

# Towards a Smart E-Waste System Utilizing Supply Chain Participants and Interactive Online Maps

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**Abstract:** Efficient electronic waste (e-waste) management is one of the vital strategies to save materials, including critical minerals and precious metals with limited global reserves. The e-waste collection issue has gained increasing attention in recent years, especially in developing countries, due to low collection rates. This study aims to search for progressive solutions in the e-waste collection sphere with close-to-zero transport and infrastructure costs and the minimization of consumers' efforts towards an enhanced e-waste management efficiency and collection rate. Along these lines, the present paper develops a smart reverse system of e-waste from end-of-life electronics holders to local recycling infrastructures based on intelligent information technology (IT) tools involving local delivery services to collect e-waste and connecting with interactive online maps of users' requests. This system considers the vehicles of local delivery services as potential mobile collection points that collect and deliver e-waste to a local recycling enterprise with a minimum deviation from the planned routes. Besides e-waste transport and infrastructure costs minimization, the proposed smart e-waste reverse system supports the reduction of CO<sub>2</sub> through the optimal deployment of e-waste collection vehicles. The present study also advances a solid rationale for involving local e-waste operators as key stakeholders of the smart e-waste reverse system. Deploying the business model canvas (BMC) toolkit, a business model of the developed system has been built for the case of Sumy city, Ukraine, and discussed in light of recent studies.

**Keywords:** waste management; circular economy; end-of-life electronics equipment; smart e-waste collection; reverse logistics; route optimization; recycling behavior



**Citation:** Shevchenko, T.; Saidani, M.; Danko, Y.; Golysheva, I.; Chovancová, J.; Vavrek, R. Towards a Smart E-Waste System Utilizing Supply Chain Participants and Interactive Online Maps. *Recycling* **2021**, *6*, 8. <https://doi.org/10.3390/recycling6010008>

Received: 16 November 2020

Accepted: 20 January 2021

Published: 1 February 2021

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## 1. Introduction

It is difficult to imagine modern life without electrical and electronic devices—household appliances, information technology (IT) equipment, and means of communication that are continually being improved. With the development of increasingly advanced technologies, new opportunities and areas for the use of electronic tools appear, which leads to the appearance of new products and, as a result, their diversity is even more significant [1]. With the advent of more advanced appliances, especially those that quickly update, their analog equivalents lose value to users even with full functionality remaining [2,3]. Over time, electrical and electronic equipment (EEE) becomes obsolete or reaches end-of-life (EoL) and is eventually considered and discarded as electronic waste (e-waste).

Although e-waste accounts for only 1–3% of solid household waste, it is among the most hazardous consumption wastes [4,5]. They contain more than 1000 different substances, representing up to 60 elements from the periodic table [6], many of which are

toxic, particularly elements such as lead, mercury, cadmium, chromium. [7]. Recent investigations conducted by American experts show that 70% of mercury and cadmium in the United States landfills come from electronic waste [8]. Moreover, waste electrical and electronic products contain precious metals, including gold, silver, copper, platinum, and palladium, having an important ecological and economic cost [9–11].

In some countries, especially in developing ones, the shortcomings of existing legislation on e-waste management leads to the development of the informal recycling sector [12,13], where the liquid and most valuable components are removed, while the rest is thrown away, impacting the environment and human health [14]. To support the proper and timely return of EoL household equipment by the customer, it is necessary to design convenient and build sufficient infrastructures, as well as to create economic incentives. However, despite the fact that a formal e-waste collection system with suitable channels has been set up, and discounts on new equipment are provided upon return of used ones in some countries, the informal system remains viable [15]. One of the reasons for the low competitiveness of the formal system is due to high transportation and infrastructure costs. With the development of new technologies, including smart ones, new opportunities arise to reduce these costs [16,17]. This study is grounded on the assumption that the e-waste collection with close-to-zero transport and infrastructure costs and the minimization of consumers' transaction costs, could be provided due to the involvement of local delivery service companies in this process. In particular, the vehicles of delivery service companies could be considered as potential mobile collection points that, without a significant deviation from the planned routes, could collect EoL or obsolete household equipment from the end-user and deliver these e-wastes to a local recycling enterprise.

Therefore, the article aims at developing a smart reverse system of e-waste from end-of-life electronics holders to local recycling infrastructures based on IT tools involving local delivery services to collect e-waste and of the use of interactive online maps to collect and track users' requests.

The study is organized as follows: The literature review section includes three sub-sections. The first one provides a synthesized analysis of global e-waste generation and collection rates, examining the e-waste challenges across various countries and considering the reality of e-waste management in Ukraine, as the country chosen for the case study. The second sub-section outlines key insights and ideas from the discussions on smart e-waste management. The third sub-section clarifies the EoL EEE holder's role in the operationalization of extended producer responsibility (EPR) with a focus on e-waste. The Results section focuses on developing the smart e-waste reverse system based on the launch of interactive online maps of users' requests for collection and the involvement of delivery services to collect this waste at a city-level. The discussion section expounds on the findings in the light of recent studies. Finally, the conclusions outline the main research contribution and the remaining challenges to be addressed in future investigations.

