Challenges in implementing the extended producer responsibility in developing economy: WEEE management in Serbia

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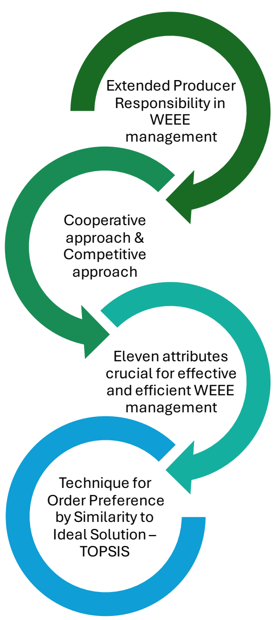
Graphical abstract



Weightage	0.15	0.125	0.1	0.025	0.05	0.15	0.15	0.025	0.05	0.075	0.1
	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11
A1	3	3	2	2	4	2	4	3	1	2	2
A2	4	4	5	4	2	4	3	5	4	3	3

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11
A1	0.090	0.075	0.037	0.011	0.045	0.067	0.120	0.013	0.012	0.042	0.055
A2	0.120	0.100	0.093	0.022	0.022	0.134	0.090	0.021	0.049	0.062	0.083
V_j^+	0.120	0.075	0.037	0.011	0.045	0.134	0.120	0.021	0.049	0.062	0.083
V_j^-	0.090	0.100	0.093	0.022	0.022	0.067	0.090	0.013	0.012	0.042	0.055

	S_i^+	S_i^-	$S_i^+ + S_i^-$	RC_i^+	Rank
A1	0.089	0.072	0.162	0.448	2
A2	0.072	0.089	0.162	0.552	1

ABSTRACT

In Serbia, waste electrical and electronic equipment (WEEE or e-waste) is classified as hazardous waste, mandated to be collected separately from other waste streams. Despite several laws and regulations governing e-waste management, the rate of properly collected and recycled equipment remains low. One of the issues stems from the inadequate implementation of the Extended Producer Responsibility (EPR) system, which has been one of the fundamental principles of the European WEEE Directive. This study presents a comprehensive analysis of eleven attributes of different EPR approaches, crucial for effective and efficient WEEE management, highlighting their strengths and weaknesses. To enable a comparative analysis of these attributes and the ranking of alternatives, the multi-criteria Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) was employed. The findings from this analysis suggest that a compliance system based on a competitive approach is the most cost-effective model for implementing producer responsibility. However, the application of the TOPSIS method reveals that the cooperative approach currently in operation is more suitable for the specific contextual conditions of Serbia, demonstrating higher efficiency in logistics and waste collection. The key findings of this analysis have been synthesized into a set of recommendations, which, along with the implemented methodology, enhance the theoretical framework and offer valuable insights to policymakers and experts in the field.

Keywords: Extended producer responsibility, MCDA, E-waste management, Environmental policy, TOPSIS, Western Balkan

1. Introduction

The growth of the global economy and rampant consumerism of raw materials reached a staggering 90 gigatons annually, putting an immense strain on the environment. According to a report published by the Organization for Economic Cooperation and Development (OECD), global consumption and extraction of raw materials are expected to double in the coming decades (from 79 Gt in 2011 to 167 Gt in 2060). In addition, the primary extraction of precious metals and rare earth metals from ores, which is necessary for the production of electrical and electronic equipment (EEE), requires significant consumption of energy and fossil fuels as well as the emission of greenhouse gases. It is estimated that annual greenhouse gas (GHG) emissions associated with the materials economy will increase to around 42.86% CO_2 equivalent by 2060 (OECD, 2019). Even more alarming is that the annual production of e-waste will more than double over the next 30 years (Parajuly et al., 2019). Conversely, effective management of e-waste can contribute to a net reduction in GHG emissions, while increased reuse and recycling of e-waste can potentially lead to a reduction in the need for primary raw materials. This is supported by the fact that the amount of precious metals in today's e-waste is far higher than the amount of metals underground. According to Gomez et al., (2023), 1 tonne of mobile phones can contain up to 53 kg of copper, 141 g of gold, 270 g of silver, 10 g of platinum, 18 g of palladium and 3.3 kg of rare earth elements, among other valuable metals. Many of these elements are found to be at least twice, and in some cases, up to 600 times more concentrated than in their natural ores. Research conducted on various printed circuit boards from mobile phones has shown that the gold content varied from 142 to 700 g ton^{-1} (Kasper and Veit, 2018). The results of gold recovery from waste printed circuit boards of mobile phones using microwave pyrolysis and hydrometallurgical methods fall within this value range, with approximately 168 grams of gold extracted from one ton of printed circuit boards. (Huang et al., 2022).More importantly, extracting

1 ton of palladium from ore produces 7221 tons of CO_2, while extracting 1 ton of palladium from recycled e-waste produces 788 tons of CO_2, which is 89% less (Schluep et al., 2009).

On the other hand, changing environmental regulations is a way to tackle the negative externalities of environmental management and creates an opportunity to improve regional efficiency through investments in green innovation. (Wen et al., 2024). The study by Zou et al. (2024) demonstrates a positive correlation among industrial technological innovation, environmental regulations, and CO_2 emissions. Furthermore, investment in and innovation of green technology will enhance the quality of development in the manufacturing industry, adjust industrial structures, and significantly accelerate the green transformation and upgrading of manufacturing enterprises (Zhang et al., 2024). According to the EU Waste Electrical and Electronic Equipment Directive, manufacturers of electrical and electronic equipment must consider product design and develop solutions that are technologically advanced and environmentally friendly. Furthermore, the increasing demand for electrical and electronic equipment is fueled by hyper-connectivity among people, organizations, and machines, which drives the growth of the digital economy. The electronics design industry is significantly reducing its environmental impact and promoting the efficient use of resources by incorporating green technologies, such as energy-efficient components, recyclable materials, and smart energy management systems. This development serves as a counterbalance to the pollution resulting from the increased production of electrical appliances. Furthermore, the analysis by Xia et al. (2025) indicates that the digital economy positively influences carbon emissions, primarily through green technological innovation and the optimization of industrial structures.As a candidate country for accession to the European Union (EU), Serbia aims to harmonize and adopt most of the Union's environmental requirements related to WEEE through national legislation, while postponing certain objectives related to the legislation currently applicable to EU member states.For example, the goal of 4 kg/inhabitant of WEEE collected had to be achieved by the end of 2019, and for EU member states this goal referred to 65% or more of collected equipment in the same year. According to the latest official report of the Serbian Environmental Protection Agency (SEPA), about 35.4 thousand tons of electrical and electronic waste were processed in 2023 (SEPA, 2024). This can also be considered the total amount of e-waste collected, which is slightly more than 5 kg/inhabitant/year. Although Serbia has thus reached its target, it is still far from the EU average of 11 kilograms per inhabitant (Eurostat, 2023). Furthermore, Serbia plans to increase the minimum collection rate to 45% of electrical and electronic equipment placed on the market in the previous 3 years by the end of 2031. This would mean that, according to the estimate, collecting and processing at least 37 thousand tons of waste is necessary.

