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ASSUMPTIONS FOR WASTE ELECTRICAL AND ELECTRONIC EQUIPMENT COLLECTION SYSTEM EVALUATION

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Purpose: The main aims of the article are to analyse the waste electrical and electronical equipment management system and present a conceptual framework for evaluating the collection system for this group of waste.
Design/methodology/approach: The research methods used in the article were desk research analysis of available source data on the structure and functioning of WEEE management systems. An additional approach to the research referred to the statistical data on waste collection of the following groups of waste
Findings: WEEE management systems are widely described in the literature because this waste are source of significant and rare secondary raw materials. However, it is still a problem to create a fully efficient system for collecting this group of waste.
Research limitations/implications: The main limitation in carrying out the research is the lack of current data on the quantity and quality of electrical and electronical waste which can be used for the production
Practical implications: Further research will focus on using the approach presented to investigate the effectiveness of the different WEEE collection solutions and the possible improvement of these systems
Originality/value: The analysis carried out indicates the need to reconstruct the WEEE management system. This approach to assessing the effectiveness of the system can be used to compare different WEEE collection options.

Keywords: waste collection system, WEEE, assessment.

Category of the paper: conceptual paper.

Introduction

The management of electrical and electronic waste is an important problem on both a local and global scale, mainly due to the increasing amount of electro-waste generated worldwide. As production increases and the life cycle of electrical and electronic equipment shortens, it is replaced more and more often so that it becomes a rapidly growing source of waste. Used electrical and electronic equipment is considered to be one of the fastest growing waste streams in the European Union, with an increase rate of 3-5% annually (Gurauskienė, 2008; Nowakowski, Szwarc, 2016). This is related to the consumer lifestyle, which results in a shortened life cycle of electrical and electronic equipment. Moreover, new devices with increasingly better parameters constantly appear on the market. Therefore, still working electrical and electronic devices become hazardous waste, which contains harmful substances such as lead, mercury, cadmium, bromine, etc. (Goodship, Stevels, Huisman, 2019; Góralczyk, Uzunow, 2013). Incorrect handling of WEEE leads to pollution of waters, soil and air, as well as to a number of threats to our health and wellbeing. In addition, loss of natural resources and increasingly difficult access to them can be observed. Paradoxically, waste is also one of the most important resources of raw materials and critical elements (Kruczek, 2017). In 2005, the Electrical and Electronic Equipment Waste Act came into force. It was the first document in Poland to regulate issues related to the collection and processing of WEEE. The Act implemented the provisions of the Directive on electrical and electronic equipment waste (Directive 2002/96/EC 2003; Applia, 2019). Although several years have passed since the WEEE collection and handling system was introduced, the solutions currently applied in Poland are still incomplete, uncoordinated, and not very flexible. This is caused by several different barriers created by an unclear legal, organizational, and financial system related to the organization of WEEE collection and handling. The purpose of this article is to present an initial concept of a model to assess the effectiveness of electrical and electronic waste equipment collection based on literature.

Development of the WEEE management system

In Polish legislation, the term equipment waste first appeared in the Regulation on waste classification issued by the Minister of Environmental Protection, Natural Resources, and Forestry (Dz.U. nr 162, poz. 1135, 1997). The Regulation contains 7 types of waste that meet the currently valid definition of equipment waste (Table 1). Neither then valid the Waste Act (1997) nor the executive regulations contained a definition of the term waste equipment.

Table 1.
Selected sub-groups and types of equipment waste

No	Code	Subgroups and types of waste
1	09 01	Waste from the photographic industry
1	09 01 09	Disposable cameras with batteries
2	09 01 10	Disposable cameras without batteries
2	16 02	Used equipment and its components
3	16 02 01	Transformers and capacitors containing PCB or PCT
4	16 02 02	Other electronic and electrical waste equipment
5	16 02 03	Devices containing freon
6	16 02 04	Equipment containing free asbestos
7	16 02 05	Other used equipment

Source: (Dz.U. nr 162, poz. 1135, 1997).

The definition of equipment and waste equipment was first introduced in the Act on electrical and electronic equipment waste (Dz.U. nr 180, poz. 1495, 2005), which transposed Directive on waste electrical and electronic equipment (Directive 2002/96/EC 2003). Article 4 of the Act dated 11th September 2015 on Waste Electrical and Electronic Equipment (Goodship, Stevels, Huisman, 2019), currently being in force, defines equipment as "a device whose correct operation depends on the supply of electric current or the presence of electromagnetic fields, as well as a device capable of generating, transmitting or measuring electric current or electromagnetic fields, designed for use with electric voltage not exceeding 1000 V for alternating current and 1500 V for direct current".

