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Challenges of Electronic Waste Growth: Recycling and Sustainable Management

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Abstract:
Electronic waste is one of the fastest-growing waste streams worldwide due to rapid technological advancements and increased reliance on IT devices and household appliances. These discarded electronic products contain hazardous materials that threaten human health and environment. This article aims to study the current state of electronic waste globally, as well as the key methods used in its management, in order to reduce the risks associated with improper disposal methods such as burning and unhealthy landfilling, which impact both human health and the environment..

Through this study, we have reached several findings, including the rise in global electronic waste volume in 2023 to 63.15 million metric tons, marking a growth rate of 51.08% during the period from 2014 to 2023. This massive and alarming increase requires proper management to mitigate its risks. In this regard, there are three possible scenarios: The formal recovery system, collection outside the formal recovery system and mixed residual waste.
Key words : Waste electrical and electronic equipment (WEEE), E-waste, recycling, E-waste Management.

I- Introduction

Discarded electronic products, also known as electronic waste, have become one of the fastest-growing waste streams in the world. This growth is attributed to advancements in the use of information technology components by individuals, institutions, and governments, alongside the increasing demand for internet-based equipment and the continuous development of household electrical appliances. This growth is driven by the rising needs of users and the technological advancements that either improve existing devices or introduce new ones.

Computers, communication devices, and electrical appliances—whether large or small—contain toxic materials that pose significant risks to human health and the environment. As such, these devices require special treatment at the end of their lifecycle. Failure to manage them properly can lead to additional problems, such as the release of toxins from concentrated lead and other harmful substances into soil, water, and human tissues.

Over the past three decades, electronic waste has received significant attention from environmental advocates, exemplified by initiatives such as the Basel Convention of 1992. This is due to the illegal transfer of waste from developed markets to emerging markets like India and China. Although the issue of waste flow in these countries is considered critical, there has been growing interest and awareness in political discourse, particularly regarding climate change. Additionally, the topic of waste recycling has been included in the agendas of both developed and developing nations due to its role in mitigating the risks posed by improper disposal methods to both human health and the environment.

This study aims to explore the reality of electronic waste recycling worldwide. To address this, the study is divided into three main sections: theoretical framework of electronic waste, the global state of electronic waste and various methods employed for managing electronic waste.

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II- Theoretical framework of electronic waste

II-1. Definition of Electronic Pollution:

Pollution is defined as the deterioration of the environment due to a disruption in the compatibility of its components, rendering it unable to perform its self-purification functions for pollutants in air, water, and land (Abdel Salam, 2011, p. 28). It is also described as the presence of foreign substances in any component of the environment, making it unsuitable or less usable (Al-Ghraibieh & Al-Farhan, 1995, p. 178).

Another definition includes the improper disposal of waste, leading to the defacement of nature and its cleanliness, and causing ecological imbalances that impair the natural role of the environment in waste disposal (Al-Shawwara, 2017, p. 98).

Electronic pollution specifically refers to the contamination caused by electronic waste that is not safely disposed of or recycled due to the absence of precautionary measures to safeguard human health and the environment (Fawzi & Mahmoud, 2016, p. 2).

II-2. Definition of Electronic Waste:

There is no universally agreed-upon definition of electronic waste. According to the OECD, it is defined as any device that uses an electrical energy source and has reached the end of its useful life. The European Directive Commission describes it as waste from electrical and electronic equipment, including all their components and subassemblies (Lundgren, 2012, p. 11). Additionally, it encompasses discarded computers, office electronics, entertainment devices, mobile phones, TVs, refrigerators, and devices still usable or recyclable (Statistics Center: Environmental Standards and Definitions, p. 8).

Shah and Shaikh (2008, p. 2) describe it as a mix of used or unwanted electronic products that have outlived their lifespan, such as computers, monitors, televisions, mobile phones, batteries, stereos, and others containing toxic materials requiring proper recycling. Moreover, electronic waste refers to all discarded electrical and electronic equipment and parts without intent for reuse, known as Waste Electrical and Electronic Equipment (WEEE) (Badlé, Forti, Kuher, & Stegmann, 2007, p. 8).

