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Review

E-Waste and End-of-Life Vehicles Management and Circular Economy Initiatives in Romania

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Abstract: E-waste and end-of-life vehicles (ELVs) are fast-growing waste streams in the EU and beyond that require specific collection and treatment activities to avoid environmental pollution and resource depletion fed by the linear economy model. This paper aims to investigate the links between e-waste and ELVs streams and the circular economy approach of the EU. Romania is examined as a relevant case study for the central and eastern European Region regarding: (i) the current e-waste and ELVs management deficiencies and challenges in line with circular economy principles promoted by EU; (ii) analysis of E-waste and ELVs flows data; and (iii) best circular economy initiatives related to e-waste and ELVs in Romania, including the opportunity to create new jobs in treatment activities that the simple operations from the first stages of e-waste recycling can produce locally and regionally in Romania. This work points out the current knowledge gaps and future research directions for these special waste streams in Romania and beyond.

Keywords: e-waste; end-of-life vehicles (ELVs); urban mining; circular economy; waste management; WEEE; pollution; Romania

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1. Introduction

Technological development changed the consumption patterns around the globe with increasing demands for electronic devices and vehicles for daily domestic, studies, health-care, or other job-related requirements besides urban expansion and population growth. The economic growth fed by unsustainable consumption patterns based on the linear economy model "make-take-use-dispose" poses serious societal and environmental concerns. E-waste and end-of-life vehicles (ELVs) are growing waste streams at the global level but there are serious discrepancies between e-waste and end-life-vehicles (ELVs) generation and waste management performances rates among countries [1,2]. On the other hand, both e-waste and ELVs have a higher recovery and recycling potential which could feed the related industries with precious secondary materials [3]. Therefore, the development of urban mining practices based on these two key waste streams is a step forward for countries to achieve a circular economy transition. Creating new jobs in e-waste treatment, decent work, and resource recovery are important factors in the green economy [4]. EU Green Deal aims to provide environmentally friendly transportation alternatives even for remote areas fed by cleaner energy sources [5]. The circular economy action plan supports the resource flows in closed-loop economic activities [6]. E-waste and electronic goods are reliable sources for various materials at the EU level that must be further expanded through enhanced urban mining operations [7]. However, high-income countries fail to manage their e-waste and ELVs flow, and less developed countries are still exposed to illegal waste trades despite the Basel Convention framework [8]. Second-hand electrical and electronic goods and second-hand vehicles are imported by low and middle-income countries with repercussions to the environment such as air and land pollution [9,10]. Additionally, the improper collection of e-waste and their landfill together with the household waste or their recycling with primitive techniques by unauthorized persons generates pollution and human health issues [11].

Air pollution and waste management are some of the most pressing environmental problems in Romania now [12,13]. For air pollution, transport, urban traffic, and also the big number of old vehicles that generate high concentrations of exhaust gases are sources of the air pollution, constantly reported [12]. From a waste point of view, the hierarchy in waste management (Waste Framework Directive 2008/98/EC) is a suitable strategy for both household waste management and e-waste management. The hierarchy suggests the importance of reducing pollution, using the waste prevention strategies first and using less hazardous substances for goods, followed by the reuse, recycling, and treatment as preferred strategies to landfilling of waste [11].

Unlike household waste management, the e-waste treatment involves ensuring health and safety conditions at all the stages of recycling and especially in the pre-treatment stage, which is often done manually [4]. Hence the need for additional steps materialized including more time and cost for certification of quality standards, collection, and adequate reporting [4,14]. Inadequate collection of complementary channels leads to material recovery losses and does not provide optimal management opportunities [4].

The International Labor Organization (ILO) Report for 2019 shows that employment in the waste recycling and waste recovery sector is expected to increase by 70% by 2030 [15], and this trend would also be followed by Romania in the effort to adopt the principles of the circular economy and job creation in the green economy. The ILO's orientation towards a fair transition to economically sustainable economies and societies calls on governments to propose coherent policies to encourage organizations to create decent jobs in the green economy through social dialogue, consultation with relevant stakeholders, recognition of workers, formalization of their activities, and promotion of decent work in the field of e-waste management and the field of recovery of the resources from the e-waste [16].

Jobs in the proper management of e-waste and ELVs have different levels of complexity, but their common goals are decent work, recovering the resources from e-waste flows, and reducing environmental pollution and health impacts through proper management of e-waste, including e-waste that is contained in the modern vehicles. Numerous studies in the field [4,10,15,17] show that in terms of e-waste, the initial manual sorting and dismantling processes are more efficient than the automatic ones in extracting and creating value, and these operations require enough workforce to ensure the good management of this rapidly growing waste stream, thus becoming a job-creation engine. A study conducted in the UK in 2010 estimated that every 1000 tons of e-waste processed in the UK created an additional 40 jobs in their collection and sorting [18]

Last but not least, the recycling of these two waste streams is a way of maintaining critical raw materials (CRMs) and other resources in the economic flow with lower energy consumption and less GHG production than by their extraction from mining, especially as reserves are limited anyway [19].

On this background, this paper aims to reveal current e-waste and ELVs management challenges in line with circular economy principles promoted by the EU in a country like Romania. This work highlights, on the other hand, the best circular economy initiatives for these two key waste streams, e-waste, and ELVs for a better recovery of resources, through actions to raise public awareness and encourage the increase of the number of jobs in the field of pretreatment of this waste for a transition to the green economy and to reduce illegal actions in the field of e-waste management and the undesirable consequences arising therefrom.

2. Materials and Methods

This review examines two key waste streams (e-waste and ELVs) for urban mining prospects in Romania under the circular economy framework supported by the EU. This review provides a holistic approach taking into consideration: (i) current e-waste management practices and ELV and various Romanian particularities in their management; (ii) circular economy practices and initiatives already applied in Romania; (iii) the potential for job growth in the activities of managing the studied waste streams, in conditions of worker safety and the environmental protection, with implications on a better recovery of resources; and (iv) other possibilities for implementing the circular economy for the studied waste streams.

For the more complex recycling activities, for which there is no available technology in Romania is preferable to export the by-products resulting from the collection and pre-treatment of e-scraps for the recovery of the critical raw materials (CRM) that they contain, by those who have the necessary technology and can ensure the conditions of protection of the environment and the health of the workers in the field. The broad analysis of this review is underlined by Figure 1.

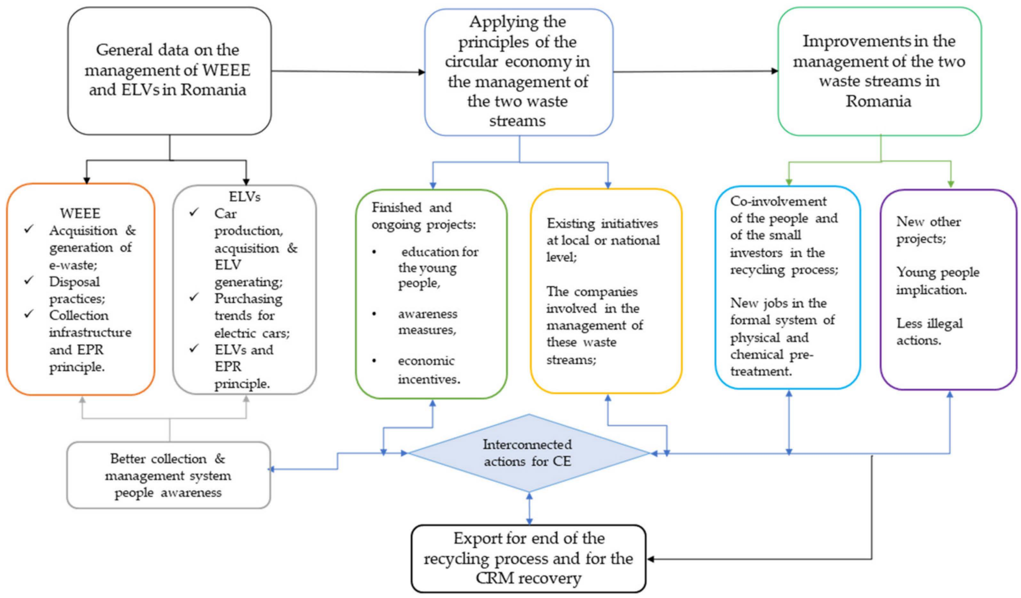

Figure 1. Schematic representation of the study on the implementation of the circular economy (CE) in the management of WEEE and ELVs in Romania.

Peer-reviewed literature combined with grey literature (e.g., environmental reports, NGOs reports), mass-media investigations, and field observations reveal the complex interactions related to e-waste and ELVs streams with the participation of both formal and informal sectors in Romania. Too often, some parts of e-waste and ELVs for the recycling market end up in landfills, co-incineration plants (cement factories), or uncontrolled waste practices such as open burning to recover metals, burying, or illegal dumping threatening the local environment and public health.

Therefore, the role of EPR policies is further examined to improve current management practices in Romania. In a broad sense, EPR policies should increase the reuse and recyclability of all electronic parts, to lead to an extended life of products with fewer energy demands and to shift the old vehicles based on fossil fuels to electric cars, motorcycles, and public transport vehicles. This work examines the factors that influence e-waste and ELVs collection, treatment, recycling, and disposal practices.

E-waste circular business models must be supported to further catalyze such initiatives in other regions of Romania. The ELVs management practices are examined in line with auto industry trends in Romania and prospects of future investments in electrical/hybrid cars. This review points out the knowledge gaps and future research perspectives related to e-waste and ELVs under the circular economy framework.

3. General Data about WEEE Management in Romania

3.1. Acquisition of the Electronic Devices and the E-Waste Generation in Romania

The increase in the quantities of WEEE produced in the world is visible in all statistics performed, globally, at the continent's level or the level of the countries, and the main reasons are the increase in the average income, urbanization, industrialization, and technology [3,20]. Existing data globally are mostly estimates, there are still undocumented e-waste streams, both in Europe and globally. Table 1 shows the quantities of electric and electronic equipment (EEE) placed on the market (POM) in Romania during 2014–2018, according to the 10 categories of Directive 2012/19/EU. Table 2 shows the quantities of the e-waste generated in the same period, according to the same source [21].

Table 1. Electronic devices placed on the market (EEE-POM) in Romania during 2014–2018, according to the National Agency for Environmental Protection [21].

Category of EEE	Quantities of EEE (Tonnes)				
EEE POM (National Register)	**2014**	**2015**	**2016**	**2017**	**2018**
1. Large household appliances	84,995.17	103,475.36	129,548.53	140,581.085	146,784.122
2. Small household appliances	10,466.12	14,667.61	16,224.62	18,467.346	22,675.815
3. IT and telecommunications equipment	13,400.46	13,469.45	13,231.54	15,230.911	16041.998
4. Consumer equipment and photovoltaic panels	148,332.53	15236.29	17,549.37	27,702.545	26,189.229
5. Lighting equipment	5350.9	6010.49	7042.15	9084.300	13,666.176
6. Electrical and electronic tools	7727.25	9654.61	11,108.44	18,030.341	23,932.625
7. Toys, leisure and sports equipment	999.47	1616.51	2150.54	3489.876	4718.894
8. Medical devices	394.51	673.90	564.86	889.331	1430.588
9. Monitoring and control instruments	938.16	2566.35	2126.21	3343.294	4538.296
10. Automatic dispensers	482.54	808.83	1093.56	1225.335	1169.179
Total	139,587.1	168,179.40	200,684.82	238,044.36	261,146.92

Source: The Romanian Ministry of Environment, Report on the State of the Environment for Romania in 2019.

Table 2. E-waste generated in Romania during 2014–2018, according to the National Agency for Environmental Protection [21].

Category of WEEE	Quantities of WEEE Collected (Tonnes)				
WEEE Collected (National Register)	**2014**	**2015**	**2016**	**2017**	**2018**
1. Large household appliances	20,465.24	24,122.22	29,592.17	31,175.22	35,755.95
2. Small household appliances	1021.16	1218.31	1320.07	1303.18	1633.02
3. IT and telecommunications equipment	4803.3	6834.44	5645.37	6571.14	9362.28
4. Consumer equipment and photovoltaic panels	3513.27	5385.17	7063.19	6545.39	9699.59
5. Lighting equipment	1140.05	1781.32	1292.77	2002.53	3171.92
6. Electrical and electronic tools	815.37	796.00	891.33	903.08	1206.34
7. Toys, leisure, and sports equipment	65.6	107.26	115.51	83.39	91.31
8. Medical devices	34.07	48.43	83.24	67.33	114.16
9. Monitoring and control instruments	236.42	383.15	411.01	700.15	2065.84
10. Automatic dispensers	64.51	94.84	239.79	337.79	678.47
Total	32,158.99	40,774.13	46,654.45	49,689.20	63,778.88

Source: The Romanian Ministry of Environment, Report on the State of the Environment in Romania in 2019.

Like other countries in Europe or the world, Romania currently has an expanding market for the acquisition of electronic products, in which modernization is also visible. (eg: switching from the CRT screens to flat screens for TVs or monitors) [22]. Most EEE purchased in Romania in the last years are new, over 55% of products in Romanian households are less than 5 years old, for each product category. The amount of the existing EEE in Romania shows an increase of 44% between 2013 and 2020, according to the estimates [23].

The literature shows that in recent years the weight of the large appliances has decreased, they have a lighter design [22,23], The increase in the quantities of EEE registered in Romania also shows the expansionist trend of the Romanian market [22], as in the case of the other countries in eastern Europe or Asia.

The study made by Magalini (2019) [23] shows the differences between the data in the E-tool (WEEE calculation tools) and the actual WEEE generation data in Romania and explain the possible origin of these differences. Thus, according to the market survey for the year 2019, at the level of Romanian households was highlighted a quantity of WEEE generated equivalent to 8.3 kg·inhab·yr$^{-1,}$ about 30% lower than the amount resulting from the E-tool calculation that proposed a target of WEEE 11.3 kg·inhab·yr^{-1}.