The fulfillment of the quantitative targets of WEEE management defined by national legislation in terms of the EU Directive has not reached the corresponding level in practice. The reason for this is the absence of an adequate collection system for waste electrical and electronic equipment from households and small businesses, along with incomplete legal regulations defining the roles, rights, and responsibilities of producers, municipalities, and consumers defined. Moreover, the infrastructure for separate e-waste collection in Serbia is not yet fully developed or does not exist in rural areas. Therefore, companies that perform WEEE treatment and recycling directly or through intermediaries also have the role of e-waste collectors (Diedler et al., 2017). As a result, e-waste is managed mostly by the informal sector, often in substandard conditions, with serious health consequences for workers and the environment.

To introduce efficient management and control of e-waste, the EU adopted the WEEE Directive 2002/96/EC, which was supplemented by Directive 2012/19/EU (EC, 2012). This directive aims to prevent the generation of e-waste and reduce its disposal in landfills by assigning responsibility to producers and other stakeholders involved in the life cycle of EEE, especially those directly involved in the collection and treatment of WEEE (Sander et al., 2007). Shifting responsibility to producers as polluters would help to achieve higher environmental standards in product design and production of electrical and electronic equipment that fully consider and facilitate their repair, reuse, dismantling, and recycling (EC, 2012). A system designed in this way would lead to efficient resource use and ensure the recovery of valuable secondary raw materials. The WEEE Directive mainly aimed to ensure a producer-provided take-back and collection system and the proper treatment of collected WEEE by setting recycling and recovery targets, while nothing was prescribed in terms of supply chain structure (Khetriwal et al., 2011). According to Huisman et al., (2008), efficient collection is a key point to achieving the policy goal. The latest data published by Forti et al., (2020) indicate that only a small fraction of e-waste is collected. In 2019, the ratio of WEEE collected to new EEE put on the market in the EU was 42.5%. Globally, the formally documented amount of e-waste collected and properly recycled was 17.4%, while in 2022 this amount increased to 22.3% (Baldé et al., 2024)

This sheds light on the lack of a clear definition of producer responsibility in terms of European directives (Forti et al., 2020).

- One of the main aspects that the WEEE Directive does not address directly who exactly is responsible for the collection of WEEE from private households. The directive leaves the producers the freedom to fulfill their responsibility by implementing their own "individual recovery system" or by participating in "collective collection schemes". Depending on the choice of the collection scheme, Member States allocate responsibility for setting up collection facilities (physical responsibility) and for financing these activities (financial responsibility for collection) in different ways (Corsini et al., 2017). The system of collective producer responsibility in comparison with individual responsibility is more dominant in the countries of the European continent (Bilitewski et al., 2018). Producer Responsibility Organizations (PROs), also referred to as Take-Back Systems or Compliance Schemes in different areas, are created by manufacturers. However, their structure, definitions, and responsibilities differ significantly across regions due to varying local legislation and market conditions. These schemes can be divided into two main models (Hobohm, 2017). Cooperative approach: A single, national PRO manages the collection and recycling of WEEE for all manufacturers in the country.

Competitive approach: Multiple PROs operate independently, while a central clearing house coordinates the collection and recycling efforts among them.

The literature indicates that there are significant similarities in political and organizational structures among member states within the same group (Mallick et al., 2024; Andersen, 2022; Ahlers et al., 2021; Corsini et al., 2017). For instance, countries like Belgium, Cyprus, Croatia, Finland, France, Greece, Sweden, and others are part of one group. Notably, in these countries, all logistics and processors operate through one or more producer compliance schemes, each responsible for collecting specific waste fractions. The second group comprises countries such as Germany, Denmark, Ireland, Italy, Poland, Romania, Slovenia, and others, where multiple system providers compete. Since Serbia does not fit into either cluster, we selected one country from each cluster for analysis to determine which system is more suitable for Serbia's conditions. Sweden was chosen as an example of one of the most effective WEEE recovery systems globally, not only due to the high quantities of WEEE collected per inhabitant annually (12.9 kg/inhabitant in 2022), but also because of the lower costs (Ylä-Mella et al., 2014; Lee and Sundin, 2012; Lehtinen et al., 2009). Conversely, the system characteristic of Germany, where more than 20 providers compete, is more aligned with the arrangement that Serbia aspires to in terms of legislation. The purpose of this paper is to explore the possibilities of establishing an efficient e-waste collection system in Serbia by adopting the basic principles of best practices used in developed EU countries. Furthermore, the objectives of this study are to examine the key features of the EPR approach implemented in selected countries, as well as the shortcomings of the Serbian e-waste management system. To determine which system is better for Serbia, we analyzed the advantages and disadvantages of eleven criteria typical of the EPR system in Sweden and Germany and whether these should be applied in Serbia. By applying the discrete method of multi-criteria analysis known as TOPSIS (Technique for Order Preference by Similarity to Ideal Solution), a decision was made on the solution closest to the ideal. The framework required for implementing the directive is outlined, along with recommendations to address the challenges of establishing a sustainable e-waste management system in Serbia.

Investigating the relationship between the application of the principle of extended producer responsibility (EPR) in managing waste electrical and electronic equipment (WEEE), a key environmental regulation, and its effects on reducing environmental impacts and resource consumption are both academically and practically important. The findings from such studies not only strengthen the theoretical framework but also provide valuable insights and guidance for policymakers and experts. Therefore, emphasizing the implementation of EPR strategies remains essential, even in countries where they are legally mandated (Forti et al., 2020).

2. Methodology

Our methodology suggests that analyzing and identifying the strengths and weaknesses of WEEE management strategies used in developed European countries can act as a valuable foundation for planning and organizing work processes in developing nations. The methodology employed involved two steps. In the first step, an analysis of the WEEE management in two selected countries, which apply different approaches to the EPR System, and Serbia was conducted. A comparative analysis highlighted the key similarities and differences between these schemes and Serbia, as summarized in Table 1. Based on this analysis, recommendations were made to address the shortcomings in the organizational and legislative structure of electrical waste management in Serbia. To define an adequate system that can be applied in Serbia, it is necessary to examine which of the above principles is more favorable regarding cost-effectiveness, logistical efficiency, complexity, the effectiveness of the collection system, and other relevant factors. Thus, the second part of the paper is based on an analysis of eleven criteria characteristic of the cooperative and competitive approach to the implementation of EPR systems in terms of their applicability to the conditions in Serbia. To effectively manage WEEE, it is crucial to consider environmental, technical, social, and economic factors, necessitating consensus among all decision-makers and political entities (Achillas et al., 2010). Multi-Criteria Decision Analysis (MCDA) is recognized as a tool that aids in decision-making when both qualitative and quantitative aspects are involved. From current literature reviews on the application of MCDA to e-waste management, it is noted that most studies address sustainable collection, social, economic, reverse logistics, and environmental aspects (Sagnak et al., 2021; Kumar and Dixit, 2019; Sirisawat and Kiatcharoenpol, 2018; An et al., 2015; Tseng 2009; Queiruga et al., 2008; Erkut and Morgan, 1991). In addressing the complexities inherent in decision-making, the MCDA method offers a framework that clarifies the preferences for different criteria and aids stakeholders in their decision-making processes. Thus, implementing MCDA is essential for facilitating thorough and adaptable decision-making, as it allows for examining the interconnections among the various criteria involved in the decision-making process (Kumar and Dixit, 2018).

Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) is a valuable tool for decision-makers facing complex choices that involve multiple criteria. TOPSIS is based on the principle that the optimal solution is the closest to the positive ideal solution and the farthest from the negative ideal solution (Chakraborty, 2022; Chakraborty and Yeh, 2012; Chakraborty and Yeh, 2009; Hwang and Yoon, 1981). In TOPSIS, the weight reflects the decision maker's relative preferences for the attributes (Chakraborty, 2022). In this paper, assigning weight coefficients is essential because they indicate the relative significance of each attribute compared to others in the decision-making process, establishing a framework specific to Serbia. Modifying these weights can greatly impact the outcome, as criteria with higher weights exert a greater influence on the overall results (Agarski, 2015).

The following are the steps of the algorithm we applied to solve the multi-criteria problem of choosing between two waste management systems suitable for Serbia using the TOPSIS method (Chakraborty, 2022; Agarski, 2015):

1. Creating a Decision Matrix (X):

   The alternatives (*Ai*) in the rows include the Swedish and German systems, along with the 11 criteria (*Cj*) listed in the columns of the decision matrix. (Element x_{ij} represents the rating (performance) of alternative *Ai* concerning criteria *Cj*).

2. Decision Matrix Normalization:

   Each element is divided by the square root of the sum of the squares of its column.

3. Normalized Matrix Weighting:

   For *m* criteria (C_1, C_2, ..., C_m) and *n* alternatives (A_1, A_2, …, A_n) of the matrix X, values (w_1, w_2, ..., w_m) are assigned to represent the weighting factors of the criteria defined by the decision-makers. The normalized values are multiplied by their respective weights, which reflect the importance of each criterion. Thus, the weighted normalized performance matrix V = (v_{ij}) is derived, where each v_{ij} represents the product of the normalized performance of the alternative and the corresponding weighting factor of the criterion.

4. Determining the Ideal (A^+) and Negative-Ideal (A^-) Solutions:

The ideal solution (the best possible outcome) is formed by selecting the maximum value for each benefit criterion and the minimum for each cost criterion.

The negative-ideal solution (the worst possible outcome) is formed by selecting the minimum value for benefit criteria and the maximum for cost criteria.

$$A^{+} = \{(max\ v_{ij}\ |j\epsilon G), (min\ v_{ij}|\ j\epsilon G'), i =\ 1, \dots, n\} = \{v_1^{+}, v_2^{+}, \dots, v_m^{+}\} \quad (1)$$

$$A^{-} = \{(min\ v_{ij}\ |j\epsilon G), (max\ v_{ij}|\ j\epsilon G'), i =\ 1, \dots, n\} = \{v_1^{-}, v_2^{-}, \dots, v_m^{-}\} \quad (2)$$

where:

$$G\ = \{j = 1, 2, \dots, m\ |\ j\ belongs\ to\ the\ criteria\ that\ are\ maximized\ \}$$

$$G'\ = \{j = 1, 2, \dots, m\ |\ j\ belongs\ to\ the\ criteria\ that\ are\ minimized\ \}$$

5. Calculating the Separation Measures:

Calculation of the distance of each alternative from the ideal and negative-ideal solution, using the Euclidean distance formula:

$$S_i^{+}\ = \sqrt{\sum_{j=1}^{m}(v_{ij} - v_j^{+})^2}\ , \mathrm{i} = 1, \dots, n \quad (3)$$

$$S_i^{-}\ = \sqrt{\sum_{j=1}^{m}(v_{ij} - v_j^{-})^2}\ , \mathrm{i} = 1, \dots, n \quad (4)$$

6. Calculating Relative Closeness to the Ideal Solution:

For each alternative, the calculation of the relative closeness to the ideal solution gives a value between 0 and 1. Relative Closeness:

$$RC_i^{+}\ = \frac{S_i^{-}}{S_i^{+} + S_i^{-}}\ , \mathrm{i} = 1, \dots, \mathrm{n} \quad (5)$$

7. Ranking the Alternatives:

   Ranking the alternatives based on their relative closeness, with higher values indicating better alternatives.

Allocation of responsibility for collection of WEEE from private households

Regarding collection facilities, the WEEE Directive does not explicitly state who should be responsible for setting up the infrastructure. It only indicates that distributors should accept WEEE from consumers on a "one-to-one" basis when selling new products, although Member States may deviate from this requirement if they can demonstrate that an alternative procedure is equally convenient for consumers (Sander et al., 2007). Consequently, each Member State is free to assign physical responsibility to either the producer, the distributor, or the local government when implementing the WEEE Directive (Corsini et al., 2017). A similar situation applies to the financial responsibility for WEEE collection from households. The WEEE Directive states that producers are financially responsible for "at least" collection from the place of collection onwards, meaning that the financial responsibility of producers starts from the place of collection and not from households. Again, the WEEE Directive does not specify a solution for allocating the responsibility for financing the collection from households. This leaves a part of the responsibility to the municipalities, which are usually in charge of e-waste collection from citizens. The WEEE Directive leaves it up to producers to decide whether they want to fulfill their responsibility by applying their own individual collection and treatment system or by participating in collective systems.

Sweden as a representative case of a compliance system with a cooperative approach

In the cooperative approach, a producer organization (system provider) takes over the collection and recycling itself or uses a subsidiary. Unlike the competitive approach, the cooperative approach does not require a common body to coordinate between different compliance schemes. Instead, a producer association coordinates collection, transport, and allocation to recovery facilities, performs reporting and monitoring tasks such as calculating recovery rates or cost-equivalent fees, and identifies unauthorized collectors (Hobohm, 2015). According to Van Rossem et al., (2006), cooperative collection systems operate in Member States where a collective collection system existed before the implementation of the WEEE Directive. They have developed, and continue to develop, national compliance schemes initiated jointly by manufacturers or their trade associations, to organize collection and recycling on behalf of their members in a practical way. In these Member States, even if different collection schemes are implemented, there is no competition between product categories, creating a protected and non-competitive market (Corsini et al., 2017).

To maintain an adequate e-waste collection system in Sweden, the Swedish Environmental Protection Agency (Swedish EPA), the Swedish Association for Waste Management and Recycling (Avfall Sverige), and two organizations called producer-responsible organizations (PRO) work together (Zhang and Bashiri, 2017). Swedish Environmental Protection Agency registers Electrical and electronic equipment (El-Kretsen, 2021). Producers responsible for household electrical and electronic equipment are required to join a collective system approved by the Swedish EPA. In Sweden, there are two collective systems for WEEE with approval. The first PRO is El-Kretsen AB and the second is *Recipo Ekonomisk förening* (Recipo). El-Kretsen was established in 2001 as a joint venture between several trade organizations (El-Kretsen, 2021). El-Kretsen has cooperation agreements with all 290 Swedish municipalities and covers 99% of the Swedish WEEE collection from households (Kjellsdotter et al., 2015). The collection system is based on municipal recycling centers, with additional alternative collection points such as mobile collection systems (El-Kretsen, 2021). The collection system that El-Kretsen has developed in collaboration with municipalities is called Elretur (Sander et al., 2007). Recipo is the second Swedish WEEE operator, originally called *Elektronikåtervinning i Sverige* (EÅF), and has set up collection points for WEEE in retail stores nationwide since 2008. The Recipo system runs in parallel with the El-Kretsen system and is responsible for approximately 25% of the electrical products placed on the Swedish market (Ylä-Mella and Román, 2019). However, since not all municipalities have a Recipo retail collection point, Recipo pays a fee for the portion of its members' WEEE that is collected by El-Kretsen (Lee and Sundin, 2012).

