www.ees.uni.opole.pl
ISSN paper version 1642-2597
ISSN electronic version 2081-8319
Economic and Environmental Studies
Vol. 16, No. 4 (40/2016), 605-625, December 2016

The e-waste management system in Poland

Marcin CHOLEWA and Joanna KULCZYCKA
AGH University of Science and Technology, Faculty of Management, Poland

Marzena SMOL
Division of Strategic Research, Mineral and Energy Economy Research Institute of the Polish Academy of Sciences (MEERI PAS), Poland

Abstract: The Waste Electronic and Electrical Equipment Regulations (WEEE) are intended to reduce the amount of e-waste being disposed of within the EU, and require EEE producers to pay for its reuse, recycling and recovery. It is estimated that 25% of the mass of WEEE produced in the EU-27 is collected and processed, and the remaining 75% is not recorded. In Poland a total of 1.5 kg/person was collected in 2008, and 4.4 kg/person in 2014, but it is not enough at the moment because in 2021 Poland will be obliged to recover 11 kg/person. The paper presents the barriers and challenges of the e-waste management system in Poland including an analysis of the legal, technological, ecological and market aspects, focusing on the recovery of non-energy raw materials. It was shown that the existing system of waste collection with Extended Producers Responsibility (EPR) based on EU regulations required some improvements to boost recovery and recycling of valuable materials and to be in line with the strategy for a circular economy. Despite the fact that there are over 1,500 companies involved in waste collection in Poland and waste is picked up for free from citizens, there are more and more activities promoting proper waste segregation, and waste collection is still the weakest link. The recycling companies are mainly SMEs that already implement the latest technologies and strategies for CSR and ISO 14001 certification and they are able to recover valuable resources. However, the variability of market conditions (low metal price) and regulations, as well as the dominance of the large Organisation of Electrical and Electronic Equipment Recovery (OEEER), results in competition with one another in order to obtain the lowest price, and as a result the recycling companies do not fully exploit their capacities. The consequence of these activities is the development of a grey zone. However, due to the increasing importance of materials recovery from waste and the fact that it is a priority in the most recent strategic documents in Poland, it should undergo dynamic development.

Keywords: Waste Electrical and Electronic Equipment (WEEE or e-waste), recycling, waste management system, WEEE management

JEL codes: O21, O32, O33, O37, O38

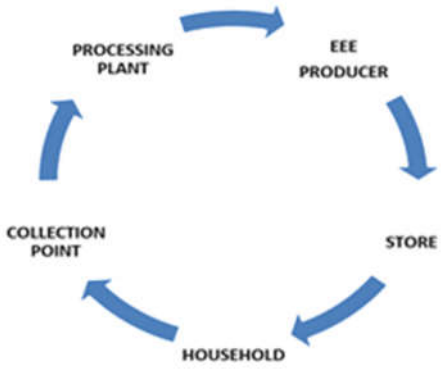
Correspondence Address: Marzena Smol, Division of Strategic Research, Mineral and Energy Economy Research Institute of the Polish Academy of Sciences (MEERI PAS), 7 Wybickiego St., 31-261 Cracow, Poland, Tel.: (+48) 12 617 1651 Fax (+48) 12 632 2245 E-mail: smol@meeri.pl

1. Introduction

In the last three decades the production and use of electrical and electronic equipment (EEE) has significantly increased (Jofre and Marioka, 2005) due to technological innovations and new applications of EEE (Buekens and Yang, 2014). It is also predicted that the scale of Waste Electronic and Electrical Equipment (WEEE or e-waste) generation will increase as IT technology and electronics are undergoing dynamic development (Maris et al., 2015), which means that electronic product life cycles are getting shorter over time and items of EEE are fast becoming outdated and must be replaced (Van Schaik et al., 2010).

The management and recovery of materials from WEEE is on the agenda of both the EU and many individual countries because improper disposal of such material could have a significant impact on the environment. Efficient WEEE management has become a key goal due to the pollution that could potentially result from the hazardous substances contained in its components. In addition the reuse of its materials could be an important potential supply of resources (Pérez-Belis et al., 2013). Moreover, the issue of the more efficient use of waste, including WEEE, is emphasised by the EU in 'A zero waste programme for Europe' (COM 398, 2014). 'Zero waste' is one of the most visionary concepts for solving waste problems and seems to be a promising avenue for the management of waste in the future (Zaman and Lehmann, 2013). It assumes that moving towards a more circular economy (CE) is an essential way to deliver the resource efficiency agenda established under the Europe 2020 Strategy for smart, sustainable and inclusive growth. Greater and sustained improvements of resource efficiency performance can bring large economic benefits (Quaghebeur et al., 2013). The proper EEE life cycle in accordance with a 'zero waste' strategy is shown in Figure 1.

Figure 1 The proper EEE life cycle



Source: Author's own diagram

The European Union has instituted policies such as the WEEE (2012/19/EU, 2012) and the Restriction of Hazardous Substances 2 RoHS, (2011/65/EU) Directives, aimed at improving the environmental performance of electronic products (Ylä-Mella et al., 2014). These two directives emphasise the concept of Extended Producer Responsibility (EPR) which makes the producer responsible for the entire lifecycle of their own products (Gamernini et al., 2010). EPR is defined by the Organization for Economic Co-operation and Development in its guidance manual for governments as "an environmental policy approach in which a producer's responsibility, physical and/or financial, for a product is extended to the post-consumer stage of a product's life cycle" (OECD, 2001) (Manomaivibool and Hong, 2014). The Member States under the EU regulations have to contribute to reduce the amount of WEEE being disposed of and require EEE producers to pay for its reuse, recycling and recovery (Sthiannopkao and Wong, 2013). It is estimated that 25% of the mass of WEEE produced in the EU-27 is collected and processed, and the remaining 75% is not recorded. This may be caused by inadequate waste processing technology. The developed countries are those most affected by the problem of the growing mass of WEEE (Osibanjo and Nnorom, 2007). In some EU countries the system is well developed, i.e. in 2013 about 17.3 kg/person of WEEE was collected in Sweden, 7.4 kg/person in the UK, and 9 kg/person in Austria. Unfortunately, most developing countries are yet to catch up with this innovation in waste management (Nnorom and Osibanjo, 2008). A total of 1.48 kg/person was collected in Poland in 2008, and 4.39 kg/person in 2014, i.e. about 168,900 tons of WEEE, but in 2021 Poland will be obliged to recover 11 kg/person. It can be seen from the amount of WEEE collected that

the waste mass is growing steadily, so ways of recovering and processing this waste have become increasingly important (Reports on the functioning…, 2006-2014; Cholewa et al., 2014).