While implementing Directive 2002/96/EC, the European Union imposed on the Member States the necessity to achieve a collection level of at least 4 kilograms of WEEE per citizen per year by 31st December 2006 at the latest. However, there was no provision for the set collection rate in the WEEE Act of 2005 (Bukowski 2018). In 2007, only 0.27 kg of WEEE per capita was collected in Poland (Cieszyńska, 2017). Figure 1 shows the volume of electrical and electronic equipment collected per capita in the years 2007 to 2017 (Figure 1).

After the amendment of the WEEE Act changes aimed at improving the functioning of WEEE management system were introduced in order to achieve the required level of collection in Poland The minimum annual levels of WEEE collection were set in the Regulation of the Minister of Environment, and then increased in 2010 (table 2) (Nowakowski, 2015).

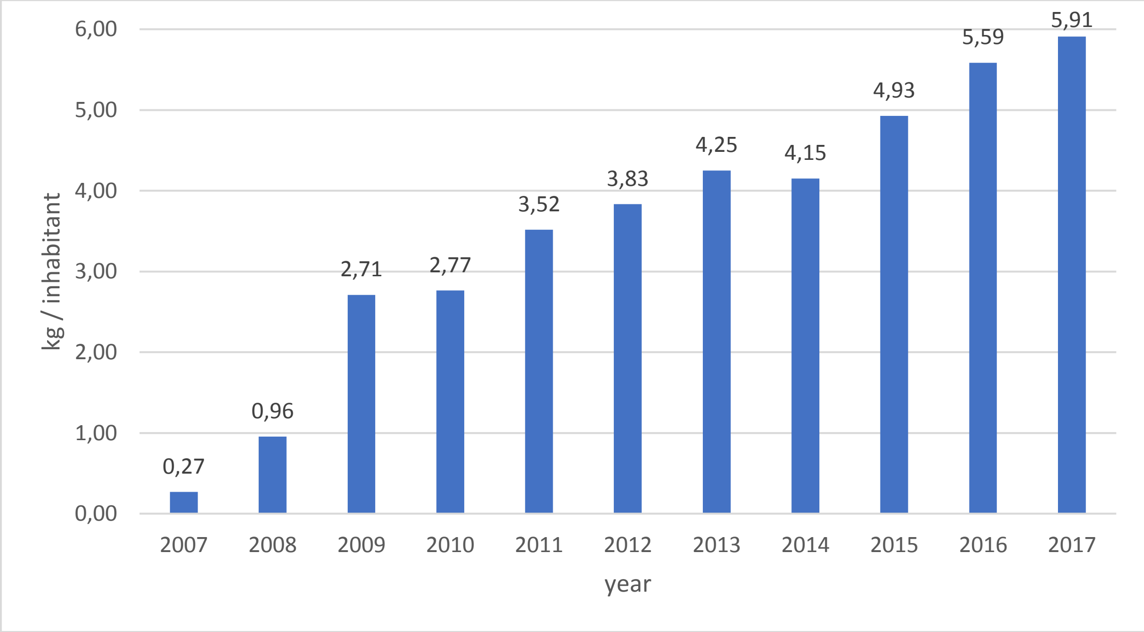

Figure 1. Weight of WEEE collected from households per capita during 2007-2017. Source (Eurostat, 2018).

Table 2.
Minimum annual levels of WEEE collection

No	Waste electrical and electronic equipment from households	Collection rate [%]	
		since 2009	since 2011
1	Large household equipment	24	35
2	Small household equipment	24	35
3	ICT and telecommunications equipment	24	35
4	Audiovisual equipment	24	35
5	Lighting equipment type 2-5	40	43
	Lighting equipment type 6	24	35
6	Electrical and electronic tools, except for large, stationary industrial tools	24	35
7	Toys, leisure and sports equipment	24	35
8	Medical devices, except for all implantable and contaminated products	-	35
9	Control and monitoring instruments	24	35

Source: (Nowakowski, 2015).