Waste electrical and electronic equipment other than household appliances (professional equipment) is generally subject to waste management regulations, but there is no obligation to join a collective scheme (Swedish EPA, 2020). As a result, some producers have developed alternative solutions mainly for WEEE from businesses by contracting with independent recovery companies. Commercial consumers such as IKEA, OnOff, and Siba contract a pre-treatment company to treat WEEE from their activities at their own expense or return this WEEE to the electrical retailer when they buy a new product with similar functions (Swedish EPA, 2020; Sasaki, 2004**).** In practice, even after the implementation of the WEEE Directive and the allocation of both physical and financial responsibility to producers, municipalities are still physically responsible for the collection of WEEE from private households. Regarding financial responsibility, municipalities in Sweden continue to bear the costs for the operation of collection sites for WEEE (Sander et al., 2007). El-Kretsen is responsible for providing the collection containers, transport, and recycling of WEEE collected at these sites. The requirements for take-back systems are very high in Sweden, making it difficult for new players to enter the market and for producers to take individual responsibility without cooperation with PROs (Kjellsdotter et al., 2015). The need for coordination by a central authority, i.e., in terms of allocation of WEEE collection points from households, is limited by the fact that El-Kretsen is a predominantly compliant system with exclusive access to municipal collection points. Therefore, the pattern of relationships and cooperation between the two organizations in Sweden is relatively fixed (Zhang and Bashiri, 2017). This facilitates both the coordination of WEEE collection in practice (in terms of container provision and collection schedules, etc.) and the monitoring of producers' compliance by the authorities. In Swedish Ordinance 2014:1075 - on producer responsibility for electrical equipment - distributors are required to offer WEEE collection on a "1-1" basis, meaning that similar waste can be returned to the distributor free of charge when new products are delivered. Distributors in retail stores with a sales area for EEE of at least 400 m² must offer the collection of small WEEE (with an external dimension of no more than 25 cm) free of charge to end-users, even if there is no obligation to purchase EEE of an equivalent type ("0-1" rule). The common method of financing the entire system involves charging product-specific fees, which are paid to the system provider for each new device sold.

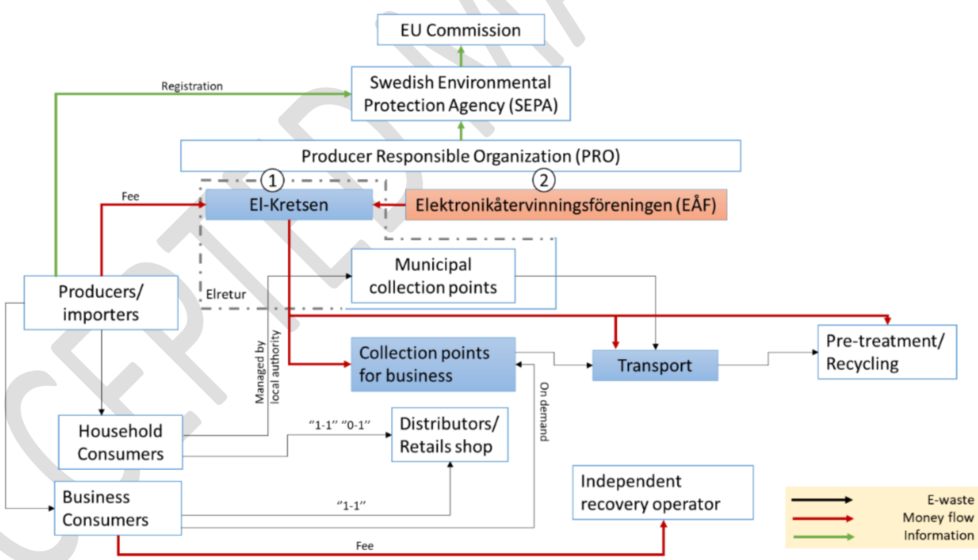


Figure 1. Swedish WEEE collection scheme

Germany as a representative case of a compliance system with a competitive approach

The German EPR legislation for WEEE, the "ElektroG", has adopted the majority of the WEEE Directive. The industry was granted the choice to take producer responsibility collectively with a competitive approach involving multiple service providers, i.e., logistics, recycling, and disposal companies, competing. Accordingly, the electronics industry established a private regulatory body, the National Registry for WEEE "Stiftung Elektro-Altgeräte Register" (EAR) (Bohr, 2007). The main objective of the foundation EAR is to act as a neutral registration body and clearing house. Entrusted with sovereign rights by the Federal Environment Agency, the foundation EAR is responsible for performing administrative tasks. This, in addition to registering producers via the Internet portal, includes allocating registration numbers to producers, recording the quantities of products placed on the market, coordinating the provision of suitable containers, and collecting WEEE from municipal collection points. It also includes calculating producers' obligations, collecting fees associated with the ElektoG, enforcing administrative decisions, and testing and certifying the financial guarantees for B2C electrical equipment. (Friege et al., 2015; Sander et al., 2007). Regarding producer responsibility for new WEEE, ElektroG gives producers the choice of either financing WEEE from their products (through sampling or sorting) or based on their share of total WEEE per type of equipment placed on the market (Sander et al., 2007). Accordingly, the take-back system can be organized independently, with producers contracting with the recovery operator, or by joining a producer responsibility organization. The first category is a mechanism in which a manufacturer independently complies with the law by contracting with a recovery operator to take back its specific brand of product. The second category is a mechanism in which manufacturers jointly comply with the law, i.e., a manufacturer joins a producer responsibility organization (PRO) and the PRO is responsible for fulfilling the manufacturer's waste recovery obligation. There are more than 20 state-approved PROs. Municipalities and producers share responsibility for waste management, with the former responsible for the fee-free collection of WEEE from private households in six different groups and the latter responsible for the transport, treatment, and quality assurance of WEEE (Bohr, 2007; Oberdörfer et al., 2017). Municipalities are not obliged to provide a defined collection infrastructure. Instead, producers are required to deploy the necessary collection containers at the municipalities' collection point free of charge (Sander et al., 2007; Oberdörfer et al., 2017). Hand-over points operated by the municipalities notify EAR when a full box is available for collection at their collection point. A producer/importer is then selected from a database that tracks the compliance status of each producer/importer, which is calculated based on market shares. To calculate market shares, EAR collects sales data from manufacturers and importers and calculates market shares in each category (Bohr, 2007). Retailers are not required to take back on a 1:1 basis, but they may offer take-back voluntarily. The take-back obligation is limited only to appliances with an edge length > 25 cm from private households (as defined by the German Waste Management and Product Recycling Act) as well as to old appliances of other origins, provided that the normal household quantity of 5 appliances is not exceeded. In contrast to manymember states, a financial guarantee is required from all manufacturers, and there is no exemption for manufacturers who are members of recycling consortia (Sander et al., 2007).