According to the existing studies, the quantity of the electronic products in Romanian households has gradually increased from 25–30 kg·inhab·yr$^{-1,}$ in 2011 [24], to 71 kg·inhab·yr^{-1} in 2015 [25], respectively to 91 kg·inhab·yr^{-1} in 2019 [23]. The latest Eurostat data for Romania show that 31.5% of electronic devices placed on the market (POM) in the last three years have been collected despite the derogation target of 45% from the EU. This is the lowest collection rate at the EU level besides Cyprus (26%) and Malta (12%) [26]. The POM EEE methodology used for the calculation of WEEE collection targets presents some difficulties in the case of Romania, and also for other countries such as Lithuania, Malta, and Poland.

The difficulties for Romania are related both to the considerable increase in the amount of EEE POM in recent years, because Romania is an expanding market [26], but also to how the Romanians get rid of the electronic products and the e-waste that have some local peculiarities different from the way of disposal used by the people in the other European countries [23] that will be explained in the Section 3.2.

The Global E-waste Monitor suggests the use of a sub-indicator for the e-waste, called "national recycling rate and tons of material recycled" to ensure the correlation with SDG 12—Responsible consumption and production; the "total e-waste generated" is defined as the amount of discarded electrical and electronic products (e-waste) due to consumption within a national territory in a given reporting year, before any collection, reuse, treatment, or export [3]. With these data, the sub-indicator on the e-waste (global) recycling rate is 17.4% for 2019 [3]. The recycled e-waste, in this case, refers to the amount of e-waste collected by the formal systems. The e-waste generated includes the entire value of e-products and e-waste that depend on the consumption of electronic products in a (national) territory in the year reported, before any process of collection, reuse, treatment, transport, or export [27].

Table 3 shows the amount of e-waste generated per capita in Romania, compared to the amount of e-waste generated on average in EU-27 countries.

Table 3. Waste electrical and electronic equipment collected from the household in Romania and UE-27 [28].

WEEE Collected from the Household (kg/Capita)	2012	2013	2014	2015	2016	2017	2018
Romania	1.04	1.55	1.5	1.79	2.19	2.53 *	3.26 *
UE-27	5.74	5.87	5.96	6.45	7.05	7.37	7.13

Legend: *- values calculated by the authors based on Romanian NEPA data and the population database on Eurostat, 2021.

The e-waste collection rate in Europe is below 40%, and Romania has the lowest e-waste collection rate per capita in the EU. It is also the only country that did not report the e-waste collection rate for 2017 and one of the few countries that did not report the collection rate for 2018 for the Eurostat database, before February 2021, when the database for the WEEE was updated. For the years 2017 and 2018, the mass of WEEE collected per capita (Table 3) was calculated by the authors based on the data of the National Agency for

Environmental Protection from the report of the Ministry of Environment (2020) and the population database on Eurostat, 2021 [28].

On the other hand, a study conducted by Mihai, (2019) [29], as well as the study done by Magalini (2019) [23] highlights the differences between the data on EEE trade found in the National Register of the National Agency for Environmental Protection and the data calculated by E-tool, which are correlated only with EEE placed on the market (EEE POM), without necessarily correlating with the real situation of the WEEE generation in Romania or with the public behavior regarding the consumption of the electronic products, collection or storage of the electronic products or the other characteristics specific to the population in the studied region [23,30].

Characteristic of the Romanian population is the time of use of electronic equipment. Coleșca et al. [24] show that over 50% of the interviewed people used electronic equipment until it breaks down, then they it is often kept in the household in hibernation (kept unused) [23]. Exceptions were mobile phones and computers, which were generally replaced more quickly as new, higher-performance models appeared on the market. For this reason, in the period 2008–2011, the Romanian households owned significant quantities of old WEEE. The study shows that in 2008, approximately 65.80% of households in the urban areas stored one or more non-functional WEEE [24]. This significant percentage is probably because 2008 was one of the years of the financial crisis. The percentage of the electronic devices kept in hibernation decreased around 2011 to about 33.40% [24]. It seems that this tendency to keep WEEE in hibernation has been maintained in Romania in the following years, especially for the small electronic equipment in the households, such as the IT range equipment or the screens, even if their percentage has gradually decreased compared with the previous years. A recent study [23] estimates that approximately 10–15% of screens or IT equipment is still kept in hibernation in households. Related to the reasons why this old equipment is kept in hibernation also at present in some of the Romanian households, studies show that this tendency can be both the result of lack of information on disposal possibilities and because of some consumption patterns or because of other factors, such as storage as a replacement part, availability of storage space, storage with a view to a possible subsequent repair, storage for discount campaigns pending, etc. [23]. It is possible that, in rural communities, these amounts of WEEE kept in hibernation will be higher.

A study regarding e-waste collection in 13 rural communities from Bacau county revealed a total e-waste collection of 7080 kg (421 electronic equipment, most of them being old TVs) resulting in a per-capita e-waste collection rate of around 0.169 kg·inhab., with the highest collection rate in Tatarasti (1531 kg) with 0.61 kg·inhab. [31].

On the other hand, it seems that with the increase of the living standards, of the urbanization, of the level of education, of the improvement of the collection infrastructure, but also other factors, including the availability of new high-performance equipment, etc., the tendency to keep WEEE in hibernation in the household could decrease more for the case of Romanian households.

According to WEEE Directive 2012/19/EU, EU Member States must recycle 85% of WEEE generated on their territory or 65% of the average weight of equipment placed on the market (POM) in the previous three years [31]. Studies based on the reports from EU Member States still place Romania among the countries with the lowest WEEE collection rate, respectively to 31% compared to POM EEE in the last three years, respectively to 23% compared to WEEE generated in the Member States, EU-28, Switzerland, Iceland, and Norway [26].

Of the total WEEE generated in Romania, a percentage of 34% of their weight (approx. 2.8 kg·inhab·yr^{-1}) are sold, donated (including to the family members), reconditioned, and a percentage of 25% of the weight (approx. 2.1 kg·inhab·yr^{-1}) is not is handed over to a correct flow of WEEE, respectively they are not managed properly [23]. This new report suggests that around 50% of WEEE discarded is managed by the informal sector, of which half would feed the formal system [23,28]. Therefore, a quarter of e-waste flow in Romania is susceptible to end up in the metal scrap sector and currently not reported, being illegally landfilled in improper conditions [28] or burnt.

At the same time, the existing collection infrastructure can provide approx. 36% of WEEE generated, i.e., approximately 3 kg·inhab·yr^{-1}, although Romania has started the procedure for registering EEE producers in the register of manufacturers and importers of electrical and electronic equipment since 2006 [23,32]. In this context, together with the demand for a sufficient and efficient collection infrastructure, public information, and awareness, but also warning the people about the impact on the environment and on the human health of the improper WEEE management can be important and appropriate.

3.2. E-Waste Disposal Practices of Inhabitants

Public awareness of the proper management of WEEE, highlighting motivating factors, and assessing their importance has been addressed in numerous literature studies [33–36], respectively also in studies that specifically analyzed the Romanian population [23,24,37,38]. Thus, the main factors influencing the behavior of the population regarding the selective collection of waste, especially WEEE, were highlighted. These are various factors, such as: (i) socio-demographic and economic factors; (ii) factors related to technical-organizational criteria; (iii) socio-psychological factors; and (iv) other factors specific to the study.

Among the socio-demographic and economic factors, we mention the age, living places (urban, rural), average income, number of residents in the individual or collective housing, owners or tenants, etc. Socio-demographic factors are not necessarily an accurate predictor of pro-recycling behaviors of the population but are important for controlling the representativeness of samples in case studies [34]. However, economic factors may play a more important role in predicting recycling behaviors, especially if additional recycling costs or rewards occur. Another significant factor seems to be education, and access to information [35].

The technical and the organizational factors are related to the planning of the waste management system, the existence and the efficiency of the collection and recycling infrastructure, the distance to the collection points, the ease with which the collection process can be performed, the frequency of collection and proper maintenance of collection points, but also the traceability to highlight the benefits of the recycling, etc. [34,39].

The socio-psychological factors are related to social norms and/or moral norms, common values, habits, awareness of the importance of environmental protection, attitudes towards recycling, etc. Pro-environmental attitudes can be improved by raising awareness of the importance of waste recycling in general, and WEEE in particular, by highlighting the environmental impact and the possible consequences for human health in the event of improper collection, etc. When there is functional management of WEEE and quality infrastructure, these factors are important for community members and influence the behavior of the individuals who are part of that community and they will also be maintained over time [24,34]. The specific factors of the study refer to various community-specific influences, habits, sometimes older, but still preserved by the community, behavior patterns or consumption patterns, multicultural communities vs. closed communities, and various other region-specific information [35]. A study done for Romanian people (2014) [24], showed that young people have more obvious pro-collection attitudes than the elderly, but also that fashion is important among young people in terms of consumption patterns of small electronic devices, especially of mobile phones. Thus, 33.20% of the respondents replace the mobile phone after a maximum of six months, 11.60% keep it for more than three years, and another 12.60% for more than five years. People over the age of 65, although not characterized by pro-collection attitudes, often use appliances for a large number of years, some people have had the same refrigerator for over 30 years and have never used an IT product [24]. As for university students, they believe that there is a link between a less polluted environment and an efficient collection of the WEEE, but over 50% do not know information about recycling campaigns, even if a large part of them come from urban areas [38]. Unlike the young people interviewed in 2014, the students interviewed in 2021 responded that the main reason why they change their small electronic equipment, such as phones and laptops, is that they no longer work, only a small percentage, less than 10%, choosing fashion as the main reason for change the mobile phone [38]. In another study done for the Romanian people in 2020 [37], the main factors influencing recycling were the attitude and awareness of consumers, followed by the perceived self-efficacy (perception of the individual's ability to carry out waste reduction activities) and social influence. The intention to recycle seems to be the main behavior through which Romanians engage in WEEE recycling processes and it is correlated with the perceived self-efficacy [37].

Regarding the WEEE disposal habits of the Romanian population, a study done by a Romanian producer responsibility organization (PRO) (2019) [23] presents the correct and incorrect variants chosen by those interviewed:

- Correct behaviors: WEEE is taken to the store or are picked up by the store (retailer), are taken to the or picked up by the town hall at municipal collection points or to the other authorized collection points, are replaced during the warranty period, are sold as second hand or are donated to be reused;
- Incorrect behaviors: Have a share of 20–25% and consist of: WEEE are deposited together with other recyclable or non-recyclable municipal waste, are given to formal or informal scrap metal collectors [23].

Producers of WEEE, producer responsibility organizations (PROs), as well as other actors, implies in the WEEE value chain, strive to understand what would be best practices for WEEE collection taking into account regional specificities or other characteristics to improve the degree of WEEE collection throughout Europe [40], and also in Romania.

The e-waste stream is a complex one and it contains various types of e-waste in shape, size, and complexity. To capture the most essential characteristics of the e-waste, but also to facilitate and standardize the reporting of them, the European Directive 2012/19/EU requires that starting with the year 2019 the classification of waste to be done in six categories, to help the correct registration of the e-waste for all actors implied in the e-waste management (Figure 2).

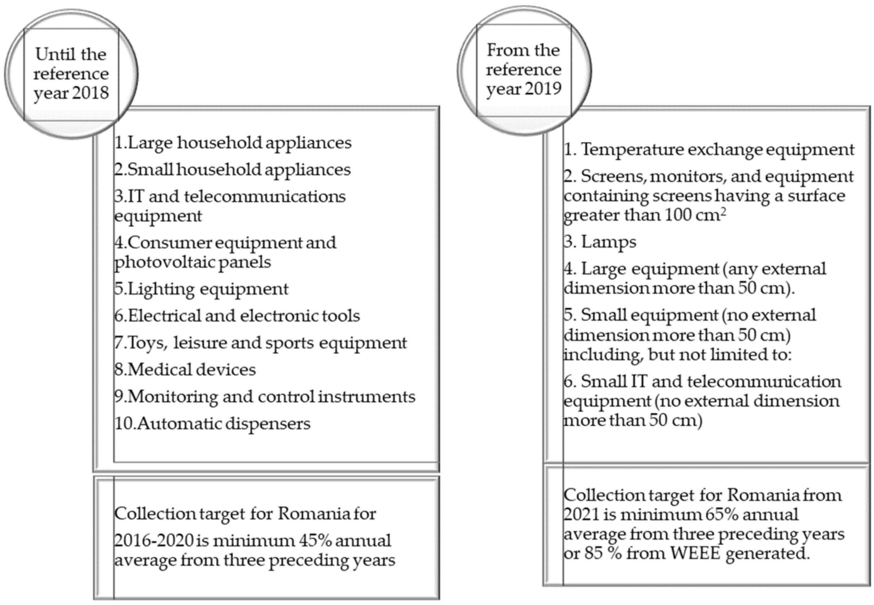

Figure 2. Classification of WEEE after Directive 2012/19/EU updated in 2018, and the collection target of WEEE for Romania.

E-waste and ELVs are recognized as some of the fastest-growing waste streams worldwide, not just in Europe. When the collection infrastructure is missing or insufficient, uncontrolled storage inevitably has consequences for the pollution of the environment and the health of the population. That is why it is important to create infrastructure, but also safe workplaces for workers and the environment [28].

3.3. E-Waste Collection Infrastructure and the EPR Principle for the E-Waste in Romania

In Romania, the general waste collection infrastructure is generally deficient (Figure 3), but the WEEE collection infrastructure has benefited from several takeover programs, such as one-day collection actions, take back system or collection centers where the users can take WEEE for free, but these actions are still insufficient. More about these programs and initiatives will be discussed in Section 5.1.