II-3. Categories of Electronic Waste:

Electronic waste can be categorized based on product type, size, or treatment technology. Six main categories are commonly identified:

- **Heat Exchange Equipment:** Includes refrigerators, freezers, air conditioners, and heat pumps.
- **Display Devices:** Includes TVs, computer screens, and digital boards.
- **Lamps:** Includes fluorescent lamps, high-intensity discharge lamps, and LED lamps.
- **Large Equipment:** Includes washing machines, dryers, dishwashers, electric stoves, large printers, copiers, and photovoltaic panels.
- **Small Equipment:** Includes vacuum cleaners, microwaves, video cameras, monitoring tools, and small control devices.
- **Small IT and Communication Devices:** Includes mobile phones, GPS systems, personal computers, printers, and phones (Flauda, Khetriwal, & Kuehr, 2016, p. 24).

II-4. Risks of Electronic Waste:

Electronic waste poses numerous environmental and health hazards due to the toxic components of electrical and electronic devices. These risks include:

- **Lead:** Found in glass screens of TVs and computers (up to 85% in colored screens), circuit boards, batteries, and printers. It can cause anemia, high blood pressure, kidney tissue atrophy, miscarriages, nervous system disorders, learning disabilities in children, and behavioral problems if ingested or inhaled (Husni Abdul-Majeed, 2016, pp. 41-42; Abdel Salam, 2011, pp. 111-121).
- **Cadmium:** Used in batteries, mobile phones, capacitors, and small connection chips. It can lead to bone fractures, reproductive issues, nervous system degeneration, immune dysfunction, genetic damage, and cancer.
- **Mercury:** Present in batteries, flat screens, medical devices, sensors, and mobile phones. Its risks include nervous system disorders, brain cell degeneration, genetic mutations, rash, fatigue, headaches, infertility, and mental disorders.
- **Beryllium:** Found in motherboards and considered carcinogenic, causing lung damage, skin diseases, and immune system suppression.

European Economic Letters
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- **Barium:** Used to shield computer users from radiation. It causes breathing difficulties, high blood pressure, muscle weakness, liver and brain swelling, kidney and heart damage, and potentially paralysis and death if consumed in large amounts.
- **Chromium:** Used in circuit boards and plastic components. Toxic emissions increase with higher oxidation levels, causing diabetes, cancer, respiratory issues, immune dysfunction, liver and lung damage, and genetic mutations.
- **Phosphor:** Coats the interior of cathode ray tube screens to enhance brightness. It contains highly toxic compounds like zinc, vanadium, and cadmium.
- **Dioxin:** A toxic gas released during the combustion of heavy metals in electronics, causing neurological damage, severe lung diseases, and spinal degeneration.

II-5-The lifecycle of electronic waste

The lifecycle of electronic waste encompasses multiple stages, from the production of electronic devices to their final disposal (lundgren,2012), this cycle begins with the extraction of raw materials, such as metals and plastics, from the earth and their use in manufacturing electronic devices through processes such as assembling circuit boards and integrating components.

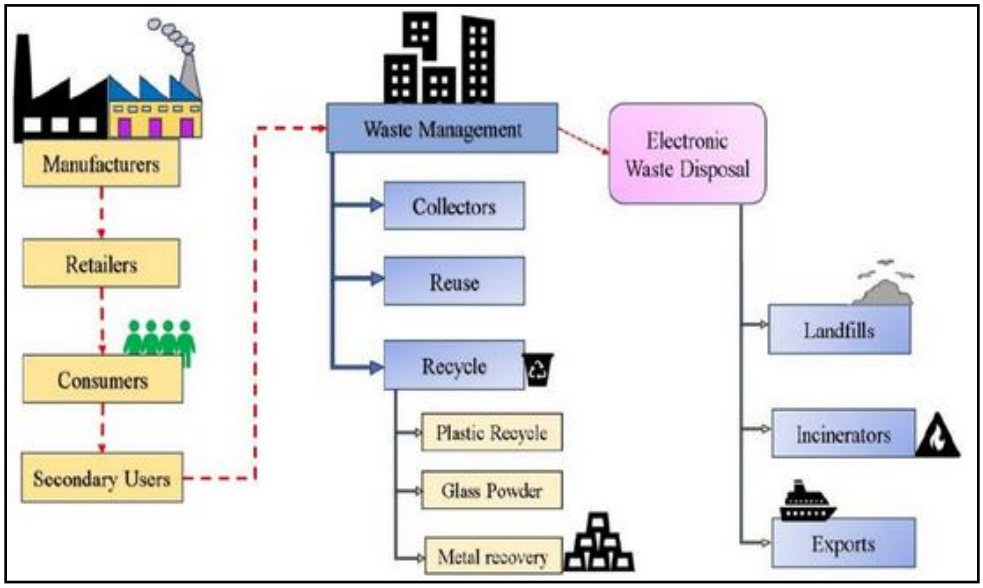
After manufacturing, the devices are distributed to consumers, entering the usage phase, during which they may undergo modifications or maintenance. Eventually, electronic devices reach the end of their lifespan, at which point decisions are made regarding their disposal, recycling, or reuse.

