Review on Present Consequences of E-waste Management and Future Perspective of Bangladesh

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ABSTRACT: Handling the increasing volume of electronic waste (e-waste) is quite challenging for Bangladesh, annual production are roughly 2.7 million tons. However, only 20–30% of this waste is properly recycled; while the rest is dumped in rivers, landfills, and public spaces, placing the environment and public health at danger. The issue is getting worse due to illegal e-waste shipments from developed nations, as well as insufficient recycling infrastructure and legal frameworks. The present situation of e-waste management in Bangladesh is examined in this analysis, which emphasizes the negative consequences of inappropriate disposal on the environment and public health. In addition, it highlights global tendencies in the handling of electronic waste, regulatory gaps, and the urgent need for improvement of laws and coordinated recovering initiatives. This study employs a review based methodology and integrates secondary data from national and international sources to observe global e-waste generation trends, management approaches, and environmental impacts. The methodical literature analysis highlights the challenges and potential solutions for sustainable e-waste management, with a focus on Bangladesh. For protecting the environment and public health, this study emphasizes the necessity for sustainable e-waste management. It also highlights the importance of education, efficient implementation, and improved recycling facilities to support the country's economy.

Keywords: E-waste; Management; Illegal Import; Recycling; Environmental Pollution; Policy

INTRODUCTION

The industrial and economic environment of the 20th century has transformed the human lifestyle a lot, the impact of this is the rising trend on electronic devices and technology equipment (Islam, 2016)developing countries face a number of issues with the generation, transboundary movement and management of e-waste. It is estimated that the world generates around 20–50 million tonnes of e-waste annually, most of it from Asian countries. Improper handling of e-waste can cause harm to the environment and human health because of its toxic components. Several countries around the world are now struggling to deal with this emerging threat. Although the current emphasis is on end-of-life management of e-waste activities, such as reuse, servicing, remanufacturing, recycling and disposal, upstream reduction of e-waste generation through green design and cleaner production is gaining much attention. Environmentally sound management (ESM. As a part of business strategies, manufacturers now design products with deliberately small lifespans, contributing to the rapid growth of electronic waste (e-waste). If these wastes not managed by effective collection and recycling process, it turned to severe environmental threats. Unmanaged e-waste can spread unsafe pollutants into soil and water bodies, and those are heavy metals like lead (Pb), chromium (Cr), silver (Ag), cadmium (Cd), and aluminum (Al) into ecosystems. The presence of these metals is an increasing environmental distress, driving the world in the direction of a serious ecological disaster (Shumon and Ahmed, 2013; Sahan et al., 2019). Electronic waste includes a wide range of expired electronic belongings, including items like computers, televisions, air conditioners, refrigerators, mobile phones, and various household appliances (Xu et al., 2016). This type of waste also includes cables, electric bulbs, and industrial equipment. E-waste management is a major challenge particularly in the low income countries whereby there are no proper waste management and recycling policies.

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These countries are bearing the load of handling e-waste from other regions, specially, developed countries export significant amounts of e-waste to the countries in Asia.

It is estimated that at any given time, 20-50 million tons of e-waste is entering the total waste streams in the world, and this figure of e-waste was increasing at an alarming rate of 3-5 percent per annum. This is approximately three times higher than other types of solid waste hence the very important requirement of sustainable and inclusive e-waste management measures (Islam, 2016; Sahan et al., 2019; San et al., 2016).

The research paper is dedicated to the significant environmental, health, and economic consequences of the electronic waste (e-waste) disposal, but with the emphasis on Bangladesh and e-waste management practices. In average 3.1 kg/capita, particularly, Bangladesh generates almost 0.4 million metric tons of e-waste annually (Haque, 2021; Baldé et al., 2024). Such waste has valuable and dangerous metals like iron, copper, aluminum, gold and platinum; and once recycled can have massive economic impact. According to the current recycling activities, 60 percent of the e-waste products are reused to produce valuable metals, 30 percent to produce plastics and 2.7 percent of other materials (San et al., 2016; UNDP, 2020). The study will explore the e-waste management and its management on a global and national scale, considering the policies, health risks and environmental issues. Through comprehensive analysis and references, the study will propose solutions that address both global and local issues, offering recommendations to mitigate the adverse effects associated with e-waste.

Bibliometric Analysis

Bibliometric analysis of the co-occurrence of words gives us the keyword network (Fig. 1). It shows how many times a keyword is mentioned and their links show how many times they were mentioned together. The term e-waste is often mentioned with recovery and recycling. It is also mentioned with data gaps which indicates the researchers think this subject still needs more research.

The other analysis that we have performed is the thematic mapping (Fig. 2). It shows themes of work. CNN and e-waste are shown to be a niche theme which means several high-level publications have been made on this. Food waste and life cycle assessment are shown to be well-established research topic however e-waste management in Asia is a basic theme which indicates that it needs more research.

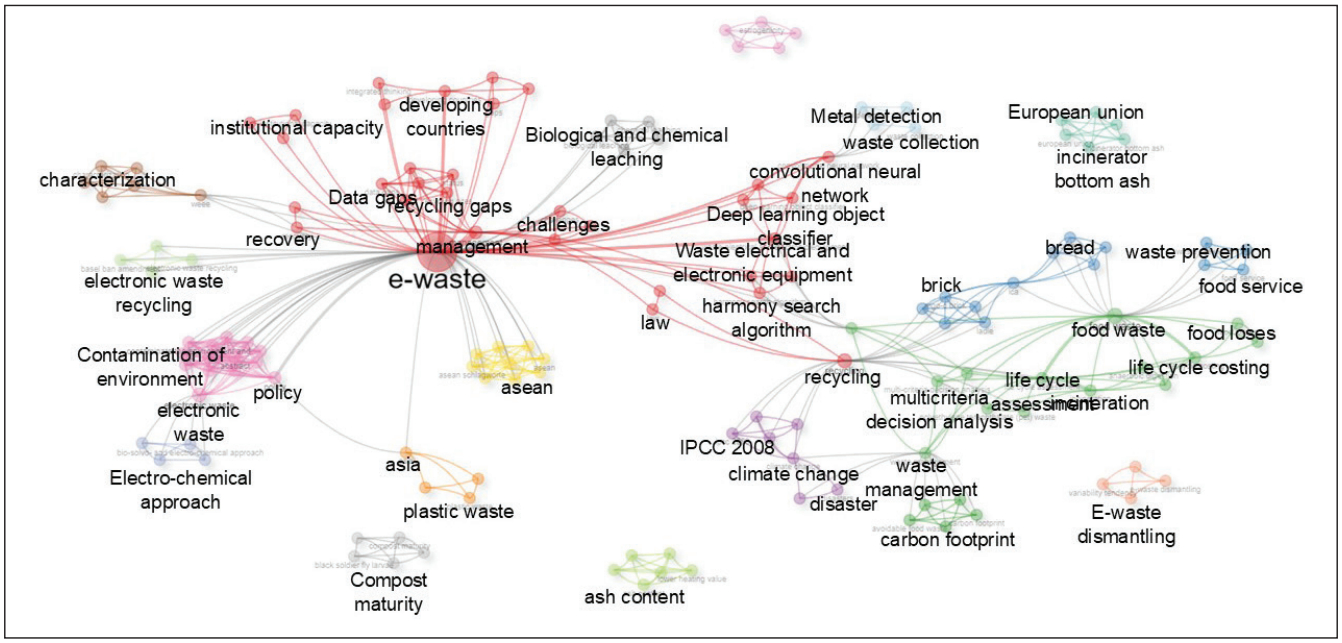

Figure 1: Network of Co-occurring Words

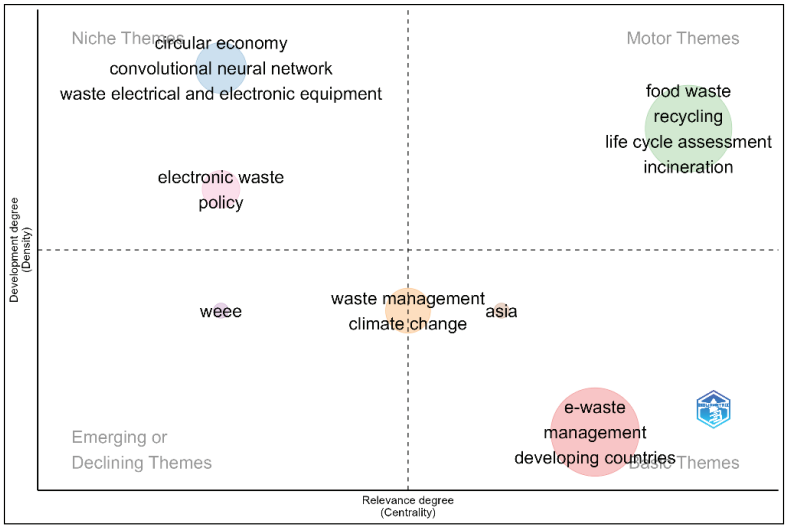

Figure 2: Thematic Map of Keywords

METHODOLOGY

This study takes a comprehensive approach by integrating secondary data from a range of reputable sources, such as research articles, newspapers, and official websites, to examine the global state of electronic waste (e-waste). With an initial emphasis on recognizing growing rates tendencies of e-waste, this study compares different years data, evaluates recycling prospective, and discovers the effects of e-waste on both human health and the environment (Shumon and Ahmed, 2013; Islam, 2016). Literature from diverse academic databases like Elsevier, Google Scholar, Springer, MDPI, and Web of Science has been reviewed, beside these, additional studies get into by personal contacts and journal citations. As a way of handling citations, I used Mendeley Citation Manager, ignoring some of the few abbreviations and methodologies because of certain notable peculiarities.