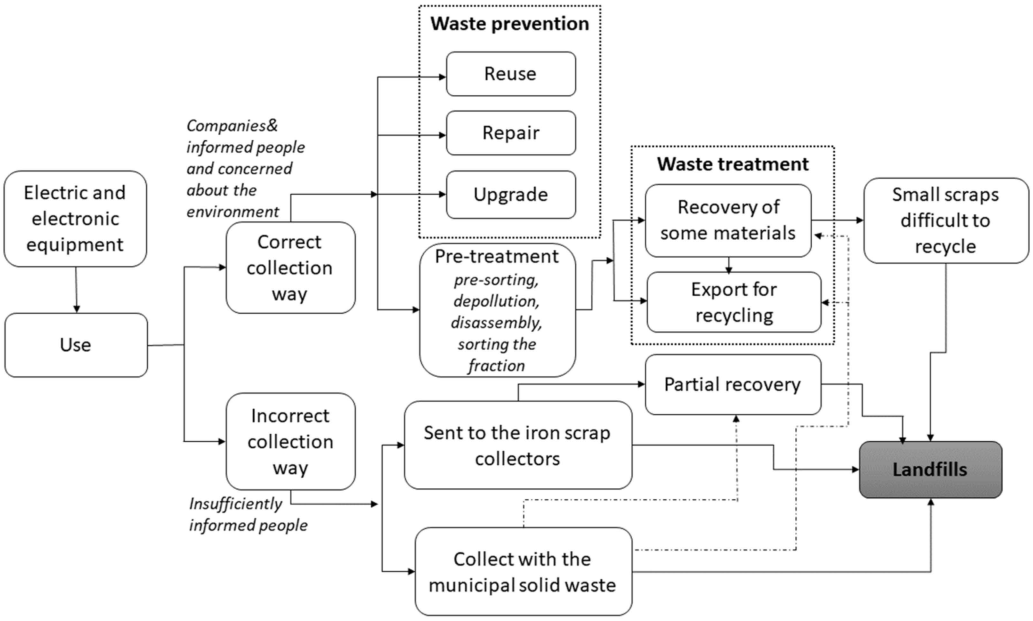

Figure 3. WEEE management in Romania. Figure made by authors based on [23,41].

There are also several EEE collection companies on the Romanian market, some authorized by the WEEELABEX authority, the pan-European organization that provides the schemes for the operational problems related to the WEEE management [42]. Additionally, according to the website of the Romanian Ministry of Environment [43], there are other companies, including those specialized in collecting industrial batteries and accumulators or from the population [44], which are still insufficient given the growing market of EEE, respectively WEEE generated.

To find the correct explanations for the lower rate of WEEE collection compared to other European countries, studies conducted in Romania related to the WEEE management investigated both the formal and informal ways of collection and also interviewed the population about their collection habits [23]. A tendency to collect WEEE more and more correctly was also observed in Romania in recent years, especially for people who are informed and concerned about the environmental issues. Unlike inhabitants, companies have proper management of the e-waste because all of them have obligations stipulated by legislation. However, some less informed people continue to get rid of WEEE either by taking them to scrap metal dealers, or less often by putting them together with the municipal solid waste. It seems that this incorrect way of disposing is not common for mobile phones that can also be sold or given in exchange to those who sell them for possible discounts.

In Romania, the Ecotic is a PRO (producer responsibility organization) and in recent years they have had ongoing projects to raise public awareness about the importance of e-waste collection, but also some programs that help the local government or the large EEE retailers to provide e-waste collection points and facilitate the links between these collection points and treatment companies, still insufficient on the Romanian market [40].

The treatment points are mainly used for the recovery of the large quantities of metals, such as those in the large household appliances (LHA) and less often the metals contained in the printed circuit boards (PCBs), where most of the critical metals are found, that are part of the critical raw materials (CRMs) [45].

The recovery of the resources contained in WEEE is partially done in Romania. In some cases, after the pretreatment operation, crushing, and multiple separations of the common metals, the recovery of the metals in shredded WEEE particles is performed completely by Romanian companies specialized in metals recovery if the access to the metals is relatively simple and they can be easily collected by leaching with various chemicals For the formal e-waste collection cycles if the metals cannot be easily separated and require more complex processes, such as hydrometallurgical, pyrometallurgical, or other newer techniques [22,41], whole e-waste or its disassembled parts are exported on the European recycling market for the e-waste. The issues are that another part of the Romanian population does not know how to collect e-waste, the collection infrastructure is not sufficiently visible throughout the country, and the number of the companies accredited to collect and those accredited to treat the e-waste is still insufficient in the country. Under these conditions, many resources and CRM are lost, and by incorrect landfill of the e-waste they become sources of environmental pollution, and those that contain dangerous substances can also affect the health of the people. More accurate e-waste management and well-highlighted and functional collection infrastructure, to which the population has direct access and is aware of its existence would ensure better implementation of the principles of the circular economy for the WEEE in Romania and also in better implementation of sustainable development (e.g., SGD 12, SGD 8).

Most often the metals from the PCBs, when they are collected correctly are not recovered in Romania, they are exported on the European critical metals market from where they will be able to be recovered by the companies authorized to do so, in safe conditions for the environment and the workers in the field.

On the other hand, For the WEEE management, Romania—as well as other countries in Europe and the world—adopted in addition to the principle "polluter pays" also the principle of "extended producer responsibility", EPR, through which the electronics manufacturers were obliged to finance the collection, recycling, proper recovery, and disposal of the WEEE deposited at the collection facilities. Extended producer responsibility (EPR) is defined as an environmental strategy that makes the product manufacturer responsible for the entire product life cycle and in particular for the "takeover", recycling, and final disposal of the product [40].

The Global E-Waste Monitor [3] shows that Europe is the continent with the highest rate of formal e-waste collection and recycling, with more than 42.5% of the e-waste generated. On all the other continents, e-waste documented as formally collected and recycled is substantially lower than e-waste estimated to be generated. However, the targets for WEEE collection are not yet reached in Europe and much less in Romania.

Using the EPR principle, the EU producers are encouraged, through legislation, to support the dismantling of their products and the recovery of the materials through an environmentally friendly product design, i.e., to have a circular approach by investing in innovation and cleaner production. Thus, the application of this principle at the European level brings benefits to both the companies and the environment [46].

For Romania, this would also create new jobs in the green economy, both for the skilled labor and for less-skilled labor, with respect to the safety measures and work ethic, with beneficial impact, both on the social level as well as on the environmental level [4].

3.4. Factors That Influence the Recycling of the E-Waste

The fact that the actors implied in the WEEE value chain have predominant access to the formal WEEE collection system is probably one of the main problems with the incomplete degree of WEEE collection in many regions [40]. The consumer behavior and the financial value of waste influence both the WEEE flows and their proper management. Other factors that may influence the WEEE management are related to the national mechanisms and policies and how they are implemented. Studies and reports on this topic [26,40] show that countries that address WEEE management by involving "all actors"—of the National Coordination Body to PROs, retailers, local authorities, citizens, WEEE treatment companies, etc.—and also using the clearinghouses and setting the obligation to have a higher rate of collection. It was observed that these countries manage to have a better rate of WEEE collection than countries that do not use the same national mechanisms of WEEE collection. Another significant factor that influences WEEE management seems to be their collection and accounting in the metal scraps, and another factor is related to the financial incentives and how they are applied at the national level [26].

More discussions with actors in the field of waste management showed that in the Romanian cities, in the residential areas with single-family homes, the way of collecting waste, including WEEE, is usually the correct one. In the areas with multifamily housing, respectively blocks apartment, the collection of waste depends a lot on the people's awareness about environmental issues, especially since the sanitation companies are often less involved than in the area of the single-family houses in the correct collection, and the local authorities accept partially and tacitly this situation. The sanitation companies motivate their behavior by saying that it is difficult to track and verify who from the apartments in the blocks collects correctly and who does not. However, in recent years, for the WEEE collection have appeared more authorized companies which collects WEEE free of charge for the National Collection System. These collectors help in the proper collection of e-waste, without discriminating between the type of houses, individual or collective.

Often the incorrect collection of WEEE appears in the suburbs of the big cities, in some small towns, or in the villages, where the people are sometimes less informed and less aware about the importance of the proper collection of the e-waste even for their health.

Therefore, in these less informed areas, the awareness-raising of the correct WEEE collection needs to be stepped up, including by making people aware of the resources and also about the hazardous substances contained in the WEEE, so they should not end up being landfilled or to be stored to pollute the environment. Despite the efforts of economic operators and authorities, the e-waste collection target was not achieved for 2014–2018 [20].

More campaigns for public information to raise the awareness of people about where can be found the nearby WEEE collection points, why the separate WEEE collection is important for the environment, but also their health, and the need to reduce the WEEE generation would be necessary. These campaigns should be carried out both in the schools and at the level of the residents' associations in blocks flats, but also in residential areas with the individual housing. Romania's transition to the circular economy involves the development of equitable and sustainable local communities in addition to the operations for resource recovery [47] both in urban and rural areas. Separate campaigns should also be carried out in rural areas, where—although the amounts of WEEE are lower—the lack of information on the correct collection of WEEE is much more serious and can have undesirable consequences.

Beyond better e-waste recycling, the ultimate goal should be the circular economy, with cleaner production and lower consumption and no loss of resources, and smaller material footprints [46].

Results below those expected for the WEEE management seem to be found, also in other European countries. The reasons are common and refer to the lower collection rates than expected rate, difficulties in the manual and mechanical preprocessing and a lack of recycling facilities on the industrial scale, and last but not least to the insufficient incentives compared to the recycling costs of WEEE [48].

The EU producers of EEE are encouraged to support the dismantling of their products and the recovery of the materials through environmentally friendly product design allowing their easy recycling [6,31,49].

Parajuly et al. (2019) [50] show that, in the world in the coming decades, the need for EEE is expected to increase and implicitly the amount of WEEE produced, and this growth will be seen especially in the expanding economies as is the case of the eastern European countries, of which Romania is a part. All this will mean challenges, but also opportunities for all the actors involved, and ensuring sustainable production and consumption for the EEE will require efforts from everyone implied in the electronic products chain. For the policymakers, locally or globally, there is an opportunity to facilitate the transition to a more circular system. Additionally, the level of public awareness will have to be addressed through actions at the political level that have the desired effects, especially as the circular system in the field will come, also, with new jobs created during the electronic products life cycle [50].

4. General Data about ELVs Management in Romania

4.1. Car Production and Acquisition, and ELV Generation in Romania

The European Automobile Manufacturers' Association (ACEA) Guide, published in 2021, shows that 23% of the total cars produced in the world are produced in Europe, and Romania occupies one of the leading places in car production and the number of employees in the automotive industry between countries of the central and eastern Europe [51].

The number of cars registered in Romania in 2019 is shown in Table 4, and the age of the Romanian car fleet is shown in Table 5.

Table 4. Vehicles in use in Romania. Table made by authors with data source from ACEA [52] (data use with copyright permission).

Type of Car	2015	2016	2017	2018	2019
Passenger cars	5,153,182	5,470,578	5,996,377	6,450,750	6,901,236
Light commercial vehicles (up to 3.5 tonnes)	670,119	679,501	720,147	758,037	811,286
Medium and heavy commercial vehicles (over 3.5 tonnes)	239,851	255,297	281,708	288,309	296,489
Buses	21,123	21,946	22,928	23,935	25,364
Total commercial vehicles and buses	931,093	956,744	1,024,783	1,070,281	1,133,139
Total motor vehicles	6,084,275	6,427,322	7,021,160	7,521,031	8,034,375

Table 5. Vehicles in use by age in Romania. Table made by authors with data source from ACEA [52] (data use with copyright permission).

Type of Car	1 Year (2019)	2–5 Years	6–10 Years	>10 Years	Average Age
Passenger cars	120,525	274,864	713,126	5,680,482	16.5
Light commercial vehicles (up to 3.5 tonnes)	12,294	54,147	87,258	657,587	16.3
Medium and heavy commercial vehicles (over 3.5 tonnes)	6089	31,993	39,781	218,626	16.1
Buses	-	2791	4,276	21,088	11.6

It is noted that, although it occupies a leading place in car production in central and eastern Europe, Romania has an outdated fleet of cars, with an average of over 16 years for most categories of the registered vehicles [52].

According to the report of the European Automobile Manufacturers Association (2021), the EU's fleet of cars—including commercial vehicles, trucks, and buses—is on average 11.5 years old. Lithuania, Estonia, and Romania have the oldest fleets, with vehicles older than 16 years, and the newest cars can be found in Luxembourg (6.5 years) and Austria (8.3 years) [52].

According to the type of fuel still used in Europe in 2019, mainly for the trucks, goods vehicles, and buses, the most used fuel is diesel. The cars that use alternative energies represent only 4.6% of the total EU fleet, respectively 0.8% of all cars on European roads are hybrid electric, while all-electric, or plug-in hybrids each represent 0.2% of all cars in circulation in Europe in 2019 [51], but the trend of buying electric cars, especially for traveling inside the city, seems to be ascending. In Romania in 2019 electric cars represent about 1% and are mostly buses [51].

On the other hand, a large number of the old cars in Romania also comes from the large import of used cars and is also reflected in the large number of end-of-life vehicles, respective, ELVs.

In a market that is characterized by a large number of ELVs, such as the Romanian market is, ELVs are one of the most recycled consumer products, especially since their recyclability potential is high [53]. In practice, the machines are disassembled and recovered in pieces. What cannot be recovered is shredded and sorted, and the resulting categories of materials—such as plastic, metal, rubber, textiles, resins, polyurethane foam, etc.—are recycled as resources, reused, or landfilled [53,54].

Automatic disassembly separates all components that have economic value. However, due to the continuous trend towards newer and more reliable machines, such as electric cars, with long warranty periods, medium-term dismantling, will register significant decreases, shows [53].