The collection and transportation process involves gathering discarded devices from various sources and transporting them to recycling facilities. At these facilities, the devices are processed and recycled through steps that include sorting, dismantling, and employing mechanical or chemical methods to extract valuable materials such as metals and plastics. Components that are still functional may undergo reuse or refurbishment in line with circular economy principles.

In the final stage (disposal phase), any remaining materials that cannot be recycled or reused are managed responsibly to minimize environmental impact. This may involve safe landfill disposal, incineration, or export to other countries for waste treatment.

A comprehensive understanding of each stage in the lifecycle of electronic waste is essential for developing sustainable practices, reducing environmental impact, and enhancing resource efficiency. These stages can be illustrated as follows:

Figure(01) : **The lifecycle of electronic waste**



Source : Onkar Nath Mishra, Chatrabhuj, Bipin Prajapati **E-Waste: Management Techniques for The Environmental Sustainabilit**y, International Research Journal on Advanced Engineering and Management Volume: 02Issue: 04 April 2024, p.788.

III-Reality of E-Waste during [2014-2023]

III-1 E-Waste generated from 2014 to 2023 (million metic tons)

European Economic Letters
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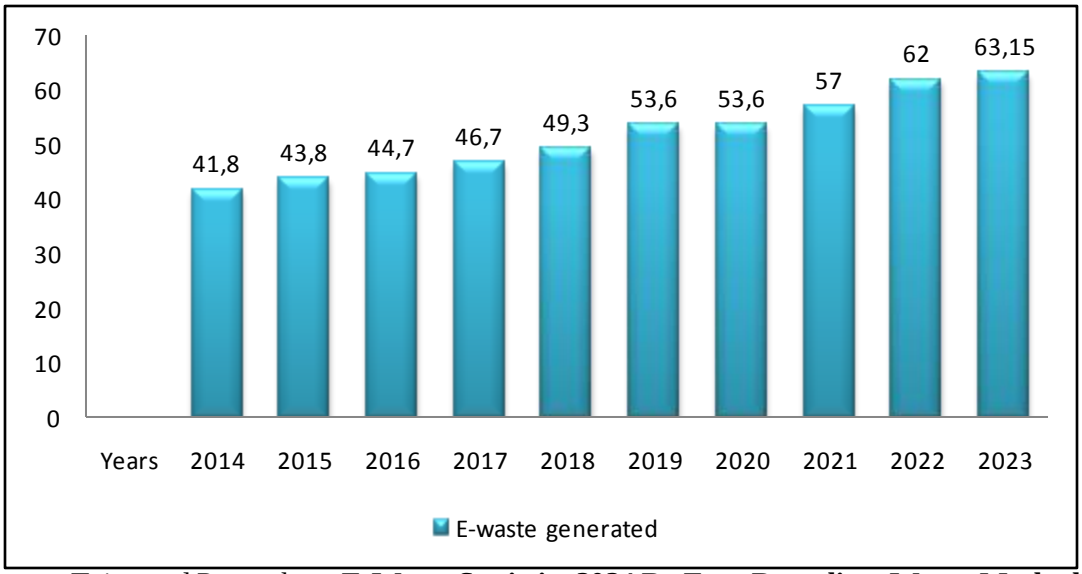
Based on figure(02) it is evident that the volume of e-waste generated globally has significantly increased during the period from 2014 to 2023, rising from 41.8 million metric tons in 2014 to 63.15 million metric tons in 2023, marking a growth rate of 51.08% due to technological progress, increased consumption, limited repair options, short lifecycles and inadequate e-waste management infrastructure, the growth in the amount of e-waste is outpacing growth in documented formal collection and recycling. . Most of this waste originates from small electronic equipment. The rise in e-waste generation is attributed to the increased use of electrical and electronic devices worldwide, driven by rapid technological advancements in information and communication technology, as well as the widespread adoption of the internet.

