Analysis of the Global Reality of Electronic Waste Recycling to Reduce Environmental and Health Risks

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This article analyses the global growth of electronic waste (e-waste) and evaluates recycling as a key solution to reduce environmental and health risks. Rapid technological advancement and rising consumption have led to unprecedented volumes of e-waste containing hazardous substances such as lead, mercury, and cadmium, which threaten ecosystems and human health. At the same time, e-waste represents a significant economic opportunity due to its high content of valuable metals. Using adescriptive-analytical approach, the study examines global trends, recycling practices, economic value, and major challenges, highlighting the need for adequate infrastructure, strict regulations, and public awareness to promote sustainable e-waste management and environmental protection.
Key words: Electronic waste (E-waste),Recycling,Environmental pollution, Public health risks,Environmental economics, Sustainable development.

Jel Codes Classification : Q53, Q56, Q57, O13

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تحليل واقع إعادة تدوير النفايات الإلكترونية عالميا للحد من المخاطر البيئية والصحية

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تحلل هذه المقالة النمو العالمي للنفايات الإلكترونية، وتقيّم إعادة التدوير كحلٍ رئيسي للحد من المخاطر البيئية والصحية. فقد أدى التقدم التكنولوجي السريع وارتفاع معدلات الاستهلاك إلى كميات غير مسبوقة من النفايات الإلكترونية التي تحتوي على مواد خطرة كالرصاص والزئبق والكادميوم، مما يهدد النظم البيئية وصحة الإنسان. وفي الوقت نفسه، تمثل النفايات الإلكترونية فرصة اقتصادية هامة نظراً لاحتوائها على نسبة عالية من المعادن القيّمة. وباستخدام منهج وصفي تحليلي، تتناول الدراسة الاتجاهات العالمية، وممارسات إعادة التدوير، والقيمة الاقتصادية، والتحديات الرئيسية، مع تسليط الضوء على الحاجة إلى بنية تحتية ملائمة، ولوائح صارمة، وتوعية عامة لتعزيز الإدارة المستدامة للنفايات الإلكترونية وحماية البيئة.

الكلمات المفاتيح: النفايات الإلكترونية، إعادة التدوير، التلوث البيئي، المخاطر الصحية العامة، الاقتصاد البيئي، التنمية المستدامة.
التصنيف Q53, Q56, Q57, O13

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Introduction:

Environmental pollution and the need to mitigate it have become among the most pressing concerns facing humanity today. The degradation resulting from irresponsible human behavior has begun to manifest clearly through climatic, environmental, and health problems, ranging from global warming to ozone layer depletion, rising temperatures, heat waves, hurricanes, and droughts affecting various regions of the world.

Amid the rapid technological development, the use of electronic devices has expanded significantly across many aspects of daily life, leading to a continuous increase in electronic waste accumulation. This type of waste represents a form of environmental pollution often referred to as the "hidden danger." Unlike many forms of industrial pollution—such as solid, liquid, or gaseous toxic emissions—which can be detected visually or through odor, electronic waste poses a more serious threat because its dangers are not immediately perceptible.

The harm caused by accumulated electronic waste is no longer limited to the environment alone. Due to the hazardous substances it contains, its effects extend to human health and society as a whole. Consequently, finding effective solutions to manage this waste has become an urgent necessity. At the same time, electronic waste is increasingly viewed as an important source of valuable and precious metals.

Recycling is considered one of the most effective and least harmful methods for managing electronic waste, especially when compared to traditional disposal methods such as incineration, landfilling, burial, or uncontrolled processing, which are still commonly used in developing countries. These traditional methods result in the loss of valuable raw materials and precious metals such as gold, silver, copper, and platinum, which represent neglected economic wealth. Moreover, improper and unregulated handling of electronic waste releases highly hazardous substances such as mercury and lead, posing severe risks to public health, particularly to children.

In light of the above, the research problem can be formulated as follows:

What is the reality of the increasing volume of electronic waste, and how can recycling contribute to reducing its environmental and health risks?

-Sub-questions:

How is electronic waste processed worldwide?

To what extent does the global community contribute to addressing the problems caused by electronic waste?

What challenges hinder the management and recycling of electronic waste?

-Research Hypotheses

To answer the main research question, the following hypotheses were formulated:

Recycling plays a major role in the management and treatment of electronic waste.

Failure to follow proper and legal methods for waste and electronic waste disposal worldwide has exacerbated environmental and health problems.

Some electronic devices contain components that are difficult to recycle, constituting one of the main challenges in this field.

- Research Objectives

This study aims to achieve the following objectives:

To define the basic concepts of waste and electronic waste;

To identify the environmental and health risks generated by electronic waste;

To highlight the importance of electronic waste recycling;

To identify the main challenges facing the implementation of electronic waste recycling.

- Importance of the Study

The importance of this study stems from the fundamental significance of human beings and their surrounding environment, particularly in light of the growing global and regional environmental problems. These issues have become central topics of international dialogue, debate, and conferences, both in public and private spheres. With rapid technological

advancement on the one hand, and the increasing speed and scale of technological consumption on the other, the contemporary era is increasingly characterized as the "age of electronic waste."

Research Methodology:

This study adopts a descriptive-analytical approach. The descriptive method is used to present concepts and theoretical foundations related to waste, electronic waste, and recycling, while the analytical method is applied to analyze data presented in tables and figures concerning the global management of electronic waste.

- Structure of the Study:

The study is structured around three main axes:
An introduction to environmental economics;
The concept of waste recycling and electronic waste recycling;
The reality of electronic waste management worldwide.