The automotive industry reports zero waste for many of the car companies around the world because, at present, some of the car companies manage to completely recover the waste they produce. The challenge is not only to recover the waste but also to recycle ELV waste as efficiently as electric cars will gradually replace the traditional cars with fossil fuels. Waste recovery could also mean energy recovery, as opposed to recycling which means the possibility of reusing materials in the same type of application. The general scheme of ELV management in Romania is shown in Figure 4.

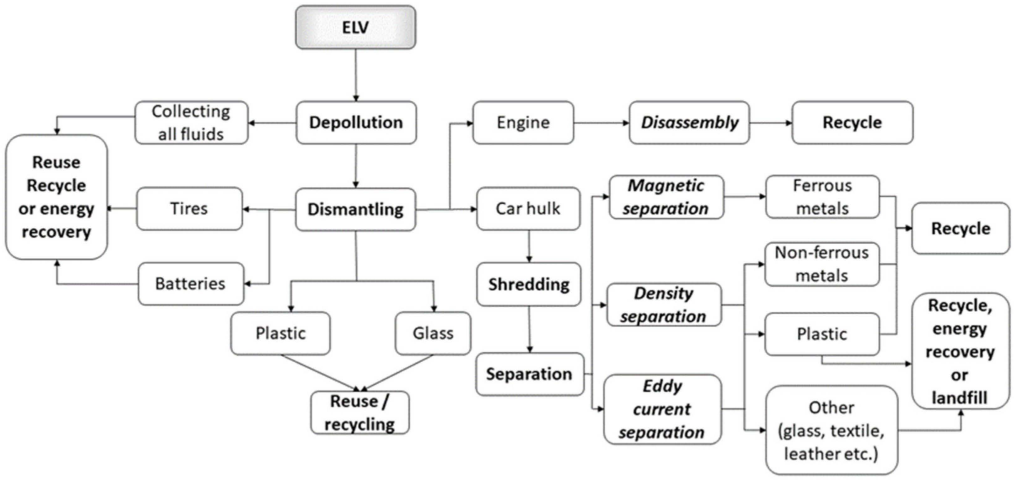

Figure 4. ELV management in Romania. Figure made by authors based on [53,55].

Eurostat shows that the recovery and reuse of the waste produced by ELV in Romania is over 90%, and the recycling of the waste is over 85%, which makes the car industry in Romania one of the industries with a high degree of recycling, as well the car companies in other parts of the world [56]. The car companies largely reuse the waste produced at the end of the life of their cars.

As in the case of the WEEE, the recycling of ELV waste in Romania will have to be done as completely as possible for the electronic components increasingly present in new cars, including new car batteries, for electric or for traditional cars.

According to Statista Portal [57], car production in Romania has a fluctuating period during the last two decades (1998–2019), with a minimum recorded in 2001 at 68,761 and a peak recorded in 2019 at 68,761 cars produced. Additionally, the car industry represents 1% of the total manufacturing industry, and 15.7% is the total employment in the automotive industry which makes Romania the fourth largest car manufacturer in central and eastern Europe [51]. At the same time, cars are the most common mode of land transport in Romania.

In 2019, 92.6% of the total number of passenger kilometers were traveled using either cars or buses and coaches [56]. Annual car sales in Romania in the last 15 years have fluctuated), with a clear increase around 2007, followed by a decrease during the economic crisis (ibid.) [56]. In 2005–2008, a large part of the cars bought in Romania there were used (second hand) cars from the western European market [57]. According to the PwC report (2016), more than half of the national car fleet around 2008 was made up of cars older than 10 years [58]. To reduce the number of old cars in circulation, a renewal program of the fleet was proposed and adopted, the "Rabla" program financed by the Administration of the Environmental Fund [59]. After 2013, car sales started to grow again, with a maximum recorded in 2019. In 2020 the decrease compared to 2019 was due to the pandemic, but the forecasts in a PwC report (2020) [60] are that the car market in Romania will recover faster than in other eastern European countries.

Other vehicles that saw an increase in sales in Romania were the tractors. By 2019, the number of tractors sold in Romania has doubled compared to 2010 [56].

In the study conducted by the company Ernst & Young (EY, 2020) in Romania [61] most of the interviewees people (85%) answered that they prefer the personal car to travel inside the city or around the city. The next preferences were public transport and taxis. For the alternative methods of transport (car sharing, bicycles, scooters), the main aspects that the interviewee's people pay attention to are related to their price and their availability [61].

The EEA (2021) shows that road transport is responsible for 20% of Europe's greenhouse gas emissions, and emissions from vehicle manufacturing should account for 60% of total emissions over the life cycle of vehicles by 2040 [62]. At the same time, the European Automobile Manufacturers Association shows that CO_2 emissions from the car production are declining, as well as the energy and water consumption or the volume of waste produced during car manufacturing processes are declining, including for the electric vehicles, over the last 15 years, 2005–2020 [63].

To reduce the emissions, the European Commission intends to encourage innovation, promote the use of electric cars, ensure the accessibility of the charging infrastructure of these cars, and tax the owners of electric vehicles less [63]. At the same time, the EU is proposing additional taxation for vehicles older than 15 years. The European Motor Vehicle Circular Initiative policy document, ICCT, proposes to revise CO_2 emission performance standards for motor vehicles over the life cycle, in line with the updated EU climate targets [62,63].

In this context, both at the European level and also in Romania in recent years, there has been an increase in the purchase of electric and hybrid vehicles. Starting from here, the challenges come both from the extended lifespan of electric cars and from the need and the possibility to recover as completely as possible the metals, especially the critical metals found in modern vehicles [63].

For ELV management, there are currently value chains in the industry through which the specialized companies provide collection, dismantling, mechanical treatment operations, followed by obtaining metals through various refining processes (electrolytic, hydrometallurgical, etc.). Metals such as Fe, Al, Cu, and some easily accessible precious metals (Au, Ag, etc.) can be recycled properly and functionally [64].

For some rare metals, however, functional recycling is not available yet. These are not precious metals, but they are rare metals and are on the list of critical metals in Europe [65], such as Ga, Ta, or various other metals found in printed circuit boards, PCBs [64]. As mentioned before, the automotive sector generates about 5% of total industrial waste, and the ELVs are an important source of waste worldwide [3], but also a source of hazardous substances and secondary resources [66].

In this context, the right recycling way of the ELV is a necessary option and an important concern for specialists [53]. Statista Portal 2021 predicts that in the EU by 2030 there will be over one million EV batteries for recycling, and this also requires adequate infrastructure [57]. According to Eurostat (2020) in Romania, the rate of reuse/recovery of ELV is 91.2% of the weight of vehicles, and the rate of reuse and recycling of vehicles is 85.1% of the weight of vehicles at the end of their life cycle. For the EU-27, Norway, Iceland,

and the UK, the reuse/recovery rate was 92.9% and the reuse/recycling rate was 87.3%, respectively in the same statistic [56].

In this case, Romania is also, below the recycling rates of the European average, but the percentage of reuse, recovery, recycling is higher than that of electronic waste, as shown by the European statistics (see Table 6). The recycling percentage of ELVs (Table 6) was calculated based on the ratio of recycled used vehicles to the total amount of ELVs generated. Recycling is important for the recovery of resources to maintain them in a circular economy.

Table 6. Management of ELVs in Romania and UE-27 Table made by authors based on Eurostat data [67].

ELVs	2012	2013	2014	2015	2016	2017	2018
Romania							
Generating ELVs (t)	50,732	34,566	38,137	38,851	44,637	48,428	66,319
Recovery and reuse ELVs (t)	43,760	30,207	33,748	35,271	41,116	44,851	61,139
Recycling and reuse ELVs (t)	42,516	28,952	32,063	33,077	37,994	41,181	56,536
Percentage of recycled ELVs (%) *	83.805	83.759	84.073	85.138	85.118	85.036	85.249
UE-27							
Generating ELVs (t)	5,109,000	5,332,000	5,279,000	5,217,000	5,130,000	5,708,000	6,758,000
Recovery and reuse ELVs (t)	4,592,000	4,831,000	4,824,000	4,843,000	4,757,000	5,348,000	6,278,000
Recycling and reuse ELVs (t)	4,320,000	4,547,000	4,510,000	4,537,000	4,467,000	5,016,000	5,898,000
Percentage of recycled ELVs (%) *	84.557	85.278	85.433	86.966	87.076	87.877	87.274

Legend- * the percentage of recycled ELVs is calculated by the authors using the Eurostat database.

4.2. Purchasing Trends for Electric Cars in Europe and Romania

When asked if they would buy an electric car in the future, Romanians were much more receptive than the respondents from the other countries from the central and south-eastern European region regarding the transition towards an electric or a hybrid car. Around 60% of them answered that they would consider this option in case of the good offers, and 25% of the Romanian people are sure that they will buy this type of car soon, compared to the respondents from Hungary (24%), the Czech Republic, Russia (8%) or Turkey (16%) [61]. However, the current preferences of the Romanian people are for the gasoline engines, 35% of them expressing this option, while the preferences for the diesel engines being decreasing, compared to the previous years, less than 19% of Romanian respondents choosing the diesel engines as an option to purchase a new car, in 2020 [61].

Most car companies operating on the Romanian market have made electric or hybrid cars available to buyers. Furthermore, a car company that works in Romania and collaborates with the Ellen McArthur Foundation (EMF) aimed to extend the life of the vehicles and the car's components and reduce the use of natural resources. According to EMF, starting in 2020 the car company aimed to grow sustainably, to create mobility solutions with a negative CO_2 balance by 2030, simultaneously with the generation of new jobs for the people [68]. In the same register, the Romanian car factory launched in 2021 the first electric model of the vehicle intended mainly for the small and medium companies to be used for transport in the intra-urban space.

The electric car charging points are available in Europe on several sites available to consumers and at the same time, the number of public charging stations has increased by 43% and almost 260,000 stations, respectively. In Romania in 2014, there were only 15 recharging points, the number increased to 434 by 2020 [57], and in September 2021 in Romania 614 public charging stations are available (electromaps.com) [69](see the Figure 5).

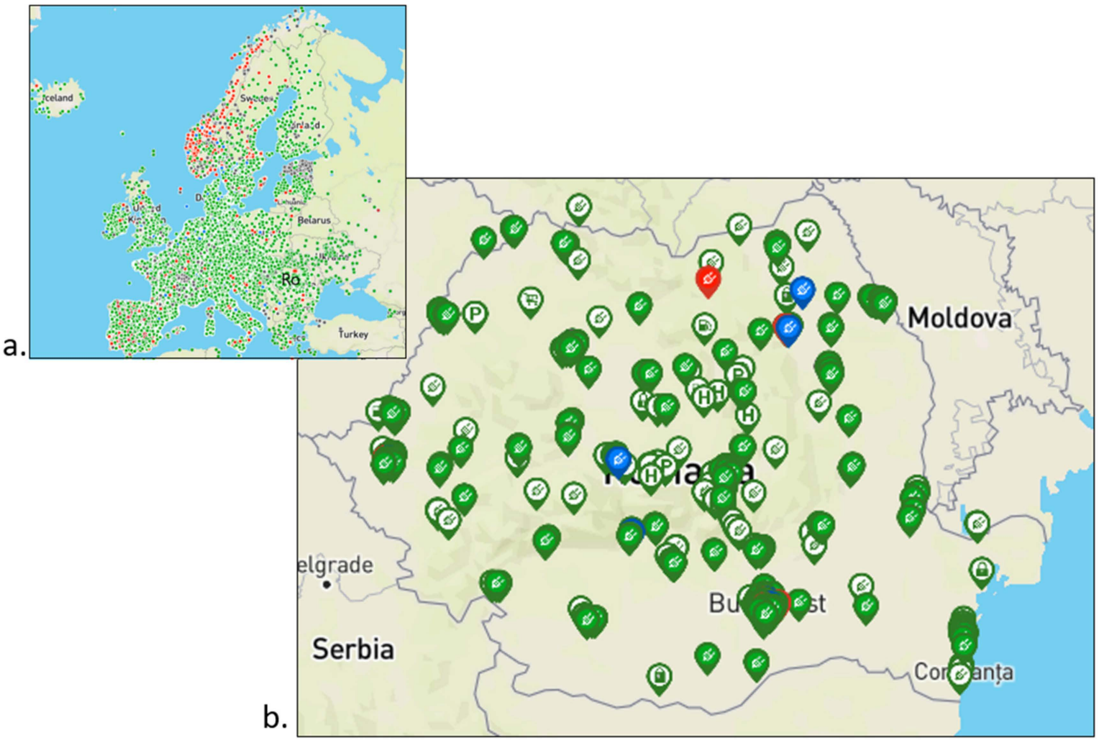

Figure 5. Charging stations for electric cars in cars in (**a**) Europe and in (**b**) Romania (614) in 2021 adapted by authors based on Electromaps [69].

The increase in the number of charging stations was a natural consequence of the higher demand for plug-in hybrid electric vehicles in Romania, double in 2020 compared to the previous year. Thus, the number of electric cars with batteries in the country amounted to over 4000 vehicles starting with 2020, and the total number of electric and hybrid cars in 2020 was about 9000 [57].

The European Environment Agency (EEA) has published provisional data on GHG emissions from new cars and vans registered in Europe in 2020. For cars, the data show a 12% decrease in average carbon dioxide (CO_2) emissions compared to 2019. The average emissions of the vans also decreased slightly, by about 1.5%, in the context in which the purchase of electric vehicles increased from 3.46% in 2019 to 11.41% in 2020 [62].

The European Environmental Agency shows that the financial incentives and taxes set by the countries can encourage consumers to buy cars with lower carbon dioxide (CO_2) emissions, and also that the increase in the electric vehicles in Europe will result in a reduction in both CO_2 emissions, as well as other air pollutants emissions, such as NOx or particulate matter (PM) emissions, with clear climate and environmental benefits. The environmental benefits are already visible in the reduction of urban pollution in northern European countries, where the purchase of electric vehicles is higher than in southern and eastern European countries [62].

