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Advances in Environmental and Engineering Research

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Review

The Importance of Responsible Electronic Waste Treatment for Sustainability

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Academic Editor: Mohammad Boshir Ahmed

Special Issue: Microbial and Sustainable Technologies for Circular Economy and Resource-Efficient Waste and Water Management

Adv Environ Eng Res
2024, volume 5, issue 3
doi:10.21926/aeer.2403016

Received: January 02, 2024
Accepted: June 21, 2024
Published: July 01, 2024

Abstract

Waste production is experiencing a significant increase in correlation with the growth of the human population and industrial activities. The kind of waste that is expanding at a rapid rate is known as "e-waste," which stands for electronic waste. In the context of electronic waste, the term refers to the waste produced during the disposal of electronic devices and any other components utilized in making or operating these devices. In the same way that different types of waste occur, electronic waste pollutes the environment and the human population. Electronic waste seriously threatens ecosystems and human health if not properly disposed of. The quantity of e-waste generated on a global scale is increasing continuously due to the short lifetime of electronic devices and the fast advancement of technology. Developing sustainable treatment methods for electronic waste is critical to address this issue. Valuable materials are utilized to fabricate electronic devices to enhance their functionality, longevity, conductivity, and efficacy. To mitigate pollution, recycling electronic waste is an absolute necessity due to the factors above. Although this fact remains true, numerous organizations exhibit reluctance towards recycling their electronic devices due to apprehensions regarding the potential exposure of sensitive information. Conversely, secure data deletion is now a reality due to the continuous development of technological capabilities.

Keywords
Sustainability; environmental impact; data destruction; internet of things (IoT); circular economy; waste electrical and electronic equipment (WEEE); printed circuit boards (PCBs); 'conflict-free' gold; secondary raw materials (SRM); electrical and electronic equipment (EEE)

1. Introduction

The number of people living in the world is continuously increasing, which inevitably directly impacts the natural world. In order to supply sufficient food, water, and prosperity for the population of the globe, we need to move from a linear economy to a circular economy. This is essential. The objective is to reduce the severity of environmental harm while maintaining safe and healthy living and working conditions.

This study investigates the significant environmental and public health concerns raised by global population expansion and industrialization, specifically through the lens of electronic waste issues, management, and the transition from a linear to a circular economy. It highlights the critical need to apply sustainable practices to reduce environmental effects while ensuring safe living and working conditions. The subject also emphasizes the critical need for systemic changes in how we handle waste, particularly electronic waste, to prevent environmental and public health damage. The governing body and nonprofit organizations promote a circular economy and improved waste management, emphasising sustainable practices and legislation that might aid the transition, particularly in developing economies.

The waste is inescapable and produced by humans and animals [1]. The rapid expansion in population and industrialization has led to an increase in garbage production [2], which has major implications for public health and the economy [3]. At this time, among these rising wastes, electronic waste is a source of toxic byproducts that can pose a risk to the environment and sustainable economic growth, which can be a threat to both the environment and the growth of the economy in a sustainable manner [4] since it is expanding at the highest rate [5]. Due to inefficient collection and disposal methods, electronic waste management is of the utmost importance in developing countries. An approach to improving electronic waste management systems in low-income and middle-income nations is needed if the goal is to enhance waste management in such countries with enterprises from across the electronics value chain [6]. Millions of tons of electronic waste are recycled yearly in ways that are disastrous for the environment. Such waste is probably unsafely stored in homes and warehouses, discarded, exported, or recycled in unsafe circumstances. When mishandled, electronic waste can release up to 1000 different chemicals into the environment, some of which are neurotoxic and harmful, like lead-3 [7].

With an increase of 82% from 2010, the production of e-waste reached a record 62 million tons in 2022. Anticipated to increase by a further 32%, reaching 82 million tonnes in 2030 [8]. Tragically, only over 20%, or around 24 tonnes, of e-waste really reaches the proper recycling facilities [8]. In

2019, the world's electronic waste reached a record 53.6 million tonnes, with $57 billion worth of gold and other components being buried or burned [9].