Directive 2012/19/EU of the European Parliament and Council on waste electrical and electronic equipment (WEEE), and later on new polnish regulacy (Dz.U. poz. 1688, 2015), was another step in creating a WEEE management system. Until 31 December 2015, the WEEE collection rate amounted to 4 kilograms per citizen. From 2016, the minimum collection rate was 45%, and from 2019 onwards it grew to 65%. By way of deviation, as of 14th August 2016, Poland was obliged to achieve a collection level lower than 45% but higher than 40%. The 65% collection rate was deferred until 14th August 2021 at the latest.

The annual level of WEEE collection from households in Poland, expressed in kilograms per capita, was just over 6.5 kg in 2017. Compared to other European countries, the level of collection in Poland was low (Figure 2). The lowest level of collection was recorded in Romania. The highest collection level in 2017 was in Norway (over 18.7 kg of WEEE per capita). Average collection volume for European Union was also higher than for Poland – 8.3 kg

Figure 2. WEEE collection level in selected European countries 2017. Source (Eurostat, 2020).

Analysis of the data contained in the reports on the functioning of the WEEE management system for the years 2007-2017 (Eurostat, 2020) indicates that the current trend in WEEE collection will not allow Poland to meet the requirements set by the European Union as regards the required levels of collection (Figure 3).

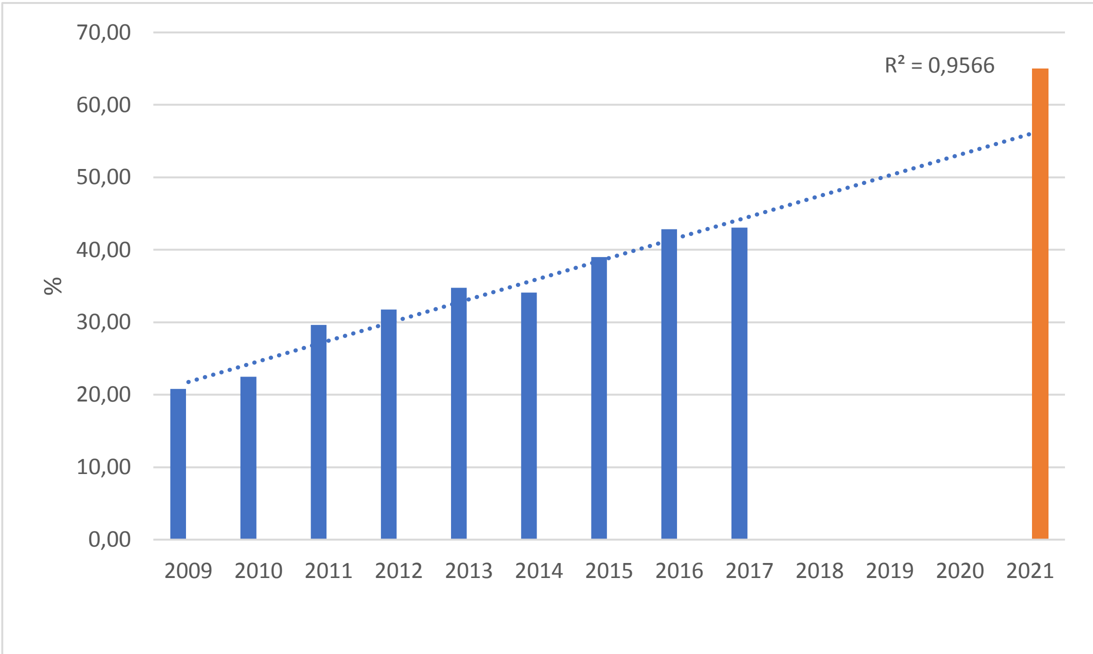

Figure 3. Level of WEEE collection in Poland in 2009-2017 with its extrapolation for 2021. Source: own calculations based on (Eurostat, 2020; Goodship, Stevels, Huisman, 2019).

The low level of WEEE collection in Poland is influenced by gaps in legislation related to the matter, for example, to the functioning of waste electrical and electronic equipment recovery organizations. Another gap is due to low awareness and poorly developed pro-environmental attitudes in the Polish society and an inefficient and ineffective waste collection system Laskowska M. (2018).

Waste electrical and electronic equipment collection system in Poland

Organization of the system of handling waste electrical and electronic equipment in Poland is mainly regulated by the Electrical and Electronic Equipment Waste Act. According to the principle of extended responsibility, producers are obliged to organize collection of WEEE from collectors and to handle WEEE from households. The WEEE management system is financed by consumers in the form of waste management cost (WMC) included in the price of each new piece of equipment.