I- Introduction to Environmental Economics

I -1-Definition of the Environment

Despite the diversity of topics and fields in which the concept of the environment has been addressed, it generally refers to the notion of a "surrounding medium." Until relatively recently, the concept of the environment did not attract significant attention from researchers and scholars, particularly before the second half of the twentieth century. This changed notably in 1972 with the holding of the Stockholm Conference on the Human Environment, which highlighted the degradation and pollution affecting various regions of the world.

Among the most prominent definitions of the environment are the following:

- One of the earliest definitions was provided by Ibn Abd Rabbih, author of *Al-ʿIqd al-Farīd*, who used the term "environment" to denote the natural setting (geographical, spatial, and biological) in which living organisms, including humans, exist. (Training, 2008, p. 02)
- According to Algerian legislation, the environment is defined in Law No. 10-03 on environmental protection within the framework of sustainable development as: "The surroundings in which human beings live, including water, air, soil, living and non-living organisms, and various facilities; thus, the environment includes both the natural and artificial environment."
- The International Organization for Standardization (ISO) defines the environment as: "The surroundings in which an organization operates, including air, water, soil, natural resources, flora, fauna, human beings, and the interrelationships among these elements, extending from the immediate surroundings of the organization to the global system" (Kataf & Alqama, 2008, p. 02).
- Boring defines the human environment as the totality of stimuli received by individuals from birth to death, encompassing physical, intellectual, economic, political, cultural, social, moral, and emotional forces, all of which influence human behavior, development, and growth (Al-Din, 2020) .
- It has also been defined as:
"The natural world in which humans, animals, and plants coexist, and which is exposed to numerous risks as a result of the destructive impacts of industrial society" (Abed, 2004, p. 19).
- Another definition describes it as:
"Everything that surrounds human beings and the milieu in which individuals develop" (REBEYROL, 2010).

This definition is considered the most widely accepted due to its comprehensive and inclusive nature.

Overall, these definitions emphasize the natural dimension of the environment and its living and non-living components. The environment has traditionally been viewed as a reservoir of natural resources intended to serve human needs. Consequently, the relationship between humans and the environment was long perceived as a linear one, focusing solely on human impact on the environment—an approach adopted by possibilist theory in interpreting this relationship. This perspective dominated environmental thought for an extended period.

I -2- Environmental Problems

An environmental problem refers to a disturbance or degradation in the ecological system that results in environmental hazards affecting all forms of life on Earth, either directly or indirectly.

The most significant environmental problems facing the world today can be summarized as follows:

I -2-1- Transboundary Pollution

The Environmental Terminology Dictionary defines pollution as:
"Any direct or indirect physical, thermal, biological, or radioactive change in the characteristics of any component of the environment that results in effective risks affecting health, safety, welfare, and all other living organisms" (Khalaf, 2007, p. 65) .

Transboundary pollution refers specifically to the impact of polluted air extending beyond the borders of the country in which it originated.

Transboundary air pollution arises from industrial activities, energy production, and various modes of transportation, including international shipping and domestic mobility. Studies by the European Environment Agency indicate that such pollution contributes to acidification, summer smog formation, and the spread of hazardous substances such as radioactive elements in the atmosphere. It also leads to eutrophication in water bodies and soil.

Pollution has been classified according to several criteria, most notably based on its nature, into three main types (Al-Haithi, 2008, pp. 27-28) :

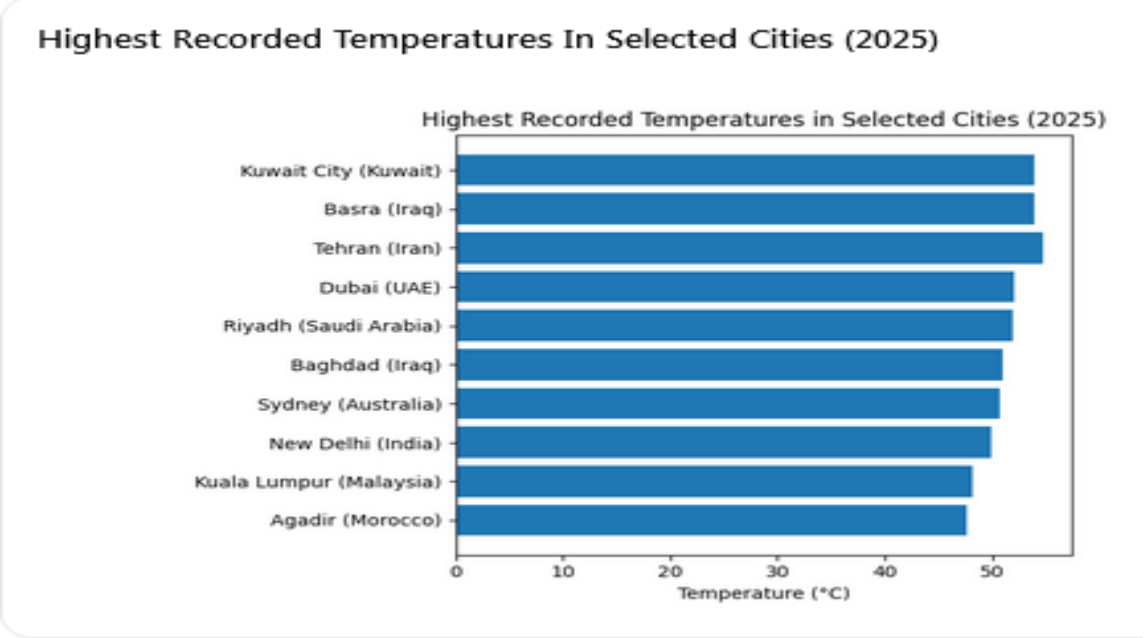
- **Biological pollution:** Pollution resulting from the activity of microorganisms during the fermentation of organic materials. These organisms multiply rapidly, consume oxygen, and may create suffocating environments or weaken immune systems, making organisms vulnerable to viruses and bacteria.
- **Physical pollution:** Includes noise, heat, and radiation, often caused by radioactive emissions in industrial areas and near nuclear reactors, which can damage living tissues and contaminate air, water, and soil.
- **Chemical pollution:** Considered no less dangerous than other types, particularly due to the widespread use of chemical substances. It results from the disposal of chemical materials and waste into the natural environment or from their accumulation at toxic levels, such as mercury, cadmium, and arsenic compounds.

