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Review

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The environmental and health impact generated by waste electrical and electronic equipment

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Abstract
A serious problem that arose with the evolution of modern industry is generation of electrical and electronic equipment waste. In the last decades, the generation of electronic waste has increased a lot and it is estimated that in 2030, almost 74 tons of electronic waste will be generated, which will represent a significant threat to the environment. The purpose of this article is to track the potential impacts on the environment, to highlight the importance of waste management strategies and to provide the latest information in the field. A presentation of the countermeasures that must be taken at the national and international level to address the sensitive problem of waste management is also realized.

Keywords: *waste, electronic equipment, environment, management*

INTRODUCTION

Any equipment that requires electricity to operate, generates electrical and electronic waste (e-waste). They become waste when they stop working or eventually break down. The most common types of electrical and electronic waste are end of life washing machines, TVs, fridges, mobile phones and laptops/computers. From the globally generated waste, an estimated 17.4% was properly disposed and the remaining 82.6% was discarded without proper recycling or treatment. E-waste management has become a significant problem due to the rapid evolution of technology and the increasing demand for electronic products from human society [1]. By the end of 2030, it is estimated that the production of electronic waste will increase considerably by about 50% (from 33.8 tons in 2010 to 74.7 tons in 2030). The annual growth rate of e-waste is about 4%. The composition of waste includes a wide range of materials such as toxic metals in 60% (mercury, cadmium, lead, arsenic, and selenium), plastics in 15% and precious metals (silver, platinum). These substances can affect water, soil and air as well as human health, and therefore can lead to certain diseases if they end up in landfills or in nature. Proper collection and recycling of electronic waste in specialized plants can eliminate the risk they pose, if heavy metals, hazardous gases and elements harmful to both the environment and people's health are properly removed. A large part of e-waste consists of components that have materials that can be recovered and reused in industry as secondary raw materials [2]. This reuse is necessary to avoid irrational exploitation of primary products. However, the amount of e-waste collected in collection programs varies around the world. For example, in the United States, household appliances such as refrigerators and washing machines do not fall into the category of electrical or electronic waste, but EU or Japanese legislation prescribes their inclusion in these types of waste. As such, nationally reported quantities of electrical and electronic waste are not easily comparable and total quantities do not necessarily reflect the true overall quantities [3].

According to HG 1037/2010 on waste equipment, the latter are managed by authorized economic operators acting on behalf of e-waste to finance the collection, treatment and environmentally sound disposal of electronic and old electrical equipment (collected and processed by specific means). The latter are legally obliged to put into production an e-waste whose design facilitates the dismantling and recovery of components and provides opportunities for reuse and recycling of e-waste, its components and materials.

WASTE CLASSIFICATION

The products represent 90% of all e-waste, thus being those that generate the most waste. The specific legislation in force in Romania includes a classification of these products, as follows (Figure 1):

Fig. 1. Major sources of e-waste.

IMPACT OF HEAVY METALS

The most common pollutants found in water, soil and sediments are heavy metals. These heavy metals even in low concentrations are a problem because their toxicity affects both humans and animals. In the treatment and recycling processes of metals from different types of electronic waste, organic substances are released, which is extremely harmful to the environment and to people. Through landfills, many contaminants from e-waste can leach into aquatic systems. In addition, acidic waste from various types of (metallurgical) processes and degraded e-waste mixes with the abiotic environment and then enters the water or soil [2-4]. Sedimentation or dissolution of atmospheric pollutants can also contaminate aquatic systems and water.

Soil

From all soil's contaminants, metals are of great importance because of their inherent toxicity, bioaccumulation, persistence and non-degradability. The most common metals that can be found in soil are Cu, Ni, Cd, Zn, Cr, As and Pb and most of them are based on electronic waste. The negative effects of metals depend on soil properties such as organic matter, clay content and pH. Metals affect the activity of soil enzymes by altering the microbial structure that normally synthesizes enzymes. Metals present toxic effects on soil biota by affecting microbial movement and reducing the number and activity of soil microbes. Conversely, the long-term effects of heavy metals can increase bacterial community strength and fungal resistance. For example, Cd exhibits higher enzyme toxicity than Pb due to its higher dynamics and lower affinity for soil colloids. Each soil enzyme has a different sensitivity to metals. Chromium is a common metal, present in soil as Cr^{3+} and Cr^{6+}, characterized by different chemical properties and toxicities. Cr^{6+} is a highly toxic strong oxidant, while Cr^{3+} is a micronutrient, a harmless species that is 10-100 times less toxic than Cr^{6+}. In general, increased metal concentrations adversely affect characteristic soil microbes. An important threat to human and animal health represent the metal uptake by plants and subsequent accumulation along the food chain. High lead content in soil can reduce soil productivity. Deficient lead levels inactivate some important plant functions. These would be mitosis, photosynthesis and water uptake and are associated with toxic symptoms such as dark green leaves, withered old leaves and short brown roots [5]. Metals are potentially toxic, causing reduced phytotoxicity to plants, growth and yield stress, and in legumes can be associated with reduced nutrient intake, impaired plant metabolism and even reduced molecular nitrogen fixation capacity. There are long-term toxic effects of metals on soils, organisms and whole ecosystems. They reduce soil enzyme activity, leading to the death of beneficial micro-organisms and plants.

