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Scenario of e-waste management: Navigating business prospects overcoming environmental challenges

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Abstract

Purpose: The main objective of this study is to determine the scenario of e-waste management from a global and Bangladeshi perspective and navigate potential business prospects in the procedure of e-waste management minimizing health hazards.

Research Methodology: The research was conducted by collecting data from reports and research papers from different international and national sources, interviews with 500 residents of Dhaka City, and five no. of recycling companies in Bangladesh. Upon descriptive analysis of the scenarios of global and Bangladeshi e-waste management, we tried to establish a relationship between proper e-waste management and business prospects.

Results: The study found that home appliances and cell phones form the majority of e-waste. Informal recycling practices are responsible for high environmental and health risks. Moving towards a structured, formal recycling process can bring significant economic benefits in the form of employment opportunities and recovery of resources from e-waste.

Conclusions: Effective e-waste management, supported by advanced technology and strong policy enforcement, is essential for protecting health and the environment while generating economic and employment opportunities.

Limitations: The sample for the interview was taken from Dhaka City only. A larger population could make the study richer.

Contribution: The study suggests setting up advanced recycling facilities and transforming entire e-waste management practices through internationally and cooperatively adopted sustainable measures. It emphasizes developing proactive policies and enhancing public awareness of proper e-waste management with a view to effectively facing the challenges and grabbing the business opportunities available from the e-waste management process.

Novelty: This research has tried to bring out economic benefits and business opportunities from the process of e-waste management. It highlights that structured and sustainable e-waste management fosters economic growth, mitigates health hazards, and saves the environment.

Keywords: *Business opportunity, E-waste management, Prospects, recycling, WEEE*

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1. Introduction

Electronic waste (e-waste) or waste of electrical and electronic equipment (WEEE) is obsolete or undesired electrical and electronic devices or their components (Cairns, 2005). Currently, electronic devices are used indiscriminately in every sphere of life worldwide. Globally, e-waste generation has skyrocketed over the last decade, with an annual growth rate of approximately 5%. Approximately 50 million tons of e-waste are added each year (Liu, Tan, Yu, & Wang, 2023). E-waste contains various toxic elements and heavy metals such as antimony, lead, tin, mercury, cadmium, and many more that can cause severe damage to the environment and ecosystem (Quan et al., 2015). Serious health issues in humans, including hormonal and renal function, can occur if they are exposed to these substances (Parvez et al., 2024). The presence of harmful compounds such as Pb, Cr6, Hg, and Cd, as well as flame retardants (Polybrominated Diphenyl Ethers and Polybrominated Biphenyls, among others), makes e-waste dangerous. In underdeveloped nations such as Bangladesh, where formal recycling technology is lacking and informal operators are collecting precious metals through shady methods for quick cash, the dumping of e-waste combined with solid urban waste is creating a greater threat to environmental damage. Printed circuit boards (PCBs) are dipped in acidic or alkaline solutions and then heated or burned to remove metals from informal units. These procedures are detrimental to the environment and workforce, which are the main issues in managing e-waste in underdeveloped nations like Bangladesh (Alam & Bahauddin, 2015). Thus, not only is managing this massive amount of e-waste necessary, but it can also provide a great business opportunity. Bangladesh is a developing country that has emphasized its IT sector as part of the digital Bangladesh initiative. Consequently, the use of electronic devices such as computers, mobile phones, televisions, air conditioners, and refrigerators has boomed in the country.

1.1 Objectives of the study

Our study aims to evaluate sustainable e-waste management and navigate the scope of opportunities for economic benefits in managing e-waste in appropriate ways, reducing health hazards and environmental risks. This research attempted to determine potential business prospects and opportunities in Bangladesh through e-waste management in accordance with the global e-waste management scenario. Another objective is to identify the challenges and how to develop e-waste management in Bangladesh, making it profitable to overcome the challenges related to this.

2. Literature review

2.1. Environmental and Health effects of e-waste

In addition to damaging wildlife and contaminating the air, soil, and water, e-waste also poses a major health risk because it contains chemicals that can be fatal. Based on the contamination factor of over 1000 different harmful components, such as organics and heavy metals, e-waste can be separated into 26 primary types. Improper handling and disposal of these components can have detrimental effects on the environment and human health (Garlapati, 2016). Human diseases such as cancer, nerve damage, asthma, hearing loss, infant mortality, vision problems, kidney problems, brain disorders, disabled baby birth, and liver and lung damage are caused by and catalyzed by e-waste (Masud et al., 2019). Various types of e-waste materials and their associated environmental and health impacts are shown in Table 1.