Literature review has been done to enhance the research design, in which abstracts were used to organize similar research. The articles were narrowed down to those that were to be understood in detail, and they were left as the rest to be studied regarding their methodology. Through this all-encompassing research, we were trying to highlight the number of e-waste generated all over the world, how to manage it, and the effects of e-waste in Bangladesh on the environment and the overall importance of the sustainable practices (Fig. 3). The selected approach manages to discourse the process of measurement and explanation of e-waste issues. Through international issues and remedies, the paper examines the process of e-waste production, overall waste amount, human and environmental health effects, recycling, laws, and policies and procedures. The analysis takes into consideration the issues and the possibilities of e-waste of the Bangladeshi and of the universal perceptions.

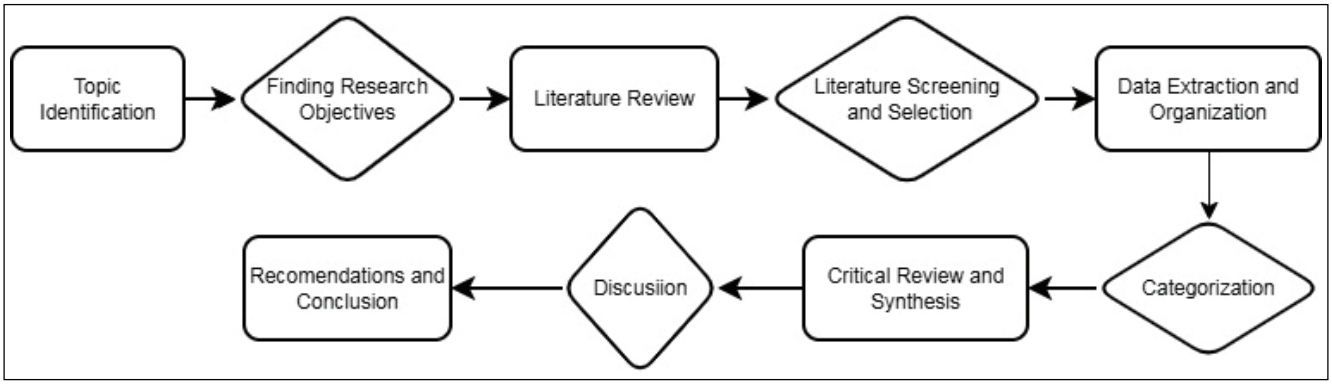

Figure 3: Flow Chart of Methodology

SUMMARY OF THE GLOBAL CONDITION OF E-WASTE

Worldwide e-waste Scenario

It is possible to unveil the rapid increase in the production of electronic waste in the world during modern times, and its correlation with the population development. Global e-waste generated (2010) amounted to 33.8 million metric tons (Mt) and the population was 6.8 billion people, which admits approximately 5 kg of e-waste per capita. By 2020, e-waste had increased to 55.5 Mt, with the worldwide population at 7.7 billion (Chemistry and Blackout, 1973). If this tendency remains, predictions estimate e-waste reaching 65.3 Mt in 2025 and 74.7 Mt by 2030, with the global population expected to grow to 8.54 billion (Fig. 4 and 5).

These analyses propose that individual e-waste generation may increase to about 9 kg per person by 2030 (Fig. 6). As electronic device usage and disposal go faster, the volume of e-waste may double or triple within a short time, indicating an crucial need for upgraded e-waste management practices and sustainable electronics usage (Iqbal et al., 2015a; Forti et al., 2020).

Table 1 mentions the tendencies in e-waste generation and recycling across different regions of the world in 2016 and 2019. However, producing the second-highest volume of e-waste, Europe had the highest collection and recycling rates. Asia generated the most e-waste and had the second-highest collection rate. There is a remarkable difference in recycling rates between regions, emphasizing the global need for improved e-waste management practices (ESDO, 2012).

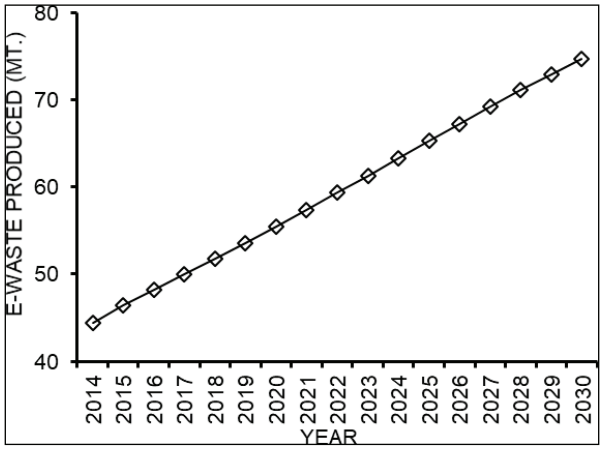

Figure 4: Year Wise Tendencies of Electronic Waste Production all Over the World with Future Projections (Forti et al., 2020)

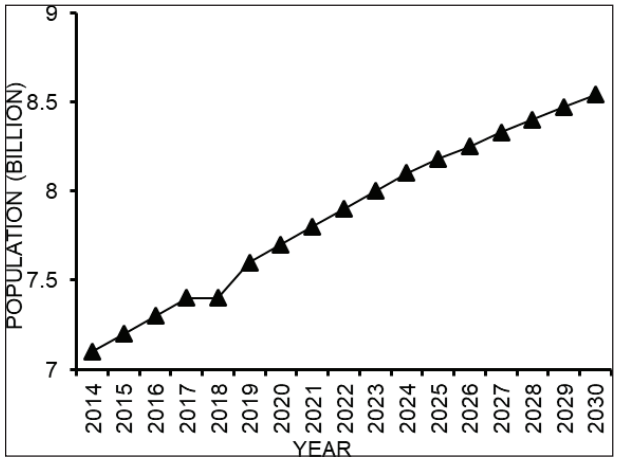

Figure 5: Year Wise World Population Growth Pattern with Future Projections (Forti et al., 2020)

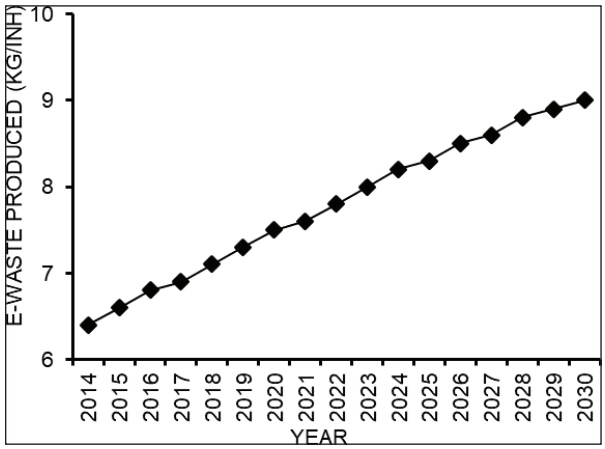

Figure 6: Year Wise Per Capita E-waste Production Rate all Over the World with Future Projections (Forti et al., 2020)

There are major differences in both e-waste production and recycling rates between developed and developing areas. Developed regions (Europe and USA) generally produce more e-waste compared to developing regions (Africa and parts of Asia). Oceania, although its small population, produces a high amount of e-waste per capita. Africa's e-waste generation is significantly low, reflecting a collection rate of 0%, suggesting that very little is being managed or recycled. The inequality in recycling rates indicates the effectiveness of waste management systems in different regions (Forti et al., 2020; Balde et al., 2017)

E-waste production in various countries is not in the same amount. Norway leads with the highest per capita e-waste at 26.8 kg per person, followed closely by the Switzerland, Australia, Iceland, France, Denmark, the Netherlands, and Belgium. In contrast with these countries, Maldives, Sri Lanka, Bhutan, India, Bangladesh and Nepal generate significantly less e-waste per capita, with figures ranging from 10.0 kg in Maldives down to 1.19 kg in Bangladesh (Fig. 7 and 8) (Forti et al., 2020; Baldé et al., 2024).