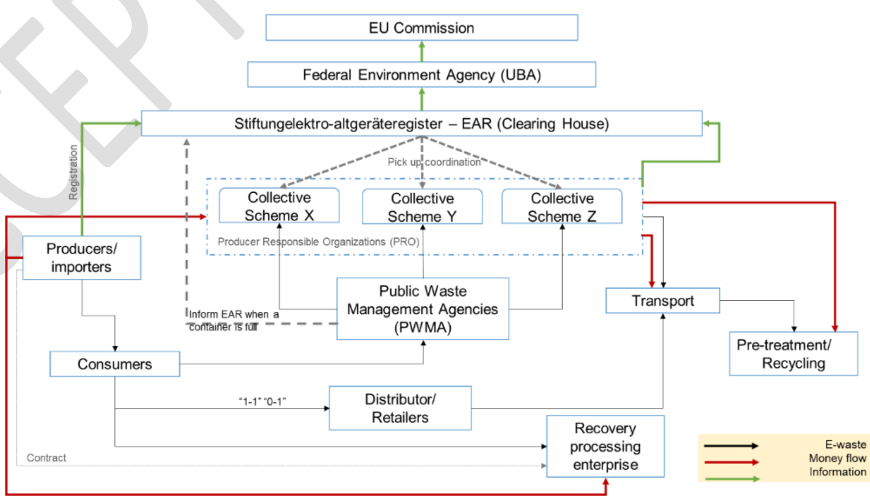


Figure 2. German WEEE collection scheme

Availability of data regarding WEEE management in Serbia

According to Oberdörfer et al., (2017), separate collection of WEEE by the official waste management sector is more or less restricted to collection from businesses and predominantly conducted by the operators of WEEE treatment plants themselves. According to legislation on WEEE, retailers must take back WEEE on a one-for-one basis, but there is an indication that this option is hardly used by end-users. Private waste collection and recycling companies organize the collection of e-waste at irregular intervals and without prior notice of the collection plan and schedule. According to the available data, the four leading recycling companies have a processing capacity of around 15,000 to 20,000 tons of e-waste per year. This is only 2.78 kg/inhabitant of e-waste, which mainly comes from the corporate sector (Marinkovic et al., 2017). There is no regular collection system for WEEE from households and small businesses. Municipalities do not provide facilities for the separate collection of household waste. However, public waste disposal companies occasionally organize the collection of bulky waste and scrap metal. WEEE, which contains valuable materials, is also collected by numerous players in the informal waste collection sector. Consequently, the collection systems for WEEE offer ample opportunities for improvement. Although the disposal of WEEE without prior treatment is not permitted, the majority of WEEE (especially from households) is still disposed of mixed with municipal waste in landfills (Diedler et al., 2017).

The Republic of Serbia is in the process of harmonizing environmental legislation with the EU acquis. Directive 2012/19/EU on waste electrical and electronic equipment has been partially transposed by the Law on Waste Management (LWM) and the Law on charges for usage of public goods. Detailed provisions were laid down in the Rulebook on the list of electric and electronic products, measures of prohibition and restriction of use of electric and electronic equipment containing hazardous substances, and the manner and procedure for management of waste originating from electric and electronic products. The Serbian Environmental Protection Agency (SEPA) collects e-waste data using the European Waste Catalogue codes and the EU-10 classification system, while the introduction of EU-6 is planned for 2024 (Iattoni et al., 2023). Additionally, the Regulation on products that become specific waste streams after use establishes a database of producers/importers, reporting procedures, and fees. According to the LWM, e-waste is classified as a specific waste stream and has the character of hazardous waste. The LWM establishes the conditions under which companies can be authorized to collect, transport, treat and store waste. For example, all companies involved in the collection or treatment of e-waste must have a permit issued by the Ministry of Environmental Protection (MEP), and they are required to record all annual quantities of WEEE collected/treated, broken down by category. Producers/importers of EEE are also required to record all annual quantities of products placed on the market. All related information must be submitted to SEPA (Diedler et al., 2017).

The Law on charges for the usage of public goods defines the payment of environmental taxes on WEEE by producers and importers of EEE. Tax rates are established according to the type of EEE placed on the market. There are 10 categories of EEE, with a range of products in each category. Taxes are based on individual products and their associated weight. Currently, producers/importers must pay tax to the Green Fund, established in 2018 as a budget fund. This Green Fund is designed to collect funds to finance the preparation, implementation, and development of programs, projects, and other activities in the field of conservation, sustainable use, protection, and improvement of the environment. The Ministry of Finance is responsible for controlling the distribution of Green Fund resources. This tax should be used to finance the management of WEEE – that is, collection, transport, and treatment. In order to avoid paying the WEEE management fee, many producers and importers of WEEE fail to comply with their obligation to collect and report all quantities of EEE placed on the market. According to SEPA (2017), only 66% of fee payers have complied with their legal reporting obligation. Therefore, the quality of the data on the quantities of electrical and electronic equipment reported to SEPA remains limited, which on the other hand lacks the funds that should be made available to recyclers and collectors as subsidies. After assessing the systematic integration of the implemented EU acquis on WEEE into the national legal framework, it can be stated that Serbia has partially transposed the WEEE Directive. Still, the level of transposition is relatively low, with slightly less than half of the provisions fully transposed through national legislation (Oberdörfer et al., 2017). The regulations on the obligation to keep records for waste electrical and electronic equipment do not apply to collection points, but only to the operator or collective operator, who must keep records of the amount of waste equipment, components, materials, and substances from equipment that enter the treatment facility, further use, or disposal. Detailed rules on how producers/importers must fulfill their obligations or delegate all their debts are still missing. While the WEEE regulations require a separate collection of this type of waste and set annual collection targets, they do not specify who is responsible for meeting these targets. In addition, the detailed reporting requirements set out in Commission Decision 2005/369/ EC on the amount of WEEE collected from private households and on the amount from sources other than private households have not been transposed. The Rulebook on WEEE does not include a calculation method as set out in the Directive. It is not defined who and in which way calculates the reuse/recycling/recovery targets and the collection targets, i.e., whether the operator/collective operator calculates the targets based on its records and submits the data to SEPA, or whether SEPA makes the calculation based on the input and output data for waste from the facility submitted by the operators. The Rulebook does not include the detailed requirements for monitoring compliance with the targets set out in Commission Decision 2005/369/ EC.

The Law on Waste Management does not provide a legal framework for the establishment of collective and individual systems based on the principle of "producer responsibility" as defined in the WEEE Directive. However, the WEEE legislation introduced the concept of "collective operator", established by producers and importers who bring more than 15,000 tons of EEE per year to the market of the Republic of Serbia. The collective operator is obliged to manage WEEE and at least one treatment facility. Unfortunately, such a body has not yet been created in Serbia, which is contrary to the provisions of the law, which stipulates that producers and importers pay compensation to the Green Fund for the WEEE they put on the market.

The Serbian LWM has established two principles that reflect the main provisions of the "extended producer responsibility" principles. The first is "producer responsibility" which requires that producers, importers, distributors, and retailers of products are responsible for the waste generated by their activities. The producer bears the greatest responsibility, as he determines the composition and characteristics of the products and their packaging. The producer is obliged to ensure the reduction of waste generation and the production of recyclable products, as well as the development of the reuse and recycling market. The producer or importer may collect e-waste independently or appoint another legal entity to collect the products on its behalf after use. According to the second "polluter pays" principle, the polluter is obliged to bear the full costs of their actions. The cost of producing, treating, and disposing of waste must be included in the price of the product. However, the polluter pay principle has not been fully implemented, while the producer responsibility principle is not represented at all in the management of special waste streams.