The accelerating growth of e-waste generation at this pace signals potential future challenges for both the environment and human health if not managed and treated properly in environmentally friendly and safe ways.

By 2030, the world is projected to be burdened with 82 million metric tons of e-waste(https://scoop.market.us/e-waste-statistics/), with an expected growth rate of 30.50% over the next decade. This waste primarily consists of refrigerators, washing machines, and other household appliances, in addition to mobile phones and computers. At the same time, such waste poses significant risks to human health and the environment, underscoring the urgent need for proper recycling methods to mitigate its future harm.

Figure (02) : Global E-Waste generated from 2014 to 2023 (million metic tons)



Source :Tajammul Pangarkar, **E-Waste Statistics 2024 By Easy Recycling, Waste, Methods**, 2023, https://scoop.market.us/e-waste-statistics.

III-2-Total Electronic Waste by Category

Small equipment, such as video cameras, toys, microwave ovens and e-cigarettes (figure03), constitutes the largest category of e-waste in terms of mass, accounting for 20 billion kg in 2022, or almost one-third of the world's total e-waste ;.

The second largest category is large equipment, excluding photovoltaic panels (15 billion kg in 2022). After photovoltaic panels, the smallest category is lamps (2 billion kg) ;

Screens and monitors currently represent 10 per cent of e-waste generated (5.9 billion kg). Small IT and telecommunication equipment - such as mobile phones, GPS devices, routers, personal computers, printers and telephones -totaled 5 billion kg in 2022 ;

The green transition and the connecting of off-grid communities will lead to a quadrupling of waste from photovoltaic panels from 0.6 billion kg in 2022 to 2.4 billion kg in 2030.

Figure(03) : Total Electronic Waste by Category2022

European Economic Letters
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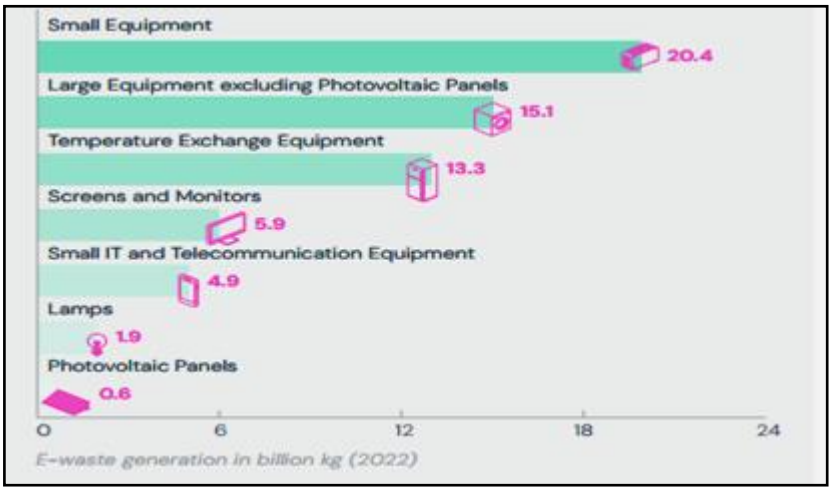
http://eelet.org.uk



Source : Cornelis P. Baldé & all, **E-Waste monitor 2024**, UNITAR, p.12

Based on Figure (04), it is evident that China ranked first in e-waste generation in 2022, producing 12.07 million metric tons, equivalent to 19.46% of global e-waste during the same year. This is largely attributed to the :

- high Population with over 1.4 billion people, China has a vast consumer base, leading to significant generation of household e-waste ;