According to EU regulations, the priority in Polish national waste management policy is to prevent waste generation or reduce its volume and harmfulness; next is materials reclamation by recycling, reuse, regeneration or other processes leading to the recovery of secondary materials; and finally safe disposal (Grodzińska-Jurczak et al., 2006). The paper presents the role of key players in WEEE chain in Poland, the barriers and challenges faced by the e-waste management system including an analysis of the legal, technological, ecological and market aspects, focusing on the recovery of non-energy raw materials from WEEE. These issues are particularly relevant in the light of the changing requirements for recovery and recycling already introduced, as well as planned, in recent strategic documents in Poland. These include the National Plan for the Development of a Low-Carbon Economy as well as a National Strategy for Smart Specialisation (www.mg.gov.pl).

2. Methods and scope

The present study is a summary of the current state of knowledge in the research area showing the importance of proper waste electrical and electronic equipment (WEEE) in Poland. The work focuses on pointing out barriers and challenges in WEEE management system, including an analysis of the legal, technological, ecological and market aspects, focusing on the recovery of non-energy raw materials. The paper present also the role of key players in WEEE chain. The review is based on world literature. The selection of primary literature was based on full-text databases (Elsevier Scopus, Elsevier ScienceDirect, Google Scholar, BazTech, EUR-lex) and available publications. The remaining resources used came from a range of peer reviewed journals. There are also EU Communications, EU Directives and Polish legal regulations used in the review. An important source of data comes from the statistical database and reports on WEEE in Poland.

3. The component materials of WEEE

Electronic products turn into e-waste when they are deemed at the end of their useful life. Nonfunctioning or obsolescent TVs, computers, printers, photocopiers, fax machines, cell phones,

home appliances, lighting equipment, games and suchlike items, become e-waste when no longer wanted (Jang, 2010; Sthiannopkao and Wong, 2013). The different types of materials found in WEEE make it difficult to give a generalised material composition for the entire waste stream. The literature data indicate five categories of materials: ferrous metals, non-ferrous metals, glass, plastics and other materials (Ongondo et al., 2011). The most common materials found in EEE (by weight) are iron and steel. They account almost half of the total weight of WEEE. The second largest component by weight is plastics, representing ~21% of WEEE. Non-ferrous metals, including precious metals, represent ~13% of the total weight of WEEE (with copper accounting for 7%). The metal content has remained the dominant fraction compared to pollutants and hazardous components which have seen a steady decline (Widmer et al., 2005). However, the EEE contain many materials requiring special end-of-life handling, most prominently lead, mercury, arsenic, chromium, cadmium, and plastics capable of releasing, dioxins and furans as well as other compounds, (Sthiannopkao and Wong, 2013). Due to the presence of hazardous substances in e-waste, there are predictable negative impacts on the environment and human health when WEEE is disposed of or recycled without any controls (Widmer et al., 2005). The main objective of selective collection is to enable proper recycling of the hazardous waste materials. The ingredients, mixtures and components which must be obligatorily removed from selectively collected e-waste are given in the Directive 2012/19/EU. These include:

- capacitors containing polychlorinated biphenyls (PCB),
- mercury containing components, such as switches or backlighting lamps,
- batteries,
- printed circuit boards of mobile phones generally, and of other devices if the surface of the printed circuit board is greater than 10 square centimetres,
- toner cartridges, liquid and paste, as well as colour toner,
- plastics containing brominated flame retardants,
- asbestos waste and components which contain asbestos,
- cathode ray tubes,
- chlorofluorocarbons (CFC), hydrochlorofluorocarbons (HCFC) or hydrofluorocarbons (HFC), hydrocarbons (HC),
- gas discharge lamps,
- liquid crystal displays,

- external electric cables,
- components containing refractory ceramic fibres, radioactive substances (Directive 2012/19/EU).

WEEE recycling should be conducted taking into consideration the concept of sustainable development (Agamuthu, Dennis, 2013). Therefore, WEEE minimisation and handling processes need special attention in both developed and developing countries (Mallawarachchi and Karunasena, 2012).

4. The WEEE management system in Poland

The recovery and recycling of WEEE, such as mobile phones, computers, screens, monitoring devices, and kitchen appliances can be one of the largest potential sources of mineral raw materials, but the rate of recovery is still low in Poland. It is estimated that, the growth rate of WEEE is three times higher than other types of waste (3-5% per year). According to the Chief Inspectorate of Environmental Protection (CIEP), every citizen in Poland generates about 14 kg of electronic waste annually of which about 4 kg are recovered. Most of the waste collected is transferred to recycling processing plants (Tables 1, 2).

Table 1. The WEEE market in Poland in 2006-2014 per capita

WEEE [kg per person]	*2006*	*2007*	*2008*	*2009*	*2 010*	*2011*	*2012*	*2013*	*2014*
Generated	6.76	14.60	14.79	11.73	12.64	13.38	12.49	12.63	13.48
Processed	0.16	0.66	1.31	2.65	2.69	3.94	4.14	4.16	4.22
Collected	0.13	0.71	1.48	2.85	2.91	3.72	4.08	4.46	4.39
Recovered in processes other than recycling	0.01	0.04	0.02	0.04	0.01	0.02	0.03	0.02	0.03
Recycled	0.01	0.40	0.58	2.30	2.29	3.35	3.47	3.37	3.31
Re-used	0.00	0.00	0.00	0.02	0.01	0.02	0.02	0.03	0.02
Polish population [thousand people]	38,125	38,116	38,136	38,167	38,530	38,538	38,533	38,496	38,479

Source: Author's own analysis based on: (Reports on the functioning of the waste electrical equipment management system for the years 2006-2014).