Concurrently, the export of electronic garbage, whether done legally or illegally, to nations with few or no facilities for recycling is contributing to increased human exposure and the release of dangerous substances into the environment [10].

Recycling has prompted several discussions and initiatives by governments, non-governmental organizations, and businesses. The world is waking up to the problem, and governments, industry, and other stakeholders are starting to act [11]. As a result, many multinational firms undertake recycling and recovery projects to help safeguard the environment. Eliminating electronic waste and driving efficient, circular value chains is, in point of fact, a kind of responsibility that we all share. The multinational technological company is recycling environmentally friendly materials, such as plastics, carbon fiber, gold, and, most recently, rare earth metals.

2. Findings from Systematic Review

2.1 Reutilization (Sustainability) - 4R:

Reutilizing refers to collecting and separating reusable materials from waste and then processing them into items that can be sold. Extending the materials' life and extracting the maximum amount of value from them decreases the demand for raw resources. Compared to the energy required to process raw materials, this method results in significant energy savings throughout the production process [12].

The term 3R, which stands for “reduce, reuse, and recycle, " involves separating resources from the waste stream [13]. Consuming and throwing out less garbage are both part of the reduction process. Utilizing the material in its primary or secondary form is an example of reuse. In a nutshell, recycle by fixing it up, selling it, or giving it away. On the other hand, there is a growing trend toward recovering the energy lost in waste products, by generating electricity from the waste landfill sites or from organic wastes by bio gasification, etc. The new “R” from the “Recover” is added to this system and forms 4R [14]. It is essential to recover as much as possible. The process of providing a material that was previously thought to be waste value by changing wastes into resources is referred to as recovering.

The management of waste electrical and electronic equipment, often known as WEEE, has two primary objectives: the first is to maximize the amount of value that may be retained through recycling, and the second is to reduce the dangers to human health and the environment (depollute) [15]. In other words, valuable compounds are separated into fractions so that they can be recovered. In contrast, hazardous substances are separated into fractions so that they can be treated using the best available techniques (BAT) and the best environmental practices (BEP) [16]. The performance indicators used to monitor WEEE treatment must allow for the evaluation of progress made toward these goals [17]. However, the current mass-based recycling and recovery rates do not consider that some recyclable elements are lost in small mass fractions. One example of this would be the loss of precious metals.

Electronic scrap can be used to collect recycled raw materials such as PCBs, depolluted devices, shredded fractions, and chips, among other things. According to Hagelüken and Corti [18], more than 300 tons of gold are used yearly for electronics production, making them a secondary source of gold. Different auditing procedures have shown that they adhere to the highest possible commercial, technical, and legal standards. Extracting metals requires a high degree of understanding of pyro and hydrometallurgical refining processes to contribute to the circular economy of e-scrap recycling via multi-metal recycling with high recovery rates of various metals.

2.2 Problems with Electronic Wastes:

Electronic waste refers to the remaining parts of electronic devices that are broken or unnecessary and thrown away in the garbage [19]. There are two main points for this issue. One of them is the potential pollution threat to the soil, water and air because of the toxic materials and heavy metals used for the components such as circuit boards. The other one is the intent to recover the precious elements from the circuit boards. This recovering process is called “gold recycling” because gold is widely used during the manufacturing process of electronic devices, especially at circuit boards due to its perfect conductivity and less corrosivity. Gold in waste resources has received considerable attention because of high price [20]. Not only gold but also silver, copper, aluminum, palladium, platinum, etc.

Harsh chemicals and acids are required to extract gold from the circuit board [21]. Toxic fumes emitted by these substances can irritate human skin, necessitating the use of personal safety protective gear and safe handling equipment such as a fume hood. These criteria are sometimes disregarded, leading to the use of unqualified, cheap labor without adequate health measures, especially in underdeveloped nations [22]. That is why gold recycling is a matter of “conflict-free gold”. Conflict-free gold refers to gold extracted without harming people or committing crimes like violating human rights or engaging in armed conflict.