Table 1. Various categories of e-waste and their associated environmental and health impacts (Garlapati, 2016; Masud et al., 2019).

Waste Category	Common Electrical Devices	Typical Hazardous materials	Impact on Health/Environment
Major household gadgets	Refrigerators, air conditioners, microwave ovens, induction cookers, washing machines	Mercury (Hg), wiring, refrigerants, copper (Cu), small electronic components, lead (Pb), motors, plastic	Neurotoxic effects, ozone layer depletion, respiratory issues, soil and water contamination

Minor household gadgets	Alarm clocks, electric kettles, CD/DVD players, grinders-juicers-mixers, video game consoles, electric chimneys	Plastic, small metal parts, mercury (Hg), circuit boards, lead (Pb), various electronic components	Plastic pollution, neurotoxic effects, endocrine disruption, developmental disorders
IT and telecommunication gadgets	Modems, teleprinters, communication satellites, mobile phones, LAN, landline phones	Palladium (Pd), arsenic, lithium (Li), plastic, cadmium (Cd), circuit boards, lead (Pb), copper (Cu)	Water and soil contamination, cancer risk, respiratory issues, neurological disorders, reproductive toxicity
User gadgets	DVD players, camcorders, MP3 players, digital cameras, radio receivers, personal computers, TV sets	Mercury (Hg), plastic, cadmium (Cd), small metal parts, beryllium, hexavalent chromium, circuit boards, lead (Pb)	Mercury poisoning, plastic pollution, cancer, respiratory issues, neurological disorders
Illumination gadgets	LED, neon lights, halogen lamps, compact fluorescent lamps, ballast lamps	Phosphorus, mercury (Hg), tungsten filament, lead (Pb), low-pressure inert gas, glass, metal contacts	Mercury poisoning, light pollution, respiratory issues, neurological disorders
Electrical and electronics tools	Wires, integrated circuits, transformers, resistors, diodes, motors, switches, relays, vacuum tubes, generators	Plastics, mercury (Hg), lead (Pb), copper (Cu), ferrous and non-ferrous metal parts, various electronic components	Plastic pollution, heavy metal poisoning, respiratory issues, neurological disorders
Toys, leisure, and sports gadgets	Batteries in toy cars, airplanes, buses, trains	Lead (Pb), mercury (Hg), lithium (Li), cadmium (Cd), plastic, small metal parts	Lead poisoning, mercury poisoning, battery acid burns, plastic pollution
Medical devices	Biomedical engineering instruments, medical thermometers	Small metal parts, mercury (Hg), lead (Pb), plastic, electronic components	Mercury poisoning, heavy metal poisoning, plastic pollution, potential biohazard risks
Monitoring and control instruments	Microcontrollers, relays, thermostats	Plastic, copper (Cu), lead (Pb), mercury (Hg), small metal parts	Plastic pollution, heavy metal poisoning, respiratory issues, neurological disorders
Automatic dispensers	Automatic soap dispensers, automatic spray dispensers, automatic water dispensers	Circuit boards, plastic, lead (Pb), small metal parts	Plastic pollution, heavy metal poisoning, respiratory issues

2.2. Stakeholder mapping analysis for e-waste management

E-waste management requires the involvement and collaboration of various stakeholders, such as government authorities, regulators, customers, suppliers, employees, communities, and investors. We can mention three scenarios for e-waste management from a global perspective. In the first scenario, e-waste is collected by government agencies, producers, and/or recognized groups in accordance with national e-waste legislation. These actions are referred to as "formal collection." Retailers, municipal collection sites, and pickup services are the means by which this occurs. A specialized treatment plant is the ultimate destination for the gathered e-waste. Precious materials are recovered in an environmentally controlled manner, whereas dangerous compounds are managed in an environmentally sound manner. Subsequently, residuals are disposed of in controlled landfills or burned.

According to formal recycling, e-waste collected by approved commercial and/or municipal collection sites and pick-up services is often recycled at facilities with cutting-edge machinery, infrastructure, and technology for the safe and effective removal of valuable materials. However, the majority of e-waste collected by private waste companies or dealers outside the official system is processed and recycled using subpar methods, typically without any measures to lessen the release of dangerous chemicals into the environment (informal recycling) (Ahirwar & Tripathi, 2021).

E-waste is collected by individual waste dealers or companies and traded through various channels in nations that have created waste management legislation. In this case, recycling facilities for plastic and metal might be used to dispose of e-waste, but the dangerous materials inside are probably not decontaminated. In this case, e-waste may also be exported and frequently not handled in a dedicated recycling facility for e-waste management.