Table 2. The WEEE market in Poland in 2006-2014 [Mg]

WEEE	*Generated*	*Processed*	*Collected*	*Recovered in processes other than recycling*	*Recycled*	*Re-used*
2006	257,726.1	6,040.1	5,031.2	349.7	457.1	0.1
2007	556,470.7	25,154.7	27,173.9	1,538.6	15,085.6	13.9
2008	564,179.2	49,790.1	56,425.8	628.8	22,137.5	9.0
2009	447,725.4	101,127.8	108,792.5	1,516.1	87,884.4	823.1
2010	487,108.3	103,689.8	112,246.2	302.5	88,162.5	340.3
2011	515,666.8	151,859.0	143,339.8	816.1	129,054.2	582.3
2012	481,230.9	159,413.7	157,178.3	1,033.7	133,701.2	795.8
2013	486,180.0	160,290.1	171,727.6	914.8	129,771.0	1,139.1
2014	518,868. 3	162,362. 8	168,932.0	1,113.9	127,190.1	658.0

Source: Author's own analysis based on: (Reports on the functioning of the waste electrical equipment management system for the years 2006-2014).

As is shown in Table 1, the amount of WEEE generated per capita in Poland in 2014 was two times higher than in 2006. The processed rate of WEEE is growing from 2.4% in 2006 to 31.3% in 2014. The progressive increase is predicted also for WEEE which is recycled and re-used. Table 2 shows that the amount of WEEE in Poland growing dynamically since 2006. In 2014 the amount to generated WEEE was more than two times higher than in 2006.

The Waste Statistics Regulation of the EU is the main existing overall measurement framework for waste in general. However it is too generalized to get sufficient insight into e-waste. For e-waste specifically, there is a reporting obligation and target setting in the WEEE Directive. Here reporting focuses on the amounts put onto the Market (PoM) and e-waste collected for respectively 10 and 6 e-waste categories. However, the reporting does not capture the complete dynamics of the e-waste flows, such as cross-boundary movement of e-waste and the export of used EEE for reuse. Most countries lack any official measurement of e-waste (Balde et al., 2015). Data on foreign trade in WEEE in Poland are not available from Central Statistics Office, mainly due to the inherent characteristics of waste. There are only summary data for selected product groups, e.g. waste containing precious metals. Table 3 shows that the trade of such waste is mainly with EU countries with exports in a dominant position. However, the total quantity of exports decreased from 592 kg in 2011 to 308 kg in 2013.

Table 3. Foreign trade of waste contained precious metals in Poland (CN code: 7112 30, 91, 92, 99)

Direction of Import/Export	*Import [kg]*			*Export [kg]*		
	2011	*2012*	*2013*	*2011*	*2012*	*2013*
Developing countries	0	0	16,377	52	0	1,596
Other developed countries	0	0	863	0	159	79
Central and East European Countries	0	0	509	0	0	0
European Union	809	4,464	26,074	591,915	746,190	772,964
Total	**809**	**4,464**	**43,823**	**591,967**	**746,349**	**307,770**
7112 30 ash containing precious metal or precious-metal compounds 7112 91 of gold, including metal clad with gold but excluding sweepings containing other precious metals 7112 92 of platinum, including metal clad with platinum but excluding sweepings containing other precious metals 7112 99 other						

Source: Source: Author's own analysis based on: (CSO, 2015).

A proportion of the world's electronic products and waste are exported to Africa and Asia, often illegally, for re-use. On the one hand this is a positive trend as it helps to reduce disparities in the development of information technologies between rich and poor countries. Also, this is correct from an environmental point of view because it extends the life of EEE. On the other hand, when it comes to the final disposal and treatment of used EEE, these countries are unprepared for the proper handling of hazardous waste. There is a lack of adequate regulation, not only in terms of environmental standards, but also in relation to the recycling and disposal systems which exist in rich countries (Second Life Electro-waste, 2012).

The market for the recovery of WEEE is growing steadily, mainly due to the activity of SMEs. However, dynamic growth will only occur after legal solutions compatible with Directive 2012/19/EU have been transposed into legal arrangements since this will result in better enforcement of regulations. This occurred in Poland in 2015.

There are many activities for promoting recycling, i.e. municipalities are obliged to provide information on such disposal points (where e-waste is collected for free from citizens) to their citizens and details are also presented on the website of the European Recycling Platform www.erp-recycling.pl. Many companies conduct ecological education dedicated to waste segregation and recycling. One form of ecological education is training for organised groups or for individual employees. The subject and scope of training is adapted to individual needs and customer knowledge - the training framework includes themes which are problematic for the customer ordering the training. Courses are normally carried out at the premises of the client

company. There is also the possibility of training conducted in the organiser's classroom. In general, training is preceded by a meeting at the headquarters of the client company in order to get acquainted with problematic issues, materials collection (e.g. training on the packages register), and often to make a local vision, take pictures in the company area and an interview with the employees responsible (e.g. training on waste segregation). Polish Municipal Waste Disposal Plants have published educational leaflets concerning the selective collection of waste. These leaflets contain all the information available related to the proper conduct of selective collection in households and instructions as to which waste should be disposed of in appropriate containers. Leaflets are periodically distributed via the Association of Municipalities of the Region concerned, mainly in schools, offices, shops, etc.

There is also the promotion of proper waste segregation in kindergartens and schools. Books are published addressed to the youngest environmentalists. The book introduces the world of recycling in a clear and readable way. Excellent descriptions and pictures show the young audience a lot of valuable and interesting information concerning the collection, recycling and disposal of waste. Numerous riddles, puzzles and crosswords check and test the knowledge acquired while reading. Schools also organise cleaning days as part of the 'Spring Cleaning of the Region' and 'Clean Up the World' events. Polish companies always take an active part in these events and their participation provides free transport and reception of the waste collected. Municipal Waste Disposal Plants also organise plant tours for children, youth and representatives of local government. The waste life cycle at the plant, from weighing the waste entering the plant to the final output (raw material recovery or ballast directed to landfill), is presented in the most simple and understandable way. The main purpose of these trips is to make people aware of the problem which municipal waste presents, and to encourage them to separate waste in their homes.

