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Research Article

Environmental perspective of the recycling system for waste electrical and electronic equipment (WEEE)

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Abstract:

Electrical and electronic equipment (EEE) manufacturing is one of the fastest growing global manufacturing activities. At the same time this also means that the amount of waste electrical and electronic equipment (WEEE) will continue to increase in the coming decades. The purpose of this paper is to raise awareness of the problem of electrical and electronic waste in our country. Specifically, this study aims to inform the public, experts and conservation policy makers about the volume and hazard of waste, increasing the financial impact on local governments and taxpayers. However, there are conventional methods for waste disposal, these methods have economic and environmental disadvantages. Recycling is a new management option. This paper provides an overview of the recycling of electrical and electronic waste, including a description of how it is generated and sorted, strategies and technologies for material recovery. Completing European standards in this field, addressing all stages of the recycling process: collection, classification, processing and benefit of new materials, is also part of the analysis of this problem in this paper.

1. Introduction

Electrical and electronic equipment (EEE) in the world today presents a problem that is increasing dramatically in quantity. E-waste is the most popular and informal name for electronic devices at the "end of their life" and is classified as hazardous waste due to their harmful chemical composition such as silica, cadmium, arsenic, mercury, chromium, beryllium, phosphorus and plastic, which is harmful to human health and a major polluter of the environment. We are talking about waste, which consists of hundreds of different materials, some of which are very dangerous and have little possibility of recycling. According to the European Commission, the total amount of waste in Europe is expected to increase by around 45% between 1995 and 2020. In response to this prediction, the European waste strategy is based on three pillars: waste prevention, recycling and reuse, and improvement of final disposal [1]. When comparing the environmental impact of WEEE recycling with that derived from the baseline scenario (incineration of all WEEE and primary production of raw materials), WEEE recycling turns out to be clearly favorable conditions from an environmental point of view. Therefore, the amount of WEEE will also increase very quickly in Europe, with an expected rate of at least 3% to 5% per year [2]. About 59.4 million tons of e-waste were produced in 2022, and unless significant improvements are made in industrial processes, consumer patterns, and the adoption of efficient laws, this amount is projected to increase annually [3]. Ineffective management of end-of-life electrical and electronic equipment damages the environment, puts people's health at risk and prevents the achievement of the Sustainable Development Goals (SDG) of the UN for 2015 [4]. The management of these devices involves a series of complex steps, such as collection, classification, treatment, recycling, recovery and final disposal of these wastes [5]. The increase in the amount of e-waste has generated the development of a new industry: e-waste recycling [6]. This paper invites to share knowledge (knowledge) and experience from the system and formulation of the thesis "Knowledge and creation of e-waste recycling partners". The aim in this paper is directed to living conditions for local countries based on better management of end-of-life electrical and electronic equipment, promotion of research, examination of health risks and adoption of economic situations. The paper consists of two parts:

a) Knowledge management;

b) Construction capacity.

a) This part focuses on the development of waste knowledge based on the "Waste Directive", the creation of websites and free access to the Internet. The directives would make progress on a continuous basis and would be based on experiences from capacity building of good and evolutionary process creation sub-projects.

b) This part analyzes the general conditions of waste recycling as in other countries with the procedure focuses on the possibility of identifying electrical and electronic waste and implementing the recycling process of this ecologically acceptable waste and preserving the environment in the country. Work in different regions is possible to organize under the local support of entities from the government, the recycling industry and research institutes [7]. During the work on the paper I have tried to present the waste directives and the obligations derived from these documents, which today are mandatory for every country. Completing European standards in this field, analysing all phases of the recycling process: collection, classification, processing and benefit of new materials, is also part of analysing the situation in the country in this field. Metals in the structure of used electrical and electronic equipment (cadmium, lead, mercury and beryllium) are very difficult to recycle. Throwing used electronic devices in general waste is a very dangerous act. This study is done with the aim of: avoiding and reducing the creation of electrical and electronic waste, reuse of important components of this waste, development of programs with educational content for electrical and electronic waste, etc. End-of-life electrical and electronic equipment, based on the latest European standards, as well as standards from the Basel Convention, are waste with transboundary impact and must be placed in the group of hazardous waste [8].

2. Material and Methods

The rapid development of recycling technology is based on ecological reasoning and the protection of the environment from such waste. The increase in public pressure for the protection of the environment has influenced the increase in expenses for the protection of waste, an influence that is also observed in the development of recycling technology.

