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Sustainability Applied to Waste Electrical and Electronic Equipment

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ABSTRACT :*Waste electrical and electronic equipment (WEEE) is a global problem due to its increasing rate of generation, its complex composition and the risks to human and ecosystem health associated with inadequate final disposal. This paper analyses this problem and investigates alternative solutions. It concludes the need for a paradigm shift towards the Circular Economy, where urban mining and recycling of WEEE constitute innovation and development alternatives for Sustainability Engineering, with the possibility of generating green jobs.*

KEYWORDS *WEEE, Sustainability, Engineering, Urban Mining.*

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I. INTRODUCTION

Electrical and electronic devices AEE are devices that operate through the use of electric current or electromagnetic fields, that is, with electrical circuits or components, and with a power source and batteries. EEE becomes waste electrical and electronic equipment, that is, WEEE, when the user decides to discard it without the intention of using it again [1].

WEEE are complex waste, as they include components of different materials and are hazardous due to their chemical composition, generating a risk of ecosystemic contamination and a danger to human health, both due to inadequate final disposal and incorrect handling [2, 3].

The increase in the generation of WEEE worldwide implies an overexploitation of natural resources, overcoming planetary limits, generation of greenhouse gases throughout the life cycle. The current linear production model is far from being sustainable, so a paradigm shift is urgently needed. Therefore, local governments must urgently implement actions for the integral management of WEEE, and thus reduce the socio-economic impacts they cause.

This paper analyzes this problem and investigates alternative solutions. It concludes the need for a paradigm shift towards the Circular Economy, where urban mining and recycling of WEEE constitute innovation and development alternatives for Sustainability Engineering, with the possibility of generating green jobs.

II. RESEARCH METHODOLOGY

The research in which this work is framed is of an exploratory-descriptive nature [4]. After a bibliographic search, a table was prepared with the main components contained in WEEE, and based on these components, the type of risk for living beings as well as for the quality of the environment was determined.

III. DEVELOPMENT OF THE RESEARCH

III.1Characterization of WEEE and Socio-Environmental Impacts

WEEE includes: Large and small household appliances; computer and telecommunications equipment; consumer electronics; power tools; toys and recreational sports equipment; medical, laboratory, research and chemistry teaching equipment; monitoring and control instruments; and others. This classification shows the variety of sizes, volumes, uses, etc. These are complex devices that include numerous parts and components: parts and housings of various materials, printed circuit boards, cathode ray tubes, liquid crystal displays, cables, electrical and electronic components, concrete counterweights, print cartridges, etc.

In an average composition, iron and aluminum are the two most common materials and account for approximately 60% of the total weight of WEEE. Plastics are the second main group present, representing 15% of the total weight. Table 1 shows a typical composition of WEEE [5].

Table 1: Typical Composition of the WEEE (Own Elaboration).

TYPICAL COMPOSITION OF THE WEEE	
ELEMENT	**PERCENTAGE IN WEIGHT (%)**
Metals	60
Plastics	15
TLC/LCD Screens	12
Mixed Plastics and Metals	5
Pollutants	3
Cards, Integrated Circuits	2
Wires	2
Others	1