## 2. Literature Review

In order to come up with a holistic vision for an increased e-waste collection rate enabled by smart technologies, this study employs a literature review as a background to achieve the aforementioned aims. To conduct a comprehensive and sound literature review, research articles were selected from scientific peer-review journals. Search engines and databases such as Elsevier's Scopus, Thomson Reuters' Web of Science, and Google Scholar, were used for the selection of literature with the combination of the following keywords: 'smart waste management', 'e-waste collection', 'waste electrical and electronic equipment', 'smart e-waste collection', 'reverse logistics', 'circular economy', and 'circular business models'. In addition, some studies were identified as relevant in the references of the initially selected papers.

## 2.1. Comparative Overview

### 2.1.1. Global Electronic Waste (E-Waste) Statistics

About 50 million tonnes of electronic waste are generated annually in the world, most of which is accumulated in the environment [18]. The volume of their generation grows by 3–5% per year [19], due to the growing demand for electronic equipment and the short term of its use. According to the Balde et al. [14], in 2016 only 8.9 million tonnes of e-waste were officially collected and disposed of (from a generated 44.7 million tonnes) on a global scale, which corresponds to 20%, while the remaining 80% (35.8 million tonnes) were not documented. Electronic waste is expected to rise to 52.2 million tonnes in 2021, showing an increase of 3–4% per year. Herewith, different product categories have different rates of annual growth. The highest growth rates are expected for EoL thermal-regulation equipment, as well as for small- and large-sized equipment [14]. According to the indicators of 2016, Asia accounts for the largest amount of electronic waste—18.2 million tonnes (4.2 kg per capita), Europe—12.3 million tonnes (16.6 kg/person), North and South America—11.3 million tons (11.6 kg/person), Africa—2.2 million tons (1.9 kg/person), Oceania—0.7 million tons (17.3 kg/person). The largest amount of e-waste generation per person is in Oceania; however, the share of officially collected and recycled waste was only 6% there. Europe had the highest e-waste collection rate as of 2016—35%, followed by North and South America—17%, Asia—15% and Oceania—6% [14,20]. According to Eurostat data [21], the most progressive European Union (EU) countries in e-waste collection, with the consistently highest collection rates over the last few years, are Scandinavian countries, Liechtenstein, and Switzerland. By 2016, most EU countries achieved the target 45% collection rates of the average volume of EEE placed on the market, including, for instance, Sweden, Norway, Ireland, Slovakia, Portugal, Hungary, Luxemburg, and the Czech Republic.

### 2.1.2. E-Waste Challenges across Countries

The countries of Oceania, Asia, and South America, due to shortcomings of existing legislation on e-waste treatment, contribute to the development of informal e-waste sectors. The collection of waste electrical and electronic equipment in all categories under informal channels is often seen as inaccessible to proper monitoring and management, where there is an uncontrolled removal of the most valuable components. The emergence and development of the informal sectors varies across these countries. For instance, in China, the «waste as value» mentality of citizens leads to informal e-waste recycling, where 94% of households dispose their e-waste through informal collection channels [22]. In some provinces, this type of waste is collected door-to-door using bicycles and carts, where EoL or obsolete electronic devices are purchased by collectors and then resold to recyclers [19,22]. In India, the informal e-waste sector is also a common practice, with 95% of e-waste volume going through informal channels [12]. Consumers are paid for end-of-life or outdated household equipment, which can be seen as an economic incentive to eliminate unnecessary items through informal collection channels. Significant damage to the environment and human health is caused by electronic waste recycling in Nigeria, where there are no elementary legal norms for its management. EoL products are recycled using coarse methods, and undesirable components are disposed of into local landfills or surface water [13,23].

Even with the operation of a formal e-waste collection system, the informal system can still remain significant [15,24]. According to research [25,26], the lack of incentives is the main reason for households to return electronic waste through the formal sector, although more than half of the respondents are aware of the importance of environmentally safe disposal. In Romania, as a recent EU member state, the informal system remains viable, despite the fact that a formal e-waste collection system with convenient collection channels has been set up, and discounts on new equipment are provided upon the return of used ones. According to a survey conducted in Romania, 42.29% of respondents said they were discarding old electricity and electronics using municipal waste management

systems, while 29.25% of respondents were disposing of old equipment through an informal collection system [15].

### 2.1.3. Reality of E-Waste Management in Ukraine

As for Ukraine, the e-waste treatment through informal channels also takes place, where end-users discard certain categories of household equipment through repair enterprises for a fee, for example. Then, the most valuable components of this equipment are removed and the rest go to municipal landfills, thus polluting the environment [27]. As of today, there is no separate infrastructure for waste electrical and electronic equipment (WEEE) collection in Ukraine by a European understanding according to Directive No 2012/19/EC, and therefore most of the WEEE goes to landfills [28]. To solve the WEEE collection problem, few attempts have been made by public organizations in the form of appropriate promotions, and some efforts are made by trading companies who take back certain types of EoL equipment, giving certain discounts on the purchase of new equipment [29]. Unfortunately, most e-waste volume goes to landfills in Ukraine, including, on a yearly basis, about 500 kg of mercury, 160 kg of cadmium, 260 tons of manganese compounds, 250 tons of sodium chloride [27]. With the signing of the Association Agreement with the EU by Ukraine, this country has been obliged to comply with a number of directives, including the Directive No 2012/19/EU, as it relates to the second stage of the process of implementation of the European legislation in the field of waste management. Therefore, in the near future, the minimum standards for the annual collection of electronic waste laid down in this Directive will become relevant for this country as well. To achieve the standards, Ukraine has to form an appropriate waste collection infrastructure that will allow end-users to return EoL electronic products at least free of charge.