2.1. Recycling of electrical and electronic equipment

As illustrated in Figure 1, the recycling process is a complex process that involves reusing materials to return them to their original high or low grade state. Removal of secondary materials from abandoned equipment so that it can be recycled or reused (where original quality is maintained) or upscaled (where components are upgraded to a higher quality or equivalent functionality). High recycling is preferred, but its sustainability is often limited [9]. Five essential steps make up electrical and electronic waste management, an essential component of recycling: collection, removal of toxins, final processing before recycling, and disposal of non-recyclable items. The effectiveness of electrical and electronic waste recycling is closely related to the procedures used, namely the disassembly and separation steps [10]. Furthermore, by reducing the emission of hazardous substances and pollutants, the ethical recycling of electrical and electronic waste makes an essential contribution to environmental protection. Reduced energy use, a lower environmental footprint, less waste produced, and thus a smaller social impact are among the environmental advantages [11]. Recycling electrical and electronic waste is beneficial for the environment and the economy as it can reduce costs by about 50% by saving 70% of materials and 60% of energy [12]. However, there are significant barriers to the recycling process due to the difficult nature of electrical and electronic waste.

2.2. The role and importance of electrical and electronic waste recycling

By defining the conditions and possibilities of the process then it can be described in this form: "Recycling must be done within the possibilities in terms of technology, ecologically appropriate and adapted to the environment at the country level" [13].

Figure 1. *Recycling of electrical and electronic waste.*

The development of recirculation technology is being done in these directions;

- identification: perfecting the methods related to the recognition of the types and composition of materials (mainly plastic).

- classification: development of mechanical-physical separation methods with high separation purity.

- the composition of the material: on the verification of the composition (important materials) which complete the data for the serial use of each material; examination of the composition of the recycling material.

- decomposition according to the temperature of the materials: with the action of the heat parameters it is mainly based on the dangerous components.
- automated separation: development of automatic action and classification of material with the help of a robot, e.g. disassembly and separation by type of computer parts with automated action is done in less than three minutes. Statistics from the European Environment Agency (EEA) show that every year EU citizens leave around 1.3 billion tons of waste, which is 3.5 tons of waste per inhabitant of the European continent. In the US per capita it generates less than 745 kg of waste. 32% is recycled, which is twice as much as 15 years ago, when recycling started as a serious process. The biggest problem is the treatment and disposal of electrical and electronic materials in terms of environmental protection [14]. Over 1000 materials including BFR, PVC, heavy metals, plastics etc. used in the construction of electronic products and their components. The presence of toxic chemicals also makes recycling electrical and electronic waste hazardous to workers and the environment.

2.3. Strategies for Electrical and Electronic Waste Management

To address the complexities of the electrical and electronic waste management process, the Republic of Kosovo must implement a comprehensive strategy that includes legislative modifications, technological advancements, and public education initiatives. Manufacturers can be encouraged to design items with end-of-life concerns by adopting extended producer responsibility (EPR) frameworks, which will make recycling and disposal simpler. Partnering with the Ministry of Education to incorporate knowledge about e-waste into curricula at different educational levels, created age-appropriate activities and educational resources to teach children about the negative effects that e-waste has on the environment and health of man, as well as the value of recycling and safe disposal. Take educational initiatives focused on multiple platforms, such as written or video materials, social media, radio and television, to respond to different segments of society in the country. Organizing training sessions and workshops in community centers, businesses, colleges and schools to provide practical advice on electrical and electronic waste management as well as experiential learning opportunities.