There are also economic instruments requiring the recovery of WEEE. These include a product fee for enterprises putting household equipment on the market which must be paid in case of failure to achieve an appropriate rate of collection. These enterprises are obliged to collect at least 45% by weight of the equipment they have introduced onto the market in the previous calendar year, and in Poland it will be a minimum level of 65% collection rate that is required in 2021.

The enterprises putting EEE on the market can sign an agreement with the Organisation of Electrical and Electronic Equipment Recovery (OEEER) which is responsible for meeting the

collecting and recycling obligations on behalf of enterprises. The enterprises putting EEE on the market can sign the agreement with many OsEEER which creates competiton among them. Unfortunately, it may encourage the creation of illegal trade with recycling companies. The OEEER should operate as a joint-stock company with a capital of at least 5 million PLN (1.2 million EUR). The list of organizations given by the CIEP is shown on Table 4. Currently, the Polish OsEEER have signed almost 5,000 contracts with companies putting EEE on the Polish market, i.e.:

- producing and putting EEE on the market under its own trademark,
- putting equipment produced by other companies on the market using its own trademark,
- being active in the import of equipment,
- being active in the intra-Community acquisition of equipment.

Those companies are obliged to collect and process WEEE and this commitment can be taken over from them by the OsEEER.

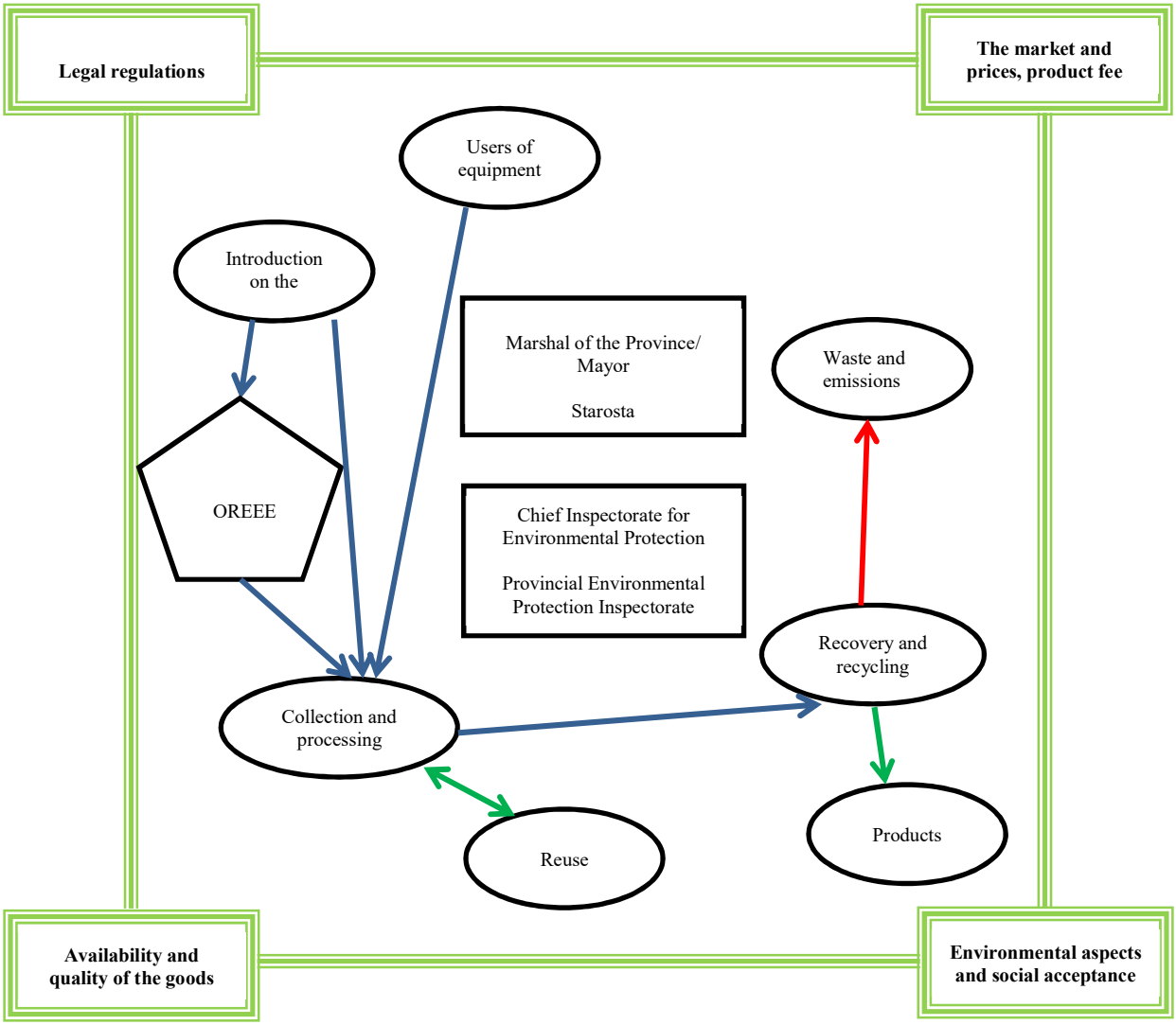
Table 4. Polish Organisations of Electrical and Electronic Equipment Recovery (OEEER)