The recent studies on e-waste management in Ukraine by Gubanov [29], Kodzhebash and Humarova [28], Andreeva and Barun [30], and Shuptar [31] have raised a wide range of issues regarding separate collection due to the interdisciplinary nature of the matter. The review of these studies shows the relevance of this issue towards sound infrastructures for WEEE collection in accordance with the EU norms and standards. The practice of the distribution of physical and financial responsibility—for the collection and disposal of electronic waste between manufacturers and distributors in the EU member states—has been explored in the studies of Gubanov [29] and Shuptar [31]. Scientists also emphasize that in order to operationalise the principle of EPR towards approaching the zero waste and circular economy (CE) model, sound consumer behavior is crucial since he or she is a buyer, product user, and holder of an EoL product which must be disposed of properly. To ensure a proper and consistent return of e-waste, it is necessary to design a convenient and construct a sufficient collection system, as well as to create adequate economic incentives [32]. For more recent EU members, including Ukraine, minimizing transport and infrastructure costs for e-waste collection and motivating the end-users to dispose of their waste products properly remain the key issues to be addressed [28,31].

### 2.2. End-of-Life (EoL) Product Holders Role in Extended Producer Responsibility (EPR) Principle Operationalization with Focus on E-Waste

In response to the e-waste challenge, legislation is gradually being developed to address the proper handling of EoL EEE mainly in developed countries [32]. Currently, the national e-waste management laws cover about 66% of the global population, according to the e-waste global monitor [14]. Actually, each country builds its own e-waste management strategy in accordance with the policy and priorities of social and economic development. The EU e-waste legislation, has reflected the goals of the “Circular Economy Action Plan” adopted by the EU in 2015 [33] with a focus on e-waste prevention and 6Rs circular strategies, namely ‘reuse–repair–refurbishment–remanufacturing–repurpose–recycling’. Due to the complexity of the e-waste problem, most countries have many laws related to e-waste, e.g., China recently enacted three laws for e-waste and 12 additional laws and regulations to manage the recycling and treatment of e-waste [34]. After the CE

concept was introduced in China in the late 1990s, it was generally accepted by all sectors of society and further elevated to the rank of national development strategy.

One of the main principles of waste management becomes the principle of EPR [35]. For a long time, producers were responsible only for waste generated in the production process, and the costs related to the disposal of consumer goods were reimbursed by the citizens and the state. With the implementation of this EPR, a prerequisite has been set for stimulating an economic entity to minimize the damage caused by its products at all stages of its life cycle, including the disposal (recycling) stage. Each state is free in allocating this responsibility in different ways, either assigning it to local governments or exploiting more complicated schemes, which may include partnerships between producers and authorities [36]. As of today, there are five types of producer responsibility [29]: financial, physical, compensatory, informational responsibility, and ownership. Financial responsibility involves the manufacturer/importer bearing all or part of the costs associated with collecting, processing, and final disposal of the used products. Physical responsibility is the responsibility of the manufacturer for the direct collection and final disposal of his products (individual or collective). The manufacturer's responsibility for the direct ecological damage caused by its products at different stages of the life cycle is called compensatory. Informational responsibility obliges the manufacturer to inform the consumer about the ecological properties of the product, as well as how to dispose of the EoL product properly. The realization of the previous obligations means that the manufacturer reserves ownership for the product that it produces when it goes into the category of waste. In most EU countries, distributors are physically and financially responsible for the collection of electronic waste [29].

It should be noted that among all participants in the chain of preserving the value of material in the economic system for as long as possible, consumers have a special role in the operationalization of the EPR principle because they act as a customer, user, and e-waste holder [32]. Dixit and Vaish [37] argued that consumers spend personal resources while returning e-waste, including effort, time, and money. Best et al. [38] noted that for household waste, the average behavioural costs are lower for a curbside recycling scheme than for a drop-off system relying on these spending personal resources. Examining post-consumer collection efforts, Wagner [35] identified five categories that underlie convenience: (1) convenience-knowledge requirements—minimum time in determining requirements; (2) proximity to a collection site—minimum distance that must be travelled; (3) opportunity to drop-off materials—maximum days and times of accepting materials; (4) the draw of the collection site—the more services offered at a drop-off site; and (5) the simplicity of the process.

Returning to the issue of the operationalization of the EPR principle, the EoL EEE holder must discard the e-waste in a proper manner, that is to say, using formal channels for e-waste collection, in order to enable the producer to realize the aforementioned obligations, otherwise the practical application of this principle would remain difficult to achieve.