2.4. Processing of electrical and electronic waste

Although it is not clearly estimated that the e-waste within itself has about 10% regular functional parts, 5% it is possible for the different parts to be processed and used again and 85% includes the material that must be broken down and classified and then be used materially. The recycling of large equipment is facilitated due to the small variety of material and easy separation into small equipment (for example televisions, radios, Wi-fi devices, video etc.) during processing the process is observed as we have the variety of materials during exposure and production. The remote processing of separate groups is undertaken by specialized recirculation landfills. The vast majority of waste belongs to metals (40-70) %. Cables and conductors without burning are divided into metal and plastic. The fine electronic waste which is part of the general mass of devices from (15 – 30) % contains 30 % metal and 70 % plastic [15]. The processing of this type of waste is done in a mechanized, automatic way of shredding, and then in separate separations of different materials (magnetic, electrostatic, inductive, etc.). Metal granules with a purity of up to 98% serve for the benefit of metals (by melting, electrolysis, chemical or electrochemical action). The recycling of metallic materials is useful and today iron, copper, aluminum, zinc, chromium, cobalt, selenium, tellurium, germanium, silicon, indium, etc. are being successfully processed. The recycling of plastic material requires separation by type, along with which the problem of classification and identification of plastic is announced. The problem is presented by 2000 different components in the polymer (softeners, colors and pigments, stabilizers), then amplifiers, but also dangerous substances (Fig.2). The important role of waste storage is the separation of toxic substances e.g. polychlorinated biophenyl (PCB), which is used as a dielectric in the capacitor, chlorofluorocarbon (CFC) in thermal insulation or as a coolant, heavy metals in batteries (mercury, cadmium, manganese, nickel, lead, etc.), parts of crystals, dangerous substances in screen pipes etc.

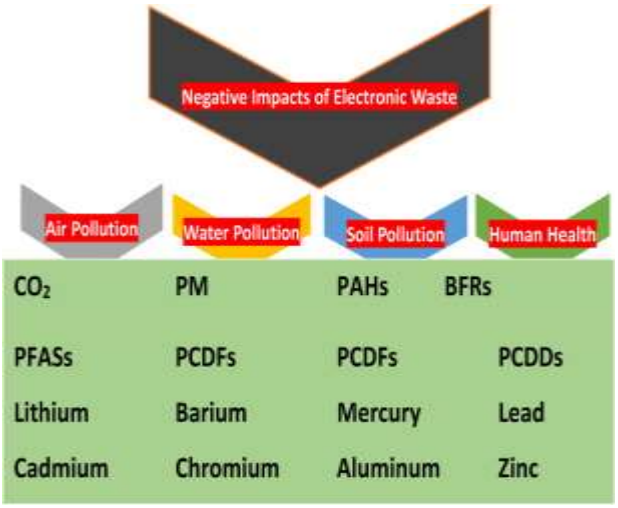

Figure 2. *Improper management of E-waste leading to formation of Major pollutants and hazardous materials.*

In waste processing, it is important to separate the elements that contain poisonous substances and take care of them in a special way, since it is seen how environmental pollution is caused when the disposal is done incorrectly. In recent years, the pressure has been increasing on the producers of e-waste, in order to increase the adaptation by means of recirculation of their products with the certain choice of material, with feasible construction and technological construction.

2.5. Structure of electrical and electronic waste recycling

The problems that appear in the processing of e-waste come from the spread of production in the market (prolonged collection), the variety of types and producers of the same production, as well as the unsuitability of production for recirculation. Directives and guidelines about e-waste care exist in some developed countries (Germany, France, Austria, Switzerland, USA, Japan, etc.), (Fig.3).

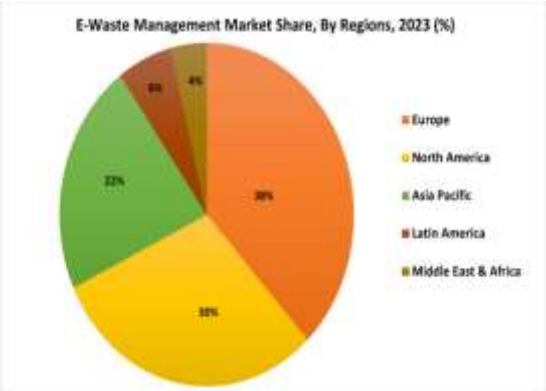

Figure 3. *Global generation of electrical and electronic waste*

The implementation and application of the provisions have been undertaken by the groups that make connections with producers, traders and processors of waste [16]. The price of e-waste care (for devices or special fractions) is confirmed by the test - disintegration, while it covers the costs of acceptance, transportation, separation, use, respectively disposal of waste. The test-dissolution protocol contains an overview of the work requirements for their separation and stay, material balance, costs of removal or remote material processing, costs of recirculation and logistics [17]. Economic conditions and their development have a direct impact on the recirculation system. The purchasing power of consumers and the length of life of electrical and electronic products determine the amount of electrical and electronic waste in the system. The necessary infrastructure, the cost of capital, the labor market and the effects of the loss of any government as the cost of the business structure (table 1).