I -2-2-Global Warming

Global warming is among the most serious environmental challenges and is defined as:
"The increase in Earth's surface temperature due to rising concentrations of greenhouse gases in the atmosphere, including carbon dioxide, which is considered the primary contributor."

Recent climate data indicate that the year 2025 recorded unprecedented temperature levels in several regions of the world, particularly in the Arabian Gulf, South Asia, and North Africa, as illustrated in the following figure:

Figure n°1: The 10 Hottest Countries Worldwide in 2025



Source: (nasa, 2025)

These figures represent a global warning that extreme heat waves have become a recurring reality and that preparedness is no longer optional but imperative. Continued climate change may lead to even higher temperatures in the coming years unless serious global measures are adopted to mitigate its effects.

I -2-3-Ozone Depletion

Ozone depletion is another climate-related environmental problem and among the most dangerous. Ozone in the atmosphere plays a dual role in maintaining Earth's thermal balance: it absorbs ultraviolet solar radiation, heating the stratosphere, and absorbs infrared radiation emitted from the Earth's surface, effectively trapping heat in the troposphere (. & Fayyad, 2020) .

In addition to the issues mentioned above, numerous other environmental problems of varying severity must not be overlooked. According to United Nations environmental programs, approximately 27 environmental problems have been identified, including 13 climate-related issues. These include biodiversity loss, desertification, food insecurity, natural disasters, nuclear risks, forest fires, acid rain, El Niño phenomena, urban expansion, and various types of waste (Shehata & Awad, 2018, p. 116) .

I -3- Causes of the Increase in Environmental Problems

Environmental problems arise from a combination of interrelated factors, the most prominent of which are the following:

- **Scientific and technological revolution:**
  The scientific and technological revolution has significantly improved human welfare and living standards. However, it has simultaneously contributed to the exacerbation of environmental problems due to the substantial increase in the consumption of natural resources and the rapid pollution of environmental systems (Al-Haithi, 2008, p. 20).
- **Population growth:**
  Demographic variables have become a central component of environmental issues, particularly concerning discussions on optimal population size and the provision of food and healthcare. This growing concern has coincided with high population growth

rates observed in recent decades (Al-Haithi, 2008, pp. 20-21).
According to reports from the United Nations Population Division, the global population is expected to reach approximately 8.5 billion by 2030, 9.7 billion by 2050, and may rise to 11.2 billion by 2100. This rapid population growth is closely linked to environmental security through its pressure on Earth's resources required to meet human needs.

- **Ecological imbalance:**
Ecology seeks to understand the interaction between living and non-living elements and the balance resulting from these interactions. Any disruption of this balance leads to environmental degradation. Human activities have increasingly disturbed ecological equilibrium, thereby intensifying environmental problems (Al-Haithi, 2008, pp. 23-24).

In addition to the above, other contributing factors include (Kafi, 2014, p. 8):

- Depletion of mineral resources;
- Production of vast quantities of hazardous chemical compounds;
- Poor agricultural practices and excessive use of chemical fertilizers and pesticides, leading to soil degradation and loss of fertility;
- Generation of large volumes of waste that are difficult to dispose of, causing contamination of surface and groundwater;
- Widespread circulation of toxic substances and increased likelihood of environmentally harmful accidents, such as chemical spills and oil leaks.

I -4- Definition of Environmental Economics

Several definitions have been proposed for environmental economics, the most significant of which include:

- Environmental economics is defined as a field concerned with applying economic analysis tools to examine the costs borne by society (or the national economy) as a result of damages caused by environmental imbalance in its various forms. These costs may include expenditures aimed at preventing environmental damage or treating its consequences. In other words, environmental economics studies the benefits gained by society from preventing or mitigating environmental degradation and the feasibility of eliminating its impacts (Shtouh, 2020, p. 84).
- It has also been defined as:
"A science that evaluates the theoretical, analytical, and accounting aspects of economic life using environmental criteria, with the aim of maintaining environmental balance that ensures sustainable growth" (Jalal, 2017, p. 45).
- Another definition describes it as:
"The application of economic science to achieve the optimal use of environmental resources in all their dimensions, with the objective of maximizing profit and satisfying basic needs at the lowest possible economic and environmental cost" (Kafi, 2014, p. 16).

I -5- Branches of Environmental Economics

Environmental economics is generally divided into two main branches:

I -5-1- Micro-Environmental Economics (Firm Level)

According to (Kafi, 2014, pp. 17-18), micro-environmental economics represents a component of firm-level economics concerned with analyzing the relationship between

enterprises and the natural environment, the qualitative development of surrounding ecosystems, and the impact of environmental policies on firms. Its key functions include:

- Studying and analyzing environmental protection measures adopted by firms and their impact on profit maximization;
- Providing guidance and consultancy aligned with environmental protection requirements;
- Contributing to the orientation of production in accordance with environmental regulations and policies;
- Examining environmental investments aimed at reducing environmental risks;
- Supplying information on environmental protection costs, investment expenditures, and their impact on profit and loss accounts, as well as conducting environmental feasibility analyses of projects;
- Offering advice, problem analysis, and future outlooks for certain sectors of the national economy—such as services, transportation, environmental protection industries, trade, and insurance—in light of environmental developments.