In addition to the proper consumer recycling behavior, the competitiveness of the formal e-waste collection sector remains open. For the legal sector, infrastructure and transport costs are the main expenses of any waste management system in a country with strong environmental legislation. Today, with the increasing development of smart technologies, new opportunities appear to mitigate these non-negligible costs.

### *2.3. Key Insights from Discussions on Smart E-Waste Management*

Smart cities are increasingly focusing upon the design and development of solutions to solve waste management problems, including e-waste collection, transport, sorting by using smart enabling technologies, such as the Internet of things or IoT (RFID tags, NFC sensors, GPS sensors), cloud computing, big data analytics, cyber-based decision support systems, artificial intelligence including machine learning and deep learning [39]. The categories of smart waste management system technologies were outlined by Esmaeilian et al. [17], among which figures the development of data acquisition and sensor-based



technologies, communication and data transmission technologies, field experiment technologies, and the technologies for setting and scheduling truck routes.

A smart waste collection system based on IoT with a special focus on the optimization of collection routes in terms of lower transport cost and material sorting was investigated by Alcayaga et al. [16]. Medvedev et al. [40] proposed the advanced decision support system for efficient waste collection in smart cities, which incorporates a model for data sharing between truck drivers in real-time in order to perform an enhanced waste collection and dynamic route optimization. This waste collection system aims to provide a high quality of service to the citizens of a smart city as well as handling the case of ineffective waste collection in inaccessible areas. The study of Fatimah et al. [41] is focused on developing a sustainable and smart country-wide waste management system using industry 4.0 technologies. The design of this waste management system considers several circular economy principles aiming at providing separate municipal waste, identifying waste characteristics, and determining sustainable waste treatment technologies through the use of IoT as the integrator.

Smart technologies can foster the transformation of waste management practices towards a more circular economy model. However, many barriers and challenges persist [39,42,43]. Fuss et al. [44] highlighted that the implementation of smart waste management systems is still in the embryonic stage. The study of Zhang et al. [39] shortlisted 12 key barriers to smart waste management in China based on interviews with experienced practitioners. These scholars identified three key causal barriers: the lack of regulatory pressures, the lack of environmental education and culture of environmental protection, and the lack of market pressures and demands [39]. An attempt has been made by Sharma et al. [42] to develop a structural framework of IoT adoption barriers that exist in the waste management systems of smart cities in developing economies. This study revealed that the lack of regulations, directions, and policy norms, and the lack of standardization and Internet connectivity are the most critical IoT barriers hindering the development of smart cities, particularly in their waste management practices [42]. According to Borghi et al. [45], any smart waste management systems should embrace an integrated planning strategy tailored for resource recovery and efficiency within a circular economy framework.

To overcome these challenges, the European Commission supports the European innovation partnership on smart cities and communities (EIP-SCC) that brings together cities, industry, small and medium-sized enterprises (SMEs), banks, researchers and others towards improving urban life through more sustainable integrated solutions and addresses city-specific challenges from different policy areas such as energy, mobility and transport, and information and communications technology (ICT) [46].

As such, a smart e-waste collection system could become an integral part of modern waste management and a smart city. The next section outlines the authors' solution for an augmented e-waste collection based on smart technologies. We assume, and justify hereafter, that the substantial reduction of transport and infrastructure costs could be provided by using the existing potential of city delivery vehicle routes without creating special, targeted vehicles and an infrastructure for separate collection.

### 3. Results

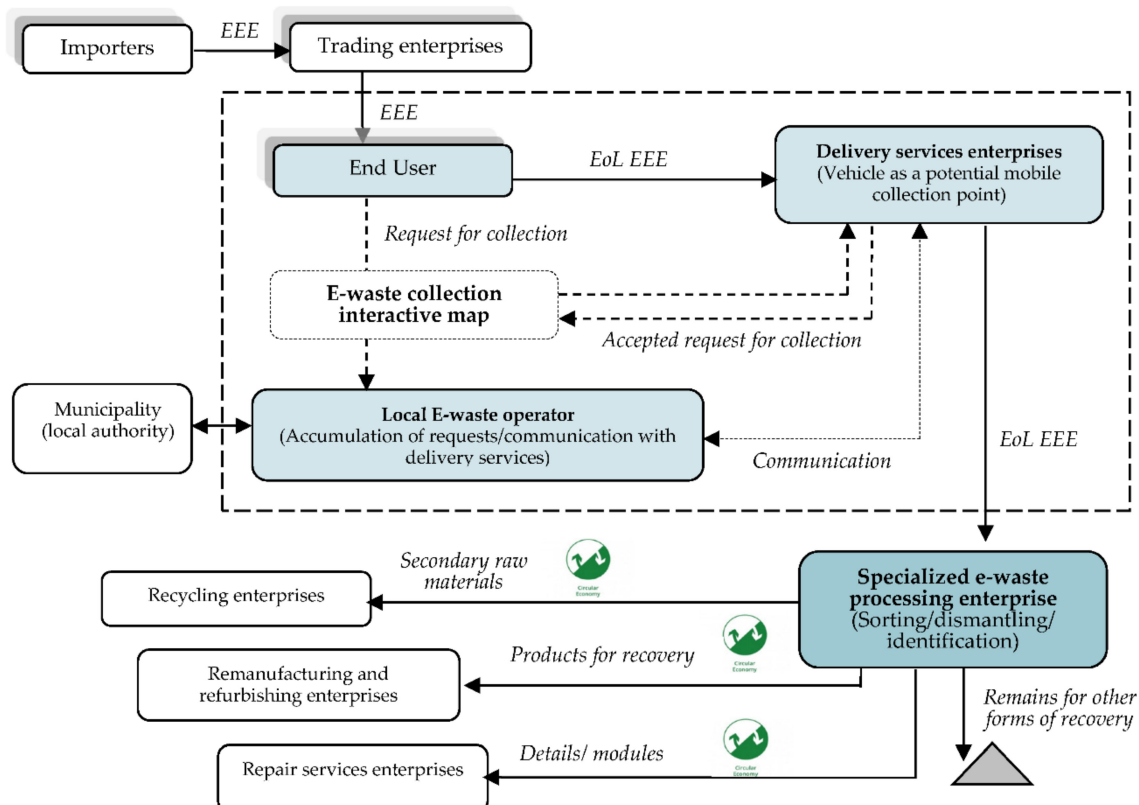
#### 3.1. Smart E-Waste Reverse System Based on the Intelligent Involvement of Local Delivery Services