Table 1: A Continent-based Summary of Electronic Waste Generation and Collection

Indicator	**Africa**		**America**		**Asia**		**Europe**		**Oceania**	
	2016	**2019**	**2016**	**2019**	**2016**	**2019**	**2016**	**2019**	**2016**	**2019**
Population in region (millions)	1,174	1305	977	1010	4,364	4586	738	745	39	42
WG (kg/inh)	1.9	2.5	11.6	13.3	4.2	5.5	16.6	16.2	17.3	16.1
Indication WG (Mt)	2.2	2.9	11.3	***13.1***	18.2	***24.9***	12.3	***12***	0.7	0.7
Documented to be recycled (Mt)	0.004	0.03	1.9	1.2	2.7	2.9	4.3	5.1	0.04	0.06
Collection Rate (in region)	0%	0.9%	17%	***9.4%***	15%	***11.7%***	35%	***42.5%***	6%	8.8%
Countries in region	53		35		49		40		13	

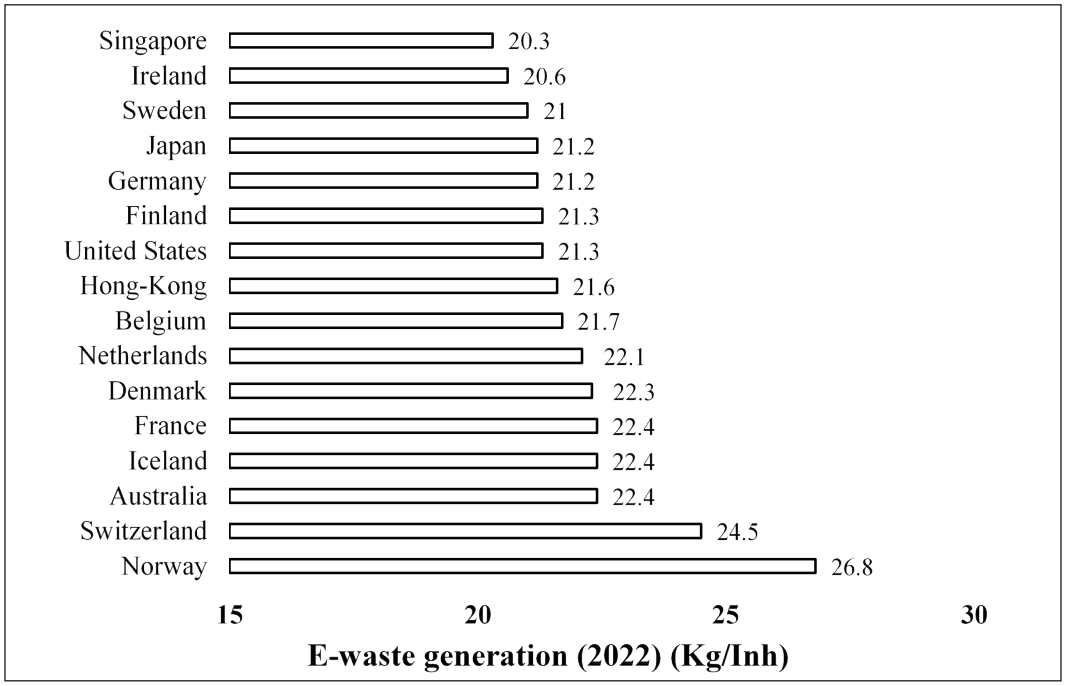

Figure 7: Scenario of the Highest E-waste Generating Countries (Forti et al., 2020)

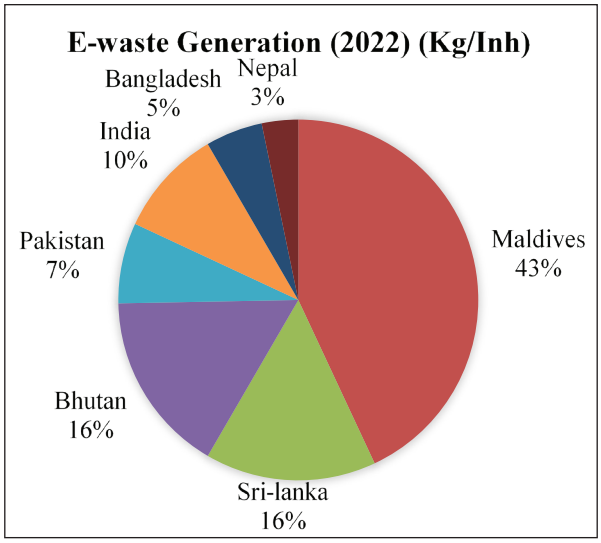

Figure 8: E-waste Generation in South Asian Countries (Baldé et al., 2024)

There are a remarkable global challenge regarding e-waste management, mostly in developed regions where industrial activity contributes to higher levels of electronic waste. Lacking of suitable policies in many countries create complications to manage this waste effectively. A large portion of the world (78 out of 193 countries) lacks adequate rules and facilities for e-waste management, which can lead to severe environmental and health consequences. In industrial zone, where the production and consumption of electronic materials are at a high rate, the situations are mainly problematic (Forti et al., 2020).

This outcome stresses the necessity for broader strategies that can run workable production practices, encourage answerable consumption manners, and address the collection and recycling of electronic waste. Governments, enterprises, and communities must collaborate to establish a more effective global e-waste management system (Baldé et al., 2024).

Typical Elements and Material Categories Recovered from E-waste

There are several types of materials extracted from electronic waste globally. Studies on the world's e-waste indicate that including other materials, ferrous and non-ferrous materials are frequently recovered.

Table 2: Typical Elements and Materials Recovered from E-waste

Category	**Samples**
Metals that are ferrous	Metals that are ferrous Iron (Fe) and steel, such as appliance bodies, casings, chassis, and structural components (Kränzler, 2010)
Base metals that are not ferrous	Base metals that are not ferrous Copper (Cu), zinc (Zn), nickel (Ni), tin (Sn), aluminum (Al), and so forth. frequently seen in heatsinks, casings, circuit boards, connectors, and wiring.
High-value and precious metals	High-value and precious metals Palladium (Pd), platinum (Pt), gold (Au), silver (Ag), and other platinum-group metals, occasionally found in trace amounts (Kränzler, 2010)
Specialty metals and rare earth elements (REEs)	Specialty metals and rare earth elements (REEs) Neodymium, dysprosium, yttrium, and gadolinium are among the materials used in magnets, electronics components, and some green technology applications (Liu et al., 2023)

Polymers, or plastics	Polymers, or plastics for instance, from device plastic components, housings, and casings. Polystyrene (PS), acrylonitrile-butadiene-styrene (ABS), polycarbonate (PC), high impact polystyrene (HIPS), polypropylene (PP), and other polymers are frequently found in e-waste (Liu et al., 2023)
Glass and materials related to glass	Glass and materials related to glass fibers in printed circuit boards (PCBs), screens, CRT glass, and glass components in displays are frequently partially recoverable.
Additional materials or potentially dangerous elements	Additional materials or potentially dangerous elements Electronic components (resistors, capacitors), batteries (containing metals and hazardous materials), circuit boards (containing both metals and non-metals), plastics with flame retardants, insulated cables and wiring, and occasionally hazardous metals (lead, cadmium, mercury) in older devices (Mamtaz and Gulshan, 2019)

Typical Ratios (by Weight, Worldwide)

As a general worldwide standard (although ratios differ by region and device type):

- By weight, ferrous metals (steel and iron) frequently comprise the largest portion of waste.
- By weight, plastics are frequently the second-largest component. Smaller but still substantial shares are made up of "others" (glass, cables, mixed materials) and non-ferrous metals (copper, aluminum, etc.).
- Although rare earth elements and precious metals typically make up a small portion of the total weight, they have significant economic value (Mamtaz and Gulshan, 2019)

Evaluation of Electronic Waste Protocols

Analyzing the global situation, it is concerning that a large amount of e-waste ends up in landfills, particularly in the United States, where regulations have not been as strict as in other developed nations like Switzerland (Nowakowski et al., 2020). Switzerland practices innovative e-waste management focusing on appropriate collection, transportation and recovering. The escalating environmental crisis is intensified by the elevated turnover rate of electronic devices in countries such as the United States, attributed to insufficient regulatory measures (Muñoz et al., 2020). A notable instance is Japan's focused strategy for regulating specific categories of appliances. Their emphasis on recovery and recycling promotes sustainable electronics consumption habits in addition to lowering landfill waste. Generally, effective e-waste management involves complete procedures, public awareness, and international cooperation to mitigate the environmental impacts of electronic waste (Hossain et al., 2018).