No.	Registration number	Organization	The managing authority's registered office	Voivodeship	Number of companies collecting and processing EEE
1	E0000007S	**ELEKTROEKO** Organisation of Electrical and Electronic Equipment Recovery SA	Warsaw	Masovian	200
2	E0000156S	The European Recycling Platform, Polish Organisation of Electrical and Electronic Equipment Recycling SA	Warsaw	Masovian	169
3	E0000413S	**AURAEKO** Organisation of Electrical and Electronic Equipment Recovery SA	Warsaw	Masovian	1,221
4	E0000628S	**BIOSYSTEM ELECTRO-RECYCLING** Organisation of Electrical and Electronic Equipment Recovery SA	Cracow	Malopolska	1,274
5	E0008826S	**CCR RELECTRA** Organisation of Electrical and Electronic Equipment Recovery SA	Warsaw	Masovian	856
6	E0009822S	**ELECTRO-SYSTEM** Organisation of Electrical and Electronic Equipment Recovery SA	Warsaw	Masovian	512
7	E0010115S	**DROP** Organisation of Electrical and Electronic Equipment Recovery SA	Warsaw	Masovian	241
8	E0011772S	**TOM** Organisation of Electrical and Electronic Equipment Recovery SA	Szczecin	Western Pomerania	472

Source: Author's own analysis based on: Chief Inspectorate for Environmental Protection, 2015 (gios.gov.pl).

Those enterprises putting EEE on the market which have not signed an agreement with this kind of organisation are required to bring financial security (for the calendar year) to finance the collection, treatment, recovery and disposal of WEEE. The existing system of WEEE management in Poland is presented on Figure 2.

Figure 2. The scheme for waste electrical and electronic equipment (WEEE) collection and recycling in Poland (OEEER - Organizations of Electrical and Electronic Equipment Recovery)



Source: (Hausner, 2015)

5. Characteristics of the WEEE market

All entities involved in bringing hardware onto the market, collecting used equipment, waste treatment, recycling and other recovery processes than recycling and also the OEEER are required to register in the register maintained by the CIEP. As of 2 October 2014, 15,435 companies and

organizations are registered. This number has increased significantly (by about 1,111) since the end of 2013. Particularly strong growth has been seen in the collection sector – 589 companies.

Table 5. The number and structure of the companies involved in the EEE trade in Poland in 2013 and 2014

Date	Entrepreneurs					
	Introduction of EEE	Recovery	Collection	Processing	Processing other than recycling	Recycling
31.12.2013	5 356	9	12 639	178	12	118
02.10.2014	5 647	8	13 228	178	13	119
Difference	+ 291	- 1	+ 589	0	+ 1	+ 1

Source: Author's own analysis based on: (Reports on the functioning of the waste electrical equipment management system for the 2013-2014, Register of companies and organisations recovering electrical and electronic equipment CIEP, 2016).

Table 5 shows the structure of the companies involved in the EEE trade in Poland at the end of 2013 and by 2 October 2014. Some of these companies operate in several areas at the same time (e.g. importers – collector). It is estimated that the Polish market for the recycling of WEEE is under development and in early growth, and still very fragmented (only 119 registered recycling companies, mainly SME). However, it is expected that in the future the sector will consolidate, which can provide many interesting business opportunities. Companies that adopt unusual business strategies or have large processing potential will be able to offer competitive services and prices (There is a growing demand…, 2013).

In 2013, 12,639 companies were operating in the field of WEEE collection, the vast majority of them (18.0%) concentrated in the Masovian Voivodship. The average rate of WEEE collection (gios.gov.pl) in 2013 amounted to 35.32% (2012: 32.66%), which is 4.44 kg per capita (Reports on the functioning, 2013), which represents a significant increase compared to previous years (0.13 kg / person was collected in 2006).

Three processes can be distinguished involved in the treatment of WEEE: processing in treatment facilities (R12), recovery other than recycling (R1- R9), recycling (R2 - R9). According to the definition contained in the Act on WEEE (Journal of Laws 2005, No. 180, Item 1495 as amended) and the Act on Waste (Journal of Laws 2013, Item 21), 178 processing plants (meeting the definition of process R12) were operating in Poland. These plants processed 160 290.1 Mg of waste equipment, and had a total processing capacity of 613 542.23 Mg / year. In terms of

recycling, 118 entrepreneurs process 129 711.0 Mg of WEEE and their processing capacity amounted to 5 613 742.0 Mg / year. However, in the case of processes other than recycling there were 13 companies which processed 914.8 Mg of WEEE and had a total capacity of 497 720.0 Mg / year. In addition, 1 139.1 Mg of WEEE has been re-used, which is approximately 0.71% of the mass of WEEE collected. Most of the re-used waste contained items of IT and telecommunications equipment. It should be noted that all waste equipment was processed in Poland. The high processing capacity of enterprises involved in the processing of WEEE and the low quantities processed are caused by the insufficient quantities of waste collected. The reason may be the relatively short duration of operation of the Polish regulations regarding the collection of WEEE and the modus operandi of the system of collecting electrowaste (Functioning and irregularities, 2010, Cholewa et al., 2014).

6. WEEE market in Poland - barriers

The effective recovery of valuable materials from WEEE is required in order to implement innovative technological solutions. In order to support the development of investment in the circular economy and reduce the reluctance of companies, the EU Commission has declared that it will demonstrate the opportunities for moving towards a CE under the EU Research and Innovation Programme (Horizon 2020) at European level through large-scale innovation projects targeted at cooperation within and between value chains, fostering the development of skills and supporting the market application of innovative solutions (COM 398, 2014). Polish recycling companies started to prepare some proposals, but they are much more active in applying for grants from Structural Funds. In Poland, there have not yet been special programmes dedicated to such solutions and recyclers have to compete with other priorities i.e. the production of renewable energy, or municipal waste management. E-waste is usually collected gratis by municipal waste companies and E-waste recycling companies are mostly SMEs which mainly have orders from OEEER. As OEEER try to reach the lowest prices by competing with each other, the recycling process often cannot be economically efficient for recycling companies which creates a ‘grey zone’ and trade in receipts (Functioning and irregularities…, 2010). Due to OEEER competing with one another in order to obtain the lowest price, the cost of collection and processing WEEE has shown a steady decrease by a few percent in recent years. For example last year the OEEER paid an

average of 0.07 PLN/kg. for the collection, transport, processing and recycling of e-waste, whereas in 2008 it was 0.9 PLN/kg. It is worth mentioning that cost of recycling 1 kg of e-waste amounted to 0.97 PLN/kg (Okońska-Kubica, 2016). As a result, it often happens that companies process only a specific type of waste, e.g. excluding waste containing the largest quantities of hazardous substances impacting negatively on the environment.