According to previous investigations [47], there is an available unused transport potential for e-waste collection in any city which has local delivery service enterprises. As such, we can argue that the vehicles of any local delivery service company or appropriate service division at trading enterprises can be considered as potential mobile collection points which, without a significant deviation from the planned routes, could collect and deliver EoL or obsolete EEE to the local specialized e-waste processing enterprise.

The involvement of delivery service enterprises to EoL EEE collection is possible if appropriate economic incentives are provided by local authorities. Using the transport potential of delivery services is economically and environmentally feasible since this allows

minimizing transport and infrastructure costs, as well as reducing CO<sub>2</sub> and other pollutants caused by the creation and deployment of target e-waste collection vehicles.

The structural and logical scheme of a smart e-waste reverse system based on involving local delivery services and using interactive online maps is presented in the Figure 1. We believe that interactive online maps for e-waste collection, as a support tool, will enable involving the vehicles of any local delivery service in the interests of e-waste management at a city-level, since online maps are a convenient tool for tracking EoL EEE holders' requests for this type of waste to be collected.



**Figure 1.** Structural and logical scheme of the smart e-waste reverse system.

Such online maps can cover user's requests for 10 categories of EEE in accordance with the EU Directive, as well as for portable waste batteries. The end-user makes a request for e-waste collection, thereby filling the interactive online-map with the required information.

In order to launch and technically maintain the smart e-waste reverse system, it is advisable to create a local e-waste reverse operator at the specialized processing enterprise. The local operator will play a principal role in the system of reversing EoL/obsolete EEE since it becomes the connecting link between (1) the EoL EEE holder (end-user) and the delivery service vehicle as potential e-waste collector, (2) the local authority and the local delivery service enterprises involved in e-waste collection, and (3) the local delivery service enterprises and the specialized e-waste processing enterprise.

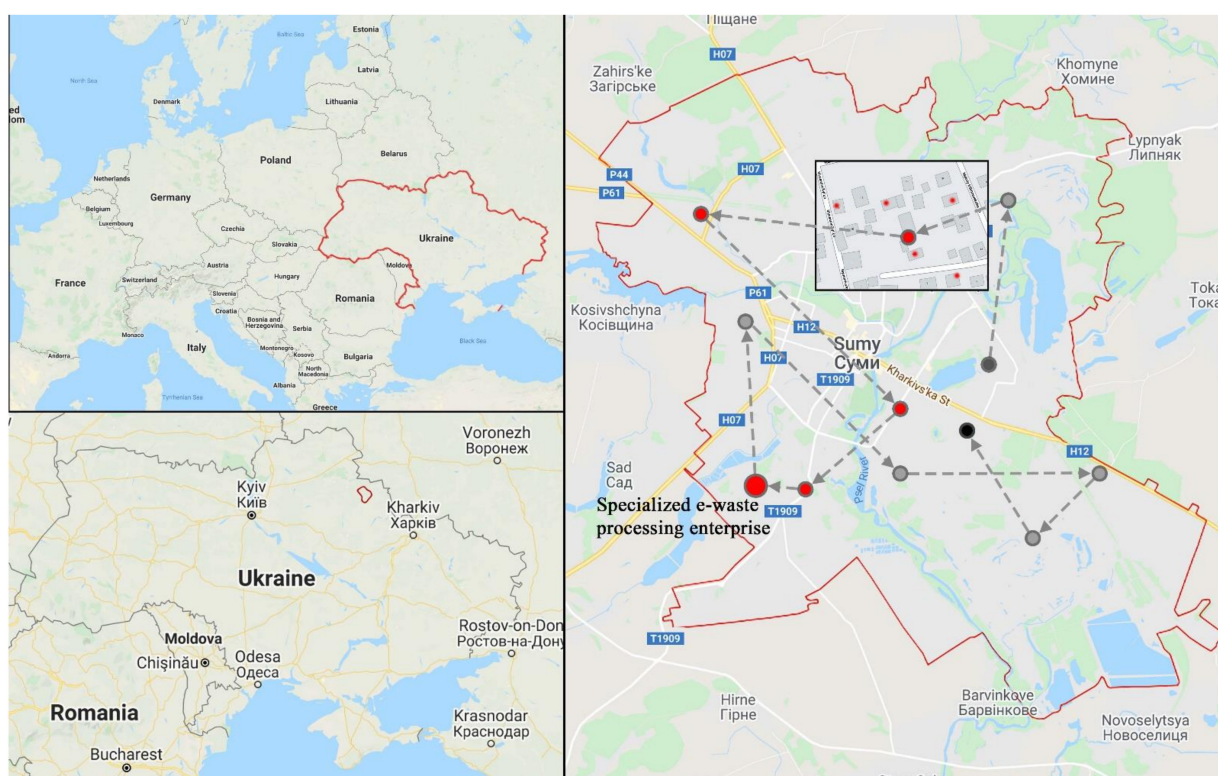
The involvement of delivery services of the city in e-waste management is possible in the case of the creation of mutually beneficial terms. The question is then who will pay for these beneficial terms, i.e., creating the economic incentives for local delivery services enterprises to be interested in participation in e-waste collection. However, the economic incentives are not only the task for the specialized enterprise but also primarily for the municipality, as it has to create the conditions for e-waste collection according to the EU Directive. In the case of smart e-waste reverse system implementation, the local authority could exempt from taxes the delivery enterprises which participate in e-waste collection.