The growing crisis of electronic waste (e-waste) is deteriorating by low recycling rates and lacking of effective take care attitude in the import export procedures of these products. Many developed countries involved in illegal transactions, shipping their e-waste to developing nations, those are often ends up as garbage (Lee et al., 2016). Besides, most commercial electronic products are designed with a lifetime of only 2-3 years (Pires et al., 2011), which causes a rapid uselessness characteristics and making them easily disposable. These short lifespan equipment making strategies results in minimal efforts for recycling or reuse. Moreover, the economic potential of these materials remains largely unused; despite the important quantities of valuable metals that can be recovered from e-waste, there is a little incentive to address this issue (Alam and Bahauddin, 2015).

The combined efforts of government, consumers, and producers can provide a feasible solution to the challenges of e-waste management. An efficient recycling process will guarantee adherence to set rules and regulations if all stakeholders can participate by taking the required steps (ESDO, 2012). These cooperative strategies can greatly aid in the management of e-waste both globally and in rural areas; all stakeholders must adhere to the guidelines set by central authorities (Shumon and Ahmed, 2013).

SCENARIO OF ELECTRONIC WASTE MANAGING PROCEDURE IN BANGLADESH

E-waste: Bangladesh Situation

The situation regarding e-waste in Bangladesh is indeed depressing. With a rapidly growing population and increasing dependence on electronic devices, the country faces major challenges in managing electronic waste (e-waste). Bangladesh covers an area of about 147,570 square kilometers and has a population of around 180 million according to Australian Sport Commision (2019). Internet and cellular diffusion are high, which is nearly 96.2 million internet subscribers and a tele density of 97.46% (Kamal and Foraji, 2019). Electronic devices are regularly used and often discarded annually, that's why. a considerable quantity of e-waste is generated. This whole amount turns to a national environmental concern. The growing IT sector in Bangladesh is contributing this improved electronic consumption without suitable waste management schemes. This condition could be the main reason for major environmental pollution from metallic pollutants. Recently, there is a lack of appropriate guidelines and strategies for the collection and disposal of e-waste. As a result, the issue is upturning and unsafe dumping practices that damage the environment. The hazardous discarding of e-waste resulting serious environmental degradation and health risks due to the discharge of contaminated materials (Baderna et al., 2019). Indicating these challenges need direct attention, and the improvement of complete policies for e-waste management, public awareness campaigns, and initiatives to endorse recycling and safe removal practices.

E-waste management in Bangladesh is very substantial, mainly concerning mobile phone waste. This is not only related to environmental challenges but also public health risks because of deadly heavy metals from improperly disposed e-waste. With about 170 million cellular subscribers, the frequency of mobile phones especially dual SIM phones indicates a high income rate, and many of these devices become outdated in two to three years. According to the Department of Environment, (2018) report, the yearly disposal of 75 million cell phones shows a significant increase in electronic waste, which could be harmful to both the environment and the health, because those materials are related to informal recycling and disposal. Lead, mercury, and cadmium are examples of hazardous materials that can have a serious negative impact on the health of workers and the communities around illegal disposal sites. People are at high risk who depend on the unofficial recycling of e-waste as an income source. Illegal disposal of electronic waste contaminates water and soil, negatively impact on both local ecosystems and environment in a broader sense. For addressing these problems and advance sustainable practices, an inclusive plan including community and governmental engagement, and cooperation with stakeholders in the electronics industry, is needed (Islam, 2016).

Mercury's toxic elements present in multiple electronic gadgets and medical apparatus in Bangladesh, which is very dangerous for human health and the environment. Common household mercury containing products are laptops, computers, televisions, radios, sporting and exercise equipment, watches, sewerage metallic pipes, irons, calculators, washing machines, lighting fixtures, electric switches, ovens, blenders, anti-lock braking systems, inverters (IPS), generators, refrigerators, fire alarm boxes, and building security systems. Mercury is present in batteries for medical devices, alarms, hearing aids, blood pressure monitors, gastrointestinal tubes, blood analyzers, pacemakers, different kinds of pumps, scales, ultrasound devices, and ventilators (Byomkesh et al., 2012). To mitigate the risks associated with mercury spreading from these products, it's essential to apply harmless discarding and recycling measures, and increasing awareness about mercury free substitutes.

Bangladesh is in transitions mood to a digital format, within the global trends, the country is increasingly dependent on various electronic devices (Forti et al., 2020). Bangladesh produced about 2.8 million metric tons (Mt) of electronic waste (e-waste) in 2020 as a result of this change. The growth rate of e-waste in Bangladesh is remarkably high, yearly which is estimated at 20%. In comparison, the global e-waste generation reached nearly 20 million Mt during the same period according to Bangladesh GDP per capita (2019-2020 Forecast).

The unsafe disposal of electronic waste (e-waste) through open air dumping, bare soil, water bodies, and landfills turned to huge risks to human health and the environment. These deadly materials are contaminating and creating vulnerable areas. In Dhaka city, major concentrations of e-waste are found in Kamrangirchar, Islampur, Mirpur (Sections 11 and 12), Gingira, and

Mohammadpur (Islam, 2016). The rapidly increasing tendency of electronic products is alarming, which is indicating a growing environmental disaster that requires immediate attention and action.

Volume of Electronic Waste in Bangladesh

After analyzing the sources and amount of e-waste in Bangladesh, the data dominantly stressing to the contribution of shipbreaking yards. Fig. 9, indicates the accounts of shipbreaking yard generated a shocking amount which is 80.65% of the total e-waste generation, whereas the remaining 19% comes from other sources like televisions, computers, cellular phones, thermometers, lighting materials made by mercury, medical and dental waste (Roy et al., 2022) metals, non-metals, plastics, cables, etc. The excessive generation of e-waste has become a significant concern in the last few decades. The current global e-waste generation is 57.4 million metric tons (MMT. According to *Islam, (2016)* developing countries face a number of issues with the generation, transboundary movement and management of e-waste. It is estimated that the world generates around 20–50 million tonnes of e-waste annually, most of it from Asian countries. Improper handling of e-waste can cause harm to the environment and human health because of its toxic components. Several countries around the world are now struggling to deal with this emerging threat. Although the current emphasis is on end-of-life management of e-waste activities, such as reuse, servicing, remanufacturing, recycling and disposal, upstream reduction of e-waste generation through green design and cleaner production is gaining much attention. Environmentally sound management (ESM, the yearly generation of e-waste in Bangladesh are around 250000 Mt/yr from ship breaking yards, 94.4 Mt/yr from electric bulb sources and 26000Mt/yr from television sources (Table 3) (UNDP, 2020). This situation increases distresses about environmental and public health issues; as improper handling of e-waste can cause hazardous materials leaching into the environment. Efforts for proper e-waste management, including recycling and safe disposal methods, are crucial in addressing these challenges (Perspective Plan,2021).

Collection Procedure of E-waste in Bangladesh

There are seven organizations in Bangladesh focusing on the gathering and recovering of e-waste. Some of the notable enlisted e-waste recyclers are M/s. Yousuf Enterprise, Azizu Trading Co., JR Enterprise, Zaman Enterprise, Green Bangla Corporation, M/s. Techno Fair, NH Enterprise etc. These organizations utilize various communication methods to reach the public, such as hotlines for the general public to call for e-waste collection and announcements made via loudspeakers in local areas to inform residents about collection services (Fig. 10) (Muyeed and Talukder, 2011). The e-waste collection includes a variety of electronic items, for example Mobile phones, Computers (including monitors, CPUs, laptops, printers, scanners), Stabilizers, Refrigerators, Air conditioners, Televisions, Washing machines etc. The public must adhere to specific conditions set by recycling agencies, which may include waiting time for collection and designated collection locations. This summary focuses the importance of structured e-waste management in Bangladesh and the efforts made to educate the public on responsible recycling practices (Kamal and Foraji, 2019).