The process of extracting these precious elements from circuit boards should be carried out in a manner that is sustainable and kind to the environment. This process should not involve harsh chemicals [23] and should result in "Conflict-Free" gold.

The Conflict Free Gold Standard offers a standardized method that gold producers can use to evaluate their gold's extraction process and provide assurance that it was done in a way that did not contribute to serious violations of human rights or violations of international humanitarian law, as well as one that did not cause, support, or benefit from unlawful armed conflict [24]. This standard was developed to address these issues. The hydrometallurgical closed-loop technology removes all potential sources of air pollution and does not produce any effluent. Without resorting to shredding, this procedure offers an alternative that is friendly to the environment. Gold, silver, palladium, platinum, and copper can all be extracted from circuit boards by the use of this technique, which concentrates material that contains precious metals [25]. This procedure uses a solution that is water-soluble and capable of being regenerated and recycled. There is no limit to the number of times this remedy can be applied. Recovering precious metals in a closed-loop system is very scalable [26]. There is potential for many processes to be deployed within recycling or refining factories worldwide, yet doing so would need very little more space. This method can be efficiently operated in smaller facilities than smelting and other labor- and resource-intensive pyrometallurgical recovery processes. This is because the equipment required for this method takes up a significantly smaller amount of space and necessitates a substantially lower level of human involvement than more conventional chemical or pyrometallurgical processing techniques [27]. This technique has been effectively expanded to create gold, silver, copper, palladium, and platinum, which are all 99.9 percent pure from circuit boards.

A solution that is safe for the environment that can extract valuable and strategically essential materials from ores, concentrates, and electronic waste. In order to extract gold without negatively impacting the surrounding ecosystem, one of the most important steps is to use this innovative technology, which does not rely on cyanide or acids. This process transforms electronic waste from today into a renewable source of metals that can be used in tomorrow's technology [28].

To improve the effectiveness and efficiency of WEEE collection and recovery, WEEE collection methods were linked to reuse and recovery through the execution and evaluation of a series of practical trials in some European countries. These trials were carried out in order to increase the efficiency of WEEE collection and recovery [29]. Automation has the potential to make the recycling process more reliable and efficient. The recycling of printed circuit boards is currently supported by an automation program available on the market (PCBs). In addition to automatically loading and sorting the printed circuit boards (PCBs), the system desolders components from both sides of the board. The same inline system is then capable of fine-sorting the components through the use of machine vision with artificial intelligence, in addition to high-speed robotic arms. The system accomplishes this [30].

3. Perspectives and Future Directions

It is necessary to increase the value of electronic waste by utilizing cutting-edge recovery solutions. The fact that recycling electronic waste is beneficial not only to the environment but also to business is why many business executives and industry leaders have taken notice of this fact [31]. As a result, recycling electronic waste and the management of e-waste is quickly becoming less of an environmental problem and more of a market opportunity.

These operations should be turned into a profitable, sustainable business with the highest economic advantage and maximum commodities return [32]. Business ventures ought to have take-back and recovery procedures for the electronics to succeed.

Factors such as available data, coverage across countries, accessibility, standardisation, integration and connectivity, quality and broad coverage make it challenging to secure responsible sources of secondary raw materials and increase recycling rates. To enhance one's knowledge of SRM from wastes produced by batteries, electronic devices, vehicles, and mining operations, it is necessary to investigate the procedures for collecting data and the suggestions derived from completed and ongoing projects. This will allow one to determine the most effective methods, design guidelines that are applicable in real-world situations, and deliver training to address specific needs. Doing so will give policymakers information and best practices, allowing them to make educated policy decisions that will enhance the supply of recycled secondary raw materials and improve recycling rates.