In this specific case of the smart e-waste reverse system implementation, there is no need to create a particular collection infrastructure similar to that of one existing through a trading network or special collection points. The delivery service vehicle could serve not only as an e-waste transport operator but also as a mobile collection point. For developing countries where there is no targeted infrastructure for e-waste collection, the proposed system can allow to significantly save on infrastructure creation and its maintenance.

Note that the proposed smart e-waste reverse system includes the involvement of non-specialized vehicles of delivery enterprises. Therefore, the safety requirements for the transportation of some sensitive categories of e-waste must be considered with extra care to avoid contamination of the delivered goods with waste materials such as fluids from EoL equipment. For instance, EoL or damaged lithium-ion or lead acid batteries should be transported in special individual mini-boxes for safety reasons.

### 3.2. Case Study

Figure 2 shows the conditional interactive online map of users' requests to collect e-waste in Sumy city (Ukraine) and the conditional route of the delivery service vehicle. Under the outlined route, the vehicle collects e-waste according to the requests marked by users on the map and transports these wastes to the local specialized processing enterprise, with almost no deviation from the planned route.



**Figure 2.** E-waste collection interactive online map with the conditional route of the delivery service's vehicle, Sumy city, Ukraine.

The online maps application for e-waste collection, to a certain extent, motivates the consumer to discard these wastes properly since this tool provides minimal consumer' transaction costs (efforts, time, etc.) compared to traditional collection systems. In practice, the use of common or shared platforms for delivery and collection services, would reduce the amount of mileage covered by the ad hoc delivery and collection vehicles, using the aforementioned smart e-waste reverse system. Such a smart e-waste reverse system would thus lead to fuel savings that could be translated in terms of cost reduction and CO<sub>2</sub> emissions mitigation. The consumer's individual request for collection must include information about the used household equipment category and the service time that is convenient



for the consumer. Furthermore, it is advisable to create economic incentives to compensate for the residual value of all categories of EoL EEE for as much consumer participation in e-waste collection as possible. To benefit from economic incentives, the consumer's request could include specific information about used household equipment characteristics to assess the compensation of residual EoL EEE value for the consumer. The registration of the request on the interactive map allows us to track these compensations.

The business model (BM) has been built using the BM canvas toolkit [48] in order to economically justify the smart e-waste reverse system implementation in Sumy city (Table 1). This model shows the economic relations that define the logic of building relationships between the main elements and actors of the business system. It contains nine numbered structural blocks where the numbering reflects the sequence of service value creation for the client (consumer). The location of the cells indicates the logical interrelation of the elements.