Logistic approach to the WEEE management system makes it possible to identify three main streams: physical (materials), informational and financial one (Kruczek, 2017; Horodyńska, 2017). The analysis of the physical stream of WEEE flow has been carried out and established waste producers, who are also waste holders, as the first link in the chain of WEEE colection. A waste holder has many opportunities to legally transfer WEEE to the next link. When purchasing new equipment, the customer (holder) may hand over the old piece free of charge, as long as it is of the same type and has the same functionality as the purchased equipment. When delivering a new device to the customer, the retailer is obliged to take back the old one. In case of retail entities with a sales area of at least 400 m^2, the customer is has the right to hand over any piece of WEEE (if none of its external dimensions exceeds 25 cm), free of charge, without the need of purchasing any new equipment. Service points are also authorized to collect WEEE. When equipment repair is technically impossible or unprofitable, the operator is obliged to accept waste equipment. Once an appropriate quantity of waste equipment is collected, it is handed over to the collection unit with which a contract has been signed. Then the equipment is transferred to the next link, which is the handling/processing plant. Entities participating in the transfer are authorized to collect waste equipment and are exempted from the obligation to obtain a waste collection permit (non-professional waste collection activities). The holder may also hand over WEEE to an entity holding a waste collection or handling/processing permit, or to a municipal waste selective collection point (MWSCP) compulsorily established by local (district) authorities (Nowakowski, 2017).

From collection points WEEE goes to treatment plants. At a handling/processing plant, hazardous substances are first removed, followed by fragmentation of parts and separation of raw materials. Hazardous substances, such as e.g. freon, are handed over to entities that deal with their disposal. In small plants, only manual disassembly is carried out. In plants operating on an industrial scale, manual dismantling is followed by mechanical dismantling, which produces raw materials such as metals or plastics. Those are, in turn, sent to recyclers or other non-recycling recovery processes. The physical flows are illustrated in the figure 4.