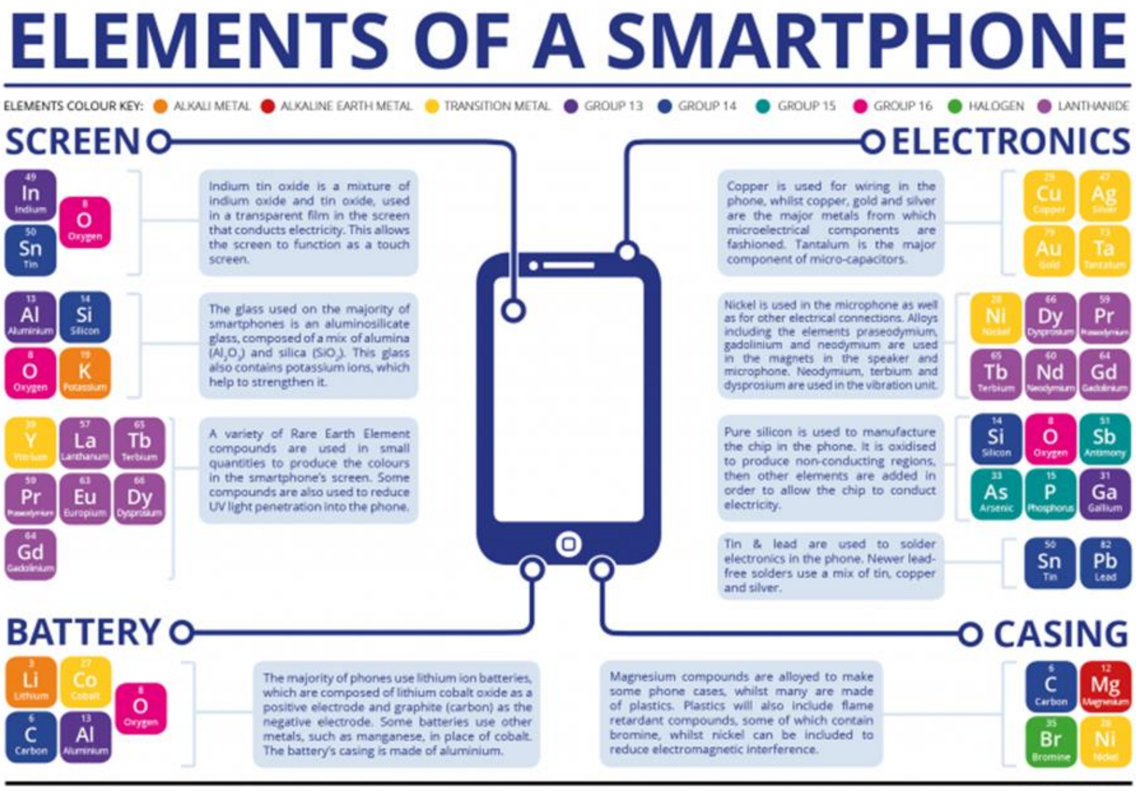

Fig. 1: Elements Present in a Smartphone (Extracted fromhttps://clickmica.fundaciondescubre.es).

Electrical and electronic waste can contain more than 1000 different substances of different degree of toxicity and hazardousness [3, 6 - 8]. Figure 1 shows the elemental composition of a cell phone. In general, there is no awareness of the large amount of precious and rare metals that the smartphone contains. In fact, it is estimated that, for every million smartphones that are recycled, 17 tons of copper, 300 kilograms of silver and 30 kilograms of gold are recovered. This means that the phones that go on the market each year contain silver and gold for an amount of 2.5 billion euros. And not only that, but of the 83 non-radioactive elements that appear in the periodic table, at least 70 can be found on a smartphone. In other words: of all the stable elements that exist in the universe, 84% are found in one of these terminals [1, 9, 10].

When WEEE is discarded without treatment in open dumps or illegal dumps, it comes into contact with ecosystems, contaminating soil, water and air. In addition, they accumulate in the food chain of living beings that inhabit them due to their bio-persistence. The main heavy metals present in WEEE are: zinc, nickel, lead, chromium, selenium, arsenic, mercury and cadmium. Mercury, lead and cadmium are very toxic, with strong effects on health, specifically affecting the nervous system, and have a very long life, remaining in the organism for up to ten years [3]. Table 2 shows the hazardous substances present in WEEE and the risks to human health [1, 11].

The leachate liquids generated by WEEE can percolate and infiltrate into groundwater, contaminating it, and the burning of these wastes not only causes the loss of valuable resources, but the smoke produced contaminates the air with substances such as dioxins.

Also, WEEE contain metals that are scarce or increasingly scarce due to the increase in their use, such as rare earths, zinc and antimony. This increase in production demand contrasts with the natural limits of availability and generates a risk in supply, as well as a socio-political situation and the need to coordinate collaborative actions between countries [12].

Table 2: Hazardous Substances Present in WEEE and Risks to Human Health (Own Elaboration).