4. Towards an Integrated Framework System

On both the economic and regulatory fronts, the mining of virgin metal is facing increasing challenges. These challenges are causing the mining industry to face challenges. When it comes to recovering valuable metals from existing sources that are now being thrown away, biometallurgy offers an approach that is both efficient about capital expenditures and kind to the environment. Research is currently being conducted to create bio-metallurgical procedures that make use of microbes to salvage valuable materials from metal waste streams while minimizing their impact on the surrounding environment. This is a form of modular approach for recovering metals that is compatible with the contemporary concept of a circular economy. This allows for more efficient utilization of limited resources.

The so-called "Open Scope," which the WEEE Directive 2012/19/EU mandated all member states to transpose by the 15th of August 2018, just marked its first anniversary. The new approach to identifying and classifying electrical and electronic equipment (EEE) presented new issues to national authorities and manufacturers. Although certain member states of the EU use alternative classifications and enforcement dates, all of the member states of the EU use the revised definition of EEE. In a nutshell, Open Scope expanded the scope of the Directive to include new businesses and products, and the authorities were required to modify their national registers as a result [29].

Even though there is almost universal consensus that lithium-ion batteries ought to be recycled, the process continues to be challenging in most countries. Several factors hamper battery recycling, including safety restrictions, a lack of established infrastructure, and an absence of established regulatory guidelines. Even if there is reason to be optimistic, there are still obstacles to how recycling can be optimized to its full potential and realize the promise of a circular economy. North America's most successful consumer battery recycling organization was founded, with more than 160 million pounds of batteries recycled since the company [33].

The increased demand for consumer, commercial, and industrial electronics worldwide contributes to a worsening international dilemma that must be managed and resolved, including disposing of unwanted electronic devices. It should come as no surprise that various experts have advocated for worldwide action to combat the world's fastest increasing waste stream. In 2018, more than 50 million tons of electronic waste were created, yet only 20 percent of them are currently recycled [34].

5. Conclusions and Policy Implications

Recovering valuable resources that can be used in place of virgin ones is one of the most significant actions that can be taken toward solving the issue that is faced by sustainability. It is vital to place primary emphasis on analyzing the current deficiencies of performance measurement of WEEE recycling, and one ought to be prepared to shed light on the following research and development that is required in this field.

With the recognition of concepts such as the '4Rs,' waste-to-resource, and the circular economy came a move to promote reduction, reuse by refurbishment, recycling, and recovery, as well as efforts to distinguish between waste and non-waste in electronic products. In addition, efforts were made to differentiate between garbage and non-waste in electronic products. By applying the idea of utilizing one waste to treat another and recover energy, there is a possibility of recycling or reusing the electronic waste that has been generated. To rescue the environment, new environmentally friendly technologies are being marketed with little concern, given the amount of e-waste they will eventually develop. A complex problem for future public policy will be to ensure that all production processes are environmentally friendly.

In a society that is becoming increasingly digitalized, developing strategies that cover all facets of electronics is an absolute must. To change the awareness, knowledge, attitudes, and behavior of the international business and consumer public, all of the shareholders should provide a global platform for sharing information, knowledge, and recommendations; it should also facilitate inclusive solutions-oriented members' dialog and cooperation; it should work internationally to develop fair and objective policies; it should support the implementation of sustainable solutions; and it should provide a scientific basis for change.

With more than $62.5 billion in materials and precious metals piling up in the global e-waste market, it is necessary to develop commercial opportunities, technologies, and strategies to harvest and recover raw materials and move towards a circular economy. This is because the global market for electronic waste is experiencing a surplus of materials and precious metals. Simply because of this, it will be seen as a valuable resource rather than a "waste," which is the phrase that is typically used to describe it.

Author Contributions

The author did all the research work for this study.

Funding

There is no organization that funded this research.

Competing Interests

The author has declared that no competing interests exist.

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