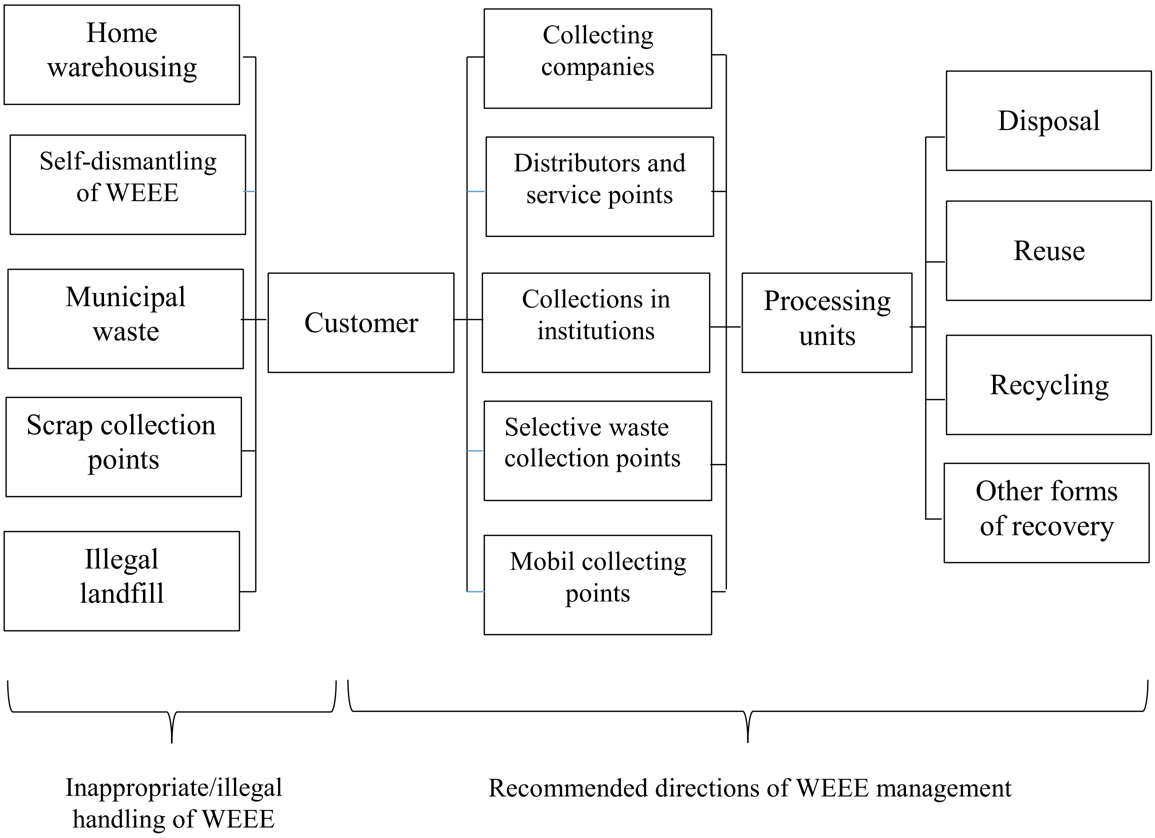

Figure 4. Overall structure of WEEE management system. Source: own elaboration.

The information flow system can distinguish between information that is necessary to perform statutory duties and information required by law, such as certificates, reports or summaries. It is also possible to divide the circulation of information into circulation between individual commercial entities and public administration, as well as between individual public administration authorities. The flow of information is shown schematically in the figure 5.

The system of WEEE management financing is based on the "polluter pays" principle, which is implemented in the form of waste management costs (WMC). WMC is a separate amount which is part of the price of each new product placed on the market. The whole cost of waste management is covered by consumers at the time of purchasing new equipment, and its amount is determined by the producer. WMC should be fully utilized to pay for the WEEE collection, treatment and recycling system. Distribution of funds from WEEE is conducted through two channels. In the first one, distributors transfer the funds to the system themselves. In the second case, the funds are distributed by intermediaries – recovery organizations, which transfer them to treatment facilities (ElektroEko, 2019).

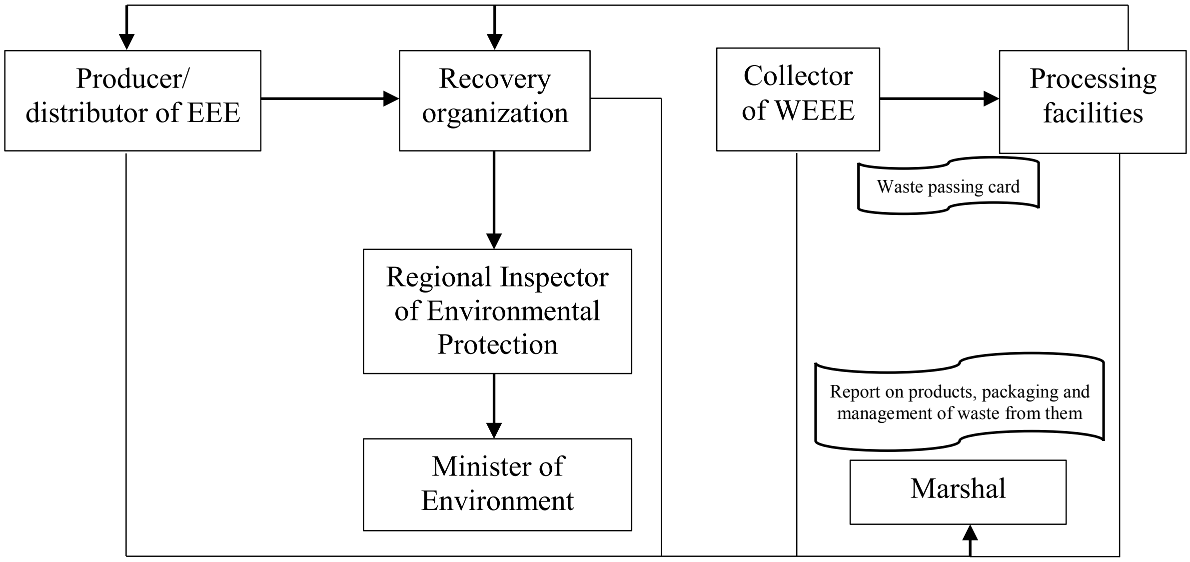

Figure 5. Information flow in the WEEE management system. Source: own elaboration.

In the presented model, a number of disturbances can be identified that affect the deterioration of system performance indicators. One of them is the transfer of WEEE to scrap yards or to municipal waste landfills, which in effect makes it impossible to indicate how much and what type of WEEE is collected and processed. Another is storage and processing of WEEE in inappropriate conditions, resulting in the release of hazardous substances to the environment, as well as high and uncompetitive costs of waste collection and processing by recovery organizations (Kruczek, 2017; Horodyńska, 2017).