Table 3: Summarized Sources and Amount of E-waste in Bangladesh

E-waste Sources	Volume	Volume (Mt/yr.)
Ship Breaking Yard	250000 Mt/yr.	250000 Mt/yr.
Electric Bulb	566.90 Mt/6yrs.	94.4 Mt/yr.
Computer	35000 Mt/10yrs.	3500 Mt/yr.
Cellular Phones	10504 Mt/21yrs.	500 Mt/yr.
Lightening materials made by mercury	1861.32 Mt/10yrs.	186.13 Mt/yr.
TV	26000 Mt/yr.	26000 Mt/yr.
Thermometer	8513.59 Mt/10yrs.	851.35 Mt/yr.
Other Medical & Dental Wastes	93478.25 Mt/10yrs.	9347.82 Mt/yr.

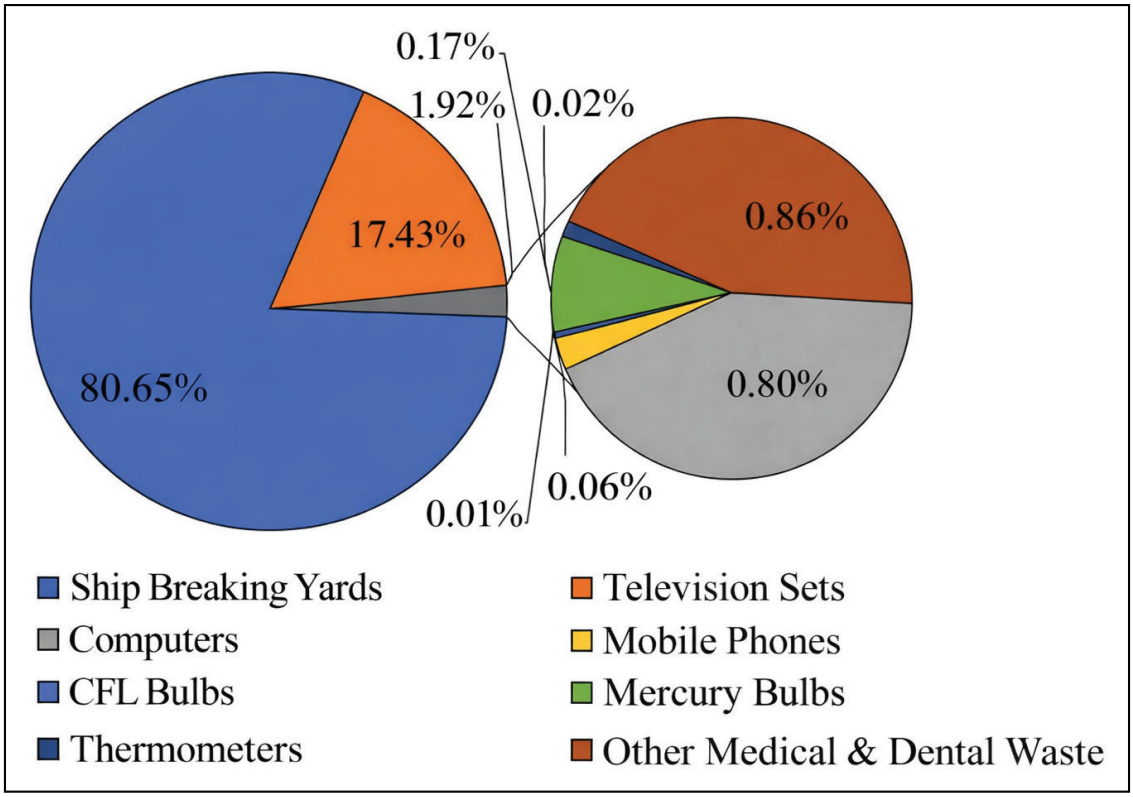

Figure 9: E-waste Generation Sectors Percentage in Bangladesh (ESDO, 2012; Roy et al., 2022)

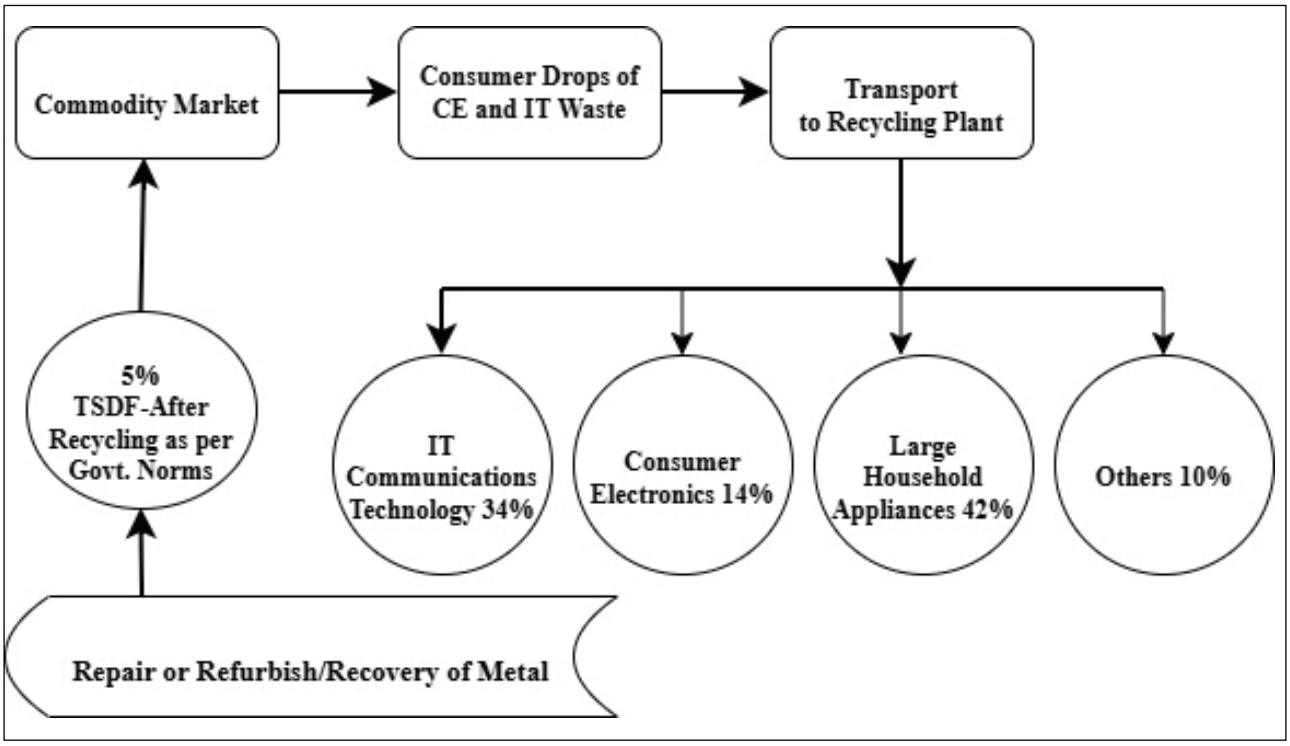

Figure 10: Flowchart of E-waste Collection Procedure (Kamal and Foraji, 2019)

Dry Flake of E-waste Imports in Bangladesh

The import of dry flakes of electronic waste (e-waste) in Bangladesh has been a growing concern. Bangladesh regularly imports flake and second hand goods from developed countries, with high trading rates. This outflow of e-waste brings economic benefits due to the high prices of these products in local markets (Xu et al., 2016). Though, the situation is complex, because some imported items are repairable and can be resold, but many are actually discarded and unfit to recover valuable materials, resulting environmental and health risks (UNDP, 2020).

According to Xu et al., (2016), Bangladesh imported 26.6, 28.3, and 30.0 million tons of dry flakes between 2008 and 2010. These materials' residues frequently combine with e-waste to create a dangerous environment that poses serious risks to the ecosystem and public health. The growing tendencies of e-waste importation highlights the necessities for strong regulations and better management practices to mitigate these risks.

Status of Discarding and Recovering of Electronic-waste in Bangladesh

The status of e-waste recovery and disposal in Bangladesh exposes big challenges and vulnerabilities in the management. Without effective approaches for e-waste management, the recovery process remains largely informal and uncontrolled. In Bangladesh, the practice of repairing and reusing electronic products is much frequent. Many individuals are engaged in the professional activities regarding these, but there is no specific monitoring systems from the government or any regulatory bodies (Quantity et al., 2010). This absence of look after means that repair shops and recycling agencies operate mainly as private enterprises, often prioritizing profit than environmental safety.