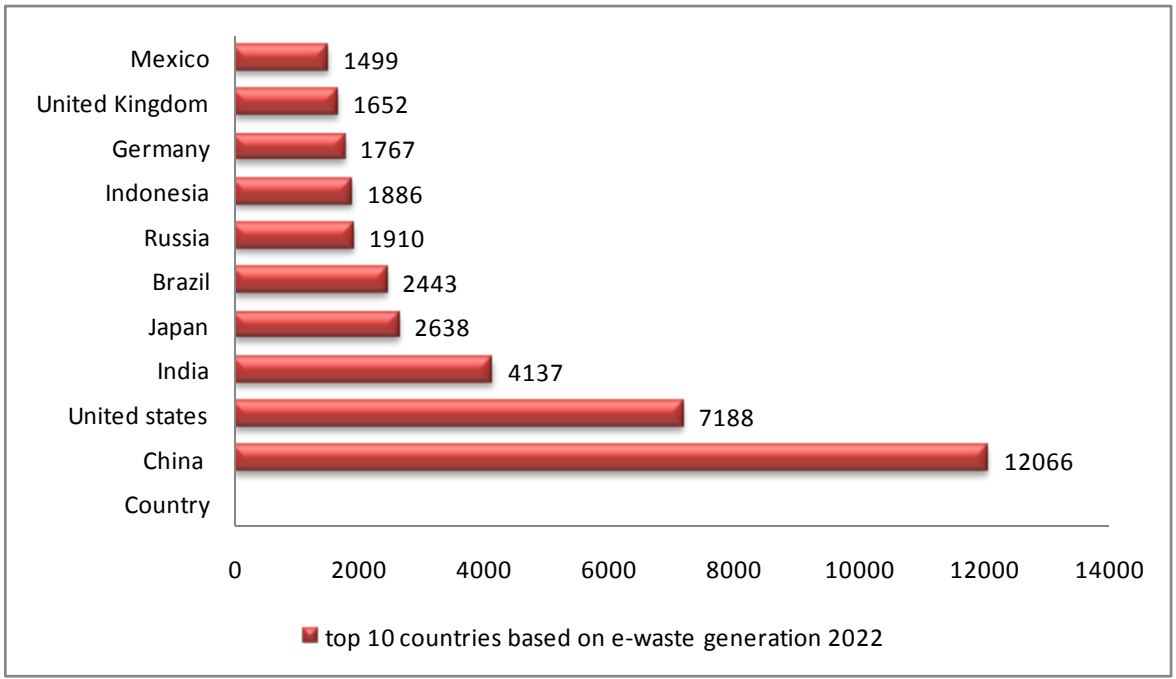
-rapid economic development increased manufacturing and consumption of electronic goods as these products reach the end of their lifecycle, they contribute significantly to e-waste ;

- influx of e-waste through illegal channels into China, despite the United Nations' ban on the trade of e-waste from developed countries to the developing world. Although the Chinese government has established regulations prohibiting the import of e-waste, significant loopholes in enforcement remain,

The United States ranked second among the world's top e-waste-producing countries, with 7.2 million metric tons, accounting for 11.6% of total global e-waste in 2022. India ranked third, generating 4.137 million metric tons of e-waste. Meanwhile, Japan and Brazil occupied the fourth and fifth positions, with 2.64 and 2.44 million metric tons, respectively, in 2022.

The top ten e-waste-producing countries—China, the United States, India, Japan, Brazil, Russia, Indonesia, Germany, the United Kingdom, and Mexico—collectively generated 37.186 million metric tons, representing 60% of the global e-waste output in 2022.

Figure (04), Leading countries based on electronic waste generation worldwide in 2022 (in 1,000 metric tons)



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Source : https://www.statista.com/statistics/499952/ewaste-generation-worldwide-by-major-country/

III-E-Waste Management

E-Waste Management involves the collection and processing of e-waste through three scenarios: the formal recovery system, mixed electronic waste, and collection outside the formal recovery system.