HAZARDOUS SUBSTANCES PRESENT IN WEEE AND RISKS TO HUMAN HEALTH	
ELEMENTS	**HUMAN HEALTH RISKS**
Antimony	Irritation of eyes, skin and lungs
Bismuth	Skin problems and depression
Cadmium	Lung damage, bone fractures, central nervous system damage, possible DNA lesions
Chrome	Lung cancer, kidney and liver damage
Cobalt	Vomiting, vision loss, heart problems, thyroid damage, asthma
Gallium	Throat irritation, breathing problems, chest pain
Germanium	Harmful effects on skin, eyes and blood
Molybdenum	Joint pain in knees, hands and feet
Nickel	Lung and nose cancer, heart conditions
Selenium	Abdominal pain, fever, heart and muscle problems, bronchial asthma, diarrhea, enlarged liver, heartburn, bronchitis, sore throat
Silver	Brain damage, kidney, eye, lung and liver problems
Lead	Reduced male fertility, increased blood pressure, kidney and brain damage, reduced learning ability in children
Tin	Irritation to eyes and skin, nausea and dizziness, stomach pains, anemia, and liver and kidney disorders
Iron	Elevated risk of lung cancer
Yttrium	Harmful effects on the liver
Zinc	Vomiting, skin irritation, decreased sense of taste and smell, congenital malformations, and stomach pains

III.2 Generation of WEEE

The generation of Waste Electrical and Electronic Equipment WEEE in the world, has grown during the last years three times faster than the rest of solid waste, at a rate of up to 5% each year [1, 2, 6, 13].

In 2019, Europe generated 12 million tons of e-waste (or 16.2 kg per capita) representing $12.9 billion in raw materials and 12.7 million tons of CO_2 equivalent emitted into the atmosphere. Some studies show that in Europe only 42.5% of these were collected and properly recycled [14 - 16]. Comparatively for the same year, in America 13.1 million tons of e-waste were generated (or 13.3 kg per capita) representing 14.2 billion dollars in raw materials and 26.3 million equivalent tons of CO_2 emitted into the atmosphere. However, in this case, collection and recycling reached 1.2 million tons of electronic waste, or 9.4%. Of these values, only 1 to 3% of WEEE was recycled in South America.

Of Latin America, the 13 participating countries in the region in the UNIDO - GEF 5554 project have legal and regulatory frameworks for waste management, but only five (Bolivia, Chile, Costa Rica, Ecuador and

Peru) have specific legislation for e-waste and Extended Producer Responsibility systems, focusing on the regulation of e-waste [16]. The absence of an adequate legal framework, combined with the waste of valuable components contained in WEEE, and the environmental impacts derived from its uncontrolled dumping and low recycling rates, imply the waste of socio-economic opportunities for the generation of green employment, the waste of the use of sustainability engineering tools and the failure to comply with an ethical responsibility [12].

III.3 Processing of WEEE

The integrated management of any type of waste involves a set of activities focused on reducing waste generation, sorting at source, and differentiated collection, transportation, recycling and appropriate final disposal. These stages are always present, to a greater or lesser extent, depending on the plans designed for this purpose, the allocation of human and economic resources, and governmental possibilities and policies.

Companies engaged in the processing of WEEE are dedicated to the development and implementation of policies and projects aimed at achieving sustainable environmental and economic management. Their areas of application include the integrated management of waste electrical and electronic equipment and hazardous waste, according to social, environmental, and economic sustainability criteria.

In addition, these companies assure their clients the following aspects: (i) destruction of data that may contain business information (hard disks, USB flash drives), (ii) shredding of electronic waste to the size required by the client to avoid inappropriate reuse, (iii) elimination or shredding of the remains of other sensitive elements, such as client brands or logos, and (iv) implementation of a notary certification service or audit of the destruction of data or information.

Once the WEEE is received at the company, it is manually sorted and disassembled according to its type. The plastic and metal materials resulting from disassembly are sold to different companies for recycling. On the other hand, printed circuit boards and batteries are treated in specific companies, where they are processed with first-class technologies that allow the recovery of high-cost raw materials, thus minimizing the waste generated.

The companies in charge of WEEE processing share a series of common processes, such as the need to have collection points, the development of a transportation, qualification and logistics system, the classification of the different WEEE received, the identification of pieces, parts or materials by process lines, and the treatment and final disposal of the hazardous waste generated. Figure 2 shows the basic WEEE procedure [1].