Over 100,000 people are thought to be engaged in e-waste recycling and associated import activities in Dhaka. The scale of e-waste generation is alarming, with around 400 tons recycled daily, which is only 20-35% of the total e-waste that produced in the city (Table 4). The remaining 75–80% is disposed of inappropriately; it may wind up in ponds, rivers, lakes, drains, channels, and roadside open spaces, or it may be carelessly dumped in bare soil (Serajul et al., 2017). This improper disposal poses serious environmental and public health risks, highlighting the urgent need for comprehensive e-waste management strategies that include effective recovery, recycling, and disposal practices.

Every year, approximately 1125-ton cellular phone waste are compiling with the general waste flow in Bangladesh. This indicate that, recovering of these unused materials can be profitable economically. Because mobile phones are made of various metallic elements with significant economic value. By proper recycling, valuable metals can be extracted such as gold, copper, silver, iron, aluminum, nickel, etc. According to San, Muntaha and Hossain, (2016), one ton of printed circuit boards (PCBs) contains approximately 0.94 kg Platinum and palladium (Pt and Pd), 0.31 kg Gold (Au), 145.15 kg Aluminum (Al), 190.51 kg Copper (Cu) etc. Based on the composition, from 1125 tons of PCB circuit boards, it would be possible to recover 348.75 kg gold (Au), 105.75 kg platinum (Pt) and palladium (Pd), 163 tons of aluminum (Al) and 214.32 tons of copper (Cu). Where the economic value of the recovered metals is roughly 0.375 Million $/Year for Pt, 30.223 Million $/Year for Au, 0.016 Million $/Year for Al, 1.134 Million $/Year for Cu (Table 5) (Price were collected from London Metal Exchange on 1 October 2018). Among these, Copper is the maximum proportion of extracted materials from mobile phones (Sahan et al., 2019). Like as these materials, other electronic devices also contribute significantly in national economy.

Table 4: Total Amount of E-waste in Bangladesh and its Recycling Rate (yearly) (Islam, 2016)

	2000	**2005**	**2007**	**2009**	**2010**	**2011**	**2012**
Total generated of e-waste (Ton)	1,900,000	2,630,000	3,010,000	3,190,000	3,320,000	3,410,000	3,420,000
E-waste trashed (Ton)	1,710,000	2,270,000	2,460,000	2,590,000	2,670,000	2,560,000	2,420,000
E-waste recycled (Ton)	190,000	360,000	550,000	600,000	650,000	850,000	1,000,000
Percent Recycled (%)	10.0	13.7	18.3	18.8	19.6	24.9	29.20

Table 5: Statistics of the Economic Value of the Recycled Materials (Sahan et al., 2019)

Materials in one ton of printed circuit board	Materials in 1125 tons of printed circuit board	Economic Value
0.94 kg Platinum and palladium (Pt and Pd)	105.75 kg Pt and Pd	0.375 Million $/Year for Pt an Pd
0.31 kg Gold (Au)	348.75 kg Gold (Au)	30.223 Million $/Year for Au
145.15 kg Aluminum (Al)	145.15 kg Aluminum (Al)	0.016 Million $/Year for Al
190.51 kg Copper (Cu)	214.32 tons of Copper (Cu)	1.134 Million $/Year for Cu

Existing Policy Frameworks for Bangladesh

The existing policy frameworks for environmental management in Bangladesh is multifaceted, aiming to address various aspects of environmental protection and pollution control. The summary of the major laws and policies are in follows:

The National Environment Policy (1992: This is a fundamental policy that aims to prevent harmful activities that endanger the environment and control pollution.

The Environmental Conservation Act (1995): This seeks to mitigate, avoid, and regulate environmental pollution. It describes regulations and responsibilities across various sectors to protect the environment.

The Environmental Court Act (2000): These aids are established by environmental courts to facilitate the enforcement of environmental legislation and the resolution of environmental conflicts.

Environmental Conservation Rules (1997): These regulations provide extensive guidelines for preserving the environment and procedures for acquiring environmental clearances.

Medical Waste Management Rules (2008): These regulations were established specifically to address anomalies in the medical sector and to tackle issues related to electronic waste management.

E-waste Policy (2017): This policy, presented in Bengali, outlines strategies for managing electronic waste, emphasizing the importance of recycling and safe disposal.

The National 3R Policy: This policy is designed to diminish waste generation and enhance resource efficiency by advocating the principles of Reduction, Reuse, and Recycling.

High Court Directives: The High Court of Bangladesh has authorized the Department of Environment (DoE) to ensure that no scrapyard activities occur without environmental approval from the authorities. Additionally, it has mandated that ships should only be disassembled following an assessment of their condition to guarantee adherence to environmental regulations.

Government Trade Permissions: Licenses are required by the government for the import and export of any goods in order to verify that environmental regulations have been followed.

Hazardous Waste Management Rules: These rules are meant to regulate the handling of hazardous waste and ensure that the proper procedures are followed for safe disposal, even though they are still being developed.

Considering these things, the policy framework Bangladesh shows a nearly complete approach to environmental preservation, waste management, pollution control, and other regulatory compliance to safeguard the environment and public health (Kamal and Foraji, 2019).

INFLUENCES OF ELECTRONIC WASTE THREAT ON ENVIRONMENT

The huge river system of Bangladesh and hot, humid climate converted to a vulnerable situation because of the negative environmental effects of electronic waste. About 54% of the country is covered by the forest canopy (BFD and UMD, 2017), which is beneficial. However, inadequate disposal of e-waste can seriously contaminate soil and water resources, placing agriculture and human health in threatening condition. Illegal e-waste disposal has a negative effect on aquatic life and exposes the production of crops and vegetables (Nowakowski and Pamuła, 2020; Haque, 2021). Additionally, toxic chemicals can change into even

more dangerous substances when e-waste is dumped in warm climates or bodies of water. Furthermore, another major effect of improper handling of e-waste is atmospheric degradation (Baldé et al., 2024).

The data and statistics highlight the serious problem of child labor in the electronic waste (e-waste) industry, especially in light of the health hazards associated with lethal substances discovered in abandoned electronics. About 40% of the 50,000 kids who participate in the informal collection and recovery of e-waste work in scrapyards. 15% of child laborers perish each year as a result of being exposed to toxic substances in e-waste. Approximately 83% of these kids have health problems as a result of e-waste. Nickel, zinc, chromium, lead, barium, silver, gold, and platinum are hazardous substances found in electronic devices. As a result, people's blood, kidneys, and nervous systems are suffering severe damage. Coban et al., (2018) solid waste management has become an important issue for developing countries. Rapidly increasing population, higher life-standards and technological advancements consistently increase the amount and the diversity of solid waste. In such a complicated environment, municipal authorities need to develop the most effective disposal solution to manage the ever-growing municipal solid waste. In this study various disposal techniques that are utilized globally are investigated and different scenarios that could be applicable to Turkey are created. These scenarios might also be implementable for other Europe and Central Asia (ECA noted that increasing public awareness of e-waste can help identify its effects. Government should implement strong guidelines concerning the handling of terminated electronic materials (Kuehr, 2015).

Communities must be made aware of the risks related with e-waste and the difficulties come across by child laborers. Initiation of campaigns to indorse ethical e-waste disposal and recycling practices at different levels, including schools, parents, and local organizations. Working in partnership with NGOs and international organizations, these initiatives can be reinforced. It is essential to ensure the suitable health and safety procedures for those who involved in the processing of e-waste. That means, providing workers with access to medical care, safety gear, and regular physical checkup facilities. There is the necessity to resolve child labor issue sophistically and public health care facilities should improve by creating a variety of programs for those families who dependent on e-waste with alternative sources of income. A multimodal strategy including community support, regulation, and education is required to address this problem and provide a safer and healthier environment for vulnerable populations (Table 6) (Baldé et al., 2024).

Table 6: Challenges and Overcomes in Bangladesh (Kamal and Foraji, 2019)

Challenges	Overcomes
Awareness build up	Proper Regulations
Collection of e-Waste	Protection of Environment
Separation of different materials	Human Resources Development
Recycling	Effective Management
Management	Enforcement
Legal Enforcement	Health Safety
Health Hazards	Govt. Incentives
Child Labor	Insurance
Risk management/safety	Tax Reduction
Pollution	Social Awareness and Policy Making

E-WASTE ASSESSMENT AND MANAGEMENT STRATEGIES

Recently, many procedures have been developed globally to manage electronic waste (e-waste) in an environmentally friendly manner, which is appropriate for both developed and developing countries. Table 7 accumulates some common strategies along with suggestions to address the challenges to manage e-waste and develop management practices.