I -5-2- Macro-Environmental Economics

Macro-environmental economics addresses environmental issues at the level of the overall economy. Its primary objective is to achieve higher levels of sustainable social welfare while maintaining environmental quality at optimal levels (Environmental economics, 2021).

II- Concept of Waste and Electronic Waste

II-1- Definition of Waste

Before addressing the concept of waste recycling and electronic waste recycling, it is essential to clarify the concept of waste itself. Several definitions have been proposed, the most important of which are as follows:

- **World Health Organization (WHO) definition:**
  Waste is defined as any material possessing physical, chemical, or biological properties that require special handling and disposal methods in order to avoid risks to public health and the environment (Ali, 2011, p. 12).
- **Algerian legislator's definition:**
  According to Algerian Law No. 01/19 on waste management, control, and disposal, Article 03 defines waste as:
  "All residues resulting from production, transformation, or use processes, and generally any substance, product, or movable object that the owner or holder disposes of, intends to dispose of, is required to dispose of, or must remove" (19/01 ،2001).
- Waste is further described as:
  "All residues resulting from the consumption of natural materials by humans, animals, and all living organisms, as well as materials generated by industrial activities that have lost their value and must be disposed of" (Fahmy, 2011, p. 116) .

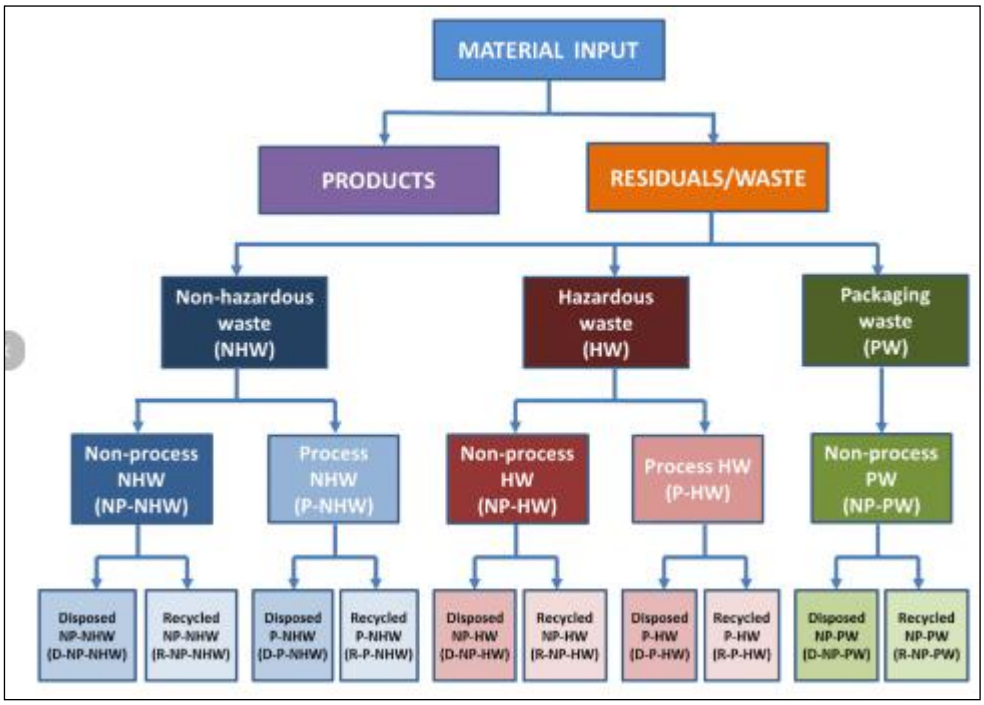
Based on these definitions, waste can be broadly understood as all residual materials generated by human, animal, or plant activities that have significant environmental impacts, particularly when accumulated. Such accumulation necessitates disposal through various legal or illegal methods, often exacerbating environmental risks and problems.

II-2- Types of Waste

Waste has been classified in multiple ways depending on the legal, economic, or environmental perspective adopted. These classifications may be based on the sector

generating the waste, its physical form, its composition, or its degree of hazard. These classifications are illustrated in the following figure:

Figure n°2: Types of Waste



Source: Donmezoglu Olmez & Aksoy (2022)

Among the most significant types of waste are **solid waste**, which includes industrial, agricultural, medical, radioactive, glass, plastic, and paper waste. This category also includes discarded electronic devices such as televisions and obsolete or end-of-life computers, which constitute the focus of this study as electronic waste.

According to Algerian legislation, waste is classified as follows (19/01 ،2001):

- Special waste, including hazardous special waste;
- Household and similar waste;
- Inert waste.

II-3- Introduction to Waste Recycling

II-3-1- Definition of Waste Recycling

Waste recycling has been defined in several ways, among the most notable are the following:

- **Definition according to Egyptian Environmental Law:**
  Waste recycling is defined as "the process that allows for the recovery or reuse of materials, such as using waste as fuel, extracting metals and organic materials, treating soil, or re-refining oils" (Gawad, 1997, p. 401).
- Waste recycling is also defined as:
  "The process of converting a low-value product or material into another product or material of greater benefit, thereby creating real added value in production, use, or consumption" (Al-Bakry, 2011, p. 14) .
- Another definition describes waste recycling as:
  "The process of transforming used materials and discarded waste into new products or useful raw materials, which reduces pollution and landfill accumulation, conserves natural resources and energy, and contributes to the green economy and sustainable

development. This includes materials such as paper, plastic, glass, metals, and organic waste that can be converted into compost" (Al-Bakry, 2011, p. 14).