The WEEE Directive requires manufacturers to register data about the company and the product. At the beginning of 2012, SEPA developed the National Pollution Register information system, which serves to register producers/importers of EEE, to electronically transmit data on the amount of EEE placed on the national market by weight and equipment category, and to prepare annual reports on the management of WEEE generated and to issue waste management permits. However, in Serbia, there is no national register for WEEE, which, in addition to registering producers, also has the task of collecting the information required by the WEEE Directive, which is necessary for the appropriate establishment of EPR systems. The register established by SEPA does not require information to be provided by the producer/importer at the time of registration, such as information on how the producer fulfills its obligations (individual or collective system, including information on the financial guarantee, sales technique used, e.g., distance selling). Also, the financial guarantee in case of insolvency is not defined in the national regulations. In addition, annual reports do not require information on the amount (by weight) of WEEE collected separately, recycled, prepared for reuse, recovered, and disposed of in the country, or shipped inside or outside the Union. Unlike data collection in EU countries, the Serbian Environmental Protection Agency receives data from the Customs Administration once a year on each import of products. However, the goods are recorded based on the customs tariff number, which at the same time may belong to products that become specific waste at the end of their life, but this cannot be determined with certainty, as more than one product may be registered under one customs tariff number. This leads to the loss of information on the share of money for different classes and subclasses of EEE in the total amount of fees.

The Directive's requirements for authorized representatives have not been transposed. Producers who sell electrical and electronic equipment at a distance must be registered in the Member State to which they sell or through their authorized representatives. Serbia, as a candidate country for EU membership, should establish a register of producers, including producers selling at a distance, and allow online entry of all relevant information into the national register. The register could be used to monitor compliance with the requirements of the WEEE Directive.

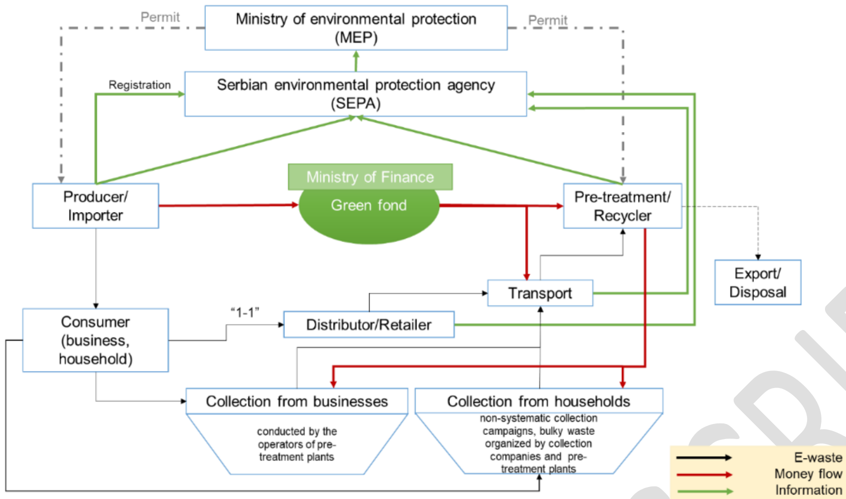


Figure 3. Serbian WEEE collection scheme

3. Results and Discussion

Legislation in the EU is highly centralized and relies on regulatory bodies established by manufacturers based on the WEEE Directive.. In Germany, for example, clearing house serves as a "national register for WEEE" and coordinates actions to achieve collection targets and fully implement producer responsibility principles (Diedler et al., 2017). In contrast to the situation in countries with a competitive approach, in Sweden, where the cooperative approach is used, the producer organization El-Kretsen coordinates collection, transport, and allocation to recycling facilities, and calculates recovery rates or cost-equivalent fees,while the Swedish Environmental Protection Agency registers producers (Bohr, 2007). Table 1 highlights the primary differences among the e-waste management approaches implemented in Germany, Sweden, and Serbia. One of the significant challenges is that Serbia does not participate in any compliance scheme established as a coalition of producers responsible for waste management. This complicates the issue of having a clear delineation of responsibilities within the WEEE management system in Serbia. The table illustrates the distinctions between household and commercial waste management, where producers and importers of products hold full accountability. It is crucial to emphasize the role of municipalities regarding waste collection from citizens. Municipalities assume both the physical and financial responsibilities for waste collection and the upkeep of collection sites. Meanwhile, the role of producers and importers is to organize the provision of containers, transportation, and treatment of e-waste.

Table 1. Comparison of the framework important for WEEE collection

Country	Serbia	Sweden	Germany
Factor		Roles and responsibilities	
Controlling body	MEP/ Env. Agency	Env. Agency; PRO	UBA/ Clearing house
EEE register	There is no national register (The Env. Agency plays a partial role)	Env. Agency	Clearing house
Compliance scheme	The Law on Waste Management does not provide a legal framework for the establishment of collective or individual schemes	Producer joins one of two producer responsibility organizations (PRO): El-Kretsen Recipo	Producer joins a producer responsibility organization(>20 PROs)

Financing of household waste collection	MEP partially subsidizes collection companies. The greater part is financed by the recyclers themselves	**Municipalities** (Municipalities bear the costs for the operation of collection sites)	**Municipalities** (Producers and importers do not reimburse municipalities for costs)
Household waste collection	No regular collection system; Informal sector and occasionally collection and recycling companies	Municipalities	Municipalities
Financing of commercial waste collection	MEP partially subsidizes collection companies from the state budget The recyclers themselves finance the greater part	Producers/ importers	Producers/ importers
Commercial waste collection	Predominantly conducted by the operators of WEEE	Contract with an independent recovery operator or on demand for	Producers enter into contracts with the recovery processing enterprise or by

	treatment plants themselves	El-Kretsen Collection points for business	joining a producer responsibility organization
Financing of recycling	MEP partially subsidizes recycling companies from the state budget The recyclers themselves finance the greater part	Producers/ importers	Producers/ importers
Method of financing	Product-specific fees	Product-specific fees	Based on the market share of the producer in the EEE market; Based on a producer's WEEE as a proportion of the total amount of that category of WEEE (sampling or sorting)
Distributor/ Retailers	"1-1"	"1-1" "0-1"	"1-1" "0-1"

Regarding producer responsibility for the new WEEE, one of the differences in the producer compliance scheme is the method of financing. Under the cooperative approach, the usual financing method is to impose product-specific fees that are paid to the system supplier for each new device sold. In the competitive approach, on the other hand, the clearing house determines the collection obligation for each manufacturer based on its market share and places the responsibility for collection and financing on the producer either directly or through a fulfillment system (Khetriwal et al., 2011). In Serbia, on the other hand, producers pay a fee when placing products on the market, but since there is no producer organization, the money goes into the state budget, i.e., under the jurisdiction of the Ministry of Environmental Protection. The relationships among stakeholders are crucial for making EPR schemes effective. Coordination between PROs, retail chains, and municipalities is essential. Take-back channels and related information from producers or PROs should be aligned, with municipalities maintaining close contact with citizens (Friege et al., 2015).

In competitive system, increased logistical effort is required due to each producer's logistics. In the interpretation of the cooperative approach, logistics are handled by a producer organization, leading to an optimization of logistics and a reduction in collection costs. Furthermore, in the competitive approach, competition leads to a constantly changing market for collection system suppliers and waste disposal companies. This leads to an increase in actors and a lack of transparency in the collection chain. Conversely, collection systems with the highest level of transparency can have a beneficial impact on the collection of WEEE, and the exchange of experience between producers and disposers leads to the continuous optimization of the collection system. Both systems have their strengths and weaknesses. However, the paper aims to determine how these systems would influence the management of electrical and electronic waste if one of them were implemented in Serbia. To set up an appropriate WEEE management system, a decision must be made on management, logistics, and infrastructure solutions, considering economic and social criteria. It is equally important to design a system that is accepted by the local population, which would contribute to greater efficiency and financial sustainability of the system. The following table outlines eleven criteria (C_1, C_2, …, C_{11}), characteristics of the cooperative and competitive systems concerning their suitability for conditions in Serbia. Each criterion includes a weighting coefficient and descriptive rating, where "Excellent" indicates that the applied criterion perfectly suits the conditions in Serbia, while a rating of "Low" signifies that it is the least suitable. These criteria were then utilized in the multi-criteria TOPSIS Method.