In most developing nations, e-waste is collected and recycled by a sizable number of unpaid independent contractors. This assortment occurs door-to-door through the purchase or collection of used EEEs or e-waste from private residences, commercial establishments, and public institutions. They offer it for disassembly, refurbishment, or repair. Dismantlers manually disassemble machinery into materials and components that can be sold and used. To convert electronic waste into secondary raw materials, recyclers burn, leach, and melt the material. This "backyard recycling" seriously harms both human health and the environment (Forti, Balde, Kuehr, & Bel, 2020). One of the main participants in the recycling process and one that helps move goods and materials around is the unorganized sector (M. T. Islam et al., 2021).

2.3. Effective E-waste Management Techniques and Navigating Business

There are some e-waste management models in the e-waste management industry through which we can navigate business and save the environment and human health from the hazardous elements of e-waste.

2.3.1 Recycling

Recycling is the best method for managing e-waste. It is possible to make money by recovering valuable metals such as copper, silver, and gold from e-waste, thereby conserving the environment in a sustainable way. Through the implementation of effective recycling procedures, companies can extract substantial value from their obsolete electronics. Generally, e-waste contains four major categories of pollutants: halogenated compounds, heavy metals, radioactive elements, and miscellaneous substances, such as plastics, ceramics, and resins. Some organic pollutants including polyaromatic hydrocarbons (PAHs), polybrominated biphenyls (PBBs), polyvinyl chloride (PVC), polychlorinated biphenyls (PCBs), brominated flame retardants (BFRs), polybrominated diphenyl ethers (PBDEs), and polychlorinated dibenzo-p-dioxin furans (PCDD/Fs) are also concurrently discharged into the environment due to improper or inadequate e-waste processing. The electronic components are also made up of precious metals (gold, palladium, platinum, silver), base metals (zinc, copper, nickel, lead), and rare earth minerals (yttrium, lanthanum, cerium, europium, neodymium) (Rene et al., 2021). Workers in the e-waste recycling process frequently experience respiratory problems owing to their extended exposure to concentrated acids used in metal recovery and dust generated during the pre-processing of resource recovery (Hsu, Barmak, West, & Park, 2019).

According to Nguyen, Lee, and Hung (2021), the four main criteria that suggest WTP for e-waste recycling are end-users' willingness to participate in recycling programs, rules and regulations, the hassle of recycling, and experience. Siringo, Herdiansyah, and Kusumastuti (2020) discovered that social pressure, environmental views, and moral standards had a major impact on engaging in (or being willing to engage in) suitable actions, including recycling. Therefore, a proper recycling process and model is significant for e-waste management businesses, considering the health issues of human beings and other animals, and maintaining the environment free from pollution caused by hazardous elements. An advanced analysis of the relationships between different e-waste recycling strategies is necessary to highlight recent developments, ongoing issues, and potential future advancements (A. Islam et al., 2021). To recycle e-waste, startups can create innovative technologies, including sophisticated separation strategies and ecologically friendly extraction procedures. These developments have the potential to increase the safety and efficiency of e-waste processing. We need to arrange an innovative business model for e-waste management in which we can use solar panels and renewable energy instead of consuming much electricity and huge amounts of energy of any kind for recycling and reproducing new products (Das et al., 2022). Technology is necessary to boost production and reduce reliance on manual systems. Significant investment and robust regulatory backing are necessary for the effective deployment of automation technology.

2.3.2. Refurbishing, Repair and Maintenance Service

Compared to the creation of new products, remanufacturing results in less environmental pollution (L. Zhang & Zhang, 2022). E-waste can be utilized through a remanufacturing process in which the replacement of specific parts of a computer or laptop with newer versions enhances the overall efficiency and gives a new life along with a warranty equivalent to a new product (Khan, Ali, & Singh, 2022; Mann, Saxena, Almanei, Okorie, & Salonitis, 2022). Prolonging the lifecycle of e-waste is one of the most efficient methods for the sustainable production and consumption of EEE (Singhal, Tripathy, & Jena, 2019).

The market for reconditioned electronics is expanding in Bangladesh. Businesses can benefit from this by restoring outdated technology and selling it for profit from consumers on a budget. For this purpose, infrastructure is needed for the collection, recycling, and disassembly of electronic trash. These facilities are able to separate valuable elements such as glass, metals, and polymers, which can either be sold to producers or used to create new goods. Currently, the repair and maintenance of e-waste is a highly profitable business. In this way, it is possible to decrease e-waste by increasing the lifespan of electronic equipment. Users of electronic equipment can be made aware that repairing and reusing electronic equipment longer is better for the environment and saves lives. The repair and maintenance of electronic products directly contribute to the national economy because they reduce the import costs of electronic items and their accessories.