II-3-2- Types of Waste Recycling

Waste recycling can be categorized into two main types (arin, 2019):

A. Product Recycling

Product recycling refers to the reuse of manufactured items through different methods and is divided into two sub-types:

- **Maintenance and reuse:**
  This involves retaining the original product while making a series of structural or functional modifications to extend its useful life.
- **Remanufacturing and reuse:**
  This process involves taking a product and remanufacturing it through a set of complex industrial procedures in order to reuse it for the same purpose.

B. Material Recycling

Material recycling involves the reuse of raw materials and is also divided into two sub-types:

- **Re-manufacturing:**
  This process involves taking materials and processing them through a series of industrial steps using various machines to restore the required quality so that they can be reused as energy-producing or industrial inputs.
- **Material treatment:**
  This involves processing materials using large-scale machinery and various techniques, such as increasing temperature or adding chemical substances.

II-3-3- Stages of the Waste Recycling Process

The stages of the waste recycling process can be summarized as follows (Ghadhban, 2015, pp. 87-92) :

- Separation of waste materials at the disposal site;
- Collection, sorting, and transportation of materials to appropriate facilities;
- Processing and conversion of materials into raw materials;
- Manufacturing new products from recycled materials;
- Marketing and selling recycled products.

For these stages to be successfully implemented, several requirements must be met. These include environmental requirements such as compliance with laws and regulations, technical requirements such as sorting, dismantling, and identification processes, and economic requirements, primarily related to the cost-effectiveness of recycling operations.

II-3-4- The Importance of Waste Recycling:

Waste recycling is of great importance as it preserves natural resources, reduces pollution (air and water), saves energy, alleviates pressure on landfills, and contributes to the economy by creating job opportunities and generating revenues, among other benefits. Its importance is reflected in the following aspects (Marwan, 2018):

- **Protection of the environment and natural resources:** This is achieved through reducing the consumption of raw materials, saving energy, reducing pollution, and preserving oxygen;

- **Economic and social benefits:** Through job creation, achieving economic returns, and reducing costs;
- **Achievement of sustainable development:** Through the circular economy and reducing the volume of waste

II-4- Concept of Electronic Waste Recycling

II-4-1- Definition of Electronic Waste

Electronic waste has been referred to by several terms, including electronic waste, electronic scrap, and waste electrical and electronic equipment (WEEE). In this study, the term **electronic waste** is used, abbreviated as **E-waste**, derived from **Electronic Waste**.

Among the most important definitions of electronic waste are the following:

- **Organisation for Economic Co-operation and Development (OECD):** Electronic waste is defined as "any device that uses electrical power supply and has reached the end of its useful life" (Programme, 2016).
- Electronic waste is also defined as: "All electrical and electronic equipment that is no longer used, is malfunctioning, broken, or no longer compatible with modern technologies, or has been discarded. Such equipment contains significant quantities of toxic substances such as lead, barium, cadmium, mercury, and chromium" (Mahmoud, Without year of publication, p. 20)
- Another definition describes electronic waste as: "Waste generated from various electronic devices such as computers, mobile phones, ovens, microwave appliances, nuclear centrifuges, televisions, and other devices that have been dismantled, sold as scrap, transported for burial or incineration, or processed to recover electronic components and precious metals" (Mohamed, 2006, p. 200).

Based on these definitions, the main categories of products included in electronic waste can be identified. The European Union classifies electronic waste into more than ten categories, the most significant of which include computer monitors, mobile phones, ovens, microwave appliances, televisions, computers and their peripherals (such as cameras, keyboards, scanners, photocopiers, printers, and video devices), household appliances (refrigerators, irons, air conditioners), lighting equipment, and electronic medical devices.

II-4-2- Hazardous Components of Electronic Devices and Their Health Impacts

The danger of electronic waste lies in the fact that it contains more than 1,000 different substances, many of which are toxic. These include lead and arsenic, which are present in high concentrations in older television screens. Table 01 presents the most significant hazardous components of electronic waste and their associated health effects.

Table n°1: Hazardous Components of Electronic Waste and Their Health Impacts

Hazardous Substance	Documented Health Effects	Typical Sources in Electronic Equipment
Chromium (Cr)	Skin irritation, allergic dermatitis	Plastic components and surface coatings
Copper (Cu)	Respiratory tract inflammation, liver and kidney damage	Electrical wiring, printed circuit boards
Lead (Pb)	Severe neurological disorders, cognitive impairment, paralysis, coma, mortality	Computers, cathode ray tube (CRT) televisions,

		batteries
Silver (Ag)	Chronic exposure may cause argyria (blue–grey skin discoloration)	Mobile and cellular phones
Mercury (Hg)	Short-term exposure: gastrointestinal disorders, pulmonary damage; Long-term exposure: neurological, renal, and fetal developmental disorders	Batteries, flat-panel displays, power inverters
Arsenic (As)	Disruption of cellular communication, growth abnormalities, cardiovascular diseases, cancer, diabetes	Microwave ovens, electronic circuit boards, power inverters, electric motors
Cadmium (Cd)	Bone demineralization, skeletal pain and fragility; Inhalation may result in lung damage and death	Batteries, mobile and cellular phones
Beryllium (Be)	Carcinogenic effects	Electrical connectors
Plastics (Polyvinyl Chloride – PVC)	Landfilling leads to soil and groundwater contamination; Incineration releases toxic gases causing immune system damage and cancer	Screens, keyboards, computer mice, laptops, USB devices
Nickel (Ni)	High exposure levels associated with carcinogenic risks	Rechargeable batteries

Source: (Wahid, 2019)

The table shows that humans are the primary victims of electronic waste exposure, followed by environmental components such as air, water, and soil. Recycling electronic waste is therefore crucial, as improper disposal leads to severe environmental pollution due to the toxic substances contained in electronic devices. These substances cause serious health problems for workers involved in informal recycling and remanufacturing activities. Furthermore, the incineration of external electronic components releases toxic gases that contribute to global warming.