Assumptions for the assessment of the WEEE collection system

An effectively and efficiently functioning WEEE collection system is one that is characterized by a high level of collection and which generates benefits for users. The system in Poland is assessed as not functioning correctly. P. Nowakowski (2017) pointed out the factors that affect the effectiveness of the WEEE collection system (table 3).

According to the WEEE Act, the WEEE collection system should take into account the density of population. An effective and efficient WEEE collection system requires that collection points are located in frequently visited places and open at convenient hours. However, a significant percentage of consumers are not even aware where these collection points are located (Goodship, Stevels, Huisman, 2019). Disposal of WEEE together with municipal waste is a common phenomenon in Poland.

Table 3.
Factors influencing the efficiency of the WEEE return logistics chain

Factors		Characteristics
Decision	Location and availability of collection points	Collection points should be easily accessible and located in frequently visited places. Opening hours should include evening time.
	Mobile collection schedules	The mobile collection should be conducted according to a schedule. The best option is repeatability, which affects residents' memory of WEEE collection dates.
	Environmentally friendly attitude	Respecting a separate collection method results in the desire for legal and, consequently, environmentally friendly waste disposal. If there is no interest in environmental protection, WEEE is disposed of together with municipal waste or abandoned.
	Education	Educational activities should be conducted for all age groups. Educational programmes cover the young generation and there are few programmes for target groups in middle age.
	Possible benefits	For many people, the possibility of getting rid of bulky equipment (e.g. washing machine, dishwasher) is connected with the possibility of additional income, e.g. in scrap yards. This method, although run through an unofficial channel, allows for metal recycling. Mass of WEEE passing through a scrap yard avoids the register but ultimately goes to a steelworks.
Economy	Arrangement of the containers	The containers should be adapted to the equipment that is being removed. When left unattended they may facilitate the theft of stored WEEE. The person responsible for supervision must report their filling. To empty containers from multiple locations, software with optimised routes is necessary.
	Design of collection routes	It is necessary to design routes adapted to the anticipated number of WEEE to be delivered. Routes have to be designed in an optimal way – this affects the number of vehicles and staff to handle the route.
	Exchange of information between manufacturers and dismantling plants	This is a requirement for equipment manufacturers, although an effective method of large-scale information exchange has not been achieved so far.
	Choice of dismantling methods	Disassembly methods require efficient staff and efficient processing lines. Depending on labour costs and current prices on the exchanges, the so-called dismantling depth can be adapted to external market conditions.

Source: (Nowakowski, 2017; Kruczek, 2017; Horodyńska, 2017; Goodship, Stevels, Huisman, 2019).

Measurement of WEEE collection efficiency indicators requires taking into account the stream of products (SEE) on the market and the outgoing stream of collected waste generated from those products (WEEE). The basic criterion of effectiveness of a WEEE collection system is the WEEE collection rate calculated by dividing the weight of collected equipment by the weight of equipment available on the market in a given calendar year (Nowakowski, 2015). Comparison of effectiveness indicators for different countries may provide a basis for assessing the effectiveness of a WEEE collection system.

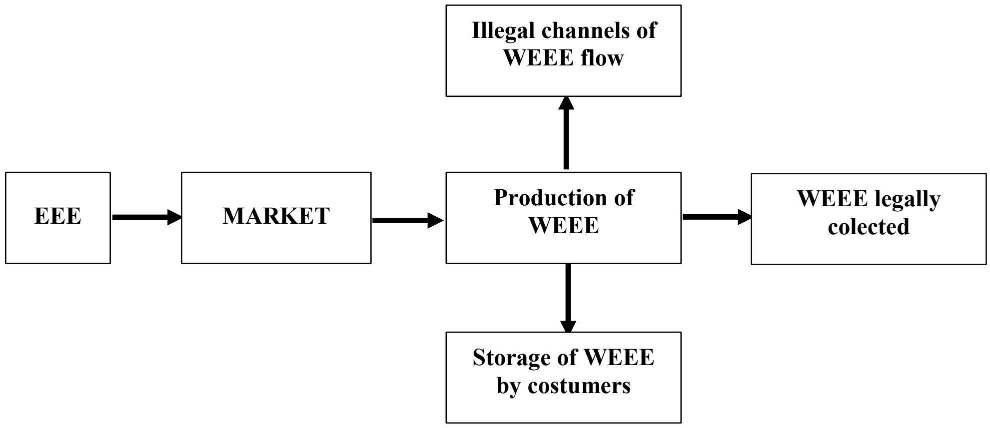

Figure 6. Product and waste streams – efficiency measurement. Source: own elaboration.

$$W_z = \frac{m_l}{m_{ur}} \cdot 100\% \qquad (1)$$

where:

W_z – collection rate,

m_l – weight of WEEE collected in a legal manner,

m_{ur} – weight of equipment placed on the market.