The public policies and their application influence not only the mode of consumption and the type of cars purchased by the population of a country or a region but also the recycling rate of the ELV in the region. The results of the study by D'Adamo et al. [2] show that there is usually a good correlation between the generated ELVs and the recycled ELVs, GDP, and purchasing power standard (PPS). Europe can move towards environmental protection practices by applying alternative business models, fostered by the economic opportunities and the circular economy practices that ensure a reduction in both the energy and the materials used in the manufacturing, also in valid strategies for end-of-life recycling, as well as in the development of sustainable supply chains. The economic opportunities resulting from this are also highlighted, but at the same time, the challenges that arise are shown, as well as the social and the economic benefits [2].

The International Council of Clean Transportation (ICCT) report (2020) examines the market trends and the key points on public policies to promote electric vehicle use in several European cities [63]. The purchase and the use of electric cars are widely adopted in the northern European countries, in high percentages, with Norway leading the way with 61% vehicles in Oslo and a lower percentage in southern European countries, for example in Spain, with 1.7% electric vehicles in Madrid [63]. It is clear that in the world the purchases of electric cars will increase and of course, the waste resulting at the end of life (EoL) for an electric car will be different from the EoL waste resulting from the cars with fossil fuels.

Mavropoulos and Nielsen (2020) [70] show that in the coming years the number of electric cars will increase a lot. By 2040 it is estimated that 300–550,000 tons of Li-ion batteries from electric cars will reach the end of their lives [70]. The quantity of the Li-ion batteries is expected to increase progressively, from 100,000 tons in 2025 to over 1.2 million tons in 2030, given that China already produces over 500,000 tons annually [71]. These batteries contain hazardous waste, as Co, Cu, Ni, Pb, substances that in large quantities pose high risks to the health and the environment [72], but which are also raw materials.

London-based Circular Energy Storage (CES) believes that recycling these batteries can be a profitable business, eliminating environmental risks and at the same time recovering large amounts of resources that can be reused to produce batteries. Experts believe that the number of metals in recycled materials will generate an economically viable metals market [71].

4.3. End-of-Life Vehicles and the EPR Principle

End-of-life vehicles (ELV) are vehicles that are no longer useful, either because they are too old or because they are defective or have been damaged as a result of an accident. The first objective of ELV legislation is to prevent the formation of waste and in the subsidiary the recovery and recycling of the waste same as in the hierarchy of waste from the Waste Framework Directive 2008/98/EC [73].

A vehicle is potentially recoverable, in a large proportion, usually, over 95%, and process optimization and raw material recovery is currently possible and also advantageous [74].

The production and the purchase of cars are growing rapidly and at the same time the end-of-life vehicles are following the same trend, the automotive sector is becoming one of the most critical sectors in the world, due to this rapid growth. Thus, end-of-life vehicle (ELV) management is increasingly important for environmental protection, resource conservation, and sustainable development. The actors involved (producers, users, waste treatment facilities) have more and more responsibilities in the ELV management process, ELV management being very important in resource conservation and the circular economy [75].

The ELV Directive is based on the principle of "producer responsibility", which means it aims to hold the economic operators accountable for their product. A central requirement is the free take-over of vehicles, encouraging the last owners to deliver their cars to authorized treatment units [76].

The ELV Directive is based on the principle of "producer responsibility", i.e., it aims to hold economic operators accountable for their products. A central requirement is the free take-over of vehicles, encouraging the last owners to deliver their cars to authorized treatment units. The principle of extended producer responsibility (EPR) works throughout Europe and is considered to be a fair social measure for the management of ELV waste. The allocation of physical, legal, and economic responsibility to producers makes them responsible for the management of the waste produced until the end of the product life cycle, in this case, the motor vehicles. That is why it is assumed that the related costs will be incorporated in the price of the new products and thus manufacturers will invest in design and innovation, will have environmental concerns in the product design, all to make the vehicles as tempting as possible, including in terms of their price. The implementation of the EPR principle has sought to mobilize businesses to find the smartest and most cost-effective solutions without too much government interference [77]. Another major contribution of EPR is that it comes with the requirement for systematic collection and reporting of end-of-life product flows [78].

The circular economy also proposes various recovery operations, recycling of the vehicles at the end of their life cycle, to protect resources, but also important energy savings [65,72].

4.4. The Factors That Influence the Recycling of the ELVs

Zhou et al. (2019) show that the factors influencing ELV recycling involve several actors, in various levels, such as authorities, industrial organizations, and last but not least the people, as the final consumers. The authorities are involved through the regulations they impose related to recycling, the implementation of the EPR principle (in Europe), the public policies to motivate consumers to deliver ELVs to recyclers, and other various subsidies and motivations for the consumers [55].

In Romania, probably one of the first initiatives adopted was the discount received when purchasing a new car battery if the old battery needs to be replaced. In this way, both the population and the companies were encouraged to properly manage the car batteries, even before 2007 because they all prefer to buy the new battery for the car with that discount.

From the perspective of the industrial organizations, they are involved in ELV recycling through their investment in cleaner production and the environmental awareness they have, through the design and the assembly of the products for easy recycling. Other factors are also important as the economic value of the recycling activities, the repair parts and the use of reconditioned parts, the re-manufacturing of the ELV parts when it is possible or the complete car dismantling techniques which help the total recycling. All of these are factors that can improve the degree of the recycling of ELV [55,79,80]. The price of the metals and their existence on the market and the natural reserves of the specific metals are also important factors that influence the availability of companies to recycle ELV, respectively the way and carefulness with which they ensure the recycling of ELV [79].

The distributors and retailers bear part of the informational responsibility of the products, and this applies to vehicles purchased in Romania. They are obliged to take over the products they sell, both in the case of WEEE and in the case of ELV, to continue handing them over to recycling companies.

From the people's point of view, the factors influencing ELV management are aware of the importance of ELV recycling, sustainable recycling requirements and public awareness of the people, the value and the availability of the recyclable materials, the acceptance of using of the reused parts, and the recovered vehicles and the market recognition of the recovered products [55]. On the other hand, the socio-economic characteristics of regions influence the technological level of equipment used in ELVs recycling and recovery operations [81].

In the urban environment at this moment, car traffic is one of the main sources of air pollution. The use of less polluting, long-lived cars and the possibility of a way for resource recovery and recycling, with the production of as little waste as possible are considered important by European citizens concerned with protecting the environment. It is known that the car industry helps to create economic value and the well-being of society in Europe. A less polluting car industry with a high degree of recycling, which also ensures sustainable use of resources is important to be proposed for the future [2].

There are few studies related to ELV management in Romania. The dedicated study made by Rovinaru et al. shows that ELV waste streams in Romania are not always clearly delimited and do not always have correct traceability [53].

They consider the causes of these inaccuracies to be multiple and belong to all the actors involved in the ELV management. There seems to be a lack of communication between the dismantling companies, the waste producers, the waste disposal companies for the ELV, and even with the authorities. The same study shows that the monetary value of parts seems to be the main motivation of companies implied in the car dismantling, and the environmental considerations are not a concern, which is why the parts that do not have a sufficiently high value are frequently sent to the landfills instead of being recycled [71]. Another cause of fewer studies about ELV management could be the costs of hazardous waste management, especially for some older ELVs, costs those recyclers have to bear, and which must be estimated correctly. All this would require investments in the modernization of the dismantling industry in Romania [53].

Stronger involvement of authorities, both central and local, would be welcome, including through more regulations to encourage sustainable recycling flows [47,53]. Probably in this context, a constant environmental education, not only for young people but also by transmitting information to the people to help raise awareness of such approaches would also be valuable. From the point of view of policies and incentives, it is important to grant them to the recycling companies, in conditions of transparency with the verification of ELV traceability.

The automotive sector where exist and operate the repair policies (EC Regulation 595/2009 on the type-approval of motor vehicles and engines) is one of the sectors that easily reuses some waste they produced [82]. Generally, in the remanufacturing activity in Europe, the prominent sectors are the aerospace and the automotive sectors, both representing almost 60% of the jobs in the remanufacturing industry, with a considerable growth potential [83]. Existing studies also indicate the positive effects generated by the wider implementation of the circular economy in the automotive industry having positive effects both in the reuse of the resources and in the result of a large number of new jobs [84].

The circular economy can have an impact on the entire life cycle of products, by promoting sustainable consumption and by ensuring the preservation of the resources in the economy, for as long as possible. For ELVs, for example, disassemblers generally do not disassemble glass, cables, electronic components, or large plastic parts before shredding, as these materials are assessed as they have no economic value [85], and this leads to the material losses that are sent either to incineration or to landfill [5].

High-value materials (e.g., batteries, tires, catalysts) are used for recycling because they have a high economic value, and there already is a market for them. For the future, complete recycling, including glass or other less attractive materials would make ELV recycling more circular. It is also important if the reuse of the parts is done correctly, if they do not require remanufacturing, on a regulated market in order, where the resale is done correctly and could be verified. The large-scale integration of the remanufactured or recycled products into new cars is also encouraged [86]. Providing attractive incentives for innovation related to recyclability and reuse of the components through a proper design could also be of interest [86].

Increasing the number of low-polluting vehicles, together with improving the recyclability of various components of vehicles are important in ensuring a better circularity of the automotive industry and extending the life cycle of vehicles in Europe, and also in Romania or other countries.

5. E-Waste and ELV Management and Circular Economy Perspectives in Romania

The European Parliament emphasizes the importance of moving from the linear economy to the circular economy, underlining the need to create the economic incentives for innovation in circular solutions for Europe [82]. Romania, as a member of the EU, is aware of the importance of the transition to the circular economy and the opportunities that will arise from here.

Various actors in politics, economics, or the social field agree that the circular model brings economic, social, and environmental benefits, also that the circular economy is based on the idea of putting private business in the service of the transition to a sustainable system [87].

In the context in which e-waste is one of the fastest-growing waste streams in Europe at the moment, with an annual growth of about 2 percent [5], and they contain a complex mix of resources [45] and dangerous substances, their recycling becomes very important. Thus, the circular economy also becomes relevant in the context of recycling this waste, in safe conditions for the health of those involved in the recycling process [88].

The circularity of the car system can be achieved in several ways, namely: (i) recovery of resources and closure of material loops; (ii) increasing the service life of the vehicle and its components; (iii) reduced of the net carbon emissions during the entire life cycle of the vehicle; and (iv) efficient use of the vehicle in time and occupancy [87].

The product design plays an important role in promoting the circular economy, as it can help to create jobs through the efficient circularity of the same natural capital, such as WEEE metals or ELV metals. A proper design can help to extend the product life, reduce hibernation time at the product end of life, and to ensure a good quality of material after recycling [89].

A study conducted by Enel and The European House—Ambrosetti (2020) [90] developed a unique and innovative econometric model that measured the stage of the circular economy in European countries (UE-27 and UK), with a focus on three countries: Spain, Italy, and Romania. The study revealed the mixed results in the EU in terms of the circular economy, and for the case of the countries studied in detail, it showed that Italy and Spain have a medium–high level of development, while Romania is at the bottom of the ranking regarding the transition to the circular economy. However, measuring performance over time, over 5 years, the same study showed a significant improvement in indicators on the transition to the circular economy in Romania, compared to Spain and Italy, and that the investments in the circular economy in Romania generated significant increases in productivity per employee (the largest increase in Europe, as 1210–1270 euros per employee) [90].

Romania's National Recovery and Resilience Plan [91] also reveals that in the transition to the circular economy Romania has some deficiencies in implementing a plan to prevent waste generation, the market for the reuse of the waste is currently unsustainable, with a landfill rate of the waste among one of the largest in Europe. Thus, it is important to ensure the waste collection infrastructure that also could ensure a sustainable market for secondary raw materials. The rapid and effective measures in this regard would have a direct impact on the management of the waste, including the electronic waste and end of life vehicles, their repair, and reuse, recovery, and recycling of the resources contained in them, and the reduction of the environmental impact and their impact to the human health [91].

The transition to the circular economy can be, also improved by encouraging investments in eco-innovation, design of the reusable products, with the extended life cycle, use of the alternative energies, the resources efficiency, ensuring the selective collection infrastructure in urban and rural areas [11] and actions to raise the public awareness of the importance of the selective collection of the waste; through the right implementation of the European legislation already adopted, through comprehensive and coordinated measures, both at local and national level, improvements related to the adoption of '3 Rs' for both the public and private sectors [92] and other like these.

The possibility to efficiently collect and recycle WEEE to reduce the environmental impact and recover the resources they contain requires the combined involvement of all the actors involved, namely, producers, retailers, organizations PRO, local authorities, the population which are the end-users of the EEE, all possible collection channels for the full or partial re-use, recycling, and the proper recovery of WEEE [40].

WEEE reuse should be prioritized, raising public awareness of reuse services and the benefits of reuse, highlighting, and correctly reporting reused WEEE are very important. The possibility of repairing WEEE should also be considered as well as the ensuring of the possibility of repairing from the beginning starting from the design phase of EEE (eco-design). Ensuring the reuse centers across Europe and the related network are some examples of useful measures that should be supported [5].

Modern cars also contain an important part of electronic products, including integrated circuit boards. Although collection flows are separate, as are public policies for e-waste and ELVs, they have similarities, both due to the content of similar resources, especially metals and CRM, and the inclusion of a wide range of electronic products in modern cars [55].

E-waste management is linked to many SDGs, such as SDG 3 on health and well-being; SDG 6 on clean water and sanitation; given the high demand for raw materials for the EEE production, e-waste is also closely linked to SDG 8 indicators on decent work and economic growth; SDG 14 on underwater life; SDG 11 sustainable and resilient cities and the rate of the waste collection in cities; SDG 12 responsible consumption and production, material footprint and consumption of the materials. In most cases, relatively general indicators are used to measure progress towards these SDGs. On the other hand, because this waste has on the one hand a hazardous potential and on the other hand a high residual value for the monitoring of e-waste flows, there is a more specific sub-indicator of this waste, as a ratio between generated and recycled e-waste [3].