III-1-The formal recovery system

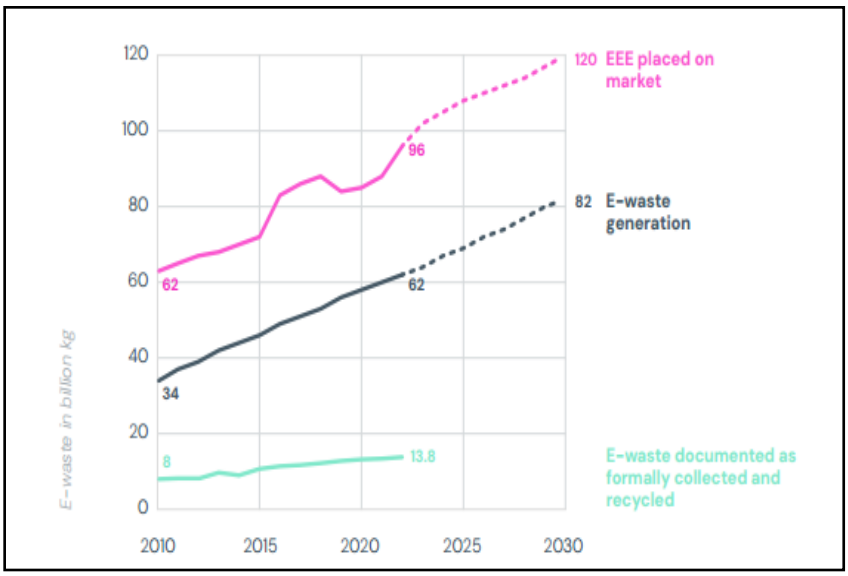
The formal recovery system involves the collection and processing of e-waste through authorized and regulated channels. These include government-backed recycling programs, certified recycling facilities, and designated drop-off points. The primary goal is to recover valuable materials, minimize environmental harm, and ensure safe disposal of hazardous components. This approach is aligned with national and international regulations to promote sustainable e-waste management..

The growth rate of countries implementing e-waste policy, legislation or regulation is decelerating, according to June 2023 data. In all, 81 countries (42 per cent of all countries worldwide) have adopted e-waste policies, covering 72 per cent of the global population.

Between 2019 and 2023, the number of countries with such legislation increased slightly, from 78 to 81. Of those 81 countries, 67 had a legal instrument governing e-waste management containing provisions promoting the environmental policy principle of extended producer responsibility (EPR).

Although some advances have been made in the amount of e-waste being documented as formally collected and recycled, rising from 8 billion kg in 2010 to 14 billion kg in 2022, this achievement is overshadowed by the rapid growth in the amount of e-waste overall. The quantity of electrical and electronic equipment (EEE) placed on the market increased from 62 billion kilograms in 2010 to 96 billion kilograms in 2022. It is expected to reach 120 billion kilograms by 2030. During the same period, the annual generation of e-waste rose from 34 billion kilograms to a record 62 billion kilograms, with projections indicating it will reach 82 billion kilograms by 2030, the above can be summarized in figure05.

Figure (05) : e-waste being documented as formally collected and recycled [2010-2022]



Source : Cornelis P. Baldé & all**, E-Waste monitor 2024**, UNITAR, p.26.

III-2-Collection Outside the formal Recovery System

Some countries have advanced waste management systems, where e-waste is collected by waste contractors or companies and traded through various channels (such as recycling of metals, plastics, and specialized e-waste) as well as exported. The primary types of waste handled in this manner include cooling and heating equipment, large appliances, and IT products.

In contrast, countries without proper waste management infrastructure, such as developing nations, rely on independent individuals who purchase end-of-life electronic equipment from consumers for refurbishment or recycling. This practice, often referred to as "backyard recycling," involves open burning to extract metals, acid leaching to recover precious metals, melting plastics without safety

measures, and the direct disposal of waste into the environment, causing severe harm to both the environment and human health.

The primary objective of e-waste recycling is to significantly increase its rate while addressing the environmental concerns associated with improper disposal. It has been observed that various governments are taking initiatives to manage and recycle e-waste. In this regard, Original Equipment Manufacturers (OEMs) and non-profit organizations are making substantial efforts to recycle such waste.

-The e-waste generated in 2022 according to E-Waste monitor 2024 contained 31 billion kg of metals, 17 billion kg of plastics and 14 billion kg of other materials(minerals, glass, composite materials, etc.)