Even though there are many SMEs on the market, the method of collection of e-waste is not effective. Moreover, not all processing plants declared activities in the processing of waste equipment, despite having the appropriate authorisation decision. The annual inspections in these plants indicate many irregularities (only 99 out of 179 inspections carried out in 2013 gave a positive result). The most frequent comments reported mainly concerned the lack of records or the existence of unreliable records on waste, waste transfer to entities not listed in the register, storage of waste inconsistent with the applicable regulations, and also failure to immediately remove hazardous waste (Cholewa et al., 2014).

Nowadays the main methods of WEEE processing in Poland are manual disassembly and a mechanical method consisting of the grinding and multi-separation of particulate materials. Additions to these two main approaches include specialised technologies focused on processing dismantled components, such as the processing of printed circuit boards using pyrolysis. The most flexible, achieving a high rate of materials recovery, is the process of manual disassembly which permits the processing of different types of WEEE. However, this is labour-intensive and requires direct human contact with WEEE containing hazardous substances. But manual disassembly is often the first stage of WEEE treatment in mechanical processing - milling - designed to isolate hazardous substances and components that can't be handled in this manner. Mechanical processing permits the efficient recovery of resources from waste but due to the high energy consumption of the process there is a great need for new technologies for the recovery of high purity materials in a highly efficient manner and not requiring such large amounts of energy. For some types of waste, mass production methods such as robots can be used to perform repetitive tasks. As a result, it becomes possible to process large volumes of waste in a cost effective manner. Currently there is a great deal of research being carried out on the use of robotics technology for WEEE processing. Examples include work on creating model lines for the disassembly of LCD monitors, or the automation of the disassembly of components from old desktop computers (Szałatkiewicz, 2011). However, most of this work is at an early stage of research, like the work on solutions for the

thermal treatment of waste. Research is being undertaken in Poland on the use of high-temperature processing and the disposal of selected types of WEEE. One of these is related to an electronic waste incineration reactor with fluidized bed furnaces or plasma.

Discussion on improving environmental performance in the EEE industries and making decisions on waste management is also an important factor. It would be worth including tools such as Environmental Management Systems (EMS) (Pieres et al., 2011) in such an analysis, especially its Environmental Impact Assessment (EIA) (Safont et al., 2012) and Social Impact Assessment (SIA) elements (Esteves et al., 2012). EMS provides a structured approach to company management and allows the regulating authority to gain awareness and control of the performance of a project that can be applied at all stages of the life cycle.

Some recycling companies have already introduced many technological as well organizational improvements by introducing the ISO 14001 standard and developing Corporate Social Responsibility (CSR) strategies.

7. SWOT analysis for WEEE in Poland

SWOT analysis can identify barriers and challenges to the development of the recycling industry dealing with the disposal of WEEE in Poland. This shows the strengths, weaknesses, opportunities and threats existing on the Polish market.

Table 6. SWOT analysis of Polish WEEE system

Strengths	Weaknesses
▪ Poland is a significant producer and exporter of EEE ▪ Presence of e-waste collecting companies ▪ Great importance of the recycling industry for global socio-economic development due to improved accessibility of resources and the development of industry using recycled products, including the use of renewable raw materials ▪ The use of recycled materials is associated with a reduction in the energy intensity of processes in many industries and the minimisation or elimination of landfill ▪ A good level of processing of secondary raw materials using innovative foreign technologies for recycling and processing which contributes to increasing innovation in the Polish economy ▪ A cooperation network of Polish SMEs from the recycling sector has already been developed (e.g. the Waste Management and Recycling Cluster).	▪ High risk in business operation for recycling companies due to fluctuations in market conditions for the range of recyclables ▪ The need to incur high levels of investment in the technological infrastructure required for the processing and recovery of certain types of waste, including e-waste ▪ Insufficient funds for investment and development companies – many companies sell semi-products ▪ Lack of real cooperation between science and business in the recycling industry ▪ No system solutions that promote recycling ▪ Lack of R & D resources in private operators in the recycling industry and very low possibility of support for research projects, and consequently a low commitment of manufacturing companies to R & D activities related to the recycling of waste and the use of secondary raw materials ▪ Lack of national high-tech (technical and technological solutions) to support recycling and materials recovery ▪ The activities of the illegal "grey" zone (e.g. collection centres conducting illegal removal of old equipment without authorisation and without the need to satisfy a number of requirements and standards) ▪ Competition between large, innovative foreign companies in acquiring and recycling waste.
Opportunities	**Threats**
▪ The presence of innovative, financially stable companies interested in implementing new technologies in this sector ▪ Access to technology and scientific achievements through increased participation in EU research projects ▪ An increase in ecological culture ▪ Customising patent law and law on inventions to stimulate technological innovation ▪ The introduction of an EU Strategic Plan for the Implementation of the European Partnership for Innovation in the Field of raw materials and the construction of a European Innovation Partnership in this area ▪ Promoting recycling and efficient sourcing of minerals within the EU, in particular via the Structural Funds and Horizon 2020. ▪ Prepared work on strategy for non-energy raw materials by Polish Ministry	▪ Illegal export of waste ▪ Inadequate state subsidies for activities related to recycling, waste treatment and environmental protection ▪ Lack of legal and organisational solutions for reducing the activity of the illegal recycling sector ▪ Frequently changing legislation on recycling and waste management and lack of clear instruments to encourage such action ▪ Low level of education in the field of technology related to recycling and substitution. ▪ Lack of real cooperation between OsEEER

Source: Author's own assessment based on: (National Plan for Smart Specialisation and Waste Management and Recycling Cluster).