Scientific studies indicate that within only four months of disposal, electronic waste can transform into a time bomb for the environment if not properly managed.

II-4-3- Disposal of Electronic Waste

According to a report issued by the *International Technology Group*, a company specialized in electronic waste recycling, approximately **50 million tons of electronic waste** are generated annually worldwide. Globally, four main methods are commonly used for the disposal of electronic waste (Wahid, 2019) :

- **Storage:**
  Storage does not constitute a viable solution, as it merely postpones the final disposal of electronic devices. Moreover, it reduces the chances of effectively reusing these devices.
- **Landfilling or incineration:**
  Electronic waste is often mixed with household waste and ultimately disposed of in landfills or incinerators. In both cases, this practice results in significant environmental pollution due to the release of hazardous substances into soil, air, and water.

- **Exportation:**
  Thousands of electronic devices—including computers, mobile phones, and household appliances—are exported each year from technologically advanced countries to developing countries for reuse or recycling. In many cases, large components of these devices are processed using unsafe and informal methods, leading to widespread environmental contamination.
- **Reuse:**
  This method involves repairing damaged components of electronic devices through relatively simple refurbishment processes in order to extend their lifespan.

Despite these approaches, there is a pressing need to intensify efforts to raise public awareness regarding safe and environmentally sound methods for disposing of electronic waste. From this perspective, promoting awareness of electronic waste recycling emerges as the safest and most sustainable solution, which will be discussed in the following section.

II-4-4- Concept of Electronic Waste Recycling

II-4-4-1- Definition of Electronic Waste Recycling

Electronic waste recycling refers to the process of recovering valuable metals and materials from discarded electronic devices. This process not only reduces environmental impact but also preserves natural resources. It involves dismantling electronic devices, separating their components, and refining materials for reuse in the manufacture of new products.

Recovered materials from electronic waste include copper, gold, silver, and palladium, which are increasingly in demand in the manufacturing sector (FASTERCAPITAL, 2025).

II-4-4-2- Stages of the Electronic Waste Recycling Process

The recycling of electronic waste involves several sequential stages, summarized as follows (Wahid, 2019):

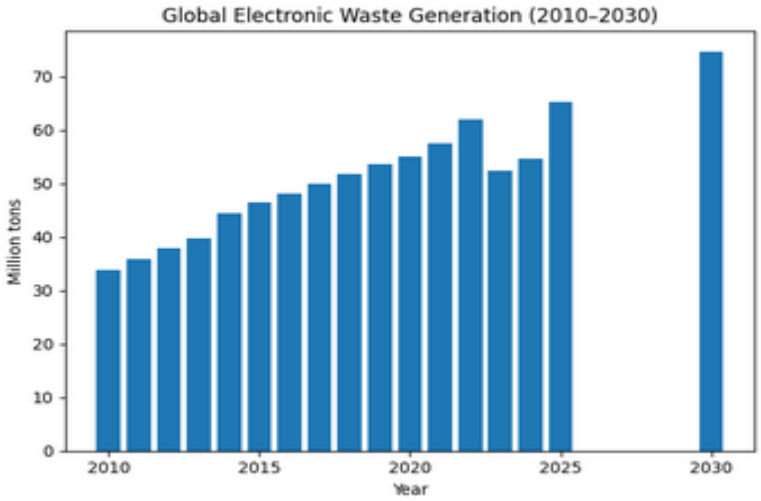
- **Extraction of hazardous materials:**
  This stage involves the careful removal of toxic substances from electronic waste while preventing environmental contamination. Examples include lead, glass extracted from screens, chlorofluorocarbon gases from refrigerators, batteries, and other hazardous elements.
- **Dismantling:**
  During this stage, electronic devices are disassembled into their main components, such as metal frames, power supplies, circuit boards, and plastic parts. One advantage of this stage is the possibility of preserving repairable components for reuse .
- **Refining:**
  Refining constitutes the final stage of electronic waste recycling. Advanced technological solutions enable the refinement of materials found in electronic waste without causing negative environmental impacts. Most components require extensive processing before they can be sold as secondary raw materials or disposed of during the final recycling phase .

III- Global Status of Electronic Waste Management

III-1- Global Volumes of Electronic Waste

Electronic waste is among the **fastest-growing waste streams worldwide**, primarily due to rapid technological change and the increasing global demand for electronic devices. The European Union has described this phenomenon as a "**tsunami of electronic waste**." Figure 03 illustrates the actual global volume of electronic waste during the period **2010–2025**, with projections extending to **2030**, based on the latest **STATISTA** reports:

Figure 03: Global Electronic Waste Volumes, 2010–2030



Source: (p. stegmamn & v. forti, 2017–2019–2020)
(electronic waste worldwide, 2010/2025)
(Forti V, 2020)

The data presented in the figure reveal a rapid and alarming increase in electronic waste volumes up to 2030. According to the latest World Bank report, global electronic waste generation could reach approximately **3.7 billion units by 2050**, representing an increase of nearly **70%**. This scenario poses a severe global environmental challenge due to the presence of toxic materials and the loss of valuable resources, unless urgent and effective measures are implemented.