Table 2. Main variables used to compare different collection schemes

Factors	Sweden (Cooperative approach)	Germany (Competitive approach)	Serbia
Logistics efficiency (C1)	Each scheme is responsible for a specific type of waste and collects it throughout the country, ensuring no overlap in logistics. This leads to lower costs and a more straightforward organizational structure.	There is an overlap in logistics. Each producer organization independently collects all types of e-waste.	The system in Serbia currently operates on a principle where recyclers collect waste and manage their networks of collectors, but it is mainly chaotic and inefficient. This inefficiency is evident in the insufficient amount of e-waste that is collected. Improved logistics would be crucial for Serbia.
	Good	Average	Weightage: 0.150

Logistics costs (C2)	In interpreting the cooperative approach, logistics are carried out through central control without duplicate truck routes. This leads to optimization in logistics and cost reduction.	In the collective system with a competitive approach, due to the logistics of each PROs, an increased logistics effort is required compared to the cooperative approach.	As the number of schemes on the market increases, so do logistics costs. The Serbian economy needs to keep costs as low as possible.
	Good	Average	Weightage: 0.125
Complexity (C3)	Based on the literature, it has been determined that it is easier to implement a national model (cooperative approach) than to build a clearing house model (competitive approach).	The clearing house model is more complex than the national model due to the number of actors involved in WEEE management. It also necessitates the establishment of a national registry and implementing a system for distributing collection points. This results in redundant infrastructure and roles, as well as increased coordination costs	Serbia is a developing country introducing waste management systems by learning from the best examples from the EU. Therefore, it is desirable that the complexity of the adopted model be as low as possible to leave room for the system to develop adequately.

		activities (Dieste et al., 2017; Ylä-Mella et al., 2014)	
	Excellent	Below average	Weightage: 0.1
Conflict of interest (C4)	In a cooperative approach, there is no conflict of interest between schemes. The only conflict of interest may arise between actors engaged as third parties (logistics, recyclers, etc.)	Conflicts of interest in a competitive approach can arise if it is not managed adequately.	A well-organized system with straightforward mechanisms reduces conflicts of interest among producers. The market in Serbia is already chaotic, with producers, recyclers, and collectors competing for every piece of e-waste.
	Good	Below average	Weightage: 0.025
Competitiveness (C5)	The impact of competition on efficiency is positive and significant (Favot et al., 2022). The disadvantage of a cooperative system is its lack of competitive effect.	The competitive approach implies strong competition and lower operating costs. The greater the competition, the more essential it is to find improved solutions and arrangements that will motivate producers to select a scheme	Competition should be strong to lower the overall cost of the scheme. However, the market in Serbia is small and poorly developed, so this concept does not fit perfectly.

	Competition is possible only between partners who cooperate with the scheme, such as logistics companies, recyclers, etc.	that offers them a lower product price. We can also anticipate a beneficial effect of "learning by doing". As the system evolves and the recycling market matures, it becomes more efficient, allowing operators to enter market niches that have not been adequately served in the past. (Denison, 2015) and *(*Favot et al., *2022)*	
	Below average	Good	Weightage: 0.05
Collection efficiency (C6)	*12.9 kg/inhabitant of electrical waste was collected in 2022 (Eurostat, 2024) The synergy between producers and other stakeholders in the WEEE waste management system fosters information sharing and collaborative problem-	* 10.8 kg/inhabitant of electrical waste was collected in 2022 (Eurostat, 2024) This approach is suitable for countries where the market is more developed and denser, making it easier and cheaper to organize collection activities, and it also allows for more	Economic indicators in Serbia reflect a developing market, although waste generation per capita remains low and collection rates are inadequate. Overall, this situation could adversely impact a system where numerous operators are

	solving, resulting in continuous innovation and ongoing optimization of the collection system (Schiefer et al., 2024; Huang et al., 2020; Hobohm, 2015; Mention, 2011; Soosay et al., 2008)	operators to compete (Denison, 2015) and (Favot et al., 2022). It is known that as the number of collection schemes increases, the market share of collection companies decreases (Dieste et al., 2017; Ylä-Mella et al., 2014)	competing. Conversely, a collaborative approach is viewed as more advantageous under the circumstances that define Serbia.
	Good	Below average	Weightage: 0.15
Cost-effectiveness (C7)	Waste collection and processing require significant infrastructure investments. Logistics costs can be reduced by forming partnerships with various service providers (i.e., transporters and recyclers). However, a lack of competition on the system provider side may result in inefficiencies or high prices	As previously explained, competition can lower operating costs, giving this system an advantage. However, the presence of multiple system operators limits economies of scale and necessitates coordination of their activities through a centralized clearing house. (Bohr, 2007)	None of these systems is ideal for Serbia regarding cost-effectiveness. For the cooperative approach to be cost-effective, a significant amount of collected waste is necessary. Conversely, the competitive system is not ideal when considering economic development and the country's size. However, the competitive approach,

	due to the substantial market power of the PRO. (Bohr, 2007)		which would have lower operating costs, offers an advantage in meeting the needs of Serbia.
	Average	Good	Weightage: 0.15
System predictability (C8)	The system is predictable because there are one or two established collection schemes	The competition in the competitive approach results in a constantly changing market for suppliers of collection systems and disposal companies. This leads to an increase in actors and a lack of transparency in the collection chain.	A cooperative approach is considered ideal in this case.
	Excellent	Average	Weightage: 0.025
Population size (C9)	Producers in small countries such as Belgium, Switzerland, Norway, Sweden, and the Netherlands often collaborate with only one producer responsibility	The clearing house system is not suitable for small nations where the volume of WEEE to retrieve likely does not justify the additional costs associated with infrastructure proliferation	Serbia is a small country, so it follows that, given this factor, a cooperative approach should be favored.

	organization that rules the market and coordinates and finances take-back, logistics, and recycling.	and function duplication, as well as the developing logistics costs and extra management resulting from the allocation of collection points and fragmented management territory. (Dieste et al., 2017; Ylä-Mella et al., 2014).	
	Good	Low	Weightage: 0.05
Country's development (C10)	In this model, it is possible to achieve economies of scale only in cases where the country's economy is at a high level and a large amount of WEEE is available	This model is adequate for countries with predominantly urban areas where a lot of WEEE is collected per unit area, unlike rural areas that collect a small amount of waste over a large area, making logistics costs much higher (Dieste et al., 2017).	Serbia is a small developing country, with a lot of rural areas that are not even fully covered by MSW collection infrastructure.
	Average	Below average	Weightage: 0.075

Citizen awareness (C11)	In this system, all equipment is collected, regardless of how many products a manufacturer has put on the market. The cooperative system attaches more importance to the promotion of recycling and raising the awareness of citizens.	The less WEEE that is officially collected, the less the resulting monetary obligation for producers – which means that producers do not have incentives to advertise and promote WEEE recycling. (Bhor, 2007)	In Serbia, citizens have low awareness and need to recycle, so a collaborative approach is preferred.
	Average	Below average	Weightage: 0.1

By assigning descriptive ratings to each criterion, the qualitative characteristics can be converted into quantitative values according to the established scale: Excellent has a rating of 5 as the highest, Good - 4, Average- 3, Below Average - 2, and Low - 1 as the lowest rated criterion. The weighting coefficients used in this study were determined by considering the general financial and management structure specific to Serbia. They were based on the accumulated experience and expertise of the authors, as well as their extensive cooperation with relevant institutions, including the Ministry of Environmental Protection and the Environmental Protection Agency, alongside companies specialized in managing electrical and electronic waste. Since the sum of the weighting coefficients in this method equals one, it is evident from the table that the highest weights are assigned to logistics and collection effectiveness, as well as the total costs of the collection scheme's functioning. Below is the decision matrix with two alternatives (A1 – competitive system in Germany, and A2 cooperative system in Sweden) and eleven criteria.