It is worth emphasising the need for more widespread environmental education in the field of collection of WEEE, but awareness is still low and many collection companies compete with each

other. There are also those that make up the agreement and clusters, such as The Waste Management and Recycling Cluster, and which implement projects through different funds e.g. Swiss Fund - CSR strategies, or such as Polblume or the Center for Recycling Cooperation.

8. Conclusions

The potential for increasing recovery and recycling of WEEE in Poland is significant. On the Polish market e-waste is mainly processed by SMEs, but now they predominantly offer semi-processed materials. The growing domestic and global demand for products and services related to recycling, a large and ready market for products from the recycling of waste and secondary raw materials, as well active national and EU policies concerning recycling are significant opportunities for the development of existing SMEs in Poland. Moreover, they have already started to cooperate, i.e. within the Waste Management and Recycling Cluster already created. The existing barriers are price variability, legal changes and relatively (for SMEs) high costs of investment for the introduction new innovative and environmentally friendly technological solutions, which allow the entrepreneurs to create high quality final products.

Under the current e-waste management system in Poland, there are many legal loopholes, inadequate monitoring, and poor supervision of companies putting EEE on the market. The consequence of this is the problem of trafficking in receipts - the issuing of false documents. It is connected with the fact that the OEEER grouping brings together many EEE producers who are looking for the lowest prices to take over the recycling obligation from them. In addition, there is a noticeable functioning of a grey zone, mainly consisting of the dismantling of collected equipment outside processing plants, in unauthorized places (most often in scrap metal collection centres, waste collection points or illegal WEEE processing plants). Moreover, despite the fact that many companies conduct more and more activities promoting proper waste segregation, waste collection is still the weakest link in the chain in Poland.

The activities of another company include the processing of waste with the lowest cost, and omitting the largest quantities of waste containing hazardous substances. This is because national legislation obliges companies to settle the collected WEEE mass according to a division into groups. Each of these groups includes different categories of equipment with different processing costs and various sizes. At the same time, an excessively complex coding system facilitates this

kind of manipulation of waste.

The inspections carried out show that nearly half of those enterprises putting EEE on the market do not fund the processing of WEEE. Among the 172 companies which processed WEEE, only 85 have concluded agreements with the organisations introducing or recovering the equipment. Moreover, not all processing plants have conducted the declared activity in the processing of used equipment, despite having appropriate permits. In view of the above information, the e-waste management system in Poland will need to be improved in coming years.

Literature

Agamuthu, P.; Dennis, V. (2013). Policy trends of e-waste management in Asia. *Journal of Material Cycles and Waste Management* 15: 411-419.

Balde, C.P.; Kuehr, R.; Blumenthal, K.; Fondeur Gill, S.; Kern, M.; Micheli, P.; Magpantay, E.; Huisman, J. (2015). *E-waste statistics Guidelines on classifications, reporting and indicators 2015*. Bonn: United Nations University, IAS – SCYCLE.

Buekens, A.; Yang, J. (2014). Recycling of WEEE plastics: a review. *Journal of Material Cycles and Waste Management* 16(3): 415-434.

Central Statistical Office (2015). Warsaw: Central Statistical Office of Poland.

Cholewa M.; Jarosiński A.; Kulczycka J. (2014). Możliwość pozyskiwania surowców nieenergetycznych z elektroodpadów w Polsce. In: ed. Czyż, M. (ed.). *Finansowe i ekologiczne aspekty działalności gospodarczej*, Cracow: AGH Press.

Commission of European Communities. Communication No. 398, 2014. Towards a circular economy: A zero waste programme for Europe. (COM, No. 398, 2014).

Directive 2012/19/EU of the European Parliament and of the Council of 4 July 2012 on waste electrical and electronic equipment (2012), Official Journal of the European Union, L 197/38.

Esteves, A. M.; Franks, D.; Vanclay, F. (2012). Social impact assessment: the state of the art. *Impact Assessment and Project Appraisal* 30(1): 34-42.

Functioning and irregularities in the management of waste electrical and electronic equipment (WEEE) in Poland (2010). Warsaw: Instytut Badań nad Gospodarką Rynkową.

Grodzińska-Jurczak, M.; Tomal, P.; Tarabuła-Fiertak, M.; Nieszporek, K.; Read, A. D. (2006). Effects of an educational campaign on public environmental attitudes and behaviour in Poland. *Resources, Conservation and Recycling* 46(2): 182-197.

Hausner, J. (2015). *Polish raw materials: the thing which does not exist, but it is necessary*. Cracow: Fundacja Gospodarki i Administracji Publicznej.

Jang, Y. C. (2010). Waste electrical and electronic equipment (WEEE) management in Korea: generation, collection, and recycling systems. *Journal of Material Cycles and Waste Management* 12(4): 283-294.

Jofre, S.; Morioka, T. (2005). Waste management of electric and electronic equipment: comparative analysis of end-of-life strategies. *Journal of Material Cycles and Waste Management* 7(1): 24-32.

Mallawarachchi, H.; Karunasena, G. (2012). Electronic and electrical waste management in Sri Lanka: suggestions for national policy enhancements. *Resources, Conservation and Recycling* 68: 44-53.

Manomaivibool, P.; Hong, J. H. (2014). Two decades, three WEEE systems: How far did EPR evolve in Korea's resource circulation policy?. *Resources, Conservation and Recycling* 83: 202-212.

Maris, E.; Botane, P.; Wavrer, P.; Froelich, D. (2015). Characterizing plastics originating from WEEE: A case study in France. *Minerals Engineering* 76: 28-37.

Nnorom, I. C.; Osibanjo, O. (2008) Overview of electronic waste (e-waste) management practices and legislations, and their poor applications in the developing countries. *Resources, Conservation and Recycling* 52(6): 843-858.

Okońska-Kubica, J. (2016). Available at: https://www.facebook.com/klasterodpadowy/posts/265262873815310. Accessed 18 June 2016.

Ongondo, F. O.; Williams, I. D.; Cherrett, T. J. (2011). How are WEEE doing? A global review of the management of electrical and electronic wastes. *Waste Management* 31(4): 714-730.