5.1. Best Initiatives Related to Proper Management of E-Waste and ELVs

In Romania, several programs offer benefits for the proper collection of the waste from the e-waste and ELV categories.

For example, for over a decade now, a program has been working with good results that offer a discount when buying a new car battery, when you replace the old one. This program, however, does not work for the batteries of e-waste, and the collection of these small batteries is not as well ensured around the country as in the case of car batteries.

In the year 2018, to encourage the proper collection of WEEE and a lower environmental impact of them, the Administration of the Environmental Fund (AEF), coordinated by the Romanian Ministry of Environment launched the "e-rabla" program, for replacing the old EEE, with higher energy demand, with newer ones with lower energy consumption. The program offers a voucher that provides discounts on the purchase of new household appliances, of the same type as the one replaced, but with a lower energy consumption [93]. By 2021, the Ministry of Environment has made the "e-rabla" program available—approximately 15 million euros (in Romanian lei)—and this program was estimated to will benefited over 100,000 people [93]. However, the subsequent information provided by the Romanian Administration of the Environmental Fund (AEF) which implemented the "e-scrap" program shows that 43% of the money allocated by the Ministry through vouchers in the "e-rabla" program was returned to the budget, and they will be allocated at a later stage [93]. It would probably be useful to review the conditions for allocating the vouchers for the household appliances, respectively the way the project is implemented by the authorities so that it will be more successful among the people.

Again, the same program is funded by the AEF but the branch for the renewal of the fleet car and called "rabla" is much more successful than "e-rabla". It has been in operation for many years, and it looks that will continue in the next years, also.

More precisely, the "rabla" program for the cars is long-established since 2005 is the main driver for replacing old vehicles with new ones based on economic incentives (vouchers) and to sustain the auto industry in Romania. The positive influence of this program is more significant from 2007 when reuse and recovery target (85%) and reuse and recycling (80%) were fulfilled at the national level for 2007–2011, while in 2010 the number of ELVs collected had a sharp increase in 2010 (197445) compared to previous years [94]. In the period 2005–2016, 553,334 vehicles were scrapped according to the Administration of the Environment Fund (AFM) which supervise this program [95]. To encourage the purchase of the less polluting cars with lower emissions, in the context in which the EU also recommends it, the Romanian Ministry of the Environment created the program "Rabla Plus" which offers a substantial scrapping premium, through the Environmental Fund Administration, for the purchase of the clean and energy-efficient cars [96].

Therefore, two main programs currently operate—"Rabla Clasic" and "Rabla Plus"—which address both individuals and economic agents. Any person with domicile or residence in Romania who owns a car older than 8 years and who has no obligations to the local budget can participate in this program. Old vehicles must have essential parts (engine, wheels, car body, etc.) and be disposed to licensed ELVs operators to receive vouchers. The eco-bonuses (around 300 euros in Romanian lei) are available if new vehicles are less polluting complying with certain parameters in terms of maximum emissions of propulsion systems [93]: (i) 96 g CO_2/km NEDC stipulated in COC (Certificat of Conformity) in mixed mode operation or engine system using compressed natural gas (CNG)/liquefied petroleum gas LPG; (ii) 105 g CO_2/km as stipulated by Worldwide Harmonized Light-Duty Vehicles Test Procedure (WLTP standard) in mixed mode operation or engine system using (CNG)/LPG; and (iii) maximum emission stipulated in COC is 124 g CO_2/km WLTP in mixed mode operation [96]. The Rabla Programme in 2021 started on 23 April and has the following financial incentive features as detailed in Table 7.

Table 7. Key financial incentives for disposing of ELVs and buying new and low polluting vehicles.

Program	Budget for 2021 (Million Euro) [1]	Scrapping Voucher/ Eco-Tickets (Plus) (Euro) [2]	Eco-Bonus (Euro) [3]	Buying New Vehicles
Rabla Clasic	88	1500	300 600	New vehicle (except motorcycles) with NEDED/WLTP emission standards stipulated in COC or engine system using CNG/LPG New vehicle equipped with hybrid propulsion system.
Rabla Plus	80	9000 4000 1100	*	Full electric vehicles hybrid plug-in cars electrical motorcycle

Legend: [1, 2, 3] the budget and the value of the vouchers are given in Romanian lei, but they were approximated in euros, 3 -* no more than 50% of the new vehicle price (Rabla Plus). Table made by the authors with data source from AFM 2021 [96].

Scrapping vouchers and eco-bonuses can be cumulated at 2400 euro (in Romanian lei) if all conditions of the new vehicle are fulfilled. From 2020, Rabla program vouchers for old vehicles can be used to buy new motorcycles and through Plus program is stimulated the transition towards electrical motorcycles. The budget of Rabla Clasic program for individuals was supplemented to 510 million lei and all of it is already reserved as October 2021 [96].

Table 8 shows some key performances indicators related to Rabla program as of 14 October 2021. This program stimulates the transition towards hybrid and electrical vehicles (cars and motorcycles) in Romania. This trend must be supported by the development of specific infrastructure (electrical charging points) across cities and main roads.

However, the transition to electric cars is not sufficient in terms of reducing GHG emissions without proper investments into green energy sources [97]. Improvement of the road network and safety is another key societal issue to be addressed in the following years [98] to reduce car accidents in Romania [99].

Another initiative aimed at reducing emissions due to transport is the car-sharing initiative that has been operating for several years in three of the cities of Romania, Bucharest, Cluj, Constanta and extends now also to Brasov. The car sharing platform is a service and an application that helps the use of a vehicle by members of a community in the area where the service is available and usually works according to the free-floating system, ie the car can be taken from any point and parked at any point in the area where the car-sharing operator operates [100]. Many car-sharing operators have low-pollution vehicles, usually hybrid or full electric.

Table 8. Rabla Classic and Plus indicators as of 13 October 2021.

	Persons	New Vehicles	New Motor-cycles	Economic Agents	New Vehicles	New Motor-cycles
Rabla Clasic	51,939	35,890	305	3450	1973	2
Rabla Plus	7365	2023 of which: 1228 (electrical) 795 (hybrid electrical)	8 (electrical)	2468	1296 792 (electrical) 504 (hybrid electrical)	2 (electrical)

Table made by authors with data source from AFM [96].

In general, the formal collection system of ELVs is better organized and easier to track, than the e-waste collection system. E-waste has a greater variety than ELVs, which have more varied dimensions and mass but are also used in many areas of activity, not just for transportation [79].

Although, in the e-waste collection system it seems that the public authorities do not have successful programs, these programs also exist in Romania implemented either by NGOs (e.g., RoRec association) or by PROs (e.g., Ecotic), various projects that have worked and continue to operate in Romania.

The Ecotic Organization is the first PRO in Romania founded in 2006 and since then it has carried out numerous projects in the country focused on education and awareness of the population at the local or national level, proposes contests, and offers prizes to the young people involved in proper e-waste management, visits localities and schools, including in the rural areas. Their work focuses on raising awareness of the importance of e-waste collection and the environmental and health impact of e-waste [101]. Ecotic has many collection points throughout the country in cities and towns (928 at the national level and 15 streets collection points in Bucharest) and is also an online platform that can be easily accessed from anywhere in Romania. Introduced the green stamp in Romania for the first time in 2007 [20,101].

The RoRec Association has developed the Local Collection Service, an online platform through partner local operators that offer the population the opportunity to get rid of e-waste correctly and easily, regardless of the county where they live [102]. The only impediment is that the population knows about the existence of the online platform and can access it.

The "Recycling Tram" initiative belongs to the Iasi Municipal Waste Collection Center. It started in April 2021 and continues every weekend (see Figure 6). The purpose is to pick up e-waste from tram stations and transport it to the collection centers in the city. The initiative is one in which the local authorities are also involved and given the continuity it helps to raise people's awareness of the importance of e-waste collection in a safe system for the environment and the population [103].

In this particular case, environmental awareness links the material recycling of e-waste (urban mining) and sustainable transport to improve environmental quality in the city.

The "Workshops without Borders" (in Romanian "Ateliere Fara Frontiere", AFF) is another NGO that initiated the Educlick program which collects e-waste, refurbishes computers, and donates them to schools and children in communities marginalized from less developed areas of Romania [104]. This is a social entrepreneurship initiative of the NGO.

Figure 6. Recycling tram in Iasi city 2021—operating on weekends on several key stations (Photo FCM on 10 October 2021).

AFF is supported by over 500 companies, organizations, and institutions from Romania. The e-waste items collected are further processed by a socio-professional workshop (reconnect) as part of the AFF organization. The e-waste items are dismantled and recycled and IT types of equipment are refurbished for reuse in schools. The social dimension is a core value of this program besides the circular economy approach. Thus, vulnerable and marginalized individuals work in Reconnect workshop gaining necessary skills, social and moral support to be later integrated into the labor market. In 2021, over 2000 refurbished computers were donated to 122 schools, social institutions, and non-profit organizations from 35 counties received in the last 6 months [105]. The COVID-19 pandemic forced the education process to an online format, increasing demand for IT types of equipment. Therefore, pupils of vulnerable families are further exposed to poor educational processes due to a lack of digital tools.

In 2020, this organization donated 2150 computers helping 5504 pupils and teachers to be connected to online school while 159 t of e-waste were collected of which 125 t recycled and 39 t were reused [106]. Furthermore, the Edu-click project donated 17,000 computers to schools and social organizations and inserted 110 vulnerable individuals on the labor market in 12 years of activity [107]. This program is a model of integrating circular and social economy principles in a country like Romania where poverty and marginalized communities are key societal issues to be addressed besides environmental concerns. Rural population access to digital infrastructure is still limited in some counties as well as for basic public utilities [47]. The social dimension must not be neglected in circular economy policies [108] and such activities must be further supported in other regions

Although there are more and more initiatives and programs in Romania aimed at the correct recycling of e-waste and ELV, the country is also facing illegal actions, including illegal imports of old cars and malfunctioning e-waste which are then incorrectly managed and often they end up improperly landfilled in the environment (see the Figure 7).

Figure 7. Illegal dumping of ELVs parts on Bahlui floodplain (Hoboca, commune, Iasi County) on 1 April 2021 (Photo: FCM).

Vulnerable individuals facing social exclusion and extreme poverty issues are often at the frontline of e-waste dismantling activities. Children exploitation is a disturbing phenomenon on an international scale [109]. International trade of second-hand electronics or e-waste items feeds such criminal networks with raw material for further processing. Rudimentary recovery practices pose serious environmental and public health issues in developing countries and the informal sector is in the frontline [110]. Vulnerable communities such as Roma should be integrated into environmental policies through social entrepreneurship in central and eastern Europe [111].

The informal groups of recyclers often use primitive and polluting techniques. Outdoor burning is the most polluting and is most often used by some of the informal e-waste recyclers [112]. In Romania, the cables are most often burned outdoor [110] for Cu and Al recovery. These activities result in organic pollutants, such as polychlorinated biphenyls, PCBs, or polybrominated dibenzo-p-dioxins/dibenzofurans-PCBB/F [112]. There are no known or reported activities involving the leaching of metals from e-waste by the informal sector, as in the case of the Chinese region of Guiyu [112].

Environmental and customs authorities are overwhelmed by the international trade magnitude of waste at Romanian borders. One key route is to develop real-time waste databases to follow the flow of such waste from source generation to the collection, treatment, and recycling operations involving all stakeholders in the process (local authorities, waste operators, waste brokers, recycling companies, and industrial actors) with the supervision of environmental authorities and NGOs. EU and national authorities must cooperate to address the problems associated with the mismanagement of e-waste, illegal shipments, and other criminal activities [113].

5.2. Assessing the Potential for the New Jobs Implied in Various Stages of the Recycling of WEEE and ELVs in Romania

In Romania, there are currently several companies for collecting and managing e-waste. On the European WEEELABEX website, there are only four companies with WEEELABEX certification from Romania that can treat e-waste. WEEELABEX certification is the new European standard, available since 2015. The WEEELABEX standard provides uniform rules for all stages of e-waste management. The purpose of WEEELABEX certification is to determine whether e-waste processing companies meet the minimum required level of recycling [42].

The website of the Romanian Ministry of Environment presents a list of 18 licensed companies and one in the licensing procedure [43], unlike in 2017 when according to the study made by Ibanescu et al. there were only seven companies licensed by the Ministry of Environment [20]. These licensed companies are, generally, organizations of the responsibility transfer (ORT), but also companies that can treat e-waste. The RTO is, according to the Romanian legislation, the organizations that can take over the responsibility of registering the EEE producers, making the annual reports for the authorities, financing the collection, treatment, and recycling of the e-waste for the companies who want to transfer these obligations required by law.

The collecting companies take care especially of the collection of e-waste produced by other companies or from the public institutions, respectively the business to business, B2B system [26]. E-waste produced by the population (respectively the business to consumer system, B2C [26]), is not as well monitored or collected, and this waste represents a significant part of the e-waste produced. To collect properly of e-waste, the population must be properly informed, both about the benefits for the environment and the protection of resources, as well as the possible damage to their health, in case of incorrect storage and incorrect collection of the e-waste. Taking into account the e-waste produced by the population have already shown an increasing trend which is expected to continue in the coming years [22], their collection and also their inclusion in a formal recovery system, with care for the environment and human health being very important.

In addition to these ORT for the treatment and collection of the e-waste, in Romania, there are also 1676 companies for batteries collection, including the industrial batteries and the car batteries distributed throughout the country. Six of these companies can also treat the batteries and accumulators [44].

For the collection and treatment of the end-of-life vehicles on the website of the National Environmental Protection Agency, there is a list of 772 economic operators in Romania, distributed in each county [114].

