bonuses on individual consumer cards is of interest in terms of creating an operating environment for a circular economy development. Another way of using accumulated bonuses could be to purchase certain products that contribute to circularity, including remanufactured, refurbished, or modernized products.

The estimation of bonus value is hard to determine based on this preparatory study, but we suggest that the residual value is likely to vary by product condition, category, and type but also within the same product type inasmuch as some manufacturers are more progressive in design for disassembly and design for the environment than others. Companies that invest in the design for disassembles of their products are more likely to be interested in collecting their products as fully as possible since they consider the remanufacturing and refurbishment strategy as a business model for creating value from waste. Hence, these companies are probably ready to offer a higher monetary incentive compared with companies that are focused on linear production. Thus, the bonus amount should be scientifically justified, and should be a topic for future research. We propose that the bonus amount must be economically and environmentally sound while providing an incentive for the end user and is related to the recycling costs. Alternatively, the bonus amount could be based on the potential economic damage from environmental pollution caused by improper disposal of specific units of e-waste.

In summary, several principles of EBCS application can be identified: (1) E-waste can be identified and connected to a specific manufacturer or distributor, thus encouraging design for disassembly and design for environment; (2) improved monitoring of collection rates of specified categories of e-waste flows based on accumulation of data on a web platform; (3) it is possible scientifically justify the amount of bonuses given out in each country to achieve the highest possible recycling rate; and (4) a financial model where the costs of the incentive are shared between the distributors, manufacturers, municipalities, and other stakeholders that are responsible for collecting e-waste in the country.

7. Limitations

The inclusion criteria for this literature review may have excluded some relevant academic papers that either were published over 15 years ago, were in a different language, or were not found before the data saturation point was reached. However, we believe that the extensive scope of this review is enough to form a basis for our recommendations.

The proposed EBCS has not been tested in real life, and thus this study is limited in its recommendation. Currently, it is difficult to predict or estimate the increase of EoL EEE collection rate due to the EBCS implementation because it has not been tested. We do not have resources for conducting testing or cost–benefit analysis, and therefore propose further studies that include these aspects.

8. Conclusions

Consumers' pro-circular behavior is an important component of a circular economy operationalization and the proper return EoL product as a one from pro-circular consumers' action allows to save the value of materials and products in economy for as long as possible and reduce environmental pollution.

Our systematic literature review showed that current prevalent determinants of consumer e-waste recycling behavior varied between some countries. In western European countries, the dominant determinant for e-waste recycling behavior is the level of awareness and knowledge, indicating that in these countries it is instructive to focus on conducting awareness-raising measures. Convenience is a prevalent determinant of consumer e-waste recycling behavior for American consumers, and in that respect, U.S. municipalities try to create convenient infrastructure. E-waste management initiatives in Asian and African countries are especially challenging due to the fact that financial attributions largely determine the consumer behavior in contrast to European or American consumers, who believe to a larger degree that they are mitigating environmental degradation by engaging in recycling activities.

Although modern programs for EoL EEE collection are aimed at providing convenience to minimize consumer efforts and transaction costs and conducting awareness-raising measures, there are still other determinants that restrain this process. Besides improper disposal, current EoL EEE recycling programs are faced with the challenges of home storage and the informal sector. Literature analysis indicated when the collection infrastructure was in place, these challenges were mainly associated with the lack of economic incentives for the proper return of used EEE, especially for those products that are expensive and quickly become morally obsolete. Therefore, we highlight that economic incentives should be in all countries for some part of EEE that refers to "up-to-date" product according to the topology proposed by Cox and colleagues [62].

We propose to introduce an economic incentive in the form of an electronic bonus card system which should motivate consumers to take part in the recycling process and hence improve collection rates. Unlike existing incentives such as coupons, discounts, prizes, and gifts, an individual bonus card can increase the level of collection because it provides the consumer with additional benefits to accumulate bonuses and exchange them for a new planned product without additional charges. Research suggests that the bonus system could be an effective motivation tool for rapid, mass involvement of the consumer in the EoL EEE collection process. The bonus card is meant to compensate consumers for an appropriate contribution in separate collection as well as in such a manner, to satisfy the perception of waste as having residual value. Aside from the motivational function, the bonus card system also performs a check-fixing function that allows the monitoring of consumer participation in proper collection and the identification of product manufacturers.

We suggest that the EBCS could minimize at least two failures of e-waste recycling programs: home storage and improperly discarding e-waste with other domestic waste. Even in developing countries with a large informal sector, the proposed system may become an instrument for compensating a portion of the residual value of the product to which the residents of these countries are accustomed, although the compensation may be less due to the need to conduct processes within the framework of the regulations that must be adopted. The proposed incentive may become more justified than a discount on the purchase of a new product or prizes.

Two methods of EBCS implementation are proposed: trading networks and collecting compliance organization. For efficient implementation of the EBCS, all stakeholders need to be involved including authorities, manufacturers, retailers, collectors, e-recyclers, consumers, and the provider of the system. In addition, for further improvements of the recycling system, the involvement of product designers and the scientific community would be beneficial.

Before implementation, further work is needed in developing the financial model, testing the potential technical solutions for EBCS, and cost–benefit calculations. After implementation, the effect should be measured to quantify the benefits for society. It is crucial to implement policies that enforce a transition to the circular economy also within the field of consumption in terms of pro-circular consumers' behavior, including a proper return EoL products action. This is especially important for

WEEE, as the improper treatment of this rapidly increasing waste product is polluting the environment, and the loss of valuable raw materials may inhibit future production of sustainable solutions, such as those based on renewable energy, that require critical materials.

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Abbreviations

DRS	Deposit Refund System
EBCS	Electronic Bonus Card System
EEE	Electrical and Electronic Equipment
EoL	End-of-Life
EPR	Extended Producer Responsibility
WEEE	Waste Electrical and Electronic Equipment

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