**Table 1.** Business model canvas (BMC) of the smart e-waste reverse system.

<p>8. Key partners</p> <p>1. Trading companies with their own delivery services (Eldorado, Epicenter, Foxtrot, Comfy).</p> <p>2. Enterprises providing delivery services («UKLON», «Nova Poshta», others).</p> <p>3. Repair companies.</p> <p>4. Companies that recycle secondary raw materials.</p> <p>5. Stations of redistribution of superfluous things.</p>	<p>7. Key activities</p> <p>Types of activity:</p> <p>1. Collection and transportation of e-waste.</p> <p>2. Pre-sorting followed by dismantling and identification of parts.</p> <p>3. Cost estimation of parts/products for reconstruction and modernization, as well as the cost estimation of raw materials.</p> <p>Sales channels:</p> <p>1. Realization of secondary raw materials to recycling enterprises.</p> <p>2. Realization of products/parts for reconstruction to repair enterprises and for modernization of manufacturing enterprises.</p> <hr/> <p>6. Key resources</p> <p>1. The local operator of technical support for interactive online maps, as well as for support consumer requests for collection.</p> <p>2. Software, website, and other communication systems.</p> <p>3. Equipment for dismantling and identification of parts of EoL products.</p> <p>4. Main, auxiliary, and service premises for pre-treatment of EoL equipment.</p>	<p>2. Value propositions</p> <p>For the end consumer</p> <p>The e-waste collection service meets consumer's needs in getting rid of extra unnecessary things that are accumulated at home with minimal transaction costs for it (time, money, effort).</p> <p>For partners</p> <p>Creating a positive image.</p> <p>For the environment</p> <p>1. Reduction of CO<sub>2</sub> emissions.</p> <p>2. Reduction of waste generation.</p> <p>3. Keeping the value of materials and products in the economic system as long as possible.</p>	<p>4. Customer relationship</p> <p>1. Delivery services provide an e-waste collection service directly to the consumer upon request via an online map.</p> <p>2. Request for collection of end-of-life (EoL) equipment is made through online application containing information about the category of equipment and service time, convenient for the consumer.</p> <p>3. It is desirable to create financial incentives for the user to compensate for the residual value of EoL equipment.</p> <hr/> <p>3. Channels of interaction</p> <p>1. The local operator interacts with consumers through city delivery services.</p> <p>2. The specialized recycling enterprise concludes contracts for the provision of transport services both with the trading companies who have their own delivery services and with the enterprises that provide such services directly.</p>	<p>1. Consumer segments</p> <p>Value proposition to collect e-waste is created for all users of electrical and electronic equipment in ten categories according to the EC Directive by a specialized recycling company.</p>
<p>9. Costs</p> <p>—Cost of equipment for sorting, dismantling, and identification of EoL products' parts.</p> <p>—Current costs of salaries, material-and-technical equipment, and other costs.</p>	<p>5. Income</p> <p>—Revenue from the sale of secondary raw materials to recycling enterprises.</p> <p>—Revenue from the sale of functioning parts of equipment to repair companies.</p> <p>—Revenue from the sale of EoL equipment to manufacturing/repair companies for the modernization/restoration of products.</p>			

According to the developed business model, the specialized e-waste processing enterprise creates a value proposition for all EoL EEE holders. The e-waste collection service on the user's request to collect e-waste, as the value proposition, meets consumer's needs in discarding unnecessary things that are accumulated at home with minimal transaction costs for it (time, money, effort). The residents of Sumy city apply for discarding e-waste using a specific interactive map intended for e-waste collection.

The local e-waste operator at the specialized enterprise interacts with the consumer through Sumy city's delivery services among which «UKLON», «Nova Poshta» etc., as well as those at the trading enterprises such as «Eldorado», «Epicenter», «Foxtrot», «Comfy», etc. To involve these delivery services in the e-waste collection process, the specialized enterprise enters into contracts for the provision of transport services, both with trade enterprises having their own delivery services and with enterprises providing such services directly. The key activities undertaken by a specialized enterprise and the local e-waste operator are: e-waste collection; pre-sorting with further disassembly and identification of products/parts; value estimation of products and modules/parts for remanufacturing, refurbishing and repair, and secondary raw materials for recycling. The source of funds for ensuring the e-waste reverse and their subsequent treatment is the revenue from the sale of secondary raw materials to recycling enterprises, functioning modules/parts to repair/remanufacturing enterprises.

#### 4. Discussion

Consumer recycling behavior is key and essential for saving the value of parts and modules, and materials in the economy as long as possible [49,50] since the proper return of EoL EEE, through formal collection channels, allows using the potential of 6R circular business models, as outlined in sub-Section 2.2 [2,51]. Recent studies showed that convenient and adequate collection infrastructures and economic incentives are required to ensure a high-level consumer involvement in e-waste collection [35,37,52].

Moreover, current waste management in countries in Oceania, Asia, and South America with weak environmental legislation is facing challenges of low competitiveness of the formal e-waste collection systems due to high transportation and infrastructure costs.

As an alternative to existing e-waste collection systems, we propose introducing a smart e-waste reverse system based on the launch of interactive online maps of users' requests for collection and involvement of city delivery services vehicles as potential mobile collection points. The smart e-waste reverse system seems promising because of the opportunity to provide close to zero the transport and infrastructure costs and the consumer's transaction costs minimization. Actually, the proposed procedure can be used as an ad hoc framework for more advanced forms of end-of-life e-product management.

The proposed smart reverse system for e-waste actually aims at searching for an appropriate and available vehicle of the delivery service which is connected to a smart system. According to the ICT development index data calculated by the International Telecommunication Union, in 2015 Ukraine had the value 5.20 (0–100), putting it in the top 50% for the indicator “Country rank and value in the ITU ICT Development Index”. This index value indicates a sufficient level of IT in Ukraine as a whole and points to the possibilities to solve transport tasks in parallel for different sectors. According to the literature review, there is an available unused transport potential for e-waste collection in any city at local delivery enterprises. Along these lines, it seems promising to integrate the online user's requests into the online delivery service system. To be practically implemented, this would require the development of special applications that the vehicle driver could install to receive such relevant information.