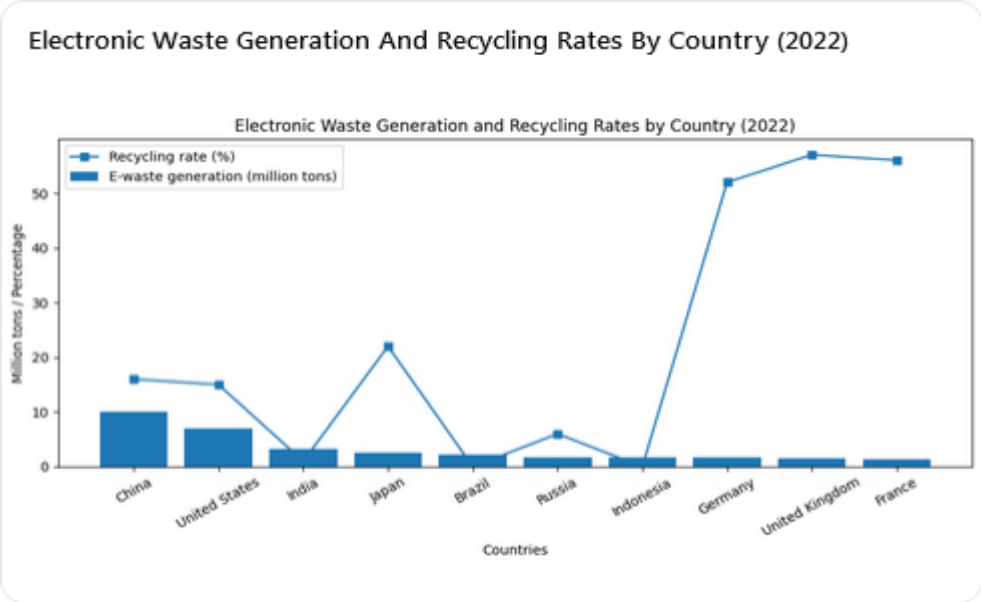
In 2025, electronic waste composition data indicate that metals accounted for approximately **31 million tons**, plastics for **19 million tons**, while other materials amounted to **15.3 million tons**.

III-2-Major Electronic Waste-Producing Countries

According to the latest **Statista** reports published in 2025 and referring to 2021 data, **China** ranked first globally in terms of electronic waste generation per capita, followed by the **United States** in second place and **India** in third place. **Germany** ranked eighth worldwide, while **France** ranked last among the top ten producing countries.

To further clarify these data, Figure 04 presents the following:

Figure 04: Top 10 Electronic Waste-Producing Countries and Their Recycling Rates (2022)



Source: (p. stegmamn & v. forti, 2017–2019–2020)
(electronic waste worldwide, 2025)

Germany, the United Kingdom, and France ranked among the lower positions within the top ten in terms of electronic waste production volume, collectively generating more than **4.5 million tons** of electronic waste. However, these countries recorded the **highest recycling rates** among the top ten, with rates of **52%**, **57%**, and **56%**, respectively.

Japan ranked fourth in terms of electronic waste volume, with a total of **2.57 million tons**, which is approximately one-fifth less than India's output. Nevertheless, Japan achieved the highest recycling rate among the top five producers, at **22%**.
Brazil, ranking fifth with **2.14 million tons** of electronic waste, exhibited a recycling rate of **0%**, highlighting the lack of effective recycling systems. These findings indicate a stronger culture of electronic waste recycling in **Western Europe** compared to other regions of the world.

III-3- Economic Value of Electronic Waste and Recovered Materials

The intrinsic value of electronic waste lies primarily in its content of **precious metals** (such as gold, silver, and platinum), **base metals** (including copper, aluminum, and iron), as well as **rare earth elements**, which are essential for green energy technologies. In addition, electronic waste contains plastics and other recoverable components whose combined value amounts to **billions of dollars annually**.

In 2024, the estimated value of recoverable materials from electronic waste exceeded **100 billion US dollars**, providing an alternative to approximately **900 million tons of raw materials** extracted from natural resources. This substitution helps mitigate the environmental damage associated with mining activities and toxic emissions.

Table 02: Global Value of Metals Contained in Electronic Waste (2022)

Raw Material	Copper	Iron	Gold	Nickel	Aluminum	Palladium	Others	Total
Value (Billion USD)	19	16	15	14	11	8	8	91

Source: (electronic waste hides treasures, 2025)

The table indicates that electronic waste generated worldwide in 2022 contained metals with an estimated total value of **91 billion US dollars**. The most valuable materials included copper (**19 billion USD**), iron (**16 billion USD**), gold (**15 billion USD**), nickel (**14 billion USD**), aluminum (**11 billion USD**), palladium (**8 billion USD**), and other materials (**8 billion USD**).

According to the **Global E-waste Monitor Report (2024)**, one of the most authoritative publications in this field, electronic waste generated in 2022 contained an estimated **31 billion kilograms of metals**.

Despite this enormous economic potential, only a **small fraction** of these valuable materials is currently recovered. The total value of recovered metals is estimated at approximately **28 billion US dollars**. More concerning is the fact that only **9 billion US dollars** of this amount were recovered through **formal and documented collection and recycling channels**, while materials worth approximately **12 billion US dollars** were recycled through **informal and unregulated methods**, primarily in low- and middle-income countries. This situation significantly increases environmental and health risks.

Even more alarming is that the **hidden external costs** associated with poor electronic waste management far exceed the value of lost materials. These externalities—affecting human health and the environment—are estimated at approximately **78 billion US dollars annually**.