2.3.3. Mobile Apps Based or Online E-Waste Disposal

A study by Y. Zhang, Qu, Wang, Yu, and Liu (2019) discovered that attitudes, subjective norms, perceived behavioral control, and economic motivation all had a favorable impact on people's readiness to deliver e-waste to online platforms. Additionally, the study indicated that people are more eager to participate in the platforms than in traditional (informal) e-waste collecting and recycling because of the greater cash incentives. According to Zhang et al. (2019), online recycling systems are preferred by young students, a growing market category. There was a correlation between incentives and willingness to use an online recycling platform.

In developing countries such as Bangladesh, creating an app that makes it easy for users to discover repair businesses, arrange pickups, and identify nearby e-waste collection stations is a convenient approach to handle e-waste. By using mobile apps, people might feel comfortable disposing of e-waste in a proper way, and recycling companies can easily collect e-waste from app service providers.

2.3.4. Upcycling Products and Artwork

Customers seek products with features that reduce adverse effects on the environment and encourage sustainability, and they select eco-friendly products to support environmental conservation (Uddin, 2023). Innovative businesspeople can turn e-waste into useful furniture, artwork, and many other artful products using metals, plastics, and other e-waste materials. This draws on eco-aware customers and encourages sustainability. This might be a big business, both in the field of manufacturing and trading, considering the increase in e-waste generation worldwide.

All these techniques can create employment generation and contribute to the national and global economy as well as save the environment.

3. Research methodology

The research was conducted by collecting data from reports, research papers, various international and national data sources, and various scholarly literature. We also obtained interviews with 500 residents of Dhaka City and 5 no. of recycling companies in Bangladesh. The global scenario of e-waste generation was mainly analyzed from the report of the Global E-waste Monitor 2024, and the E-waste generation of Dhaka city was estimated based on the device used per 500 people, average life span of the devices, average weight of E-waste per device, and awareness of the people regarding e-waste management and health effects. We interviewed the owners and concerned high officials of the recycling plants to analyze the business prospects and challenges they face regarding e-waste management in Bangladesh. Upon descriptive analysis of the scenarios of global and Bangladeshi e-waste management, we tried to establish a relationship between e-waste generation and economic prospects.

4. Results and discussions

4.1. Global E-waste Generation and Management Scenario

The Global E-waste Monitor 2024 (Unitar, 2024) reports that by 2022, 62 billion kg of e-waste, or 7.8 kg per person, was produced worldwide; only 22.3 percent (13.8 billion kg) of that amount was reported to have been collected and recycled appropriately; 34 billion kg of e-waste was produced worldwide in 2010, and that amount has increased by an average of 2.3 billion kg per year since then; Europe has a recorded formal collection and recycling percentage of 42.8%, although rates vary widely by region. The figure below illustrates the global e-waste generation and collection scenarios.