At the same time, there are a few unresolved issues regarding this system implementation, namely (1) responsibility for financing the system, i.e., how e-waste collection costs should be shared between stakeholders (municipality, manufacturers, and distributors), (2) whether costs for economic incentives to encourage consumer recycling behavior can

be shared among interested stakeholders, and (3) what are the financial conditions for the delivery services and how these costs will be distributed among the stakeholders.

Among these issues, the principal one to be discussed is who will ultimately pay to local delivery services enterprises for e-waste collection. One option is to share costs between the interested stakeholders, namely EEE distributors, manufacturers, and municipalities in the same way as recycling costs are shared today. However, this cost-sharing depends on the legislation, which varies across countries [3,12]. Further, the economic incentive for the consumer to discard e-waste properly under the proposed system is one more issue to be addressed. In the case of developed countries, it is probable that the manufacturing enterprises will be ready to offer monetary incentives for consumers compared with enterprises that are focused on linear production since they invest in circular product design [53]. These enterprises are more likely to be interested in a possible and proper collection of their EoL products since they consider the remanufacturing and refurbishment strategies as business models for capitalizing on residual products. Along these lines, this research contributes in proposing a new and operational circular business model for e-waste to support a sustainable value chain [54] through the use of IT tools and digitalization principles [55].

Lastly, the smart e-waste reverse system is of particular interest for developing countries since it generates consumer recycling behavior in a short period with close to zero infrastructure and transport costs for collection. However, in countries with low environmental legislation and a huge informal sector, it is challenging to promote formal e-waste collection, including the proposed system. At the same time, it may become a reliable tool for stopping the informal e-waste collection sector in the case that stronger waste management regulations will be adopted.

The proposed smart e-waste reverse system 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 the EoL EEE collection rate due to this system's implementation without pilot testing. More resources and investigations are needed for conducting such testing, as well as cost-benefit analyses, and therefore we encourage future studies to include these aspects.

## 5. Conclusions

The article develops a new smart reverse system for e-waste from the user to recycling enterprise based on the launch of interactive online maps of consumers' requests for collection and involvement of city delivery services in e-waste collection. In the proposed and illustrated smart e-waste reverse system, vehicles of delivery services can be considered as potential mobile collection points, which could collect e-waste and deliver it to the specialized enterprise almost without deviation from the planned route. Besides e-waste collection costs minimization, the smart e-waste reverse system can ensure the reduction of CO<sub>2</sub> emission due to the optimization of transport routes of vehicles. In the case of the smart e-waste reverse system implementation, there is no need to create a special collection infrastructure similar to one that exists through a trading network or special collection points. Hence the delivery service vehicle could serve not only as an e-waste transport operator but also as a mobile collection point. Furthermore, the study highlights that it is commendable to create a local e-waste reverse operator at the specialized enterprise to launch and technically maintain the interactive online maps. Apart from that, the local operator can serve as a connecting link between the consumer and the delivery service vehicles as potential e-waste collectors. The integration of an online user's requests into the online delivery service system could enable the search for an appropriate (e.g., in terms of location, size and capacity) and available vehicle of a delivery service which is connected to a smart system. In addition, the proposed collection system allows the collection of old and/or obsolete products with minimal transaction costs for consumers, which motivate them to discard EoL products properly. It is noteworthy that for as full e-waste collection as possible through a formal channel rather than an informal one, it is advisable to create economic incentives for consumers to compensate for the residual value of EoL EEE. Lastly,

applying the business model canvas toolkit, an initial business model for a smart e-waste reverse system was built and discussed. A promising line for future research would be to experiment with such a smart e-waste reverse system on a real-life case study and quantify the benefits associated with it for the key stakeholders involved and the environment.

**Author Contributions:** Writing—original draft preparation, review and editing, T.S.; Formal analysis and investigation, Y.D., I.G.; Writing—validation, review and editing, M.S., J.C. and R.V. All authors have read and agreed to the published version of the manuscript.

**Funding:** This study is co-funded by the Erasmus+ Programme of the European Union within the project “Towards circular economy thinking and ideation in Ukraine according to the EU action plan” (grant number 620966-EPP-1-2020), the Student Grant Competition in VŠB—Technical University of Ostrava (grant number SP2021/18).

**Institutional Review Board Statement:** Not applicable.

**Informed Consent Statement:** Not applicable.

**Data Availability Statement:** No new data were created or analyzed in this study. Data sharing is not applicable to this article.

**Acknowledgments:** This work was supported by Sumy National Agrarian University in Ukraine, University of Paris-Saclay in France, University of Presov in Slovak Republic, VŠB-TU Ostrava in Czechia. In addition, we would like to thank the anonymous reviewers whose comments have greatly improved this manuscript.

**Conflicts of Interest:** The authors declare no conflict of interest.

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