Table 3. Decision Matrix and weightage coefficients

Weightage	**0.15**	**0.125**	**0.1**	**0.025**	**0.05**	**0.15**	**0.15**	**0.025**	**0.05**	**0.075**	**0.1**
	C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**	**C10**	**C11**
A1	3	3	2	2	4	2	4	3	1	2	2
A2	4	4	5	4	2	4	3	5	4	3	3

Table 4. Normalized Decision Matrix and determined ideal and negative-ideal solutions

	C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**	**C10**	**C11**
A1	0.090	0.075	0.037	0.011	0.045	0.067	0.120	0.013	0.012	0.042	0.055

A2	0.120	0.100	0.093	0.022	0.022	0.134	0.090	0.021	0.049	0.062	0.083
Vj^+	0.120	0.075	0.037	0.011	0.045	0.134	0.120	0.021	0.049	0.062	0.083
Vj^-	0.090	0.100	0.093	0.022	0.022	0.067	0.090	0.013	0.012	0.042	0.055

Table 5. Distance of alternatives from ideal and negative-ideal solutions and ranking of alternatives

	Si^+	**Si^-**	**$Si^+ + Si^-$**	**RC_i^+**	**Rank**
A1	0.089	0.072	0.162	0.448	2
A2	0.072	0.089	0.162	0.552	1

By applying the TOPSIS method during the ranking, a small difference between the alternatives was observed, with the second option, a system with a cooperative approach as implemented in Sweden, gaining the advantage. Considering the economic development and market conditions affecting a country's economy, changes occur in the ratings and weights of the criteria that are crucial to the process. This can influence the result. Currently, given the small population and limited purchasing power, the quantity of products collected is also low. This situation negatively impacts collection costs, especially when multiple collection schemes are involved. Complexity, as a detrimental attribute, arises from the absence of a clearing house or other organization that could manage numerous tasks effectively within the system. As Serbia is a developing country, there is potential to overcome financial and infrastructural obstacles in the near future, which would significantly influence the choice of model adopted.

4. Conclusion

The adoption of the WEEE Directive in Serbia has highlighted the limited cooperation between the different actors in the e-waste management system and the insufficient technical competence to achieve the objectives set in the regulation. The four leading recycling companies, which also act as e-waste collectors, collect e-waste separately throughout the country, causing their paths to cross, which increases logistics costs and reduces collection efficiency. Based on the analysis conducted, it can be stated that the current situation in the e-waste management system in Serbia does not follow any compliance scheme to meet the objectives of the EPR principle and that the legislation aims at a competitive system where SEPA will be the main administrative body for registration and reporting, while MEP will provide financing through the Green Fund. Serbia, as a developing country, should harmonize its national WEEE regulations with existing policy instruments and standards when implementing the WEEE Directive, which would create a hierarchy in the e-waste management system. However, some essential provisions necessary for establishing a functioning WEEE management system in Serbia are missing. Insufficient enforcement of existing legislation, as well as partially adopted or omitted parts of the WEEE Directive related to leading roles and obligations in the EPR system, resulted in a limited collection outcome. Strong coordination between key players in the EPR system and environmental policy is needed to implement an adequate WEEE management system. First and foremost, it is necessary to establish a national WEEE registry by the WEEE Directive and to define who is responsible for coordinating the flow of money, information, and materials through the system.

Previous analyses of various e-waste collection systems have revealed that municipalities serve a crucial role in collecting e-waste from households. However, this is not adequately addressed in the current practices in Serbia. In alignment with the best practice models observed in developed EU nations, municipalities must provide citizens with accessible options for depositing their e-waste at municipal collection points, without being obliged to establish a collection infrastructure. Instead, producers or importers should organize the provision of containers, as well as the transport and treatment of e-waste. Since the collection of e-waste from households is managed by municipalities or public services, it is essential to delineate their roles and responsibilities within national legislation. In contrast to the EU member states, Serbia has yet to establish regulations governing producer compliance with EPR requirements. In countries that adopt a competitive approach, clearing houses typically play a crucial role in monitoring and ensuring the equitable distribution of resources among competing collective systems. Conversely, in nations employing a cooperative approach, a predominant collection system often consolidates the responsibilities of all producers, thereby assuming full financial accountability for the entire system. The definitions, roles, and obligations of each stakeholder involved in the e-waste management process must be explicitly articulated in regulatory frameworks. Specifically, the following recommendations are proposed:

- definitions of the roles of municipalities and the government.
- establishment of a national registration body.
- a clear definition of who is responsible for organizing the collection and recycling.
- a clear definition of who is responsible for financing the collection and recycling of e-waste.
- a clear definition of who is responsible for achieving collection targets.
- ensuring the implementation of the principles of "producer responsibility" and "polluter pays", and truthful reporting.
- adoption of the principle of extended producer responsibility.
- a clear definition of "producer, " particularly if the system is based on the EPR principle (without this, no producer will feel obliged to comply, making fair enforcement of legal provisions across the industry more difficult).
- documentation of producers’ compliance status and a clear description of the goals and targets of the legislation.

- detailed rules on how producers/importers must comply with their obligations or delegate them entirely.
- changing collection targets and introducing a system of shared responsibility for achieving them.
- definition of who is responsible for the public information campaign.

Through our analysis, it has been determined that a compliance system based on the competitive approach presents the most cost-effective means of implementing producer responsibility. However, a notable advantage of the cooperative system lies in its enhanced efficiency regarding logistics and waste collection processes. By employing the multi-criteria TOPSIS method to analyze eleven relevant factors, our findings indicate that the system currently operational in Sweden with a cooperative approach is more appropriately aligned with the conditions present in Serbia. Our study presents a roadmap for establishing an adequate WEEE management system in Serbia. The implemented methodology and identified influencing factors can greatly assist decision-makers in our country, as well as experts from other developing nations facing similar challenges.

Nevertheless, this study acknowledges several limitations. Firstly, the unique socio-economic contexts of different countries imply that no singular methodology or business approach can be universally applied without necessary adaptations to specific circumstances. A critical limitation is the prevailing lack of awareness among citizens concerning environmental protection and the importance of recycling initiatives, which may affect the success of WEEE management implementation. Furthermore, the involvement of the informal sector in the collection of WEEE adversely impacts the formal collection systems and poses significant health and environmental risks to those engaged in such activities.

Future research endeavors will concentrate on identifying the infrastructural, economic, sociological, and environmental factors that affect the implementation and efficient operation of electrical and electronic waste management systems in Serbia.

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