-13.8 billion kg of e-waste is documented as formally collected and recycled in an environmentally sound manner

-16 billion kg of e-waste is estimated to be collected and recycled outside of formal systems in high-andupper-middle-income countries with developed e-waste management infrastructure.

-18 billion kg of e-waste is estimated to be handled in low- and lower-middle-income countries with no developed e-waste management infrastructure, mostly by the informal sector.

-14 billion kg of e-waste is estimated to be disposed of as residual waste, the majority of which is landfilled globally.

-Most e-waste is managed outside formal collection and recycling schemes. As a result of non-compliant e-waste management, 58 thousand kg of mercury and 45 million kg of plastics containing brominated flame retardants are released into the environment every year. This has a direct and severe impact on the environment and people's health

-The growth rate of countries implementing e-waste policy, legislation or regulation is decelerating, according to June 2023 data. In all, 81 countries (42 per cent of all countries worldwide) have adopted e-waste policies, covering 72 per cent of the global population.

III-3-Mixed Residual Waste: This occurs when consumers dispose of electrical and electronic equipment in regular trash bins along with other types of household waste. In this case, these items are processed together with other waste by being sent to landfills or waste incinerators, with a low likelihood of being sorted before reaching their final destination. This leads to a loss of resources on one hand and negative environmental impacts on the other, due to the leaching of toxins into nature and the release of toxic gases from incineration.

IV-Conclusion and Recommendations

Electronic waste today poses a significant threat to human health and the environment, as it contains toxic materials harmful to both. Most devices and products in the field of information technology rely heavily on chemicals in their manufacturing. Electronic devices contain over a thousand types of chemical elements, including chlorinated solvents, polyvinyl chloride, heavy metals, plastics, and gases. This calls for better and more effective management of electronic waste and overcoming the linear economic model of "produce, consume, dispose." Instead, adopting a circular economy approach aims to retain product value for as long as possible by enhancing reuse, repair, redistribution, refurbishment, and remanufacturing before recycling materials. This reduces environmental pressures related to resource extraction, emissions, and waste. Based on this research, we reached the following findings:

- **Recycling plays a crucial role** in reducing the volume of electronic waste, especially when financial and material resources are available. Institutions in the electronics sector must focus more on recycling strategies due to their advantages, such as reducing costs by reusing materials and thereby increasing profits, in addition to the benefits for natural resources.
- **Recycling is currently one of the most effective practices globally** for managing waste, particularly electronic waste. This is due to the benefits it offers, including preventing the depletion of natural resources and maximizing the use of secondary raw materials generated from recycling electronic waste. This, in turn, lowers the costs of acquiring raw materials necessary for manufacturing.
- **Despite its risks, electronic waste contains a significant amount of rare valuable materials and metals.** Institutions that master the process of recycling electronic waste effectively can gradually, if not entirely, reduce their reliance on purchasing or importing primary raw materials for manufacturing. This contributes to reducing electronic waste volumes.

In conclusion, efforts must be united at the individual, collective, local government, and international levels to manage and dispose of this waste with minimal harm. Proposed solutions to reduce electronic pollution include:

For individuals: Collect electronic waste from their homes or workplaces, refrain from discarding it with regular waste, and locate the nearest recycling points, often available at certified electronics retailers.

Promoting environmental awareness: Foster community awareness to protect public health and environmental safety through various educational tools, starting from schools and extending to different media platforms.

Enacting suitable legislation: Provide the necessary measures and procedures that enable citizens to safely dispose of electronic waste. This includes designating electronic waste collection centers across neighborhoods and cities for recycling purposes, enhancing partnerships with the private sector for environmental sustainability, and adopting environmentally sound technologies for waste management.

Involving major electronics companies: Encourage these companies to address the challenge of electronic waste disposal by eliminating toxic chemicals in their manufacturing processes and improving recycling programs. These companies must adhere to preventive and environmentally sound standards imposed by strict governmental regulations to ensure the safe remanufacturing of their products.

By implementing these measures, we can move closer to reducing the harmful effects of electronic waste and fostering a more sustainable and environmentally friendly approach to waste management

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