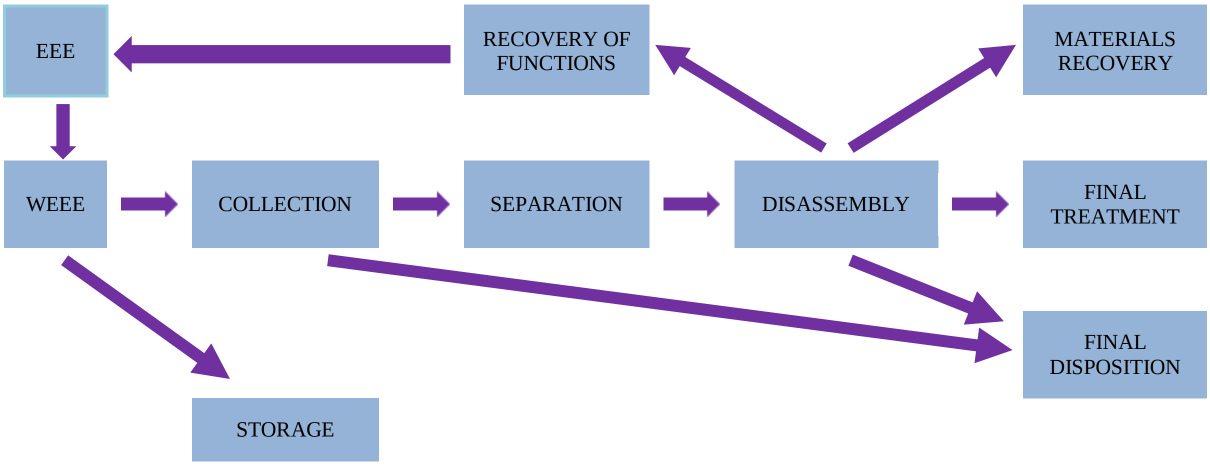

Fig. 2: WEEE Processing (Own Elaboration).

The WEEE management process basically consists of several stages:

- Collection: WEEE is collected from designated collection points (clean points, stores, recycling centers, etc.) and transported to treatment facilities.
- Classification: WEEE is separated according to its type and characteristics, to facilitate its subsequent treatment.
- Disassembly: equipment and appliances are disassembled, separating the different parts and materials (plastic, metal, glass, etc.).
- Shredding: larger items, such as household appliances, are shredded to reduce their size and facilitate their handling and treatment.
- Metal separation: some valuable metals, such as copper and aluminum, are separated for subsequent recycling.

- Hazardous waste treatment/storage/transfer: Hazardous components are separated and treated (if the plant has this capability) or stored in a safety cell before being transferred to a company specializing in hazardous waste treatment and disposal.
- Recycling: materials recovered from WEEE are reused in the manufacture of new products or sold to metal manufacturers for use in other fields.
- Final disposal: those materials that cannot be recycled are disposed of in an appropriate manner to minimize their environmental impact.

IV. PARADIGM SHIFT

The problems raised respond, on the one hand, to a linear production model (extract, produce, consume, generate waste) whose main objective is economic, without taking into account social sustainability and environmental sustainability, i.e. overexploitation of natural resources, generation of greenhouse gases, labor conditions, and which generates waste without assuming corporate responsibility. On the other hand, issues related to education, awareness, and social habits, collaborate negatively to this situation, worsening and complicating the panorama, and even without knowing it, decreasing the quality of life of the same people, and of all living beings [11].

A paradigm shift is therefore needed to modify both social and productive behaviors. The Circular Economy is a framework of systemic solutions, differentiated between technical and biological cycles, that addresses global challenges, with the objective of minimizing the extraction of finite natural goods, designing products and services to circulate as long as possible, extending the useful life of products. Figure 3 shows a synthesis of both economic systems, applied to WEEE[6, 17, 18].

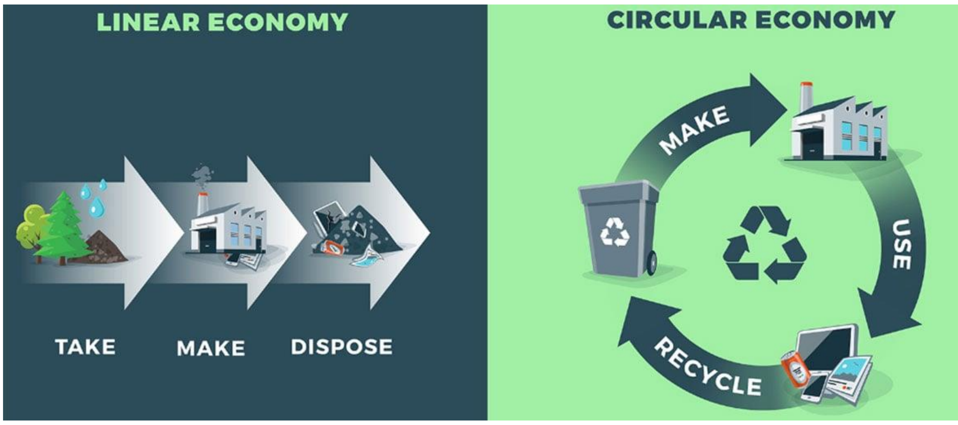

Fig. 3: Comparison of the Linear and Circular Models (Extracted from Kowszyk, 2019).