Research has broadly documented e-waste production and disposal activities. For example, collected data from the Iranian Ministry and examined it through various surveys and interviews highlighted on eight specific electronic materials, measuring their present condition in terms of waste management (Taghipour et al., 2012)owing to an increase in consumption of electrical and electronic equipment. Nevertheless, as is the case in some other countries, E-waste management has not received sufficient attention. For the successful implementation of any waste management plan (including an E-waste management plan. Moreover, a study discovering e-waste situations in African communities employed qualitative methods, including semi-structured interviews, regression analysis to quantify the total amount of e-waste, shedding light on its scale and effects. Also, to understand the policy outline and coordination nearby e-waste management, a research covering all ASEAN countries was conducted (Asiimwe and Åke, 2012)handling of e-Waste needs to be organized in ways that minimize the adverse effects. This chapter investigates how the East African Community (EAC. A new study go through existing policies and decisions from several key conferences on waste management to inform this analysis (Ibitz, 2012) the rapid growth of volumes of waste from electrical and electronic equipment (e-waste (Table 7).

Numerous studies highlight different approaches to managing and recovering e-waste. Another study uses a review of the literature to highlight waste management techniques. It highlights the need for inclusive research on e-waste generation and recycling processes in Malaysia and points out a gap in the existing literature and practical operations. The dearth of research on e-waste management in Malaysia highlights the importance of regional studies and environmentally focused policies (Pariatamby and Victor, 2013). A formal study directs the use of progressive prediction methods, namely the Variational Mode Decomposition (VMD) in combination with the Exponential Smoothing Model (ESM) and Grey Model (GM). This new strategy seeks to precisely forecast the production of e-waste using information from well-established techniques in the USA and the UK. Successful methods that can significantly improve the understanding of e-waste tendencies are VMD, ESM, and GM (Shumon and Ahmed, 2013). After conducting extensive market research, another study looks at the combination of General Enterprise Architecting (GEA) and Strategic Environmental Assessment (SEA) as a policy outline for e-waste management in the review paper. Planned structures like GEA and SEA can help accomplish e-waste more methodically (Alam and Bahauddin, 2015).

Another study compares Pakistan e-waste situation with other countries for identifying data gaps concerning. This relative analysis highlights data collection and reporting process in e-waste management (Iqbal et al., 2015) (Table 8). One researcher examines the challenges and issues associated with e-waste management utilizing both primary and secondary data, which designates the understanding of challenges for developing effective policies and solutions to address e-waste issues (Islam, 2016). These studies collectively underline the difficulty of e-waste management and the importance of personalized techniques that consider local perspectives though learning from global best practices.

Table 7: Published Year and Journal Name of Case Study, its Country, Author, and Research Title

S L No.	Year	Journal Name	Country Covered	Title of the Article
1.	2012	Waste Management and Research	Iran (Taghipour et al., 2012)	E-waste management challenges in Iran: presenting some strategies for improvement of current conditions
2.	2012	ASEAS (Australian Journal of South-East Asian Study)	ASEAN Countries (Ibitz, 2012)	Environmental Policy Coordination in ASEAN: The Case of Waste From Electrical and Electronic Equipment

3.	2012	Handbook of Research on E-government in Emerging Economics: Adaptation, E-participation and legal Frameworks'' by Swedish Business School.	Africa (Asiimwe and Åke, 2012)	E-waste Management in East African Community
4.	2013	Elsevier-Science Direct	Asia (Pariatamby and Victor, 2013)	Policy trends of strategic environmental assessment in Asia
5.	2013	2nd International Conference on Mechanical Engineering Research (ICMER 2013), organized by the University of Malaya	Malaysia (Shumon and Ahmed, 2013)	Sustainable WEE management in Malaysia: present scenarios and future perspectives
6.	2015	Elsevier-Environmental Pollution	Pakistan (Iqbal et al., 2015a)	Emerging issue of e-waste in Pakistan: A review of status, research needs and data gaps
7.	2015	Present Environment and Sustainable Development	Bangladesh (Alam and Bahauddin, 2015)	Electronic Waste in Bangladesh: Evaluating The Situation, Legislation and Policy and Way Forward With Strategy And Approach
8.	2016	International Journal of Innovative Human Ecology and Nature Studies(IJIHES)	Bangladesh (Islam, 2016)	E-waste Management of Bangladesh
9.	2023	MDPI	Saudi Arabia (Madkhali et al., 2023)	A Comprehensive Review on E-Waste Management Strategies and Prediction Methods: A Saudi Arabia Perspective
10.	2023	Elsevier-Waste Management Bulletin	India (Jain et al., 2023)	Review on E-waste management and its impact on the environment and society

Table 8: Summary of Methodologies and Proposed Suggestions of the Reviewed Articles

Country Covered And Author	**Application Purpose**	**Methodology**	**Proposed Suggestions**
1.Iran (Taghipour et al., 2012)	Selected 8 particular e-products and find out the current status of the aspect of waste management.	Data collected from the Iranian Ministry and analyzed. Preparing a checklist, site visit, and walk-through survey was the method.	--Improve legislation. --Implement EPR program allocation with funds. --Improve the collection and recovery system.

2. Africa (Asiimwe and Åke, 2012)	Investigation of e-waste in the African community	-Qualitative method -Regression Analysis -Semi-structured interview -Literature review	--Educate citizens. --Improve private sectors including government laws. --Promote a green environment. --Control movement of hazardous materials. --Develop a tracker system to trace the flow of e-waste. --Recycle old materials.
3 . A S E A N Countries (Ibitz, 2012)	Environmental policy co-ordination for e-waste issues	Reviewing existing policies and different conference decisions	--Suggested to move ahead with an agreement combined with all ASEAN Countries. --Promoting the production of green electronics. --Improve regional environmental governance.
4. Asia (Pariatamby and Victor, 2013)	Providing strategy for waste management	Literature review	--Formulation and Implementation of SEA (Strategic Environmental Assessment) --Based on SEA, practice problems and progress --Established linkage with government agencies, private organizations, academic researchers, NGO's and the Public.
5. Malaysia (Shumon and Ahmed, 2013)	Explore e-waste generation, recycling and fix future management system	-Review e-waste management systems in the EU, USA, and Japan as a benchmark. -Used VMD (variational mode decomposition) which is combined with ESM (exponential smoothing model) and GM (grey model)	--Launch integrated system for collection, recovery, and remanufacturing --Shaping the behavior of stakeholders --Have forecast regular e- waste amount
6. Bangladesh (Alam and B a h a u d d i n , 2015)	Evaluation, policy, and law, way forward with a strategy	-Reviewing journal papers	--Suggested integrating the GEA and SEA approach as a part of the National policy framework
7. Pakistan (Iqbal et al., 2015a)	Finding present status and data gaps	Compare the present situation of Pakistan with other countries	--Improve regulatory measures, public awareness, and technical improvements.
8. Bangladesh (M. N. Islam, 2016)	Review the challenges and issues regarding e-waste	Data analysis performed by primary and secondary data	--Develop policy --Improve the collection system --Capacity development of recycler --To develop e-waste tracking system --Awareness raising
9.Saudi Arabia (Madkhali et al., 2023)	Waste management strategies and prediction	Literature review	--Formal collection, segregation and recycling system --Adequately regulated network --Raising social awareness

10. India (Jain et al., 2023)	Find out the sources of e-waste and plan to tackle the issues	Literature review	--Improve legislation --Make a global plan concentrate on children and other vulnerable peoples --Work together with NGOs and the Government.

All the studies address the challenges in e-waste management and suggest a combination of theoretical frameworks and practical data collection as a requirement. Numerous studies have suggested various methods to improve e-waste management, stressing the need for improvisation in law and legislation (Taghipour et al., 2012; Madkhali et al., 2023). An important suggestion is to educate citizens and increase public awareness regarding e-waste management. Among other predictions, few study highlight the importance of establishing an improved collection and tracking system, along with enhancing the recycling process (Iqbal et al., 2015).