Osibanjo, O.; Nnorom, I. C. (2007). The challenge of electronic waste (e-waste) management in developing countries. *Waste Management & Research* 25(6): 489-501.

Pérez-Belis, V.; Bovea, M. D. ; Gómez, A. (2013). Waste electric and electronic toys: Management practices and characterisation. *Resources, Conservation and Recycling* 77: 1-12.

Pires, A.; Martinho, G.; Chang, N. B. (2011). Solid waste management in European countries: A review of systems analysis techniques. *Journal of Environmental Management* 92(4): 1033-1050.

Quaghebeur, M.; Laenen, B.; Geysen, D.; Nielsen, P.; Pontikes, Y.; Van Gerven, T.; Spooren, J. (2013). Characterization of landfilled materials: screening of the enhanced landfill mining potential. *Journal of Cleaner Production* 55: 72-83.

Register of companies and organizations recovery of electrical and electronic equipment (Rejestr przedsiębiorców i organizacji odzysku sprzętu elektrycznego i elektronicznego), CIEP, Available at: http://www.gios.gov.pl/. Accessed 21 October 2016.

Reports on the functioning of the waste electrical equipment management system for the years 2006-2014 (Raporty o funkcjonowaniu systemu gospodarki zużytym sprzętem elektrycznym za lata 2006-2014). CIEP, Warsaw 2007-2015.

Safont, E.; Vegas-Vilarrúbia, T.; Rull, V. (2012). Use of Environmental Impact Assessment (EIA) tools to set priorities and optimize strategies in biodiversity conservation. *Biological Conservation* 149(1): 113-121.

Second Life Electro-waste (Drugie Życie Elektrośmieci), 2012. Available at: http://drugiezycieelektrosmieci.pl/2012/materialy/33.pdf. Accessed 21 October 2016.

Sthiannopkao, S.; Wong, M. H. (2013). Handling e-waste in developed and developing countries: Initiatives, practices, and consequences. *Science of the Total Environment* 463: 1147-1153.

Szałatkiewicz, J. (2011). Zrobotyzowany demontaż odpadów zużytego sprzętu elektrycznego i elektronicznego w celu odzysku surowców. *Pomiary, Automatyka, Robotyka* 15: 236-245.

The Act of 14 December 2012 on waste (Journal of Laws 2013, Item 21).

The Act of 29 July 2005 on waste electrical and electronic equipment. (Journal of Laws 2005, No. 180, Item 1495 as amended).

There is a growing demand for the recycling of waste electrical and electronic equipment in Europe (Rośnie popyt na recykling zużytego sprzętu elektrycznego i elektronicznego w Europie), Frost & Sullivan 2013. Available at: http://www.frost.com/prod/servlet/press-release.pag?docid=286356739. Accessed 21 October 2016.

Van Schaik, A.; Reuter, M. A. (2010). Dynamic modelling of E-waste recycling system performance based on product design. *Minerals Engineering* 23(3): 192-210.

Widmer, R.; Oswald-Krapf, H.; Sinha-Khetriwal, D.; Schnellmann, M.; Böni, H. (2005). Global perspectives on e-waste. *Environmental Impact Assessment Review* 25(5): 436-458.

Ylä-Mella, J.; Poikela, K.; Lehtinen, U., Keiski, R. L.; Pongrácz, E. (2014). Implementation of waste electrical and electronic equipment directive in Finland: evaluation of the collection network and challenges of the effective WEEE management. *Resources, Conservation and Recycling* 86: 38-46.

Zaman, A. U.; Lehmann, S. (2013). The zero waste index: a performance measurement tool for waste management systems in a 'zero waste city'. *Journal of Cleaner Production* 50: 123-132.

System zarządzania ZSEE w Polsce

Streszczenie

Przepisy prawne dotyczące zużytego sprzętu elektrycznego i elektronicznego (ZSEE) regulują zasady postępowania z zużytym sprzętem w sposób zapewniający bezpieczeństwo zdrowia i życia ludzi oraz ochronę środowiska. Zgodnie z zasadami zrównoważonego rozwoju, wprowadzający sprzęt elektryczny i elektroniczny są zobowiązani do organizowania i finansowania całego systemu zbiórki. Są to przedsiębiorcy, którzy produkują i wprowadzają sprzęt do obrotu pod własnym oznaczeniem, wprowadzają do obrotu pod własnym oznaczeniem sprzęt wyprodukowany przez innego przedsiębiorcę lub tacy, którzy sprzęt importują. Szacuje się, że 25% masy ZSREE wytwarzanego w UE-27 jest gromadzone i przetwarzane, a pozostałe 75% nie jest w żaden sposób rejestrowane. W Polsce, w przeliczeniu na jednego mieszkańca w roku zbierano ok. 1,5 kg ZSEE z gospodarstw domowych, w roku 2014 udało się zebrać 4,4 kg ZSEE/ 1 mieszkańca, jednak wciąż jest to dużo mniej niż obowiązujący od 2021 r. wymóg zbiórki minimum 11 kg ZSEE/ 1 mieszkańca.
W pracy przedstawiono bariery i wyzwania systemu zarządzania ZSEE w Polsce, w tym analizę aspektów prawnych, technologicznych, ekologicznych i rynku, koncentrując się na odzysku surowców nieenergetycznych. Wykazano, że istniejący system zbiórki odpadów, zgodny z rozszerzoną odpowiedzialnością producentów (EPR) UE wymaga pewnych ulepszeń, aby zwiększyć poziom odzysku i recyklingu cennych materiałów. Pomimo iż obecnie ponad 1500 firmw Polsce zajmuje się zbiórką ZSEE, odpady te zbierane są bezpłatnie od obywateli oraz istnieje coraz więcej działań promujących właściwą segregację e-odpadów, to selektywne zbieranie ZSEE jest nadal najsłabszym elementem systemu zarządzania ZSEE.

***Słowa kluczowe**:* zużyty sprzęt elektryczny i elektroniczny (ZSEE), recykling, zarządzanie odpadami, zarządzanie ZSEE