Water

When aquatic organisms (fish) accumulate metals, they can affect human health. When distributed in aquatic ecosystems, metals and other contaminants stimulate the production of reactive oxygen species, which can damage fish and other aquatic organisms. Consumption of metal-rich fish is of concern because chronic exposure to metals can cause health problems. Metals are transported to fish via the bloodstream, and ions are usually bound to proteins [5, 6]. The metal comes into contact with the fish's organs and tissues and as a result, it molds into different fish organs and tissues to varying degrees. In short, metal-contaminated water adversely affects aquatic organisms, ultimately harming the entire aquatic ecosystem through biological magnetization of heavy metals.

Human health

High levels of metal uptake from soil by plants can pose serious health risks, given their impact on the food chain. The use of metal-contaminated food crops is the main route of human exposure through the food chain. Planting in contaminated soil is a potential risk as plant tissue can accumulate metals. Metals become toxic if the body does not metabolize and accumulates them in soft tissues. Chronic ingestion of toxic metals has undesirable effects on humans, and the associated harmful effects only become apparent after long-term exposure. Zinc is considered relatively non-toxic, especially in small amounts, but excessive intake can cause dysfunctions in the systems linked with growth and reproduction. Lead is considered physiologically and neurologically toxic to humans and can also cause dysfunction of the reproductive system, kidneys, liver and brain, leading to illness and death. Humans depend on plants and animals for their survival, and eating food contaminated with metals puts them at risk.

Technologies for resource recovery from e-waste

There are three types of technologies recovery of precious and base metals from electronic waste. These are pyro metallurgical (thermal), hydrometallurgical (chemical) and thermal cracking (pyrolysis) [7-10].

Pyro metallurgical

Pyro metallurgy is a branch of extractive metallurgy. It involves the heat treatment of ores and mineral and metallurgical concentrates to produce physical and chemical transformations in the material, allowing the recovery of precious metals. Pyro metallurgical processing can produce marketable products suitable for further processing, such as pure metals and intermediate compounds or alloys. Examples of elements extracted by pyro metallurgical processes include oxides of less reactive elements such as iron, copper, zinc, chromium, tin and manganese. The main challenge of pyro metallurgical processes is to improve the purity of the final metal product, as e-waste consists of pure metals and alloys. Pure metal forms are handled effortlessly by melting. Pyro metallurgy uses advanced techniques to volatilize certain metals, which are then concentrated and recovered.

Hydrometallurgical

Hydrometallurgical techniques use large quantities of hazardous, strongly acidic, alkaline or flammable components, releasing large quantities of solid waste and effluents. Hydrometallurgy involves suspending the metal parts of e-waste in an acidic or alkaline solution, depending on the amount of precious metal recovered. Most hydrometallurgical processes used to extract metals from e-waste produce cyanides, thioureas, thiosulphates and halides. Hydrometallurgical techniques have been widely studied for recovery of copper (Cu), zinc (Zn) and manganese (Mn) by leaching and precipitation. In addition to base metals such as copper and zinc, precious metals such as gold, silver and platinum have also been successfully extracted from e-waste. WEEE also contains large amounts of key metals such as cobalt, indium and gallium, as well as rare elements such as neodymium, dysprosium, praseodymium and samarium [11-13]. To recover these elements from e-waste, hydrometallurgy has proven effective. Hydrometallurgical techniques require large quantities of chemicals and have a significant environmental impact, especially during leaching. They also require more energy, followed by reconditioning, recycling and reuse.