Strategic Environmental Assessments (SEA) and Environmental Impact Assessments (EIA) should be implemented before launching new projects, and collaboration with government agencies and non-governmental organizations is crucial (Shumon and Ahmed, 2013; Ibitz, 2012). As well, the promotion of green technology and lengthening the lifecycle of electronic products appeared as major recommendations (Madkhali et al., 2023; Jain et al., 2023).

DISCUSSION

Assessment of E-waste

High population density of Bangladesh really enhances extensive challenges to waste management, particularly as electronic waste (e-waste) grows quickly due to the increasing usage of electronic devices. Whereas the country has made growth in handling solid waste by landfill construction and applying various waste collection strategies, after that, e-waste remains largely unaddressed also. Bangladesh's general populace is not well-informed about e-waste, which results in the incorrect disposal of outdated electronics. E-waste poses health risks in addition to harming the environment because it contains hazardous materials like lead, mercury, and cadmium.

To reduce the negative effects on the environment and ensure a long-term solution to the increasing amount of electronic waste, a systematic e-waste management system must be established. Launching public counseling centers for raising awareness about the threats of e-waste, formal e-waste collection centers for the collection and processing of e-waste; and encourage people for responsible disposal, engage public and private sectors together developing a sustainable system.

Generation of E-waste and its Future Trend in Bangladesh

The generation of electronic waste (e-waste) in Bangladesh has been rising rapidly due to increasing urbanization, economic growth, and the use of electronic devices such as mobile phones, computers, and household appliances. With the increasing dependencies on technology, millions of outdated devices are discarded every year without proper recycling or disposal systems. Future trends indicate that e-waste generation will continue to grow significantly for digitalization and improved lifestyle of consumers. Without effective policies, formal collection mechanisms, and public awareness programs, Bangladesh may face a severe e-waste management crisis in the coming decade.

A study found that in 2012, Bangladesh produces about 3.42 million tons. Indeed, more than 26000Mt/year television sets are outdated each year, producing about 0.26 million tons (Table 3) of e-waste. The statistics of other E-waste amount is really huge, such as ship breaking yard generate 2.50 million tons/year. Meanwhile, 1.00 million tons of this waste is formally recycled in some extent and estimated around 29.20% is processed properly (Table 1). If current trends continue without healthy strategy, Bangladesh is likely to face a crucial e-waste management crisis in the coming years.

Policies and Regulations Gaps in Bangladesh

In Bangladesh, there is the lack of clear guidelines or dedicated infrastructure from the government, manufacturers, or suppliers means that users are often unaware of responsible disposal options. On behalf of Government, it should be formulated policies and regulations on e-waste disposal, encouraging recycling,

and incentivizing manufacturers to establish take-back programs. Governments should establish clear, enforceable regulations regarding the import, export, and management of e-waste. The flow of hazardous materials can be managed with the aid of a stringent monitoring and compliance system, which can also guarantee that recycling and safe disposal regulations are followed. Setting up recycling plants and promoting reuse or repair of disposed materials. Create facilities to separate valuable metals from hazardous materials in e-waste, which can be recycled or handled in accordance with safety regulations. Verify that every step from collection to disposal is recorded to establish an open and accountable process.

Resource Recovery Potential of E-waste

Ferrous metals (iron and steel), non-ferrous base metals (copper, aluminum, nickel, zinc, tin), high-value precious metals (gold, silver, platinum, palladium), rare earth elements used in electronics and magnets, plastics (Table 2) and glass components from screens and circuit boards are just a few of the materials that can be recovered from e-waste, according to studies conducted worldwide. Non-ferrous metals and glass make up smaller but noteworthy percentages, while ferrous metals and plastics make up the largest share by weight. Even though they are found in small amounts, rare earth elements and precious metals have significant economic value. Moreover, among the possibly hazardous materials found in e-waste are batteries, fire-resistant plastics, and outdated electronics that contain lead, cadmium, or mercury, stressing the significance of proper recycling and material recovery.

To improve engagement, concentrate on these issues and work with stakeholders like importers, manufacturers, retailers, customers, and recycling organizations must be included in the e-waste management context. By influencing resources from both public and private sectors, partnerships activities can promote sustainability and economy. Create incentive programs and a cash-back or take-back program that allows consumers to return out-of-date electronics for an insignificant compensation. This not only promotes proper disposal but also helps manufacturers find valuable metals that can be recycled. Different collection rates may be used based on the toxicity or material value of the elements. By combined efforts, e-waste recycling can support resource conservation, economic growth, and environmental conservation by taking a sustainable method to waste management.

CONCLUSIONS

People all over the world are becoming more and more dependent on electronics, which is creating a huge amount of e-waste. For environmental protection, especially the soil, water, air, and human health; discarded electronic products must be properly collected and recycled. By recovering valuable materials, producing cost of new electronic devices can be reduced; and recycling prevents thousands of tons contaminated materials which ending up in landfills across the globe. Furthermore, the recycling process facilitates vulnerability assessment and gradually transforms e-waste into valuable resources. This process will also support the e-waste management sectors of a country as well as sustainable development.

Government programs that monitor electronic devices are crucial for building a robust monitoring system in Bangladesh. Producers and consumers need to be equally involved and concerned about the safe management of e-products due to the risks for human health and the environment. The appropriate authorities could develop a tracking app and implement strict regulations that must be observed. Ecological stability and environmentally responsible e-waste management will be encouraged by this strategy.

Strengthening administrative frameworks and promoting cooperation between government organizations, producers, recyclers, and consumers are also essential to ensure the long-term feasibility of e-waste management in Bangladesh. By creating certified recycling facilities, encouraging public-private partnerships, and implementing community-level training, education, and awareness campaigns, waste handling practices can be greatly expanded. Encouraging manufacturers to embrace ecofriendly principles and long-term manufacturer responsibility will increase support for the reuse and recycling of e-waste. These combined efforts will help Bangladesh become a cleaner, safer, and more resource efficient future by managing electronic waste.

RECOMMENDATIONS FOR FUTURE WORK

The fast urbanization process of Bangladesh, its technical progressions, and growing consumer demand for electronics have all contributed to growing e-waste problem. Lacking of strict policies and application on e-waste management indeed improves this issue. Without clear guidelines or a strong framework for managing e-waste, both producers and consumers often engage in improper disposal practices, leading to various environmental and health risks. As proposed actions for e-waste management in Bangladesh there are several steps have to be followed. Update e-waste management technologies by launching specific procedures to integrate advanced e-waste management technologies that can enhance efficiency and effectiveness in handling e-waste. Incorporate environmental management systems, develop and integrate an Environmental Management System, specifically for e-waste management, including a financial allocation (deposit) to support these initiatives. Establish e-waste management cells and create dedicated e-waste management cells in major cities to facilitate collection and public awareness campaigns regarding e-waste disposal.

Although rising awareness, several challenges can reduce in e-waste management sector in Bangladesh. Major problems include lacking of formal collection procedure, inadequate training for recovering workforces, limited public awareness, health hazards, child labor, safeties/ risk management and weak application of existing guidelines (Table 6). Informal recyclers often handle hazardous elements without proper safety measures, that's why environmental pollution and health risks are increasing day by day. As well, less synchronization among government agencies and private sectors, the absence of traceability systems makes it challenging to monitor e-waste flow and prevent illegal imports or dumping.

Enhance collection methodologies, implement effective collection strategies to ensure that e-waste is gathered systematically and responsibly. Training for e-waste recycling workers, provide formal training programs for workers involved in e-waste recycling to improve their skills and knowledge about safe and efficient recycling practices. Traceability of expired electronic devices, develop a tracing system based on consumer information collected from retailers to track expired electronic devices and ensure proper disposal. To monitor import and export procedures, have establish strict supervision to prevent illegal handling of electronic waste and ensure compliance with environmental standards. Provide electronics manufacturers specific guidelines on how to reduce the use of toxic materials in their products and implement recycling friendly practices.

Government incentives, insurance programs, and safety principles can support to reduce legal action gaps and health risks. As well, addressing child labor, ensuring workplace safety, and reducing pollution; required tax breaks, social awareness campaigns, and comprehensive policy to create an accountable and long-lasting e-waste management system. And implement Strategic Environmental Assessment, in addition to Environmental Impact Assessments as the prerequisite of SEA for new projects, revising policies bring into line with project policies and environmental sustainability.

These initiatives can produce a wide-ranging plan for managing e-waste in Bangladesh, promoting eco-friendly environment, and protecting public health. To make these initiatives more successful, collaboration among stakeholder, consumer, producer and government will be essential. Although placing these procedures into practice will take time and investment, after that it will reduce the e-waste problem of Bangladesh and support create a cleaner environment.

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