A simple economic assessment reveals that the overall impact of electronic waste management in 2022 resulted in a **net global loss of approximately 37 billion US dollars**. If current practices persist, this loss is expected to rise to nearly **40 billion US dollars annually by 2030**, underscoring the urgency of addressing electronic waste as a critical global challenge.

III-4- Global Challenges of Electronic Waste Recycling and Proposed Solutions

Electronic waste recycling represents a viable solution for mitigating the negative impacts of electronic waste; however, it is accompanied by a range of complex challenges. The most significant challenges and their corresponding solutions are summarized as follows (FASTERCAPITAL, 2025):

- ✓ **Lack of Appropriate Infrastructure**

One of the major challenges in electronic waste recycling is the lack of adequate infrastructure for proper disposal and processing. Most countries around the world lack specialized facilities capable of handling electronic waste safely and efficiently. As a result, electronic waste is often disposed of improperly, leading to severe environmental consequences.

- ✓ **Proposed solution:**
  Governments and private-sector organizations should invest in the development of electronic waste recycling infrastructure. For example, the European Union has introduced regulations requiring member states to establish dedicated e-waste recycling facilities. Similarly, the United States has enacted electronic waste recycling laws that obligate manufacturers to take responsibility for recycling their products.
- ✓ **Lack of Awareness and Education**

Another major challenge is the lack of public awareness and education regarding the importance of proper electronic waste disposal. Many individuals remain unaware of the dangers associated with improper disposal, resulting in widespread illegal dumping.

- ✓ **Proposed solution:**
  It is essential to educate the public about the importance of electronic waste recycling and the risks associated with improper disposal. Manufacturers should also provide clear guidance on how to dispose of electronic products responsibly. For instance, Apple has

implemented recycling programs aimed at educating consumers on how to return and recycle their devices.

✓ **Difficulty in Recycling Certain Components**

Some electronic devices contain components that are particularly difficult to recycle. For example, cathode ray tubes (CRTs) used in older televisions and computer monitors contain lead, making them hazardous to the environment.

✓ **Proposed solution:**
Developing alternative recycling technologies is crucial. Some companies have introduced innovative methods for recycling CRTs, such as repurposing them in road construction materials.

✓ **High Cost of Recycling**

Electronic waste recycling can be costly, which discourages some organizations from investing in recycling activities.

✓ **Proposed solution:**
Several manufacturers have implemented take-back programs, whereby products are returned at the end of their life cycle and recycled by the producer. This approach reduces recycling costs for consumers. Governments can also provide financial incentives to organizations that invest in electronic waste recycling.

✓ **Illegal Disposal of Electronic Waste**

Illegal dumping and informal processing of electronic waste remain significant challenges. Some individuals and organizations resort to illegal disposal practices to avoid recycling costs, posing serious threats to both environmental and human health.

- **Conclusion**

At present, electronic waste represents a **serious environmental and health threat** due to its continuous accumulation and rapid obsolescence. This situation constitutes a major challenge for countries worldwide in terms of safe disposal and the recovery of valuable materials. Numerous environmental and public health studies classify electronic waste among the **ten most hazardous pollutants** affecting the world today.

Technological advancement, increasing consumerism, rapid population growth, weak awareness of responsible consumption, and other contributing factors have significantly increased the volume of electronic waste. Consequently, addressing this issue has become an urgent global priority.

Electronic waste recycling has evolved into a **distinct industrial sector** that generates substantial benefits for the economy, the environment, and public health simultaneously. Recycling contributes to environmental protection, reduces pollution levels, and generates significant economic value when recycled materials are optimally reintegrated into production processes.

✓ **Hypotheses Testing**

Based on the findings of this study, the following conclusions can be drawn:

- The **first hypothesis** is confirmed: electronic waste recycling is among the most effective methods for managing electronic waste.
- The **second hypothesis** is rejected and reformulated: the failure to follow proper and legal methods for disposing of waste and electronic waste worldwide has led to an increase in health problems, particularly among children.

- The **third hypothesis** is confirmed: some electronic devices contain components that are difficult to recycle, representing one of the most significant challenges in electronic waste recycling.

✓ **Results**

The main results derived from this study can be summarized as follows:

- Waste in general, and electronic waste in particular, has become a global problem affecting all countries, whether developed or developing, producers or consumers of electronic devices.
- Electronic waste is considered one of the most hazardous waste streams, yet it also represents a valuable resource due to its high content of precious metals and costly raw materials such as gold and silver.
- Effective electronic waste recycling requires an **integrated infrastructure** that enables safe and efficient recycling processes.
- Expected global population growth and the increasing use of electronic devices will have severe environmental consequences unless electronic waste is managed rapidly and responsibly.
- Electronic waste poses serious environmental and health risks due to its accumulation and aging, making it a major challenge for governments seeking sustainable disposal or recycling solutions.
- The absence of proper and legal disposal methods worldwide has contributed to the rise of health problems, particularly among children.

✓ **Recommendations**

Based on the findings of this study, the following recommendations are proposed:

- Specialized local private-sector companies should assume responsibility for electronic waste recycling, either independently or through strategic partnerships with international firms specialized in this industry.
- Dedicated administrative bodies should be established to oversee the collection and recycling of electronic waste.
- Robust and adaptive legislation should be developed to keep pace with global technological advancements and to strengthen cooperation among community members in waste sorting and recycling, particularly electronic waste.
- National legislation governing electronic waste management should be enacted and enforced to protect public health.
- Public awareness initiatives should be strengthened to educate society about the components of electronic waste and their negative impacts on health and the environment.
- Electronic waste must be managed in a regulated and environmentally sound manner to ensure maximum benefit while minimizing harm to humans and the surrounding environment.

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