The process of e-waste recovery consists of several stages that each have their role. It begins with the collection stage, followed by a physical pre-treatment phase and then the recovery phase of as many resources as possible by various methods [115]. The collection infrastructure is important and hazardous materials must be collected separately, according to the specific requirements of each of them [116]. Due to the great diversity of materials and the existence of various technical solutions, there are different technical solutions for the pre-treatment of e-waste [115]. For example, Ardente et al. (2014) show that if comparing the operation of pre-treating TVs by mechanical shredding and by manual disassembly, the manual disassembly allows a resource recovery rate of over 90%, while the mechanical shredding allows the recovery of less than 10% of precious metals contained in these [117]. Vanegas et al. (2018) also show that mechanical crushing plays an important role in the quick and easy recovery of certain materials such as steel and aluminum, but it has poor performance in recovering precious metals and critical metals that are found in small quantities, and which by the mechanical shredding can be easily lost [118]. Moreover, many e-wastes contain various miscellaneous materials that require separation before the product can be efficiently recycled. The summary of the manual dismantling process is shown in Table 9.

On the other hand, several studies show that parameters—such as the amount of production, processing times, and the amount of WEEE to be processed—do not significantly influence the total cost of processing, but influence the total profit of the resource recovery, reason for which the processes must be analyzed correctly and from many points of view. It is also important to identify the best and the worst design practices in terms of disassembly [115,119].

The proper collection of the e-waste from the population, not only from the companies and public institutions, and then separation and pre-treatment are important steps in recovering the resources contained in e-waste, but also in creating new jobs in the green economy [4,118,120]. The conforming treatment of WEEE requires attention to health and safety conditions, material separation, and selective treatments that are preferred to be done manually to ensure the recycling targets. Pre-treatment of the e-waste has to begin with the removal of all fluids and hazardous substances [4].

The WEEE Recycling Economics report underlying that a European compliant recycler, respectively meeting of the technical requirements and the additional costs in the preparations for audit or reporting, etc. involves substantially higher costs than for a non-compliant recycler [4,14].

Taking into account that the requirements of the Directive 2012/19/EU require for Romania to collect beginning to 2021, 65% of EEE POM annual average of three preceding years or 85% of WEEE generated this means that the amount of the e-waste collected will increase and their proper treatment is necessary to a better recovery of the resources through reuse and recycling [31]. After the year 2019, classification of the e-waste is done in six categories, instead of 10 categories as before. The collection will be done by the categories, by weight, by the resources contained, and by the hazardous waste contained in the e-waste that has to be managed safely.

After the disassembly of the e-waste, some components can be sent for reuse and others will be sent for various recycling and material recovery processes. Reusing components, especially in the case of computers and other equipment in the ICT sector, helps to avoid unnecessary costs and has environmental benefits. The market for reused equipment is growing, the main barriers are the limited supply of ICT equipment and consumer perception. Gåvertsson (2020) proposes a label for reused products to increase consumer confidence in the quality of remanufactured equipment and shows that a remanufactured computer of superior quality is better than a new and cheap computer, and its manufacturers often give a one-year warranty [121].

Table 9. Summary about manual dismantling, main components of some e-waste, and mass required for a full-time job equivalent.

Type of E-waste	Main Components/ Manual Dismantling Steps	Mass Required for a Full-Time Job Equivalent
Washing machine and other LHA	- Motor, metal shell, and plastic top [4] - tub, drain hose, wires, salt waste [122]	1692 tonnes washing machine or 1967 of LHA [4]
Cooling equipment, including freezer	Collecting CFC with a pump; Remove the motor, the metal shell and plastic interior, and glass/plastic shelving [123] Tubes, liners, condenser, wires, refrigerant [122]	13,407 * tonnes of fridges [4]
ICT and consumer equipment	Manually dismantled into fractions such as PCBs, plastics, ferrous and non-ferrous metals, glass, and PVC cabling using pneumatic screw drivers, drills, grinders, and hammers [123]	476 tonnes of CRTs displays [4] 338 tonnes of LCD/LED displays [4]
TVs and screens	Dismantling of Casings/external frames/support External cables Extraction of valuable parts: - PCBs - Ferrous/non- ferrous parts - PMMA board and plastic foils - Internal cables - Dismantling of potentially hazardous parts: - Fluorescent lamps - LCD-capacitor - Residual parts: - speakers and fans - fasteners - minor plastic part - minor metal parts [117] - LEDs and LCDs are treated separately from CRT televisions [4];	
Mixed waste (often small house appliances)	Manually sorted; Removing pieces unsuitable for the subsequent mechanized process such as cables, glass, and products containing batteries [4].	362–453 tonnes [4]

Legend: * The quantity of the refrigerators for one full-time job equivalent is not calculated for the dismantling, but only for palletizing and sending the fridges for disassembly to another company. The company that dismantles the refrigerators must be able to collect all the fluids and hazardous substances from them before dismantling them.

Reusing is accepted and promoted by the circular economy. When the equipment cannot be reused, it is also proposed to recover the resources from this equipment in the highest possible percentage.

Once the e-waste is disassembled, the metals and other resources contained in them are more easily recycled. From the PCBs manually disassembled, metals are recovered more efficiently than from the mechanically crushed pieces, where there are losses [117,118].

Metals found in large quantities, generally ferrous metals or copper and aluminum, are also recycled in Romania. PCBs and the metals they contain, however, most often end up on the European or international metal market, where they are bought for recycling.

In Romania, several experienced companies also recover critical metals, especially metals from the platinum group metals (iridium, platinum, palladium, rhodium, ruthenium) [45] and the precious metal after the manual dismantling of ICTs waste. These companies usually use simple chemical methods of solvent leaching and work on a small scale. Most metals are recovered, as mentioned before, after the export of either disassembled materials or e-waste to the international recovery market.

In Romania, some companies collect and can disassemble refrigerators, because they have the necessary technology to collect the refrigerants, oils and in general, the dangerous substances contained in them (Hg, Cd, Pb, Sb) [124].

Several studies highlight the importance of dismantling before shredding. The removal of the glass, metal components containing Cu, Al, and Mg, removal of the tires and the large plastic components—such as bumpers, dashboards, fluid containers—so that they can be recycled and so the materials have a lower environmental impact than the impact of ELV shredding and also are in line with the new European requirements on the material recycling [125,126]. All fluids that are still contained in the ELVs are removed from the vehicles before the treatment and also the engine, batteries, and other hazardous parts [126].

Anderson et al. (2019) also highlights the importance of dismantling skills in the stages of WEEE and ELV treatment, showing that, thus, in the subsequent stages, the use of physical capital is intensified. From older vehicles, the main resources are Fe and Al.

Although there are PCBs, metals in smaller quantities are often lost in regular refining and most often end up in slag [79,127]. New, modern cars, however, contain electronic control units and other electronic parts with metal content and CRM. Cullbrand and Magnusson (2011) mapped 31 main materials in four different cars of the same manufacturer as follows, one hybrid car and the other, cars with conventional fuels of different sizes, medium, small, and large. Most of the analyzed materials were found in electronic and electrical applications. The highest total mass for all determined materials was found in the hybrid machine, the second largest in the conventional medium-sized machine with high specifications, the third-largest mass in the small conventional machine, and the smallest mass in the larger conventional machine with medium specifications [128]. For the electric cars, there is a substantial increase in the use of some metals such as Al, Ag, Cu, Nd, and Dy and for the battery Li and Co, and substantial reductions in the use of other materials such as Fe, La, Pd, Pt, and Rh [129]. Various ways of the plastic recycling contained by the ELVs are also being tried with increasing success, so that the waste sent to the incineration be less, and also the environmental impact of ELV be reduced [130].

In Romania at the moment, the vehicles are not disassembled, most often they are crushed, and then the metals of type Fe, Cu, and Al are recovered. With the appearance of the Romanian market of hybrid or all-electric cars, which starts with the year 2021 began to visibly increase, the management of ELVs must be rethought, and the disassembly before the shredding will have to be considered for a better recovery of the resources.

Figure 8 shows how the recycling of the various components is more efficient in the case of the manual disassembly of ELVs than in the case of the mechanical crushing [125]. Similar to e-waste treatment, some new jobs are emerging in the green economy, and better resource recovery will reduce, also the environmental impact.

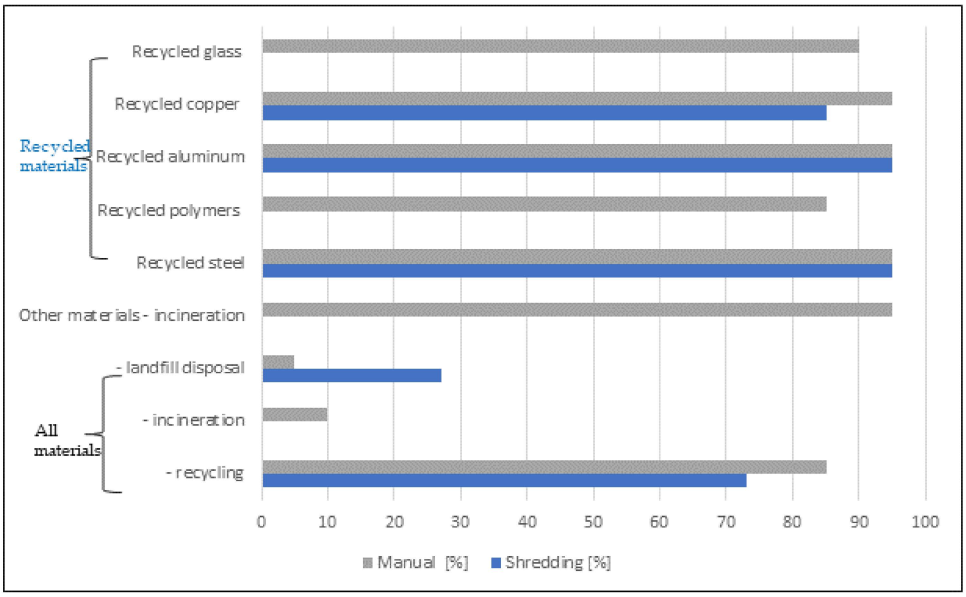

Figure 8. Material recovery rates from ELVs in two scenarios, shredding and manual dismantling, adapted after [125].

So far, no other materials are being recovered from ELVs, namely those contained in PCBs. Taking into account the European requirements to better resources recovery [5] and the fact that in the electric or hybrid cars the content of the critical metals is richer [128,129], in the following years the recovery rate of these metals will increase and the disassembly steps performed before the mechanical shredding will become more used.

5.3. Recycling and Recovery Performances of E-Waste and ELVs Flows

The principles of the circular economy fit well with the two streams of waste studied in this paper, the e-waste and the ELV because they both contain critical raw materials that need to be kept in the economic circuit. Additionally, a large part of the materials contained in these two waste streams are metals, and metals are usually stable materials over time that do not lose their properties through successive uses or recycling. The metals can be melted and re-melted an indefinite number of times and except for some possible losses in the production process, which are intended to be as small as possible for obvious economic reasons, they do not change their composition or structure and can be used on the same purpose for which they were also used initially.

Romania still has stages to go for the complete collection of the two studied waste streams, especially for e-waste, because the accessed statistical data showed that there are higher losses in the collection process for e-waste.

Table 10 shows that the collection targets for the years 2017 (65.15% of the collection target) and 2018 (70.05% of the collection target) have not been met, and from the older data it is known that the collection targets were not reached either in the years before 2017 [20,131]. The targets for 2017 and 2018 required the collection of 45% of the EEE-POM annual average of three preceding years. By 2021 the collection target according to European requirements increased to 65% of the EEE-POM annual average of three preceding years or 85% of the e-waste generated (Figure 2). On the other hand, it seems that several collection companies have appeared on the Romanian market compared to their number in previous years, and some of them have WEEELABEX authorization, which is a confirmation of the interest of these companies for e-waste recycling.

Table 10. Percentage in which the e-waste collection target was achieved in Romania (years 2017 and 2018) was calculated by the authors according to the information of N.E.P.A.

	45% EEE-POM Average 2014–2016 (t)	Percentage Achieved of 2017 Collected Target	45% EEE-POM Average 2015–2017 (t)	Percentage Achieved of 2018 Collected Target
1. Large household appliances	47,686.36	65.37%	56,040.75	63.80%
2. Small household appliances	6203.752	21.00%	7403.936	22.05%
3. IT and telecommunications equipment	6015.218	109.24%	6289.785	148.84%
4. Consumer equipment and photovoltaic panels	37,323.43	17.53%	10,181.68	95.26%
5. Lighting equipment	2760.531	72.54%	3320.541	95.52%
6. Electrical and electronic tools	4273.545	21.13%	5819.009	20.73%
7. Toys, leisure, and sports equipment	714.978	11.66%	1088.539	8.38%
8. Medical devices	244.9905	27.48%	319.2137	35.76%
9. Monitoring and control instruments	844.608	82.89%	1205.378	171.38%
10. Automatic dispensers	357.7395	94.42%	469.1588	144.61%
Total	**76,267.7**	**65.15%**	**91,036.29**	**70.05%**

In Romania, at present, the market dictates what kind of metals are collected from the e-waste, because it is preferred to collect the metals with high market price, which are generally found in the PCBs, hard disks, or some magnets [132]. For the metals that do not have a high price on the international market, recycling is possible, eventually, when large enough quantities of the e-waste are available to allow the extraction of sufficient quantities of metal to be recovered; it is about the e-waste from the categories of large equipment (mainly various types of washing machines) or the temperature exchange equipment (mainly refrigerators) that contain sufficient quantities of the ferrous metals, but also copper that can be collected and then recovered.

Table 10 also shows that the collection rate of the equipment in the category "IT and telecommunication equipment" range exceeds the required value for both the years 2017 and 2018.

In the case of the equipment in the LHA category, the surveys conducted in Romania have shown that the tendency of the population to use this type of equipment in the households, usually more years and often as long as they are functional, especially if their consumption of energy is not intensive [23,37]. For this reason, for the equipment of this type in the case of Romania, the calculation based on the EEE-POM average of the previous three years should be re-evaluated. Related to other types of e-waste, the collection should be improved through the awareness-raising actions of the people and the education of the children and young people starting from kindergarten and school in various ways, specific for each age.