Table 1. *Waste processing costs from production groups [18].*

production group	price, euro
display devices	12.00–30.00
electronic calculators, kg	0.25-0.50
entertainment electronics, kg	0.30 – 1.25
remaining IT equipment, kg	0.40 - 0.90
large household appliances	7.00 – 50.00

Political structures form the government's strategy in the field of work, public health and the environment. These strategies influence the legislation and the practical implementation of the law, i.e. the structure and development attitudes of the recirculation system. Research and development are important for the application of new technology. The introduction of technology and the establishment of practical knowledge in the process serve in the recirculation system. Cultural aspects such as knowledge about the environment and education are an important part of the structure for the recirculation system. Knowledge about the environment has the ability to influence the creation of the structure. The right distribution of income (Gini Index) describes the imbalance of social obligations in a society where the structure of informal business has a lot of opportunity to grow.

2.6. Focusing

Focusing on the e-waste recycling process includes many parameters, where first the procedure is created which mainly consists of systemizing the indicators in the process, then we continue with the instruments that are necessary in the formulation of the recycling process (table 2). The short description

is necessary because it defines the development of the whole recirculation process [19].

Table 2. *Parameters focused in study*

Procedures	Instruments	Short description
Collection of indicators	Inspiration, idea	Collection of ideas
Groups of indicators	Moderation	Participation of instructions from processor groups.
Defining system constraints	Pragmatic definition	The definition depends on the findings of the knowledge during the visit of the actors and/or the data used.
Development of model indicators	Creating the vision	The formulation of the vision coming from abroad.

Concrete actions are identified based on the possibility of understanding the situation. It continues with the selection of partners in Kosovo, the identification and visits of actors that enable knowledge about the aspects of electronic waste in the region, the following table shows.

3. Results and Discussions

Economic conditions and their development directly affect the recycling system, as well as the purchasing power of consumers and the lifespan of electrical and electronic products in the system. The infrastructure required, the overhead cost, the labor market, and any substitution effects of government have an impact on the structure of the business calculation. The mentality and attitude of the actors involved can also change the empowerment of corruption. Political structures form the governance strategy in the field of work, public health and the environment [20].

Research and development are important for the application of new technology. Introduction to the recognition of new technology, how it defines the processes used in the recirculation system. Cultural aspects such as environmental knowledge and education are another important aspect of the structure of the recycling system. Knowledge of the environment is created to create impact on the systematization of the structure. Income distribution (Gini Index) describes the imbalance of society, where informal business structures have the opportunity to advance. To gain an understanding of the current studies, policies, and practices pertaining to the management of e-waste in Kosovo, start with a thorough examination of the literature. The strengths, flaws, possibilities, and threats of Kosovo's current e-waste management plans were considered. The Gross Domestic Product (GDP) during 2023 has reached 7.96 billion euros, where per capita it is 4,486 euros [21]. The results obtained by this study will serve as a reference for possible future changes [22]. Therefore, full use of on-site decay methods should be utilized so that waste can be disposed of at the clearance levels authorized by the relevant regulatory agency based on risk assessment [23].

4. Conclusions

Today's policy of the developed countries of the world, which is oriented towards the export of electrical and electronic waste, hinders the path of innovations that are necessary to achieve the real solution at the source, that is, at the place of design and production. This allows manufacturers to continue with the presence of large concentrations of toxic substances and their reduction in their products. Each country, including Kosovo, must have its own strategy for the treatment of electrical and electronic waste. Contribution to the solution of this problem is also the data from this paper for the entire complexity of electrical and electronic waste. Electrical and electronic devices present a major problem due to their toxicity and the speed with which they expire. Based on these data, as well as the impossibility of treating these wastes in our country, we prefer that at least some stages of the treatment are carried out here and the rest of the process continues (exported) to other countries. The waste recycling infrastructure for collection and processing is still not a well-functioning system. Exporting waste to poor countries is not fair. Recirculation technology is not very effective and is not automated as it also depends on manual operations, i.e. separation of parts by hand. The real solution is responsible production, cleanliness and high technical industrial safety. Manufacturers are responsible together with state authorities for the recycling of electrical and electronic waste, it is the best way to solve this rapidly growing problem.

Author Statements:

- **Ethical approval:** The conducted research is not related to either human or animal use.
- **Conflict of interest:** The authors declare that they have no known competing financial interests or personal relationships that could have

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- **Data availability statement:** The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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