Thermal cracking (pyrolysis)

Thermal cracking (pyrolysis) of e-waste is beneficial if the aim is to recover energy and materials to facilitate waste-to-energy systems. Most studies on thermal conversion of e-waste are limited to pilot-scale level, as information on thermal conversion kinetics, activation energies and yields of e-waste components for the residues remaining after the pyrolysis step is limited. It will contain metals and organics, which can be separated to recover higher quality metals. In laboratory-scale studies, pretreatment was done by shredding e-waste prior to pyrolysis to improve metal recovery. By checking the particle size and pyrolysis temperature, it was found that to recover a large amount of metal (Cu=92% and Sn=99.8%), the particle size and pyrolysis temperature should be 4.0 cm and 330°C respectively. After adopting this strategy, the main results of this study are: copper recovery rate is 96% using a two-stage acid leaching process and gold recovery rate is 80%.

Advantages and limitations of the technologies

A comparative analysis of the major advantages and limitations of these technologies is presented in Table 1.

Table 1. Advantages and limitations of the technologies

TECHNOLOGIES	ADVANTAGES	LIMITATIONS
Pyro metallurgical	- very fast processing time - produces a Cu-rich end product that can be separated and further processed	- energy consumer - high investment costs - corrosion-resistant reactor design required - low metal conversion/recovery efficiency
Hydrometallurgical	- easy to apply and manage - fast reaction kinetics and good extraction efficiency for different metals - low gas emissions - no slag generation and high metal recovery	- produces large quantities of leachate - special corrosion-resistant equipment is required. - high costs for selective recovery of desired metals, - requires more chemicals to recover different metals

Thermal cracking (Pyrolysis)	- e-waste can be used in the condition in which it is available, regardless of the electronic or electrical appliance discarded - very short processing time - reduces the volume of e-waste - produces gas, oil and even metals containing carbon and can be processed further	- energy intensive, high investment costs - requires subsequent treatment of generated toxic gases - low metal recovery rates and lower purity of the final product, - requires further treatment to increase metal recovery from e-waste

Gaps and future recommendations

The generation of e-waste is increasing every day. This has led to an increase of heavy metals from e-waste in soil, sediments and water. Therefore, appropriate control measures are needed for the generation and disposal of e-waste [14-16]. Appropriate remediation techniques are also needed to reduce pollutants in e-waste, especially metals in e-waste. Remediation techniques have certain effects, such as: complete or partial degradation of environmental contaminants; removal of pollutants for subsequent treatment or decontamination; stabilization of contaminants from highly toxic to less toxic; separation of uncontaminated substances from pollutants; restricted disposal of polluted materials into the wider environment; long-term effectiveness of more efficient remediation technologies.

However, the use of different remediation techniques depends mainly on several factors, such as the area of contamination, the cost of remediation techniques and the quantity and quality of contaminants. Physical processes are less effective and chemical processes have higher metal removal efficiencies but are not environmentally friendly. Recently, hybrid treatment techniques have become the most popular in metal recovery because they are more efficient than single treatment processes. But a good combination of different approaches is required for the hybrid technique. Recently, 3D printing technology and very thin metal oxide layers are being produced in various devices for different applications. These are very promising technologies for reducing material use. However, they may become an additional burden in the future. Therefore, this e-waste must be properly disposed of before it is released into the environment. In addition, new innovative technologies are expected to emerge to tackle these types of pollutants. The interaction of microplastics with the metal particles of e-waste should be studied in depth in the future in order to detect and dispose of them using appropriate technologies. Each remedy has advantages and disadvantages compared to other alternatives. The best remediation technique depends largely on the contaminated area, concentration of contaminants and other considerations [16-18]. The development of a new treatment technique is currently a major problem for researchers, so new hybrid techniques are constantly being developed and more research is needed in the future to achieve optimal results.

CONCLUSION

Currently, technological advances and recycling practices for e-waste recycling have been established nationally and globally. E-waste recycling is mandatory to reduce the environmental burden, manage existing natural resources efficiently and, above all, for economic reasons. Recycling and reuse of e-waste and other urban waste is imperative to improve resource efficiency. Proper treatment of e-waste for metal recovery is essential to reduce carbon emissions. Although recycling can lead to the recovery of metals or other electronic components, due to high labor and strict environmental protocols, developed countries are reluctant to recycle e-waste. In order to promote e-waste management, the recycling of e-waste components, at national level, developing countries should provide more subsidies to e-waste recyclers.

From a circular economy and environmental perspective, e-waste recycling will be an authoritative and important sector in the near future [19-20]. The integration of technology into every aspect of our daily lives has led to the increased use of electronic devices by people. However, increasing sales of IT accessories, combined with the short lifespan of many electronic devices will also cause an increase in e-waste generation. Therefore, there is an urgent need to review existing practices, legislation and recycling infrastructures that are cost-effective, safe and environmentally sound.

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