The European Union has obliged Member States to achieve sufficiently high collection rates. The collection rate is expressed as the ratio of the weight of WEEE collected to the average annual weight of SEE available on the market during the previous three years in the Member State concerned.

$$P_z = \frac{m_l}{M_{ur}} \times 100\% \qquad (2)$$

where:

P_z – collection level,

m_l – weight of WEEE legally collected,

M_{ur} – average annual weight of equipment placed on the market calculated according to the formula:

$$M_{ur} = \frac{m_{1ur}+m_{2ur}+m_{3ur}}{3} \qquad (3)$$

where:

m_{1ur}, m_{2ur}, m_{3ur} – weight of equipment placed on the market in each 3 years preceding the year in question.

The level of collection allows to determine the degree of achievement of the Union requirements in accordance with the formula below:

$$S_{ow} = \frac{P_z}{P_{UE}} \qquad (4)$$

where:
S_{ow} – the degree of achievement of EU requirements,
P_z – collection level (in Poland),
P_{UE} – collection level required by the European Union.

Improper handling of WEEE by consumers leads to a reduction in the weight of waste collected by legal means and thus affects the size of the collection rate. Results of studies concerning influence of citizens' behaviour on the effectiveness of waste electrical and electronic equipment collection published by Nowakowski (2015) make it possible to determine the total weight of generated WEEE.

$$m_c = m_l + m_{nl} + m_s \quad (5)$$

$$m_l = \sum_{i=1}^{n} m_i \quad (6)$$

$$m_{nl} = \sum_{j=1}^{k} m_j \quad (7)$$

$$m_s = \sum_{p=1}^{1} m_p \quad (8)$$

where:
m_c – total mass of WEEE (mass of WEEE produced by consumers),
m_l – mass of WEEE legally collected,
m_{nl} – mass of WEEE removed from households illegally,
m_s – mass of WEEE stored,
n – number of waste appliances legally collected,
k – number of waste appliances removed from households,
l – number of waste appliances stored in households.

On the basis of the total weight and the weight of WEEE legally collected, an efficiency index for disposal of WEEE from households can be determined:

$$W_u = \frac{m_l}{m_c} \quad (9)$$

where:
W_u – efficiency ratio for the disposal of WEEE from households,
m_l – mass of WEEE legally collected,
m_c – total mass of WEEE.

Available literature very often uses the annual WEEE collection rate per citizen. It is calculated based on the mass of WEEE collected in a given country during the year divided by the population of that country.

$$w_z = \frac{m_l}{L} \quad (10)$$

where:
w_z – collection rate,
m_l – weight of WEEE legally collected,
L – country population.

The above-mentioned indicators make it possible to assess the WEEE collection system by individual groups of equipment and to compare collection systems operating in different regions.

Summary

The aim of the environmental policy of the European Union is to preserve, protect, and improve the quality of the environment and to use natural resources rationally. This policy necessitates the development of an economic concept in which products, materials and raw resources should remain in the economy for as long as possible and waste generation should be minimized as much as possible. Despite the introduction of Directive 2002/95/EC aimed at limiting the use of certain hazardous substances in electrical and electronic equipment, substances such as mercury, cadmium, lead, chromium, polychlorinated biphenyls (PCBs) and ozone depleting compounds will still be present in WEEE for many years (Nowakowski, 2015). Hazardous substances are still a major problem in waste management and insufficient recycling causes loss of valuable resources. Therefore, improvement of the efficiency and effectiveness of WEEE waste collection as well as putting the resulting materials back into circulation are a serious issue. This will significantly contribute to a more economical use of raw materials and will reduce the amount of generated waste. Against that background, the concept of circular economy is developing more and more intensively, taking into account all stages of life of products: from their design, through production, consumption, collection of waste, to their recycling. The Polish WEEE waste management system still lacks solutions aimed at closing the material flow loop. This situation is aggravated by gaps in the existing system, and therefore striving for its parameterization and ordering of flows is crucial for the elimination of disruptions and successful implementation of the new management concept.

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