Sustainability Engineering has much to contribute, as the application of strategies throughout the production chain and the use of products and services, in the search for improvements in all its dimensions.

For a paradigm shift to the Circular Economy, in the case of WEEE, urban mining and recycling processes are fundamental. Just as traditional mining extracts resources to incorporate them into products, urban mining involves understanding waste as raw material, and taking advantage of the waste generated in cities for their incorporation into new, more sustainable production processes. In this sense, the most recovered metals are iron, copper and aluminum, in the form of scrap, but it has also been reported the recovery of up to 400 grams of gold and 700 grams of silver on average, for each ton of cell phones. It is worth noting that the cost of obtaining materials by recycling is about 5 times lower than the cost of primary extraction, and recycled copper needs 85% less energy than primary production. On a global scale, this fact represents a saving of 40 million tons of CO_2[2, 14, 15, 19].

This represents a potential for scientific-technological innovation in engineering, in the development of physical, chemical, metallurgical and mechanical processes that bet on sustainability, and in the design of recycling plants for telecommunication devices, monitors and televisions, which are the electronic waste with the highest composition of valuable materials. An integrated management of WEEE would contribute to environmental sustainability, with the recovery of potentially hazardous metals and minerals, avoiding their impact on nature, and to economic sustainability, by obtaining metals and minerals that are scarce in nature and can be reused in industry as raw materials, in accordance with the Circular Economy It is worth noting that the cost of obtaining materials by recycling is about 5 times lower than the cost of primary extraction. , and recycled copper needs 85% less energy than primary production. On a global scale, this fact represents a saving of 40 million tons of CO_2 [12].

It would also contribute to the ge”erat’on of green jobs, understanding them as those decent jobs, with a living wage, without health risks, with participation in decision making and gender parity, through which a positive environmental impact is achieved. According to reports from the International Labor Organization, in 2017 in Argentina more than 95% of the 34,000 jobs were concentrated in technical repair services of EEE, while, in another study conducted in 2020, it was reported the existence of more than 2000 jobs corresponding to about 300 private companies and cooperatives of the Social and Solidarity Economy, throughout the country It is worth noting that the cost of obtaining materials by recycling is about 5 times lower than the cost of primary extraction, and recycled copper needs 85% less energy than primary production. On a global scale, this fact represents a saving of 40 million tons of CO_2 [9, 20 – 23].

V. CONCLUSIONS

Electrical and electronic equipment produce greenhouse gases throughout their life cycle, emissions that contribute to global warming. Their waste, WEEE, is generated at an increasing rate worldwide, basically due to: (i) short useful lifetime, (ii) lack of corporate responsibility, (iii) lack of user awareness, and (iv) lack of specific regulations that establish clear and defined processes for their treatment.

Due to their volume and complexity, as well as the chemical elements present in them, they are considered very risky for both human health and ecosystems.

To face an adequate and integral WEEE management implies considering all the stages of the life cycle of this type of products, with a systemic approach and the application of multidisciplinary alternatives. Therefore, it entails having to face a very complex and multivariable problem, which basically focuses on the following aspects: (i) issues related to education, (ii) cultural habits regarding consumption and discarding, (iii) logistics, (iv) updated and adequate legal regulations, (v) economic aspects, since it is essential to allocate public funds for the transportation, installation and operation of WEEE management plants, (vi) environmental issues referred to minimize and/or prevent the generation of waste and environmental pollution, and (vii) health issues referred to inadequate final disposal.

Finally, it can be said that the linear production model is unsustainable and involves unpredictable socio-environmental impacts, therefore a paradigm shift to the Circular Economy is urgently needed, incorporating strategies such as urban mining and recycling, transforming waste into raw material for new sustainable processes. Process and materials engineering developments can make significant contributions towards sustainability and the generation of green jobs.

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