Related to the collection of e-waste in Romania is also important to observe the way of collecting e-waste, formal and correct or informal and not always correct (see Figure 3). Often the e-waste collected informally ends up in the recycling of scrap metal, and all the rest of the material is lost through landfills.

In Europe and around the world, some research groups are also trying to recycle the plastics from the e-waste, including those containing flame retardants [130,133]. In Romania, there is currently no recycling of plastic from the e-waste, except for authorized WEEELABEX companies that must ensure that the plastic, as well as all other resources, contain in the e-waste, reach a company from Romania or from abroad that recycles or treats them.

In the case of the ELVs due to the low content of salable materials on the market, neither in Romania nor, often in other countries, metals and CRM in small quantities from the electronic components of cars are not extracted separately because it does not seem to be economically profitable. However, batteries are collected separately, and those for electric or hybrid cars are also economically feasible [132].

In Romania, the electric and hybrid vehicles started to be purchased only recently, respectively, most of them after the year 2019, both, due to the voucher offered by the Romanian Administration of the Environmental Fund (AEF), and also due to the trends on the European vehicle market to use less polluting cars. Some of the first electric vehicles bought were a few buses in several cities in Romania [52]. Therefore, in Romania, these vehicles have been purchased too recently to have become waste, and Romania has not yet faced the need to recycle them.

D'Adamo et al. (2019) and Andresson et al. (2019) used three parameters to predict ELVs generated and recycled in Europe [2,79]. Similarly, in this paper, these three variables were analyzed for Romania to observe the possible dependencies between the generated and recycled ELVs and GDP PPS and the number of the population of the country, using historical data from 2012–2018, available on Eurostat (see the Tables 6 and 11 and the Figures 9 and 10).

Table 6 shows that the percentage of the recycled ELVs from the generated ELVs in Romania is between 83,759% (2012) and 85,249% (2018) and has a predominantly increasing trend throughout the studied period.

Romania's population has had a visibly decreasing trend in recent years and the trend will probably not change in the coming years, but the gross domestic product in terms of the purchasing power standard has an increasing trend, which makes us estimate that it will also be increasing. the acquisition of electronic products, respectively the generation of electronic waste in Romania (Eurostat, 2021).

Table 11. Correlation coefficients between GDP-PPS and population number and generation, respectively recycling of ELVs in Romania and EU-27.

	Correlation Factor with GDP PPS	Correlation Factor with Population
Generating ELVs in Romania	0.703	−0.650
Recycling ELVs in Romania	0.720	−0.671
Generating ELVs in UE-27	0.771	0.660
Recycling ELVs in UE-27	0.834	0.730

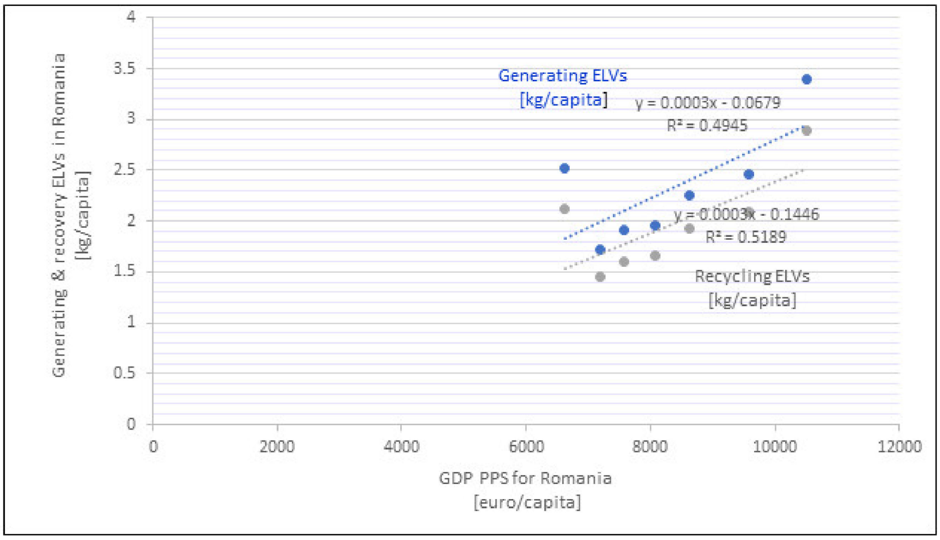

Figure 9. Correlation between ELVs generating and recycling in Romania during 2012–2018 and GDP PP in the same period.

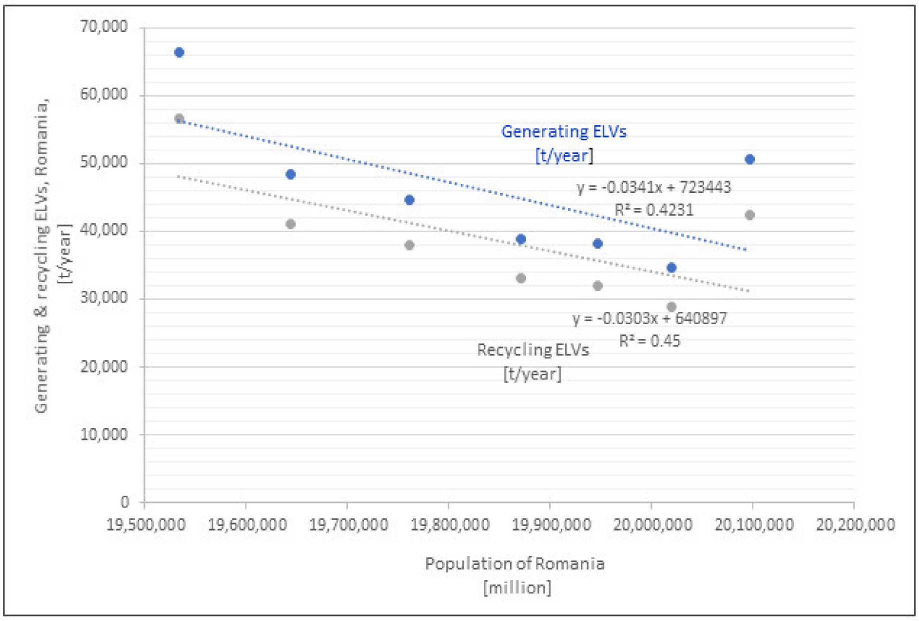

Figure 10. Correlation between ELVs generating and recycling in Romania during 2012–2018 and the population in the same period.

Table 11 shows the correlations between the GDP PPS and the population and trends in the generation and recycling of ELVs in Romania and EU-27. The data were extracted from the Eurostat database, and the calculation was made according to the formula

$$r = \frac{\Sigma(x - \ x\ )(y - \ y\ )}{\sqrt{\Sigma(x-\overline{x})^2 \cdot \Sigma(y-\overline{y})^2}} \tag{1}$$

The correlation between GDP-PPS and the generation, respectively the recycling of the ELVs is, as we expected, a direct and positive correlation. At the same time, there is an inverse, predictable correlation between the number of the population and the ELVs generated and recycled, when the number of the population is decreasing in Romania, and the generation and recycling of the ELVs has an increasing trend.

As it can be seen from Table 11, the percentage in which Romania generates and recycles ELVs is close to the European percentage, in terms of correlation with GDP PPS. However, the population trend in Romania is not as predictable, although it continues to decrease.

The GDP PPS growth in the case of Romania was 5.8% per year on average for the period 2010–2020. Considering the same increase for the next decade and using the calculation formulas ($y = 0.0003x - 0.0679$) for generated ELVs, respectively ($y = 0.0003x - 0.1446$), (see Figure 7) for ELVs correlated with GDP PPS, according to the model of D'Adamo et al. (2020) [2], as the future projection for 2030, Romania will generate an average of 5.92 kg per capita of ELV waste and will recycle 5.84 kg per capita

It should also be noted that at the moment, manual dismantling is a good solution for pre-treating many of the e-waste and ELVs because it ensures a better recovery of the resources. This comes with some disadvantages, because the time for dismantling increases, but the number of new jobs in this field that can be paid from the resources recycling can partially counteract this disadvantage. The machines that disassemble automatically, do it by shredding, and for resources in small amounts in the waste stream, this means many losses. Automatic disassembly without losses can only be done with some highly specialized machines, and thinking about a large number of the types of e-waste, this is not feasible at this time.

In addition to jobs in the e-waste and ELVs dismantling, the PROs and NGOs have projects to help raise people's awareness of the importance of properly collecting e-waste and ELVs. For example, they set out to make available to the large retailer networks in Romania the collection containers to collect the e-waste by the category. The PRO Ecotic, also wants to propose to the local authorities to organize some well-established collection points of the e-waste and to inform the public about these collection points and the environmental impact and health impact of the e-waste improper management.

6. Knowledge Gaps and Future Research Perspectives

E-waste and ELVs statistical data are centralized at the national level by National Environmental Protection Agency but the data provided in annual environmental reports provide a general situation without looking into details regarding regional disparities and inequalities in population access to e-waste collection and treatment facilities. The regional e-waste and ELVs statistics are centralized by regional environmental protection agencies. However, there is poor monitoring of regional interconnections between e-waste and ELVs flows. The e-waste amounts collected and treated in one county could include e-waste items collected from another county [108]. The same situation could happen in the case of the number and weight of ELVs collected and treated. Therefore, the comparability of e-waste and ELVs flow within development regions (Nomenclature of Territorial Units for Statistics—NUTS2) or county levels (NUTS3) is difficult to examine [58]. Furthermore, the lack of waste statistics data at municipality levels (urban and rural municipalities) leads to serious knowledge gaps regarding e-waste and ELVs flows at the national and local levels. Therefore, the traceability of these special waste streams must be improved in a multi-scale context (local-regional-national-EU) to properly examine the circular economy activities. Additionally, open data and mapping waste streams through GIS tools supported by open science would further enhance the related research topics for academics, professionals, and NGOs engaging in citizen-science projects [134].

Studies related to e-waste and ELVs generation rates and composition based on experimental studies are needed in a diverse range of cities (from larger to medium and small towns) combined with circular performance assessment of various stakeholders (recycling companies, waste operators, industrial facilities, PROs, SMEs). Rural municipalities must be also investigated at least in case of domestic e-waste flow. The role of illegal waste trade activities and assessment of informal recovery and recycling practices magnitude at local and regional levels are required. Therefore, key topics should be further investigated:

- ➢ Cause, distribution, and magnitude of illegal e-waste and ELVs management practices and environmental impact assessment;
- ➢ The scale of criminal networks in dismantling of ELVs and e-waste items in Romania and role of international trade;
- ➢ Role of the informal sector in circular mechanism related to e-waste and ELVs in Romania;
- ➢ Case studies about urban mining as a sustainable development route for smart cities;
- ➢ Factors and policy incentives that facilitate reuse, repair, refurbish, resource recovery practices of e-waste, and ELV waste streams by formal sector;
- ➢ Assessment of EPR policies in e-waste and ELV sectors under circular economy framework;
- ➢ Expanding best practices identified at micro-level (business, NGOs) to local and regional levels, including social dimensions beside circular economy principles;
- ➢ Mapping e-waste and ELVs flow at the micro (organization level) and regional levels (urban/rural municipalities, counties, development regions);
- ➢ Stimulating pro-environmental behaviors of people and supporting citizen-science actions related to circular economy mechanisms;
- ➢ Better involvement of local and central authorities as necessary actors in the process of correct e-waste management, through coherent public policies;
- ➢ Raising public awareness of the dangerous nature of e-waste on health and the environment;
- ➢ Improving e-waste collection networks in rural areas and small towns;
- ➢ Stimulating research in the area of e-waste management, resource recovery, e-waste design, extended long life of e-waste, etc.

7. Conclusions

Romania is still a landfill-based country where linear economy practices prevail in the waste management sector. Romania is facing the EU Court of Justice because of the problems related to non-compliant landfills [135]. E-waste and ELVs are two key waste streams that could catalyze Romania's efforts in the transition towards a circular society. Despite the recent improvements of waste management infrastructure, the e-waste and ELV sectors need further attention in waste stream diversion from landfills and preventing environmental pollution through open burning or illegal dumping practices for e-waste/ELVs items with a less economic value on the recycling market. This review highlights a complex picture of the Romanian systems of e-waste and ELVs management. Formal infrastructure development to every county combined with a proper monitoring system of waste flows is critical to improving CRM materials in future closed-loop economic activities.

On the other side, this work points out successful programs such as "Rabla" in replacing old vehicles with new and less polluting cars/motorcycles as the main driver in achieving recycling/recovery targets for ELVs and stimulating the purchasing trend of hybrid and electrical cars in Romania. Furthermore, innovative projects (e.g., Educlick) for circular economy development include a social dimension in a country where vulnerable communities are often ignored. Therefore, EPR policies need to be further addressed to stimulate the best circular business initiatives in Romania and environmental awareness campaigns to improve the current collection rates of e-waste items. This review provides future research perspectives to fill the current knowledge gaps related to e-waste and ELVs.

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Abbreviations

CRM	Critical Raw Material
EEE	Electronic and Electrical Equipment
ELV	End of Life of Vehicles
EoL	End of Life
EPR	Extended Producer Responsibility
GDP	Gross Domestic Product
ICT	Information and Communication Technology (including the devices)
LHA	Large Household Appliances
NEPA	National Environmental Protection Agency (of Romania)
NGO	Non-Governmental Organization
NUTS	Nomenclature of Territorial Units for Statistics
OTR	Organizations of the Responsibility Transfer
PCB	Printed Circuit Board
POM	Placed on the Market
PPS	Purchasing Power Standard
PRO	Producer Responsibility Organization
SDG	Sustainable Development Goals
WEEE	Waste from Electrical and Electronic Equipment

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