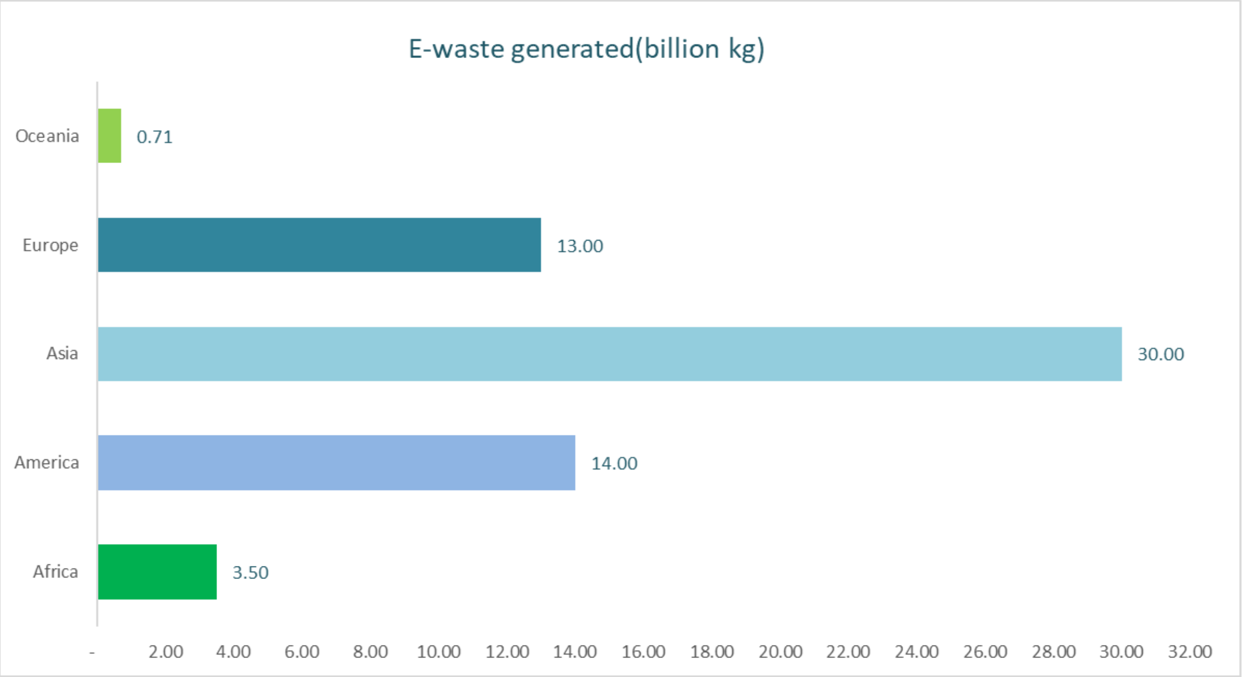


Figure 1

Source: Global E-waste Monitor 2024. The figure shows the amount of global e-waste generation content in 2022.

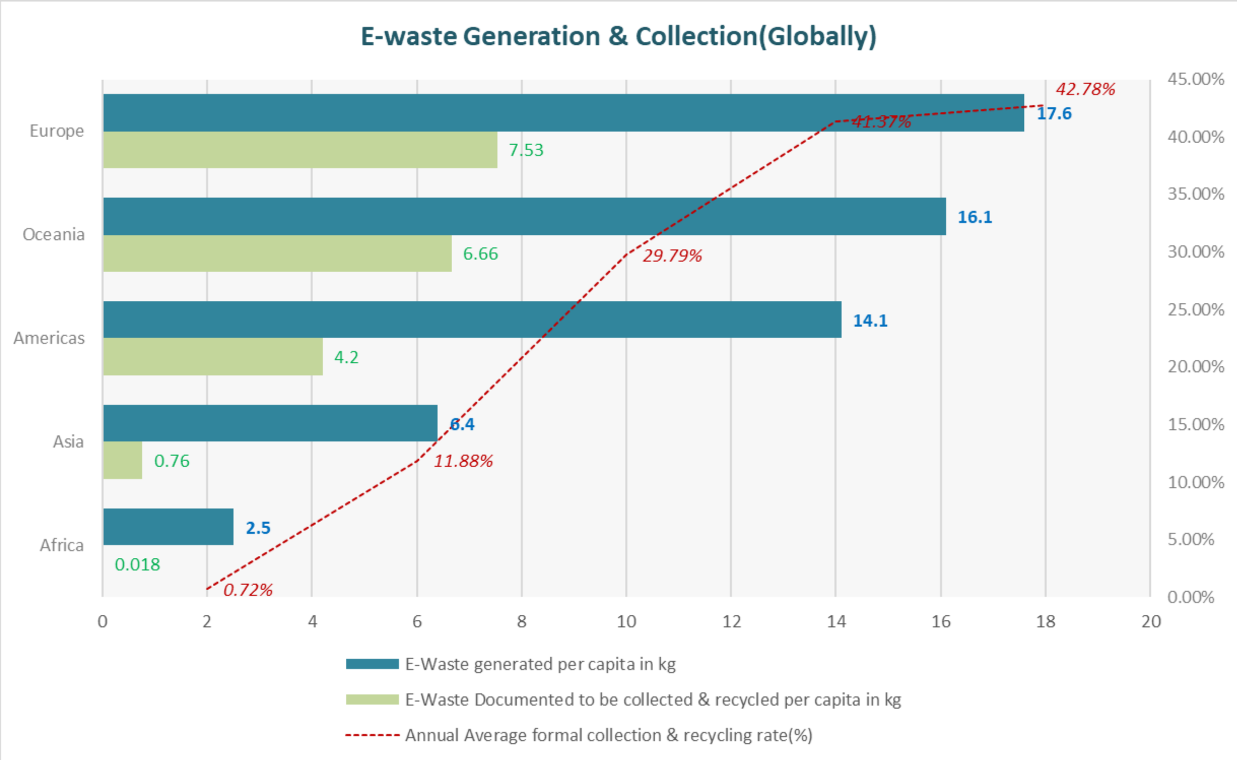


Figure 2

Source: Global E-waste Monitor 2024. The Figure shows the amount of global e-waste generation per capita in kilograms, documented formally collected and recycled per capita in kilograms, and the rate of annual average formal collection and recycling in 2022.

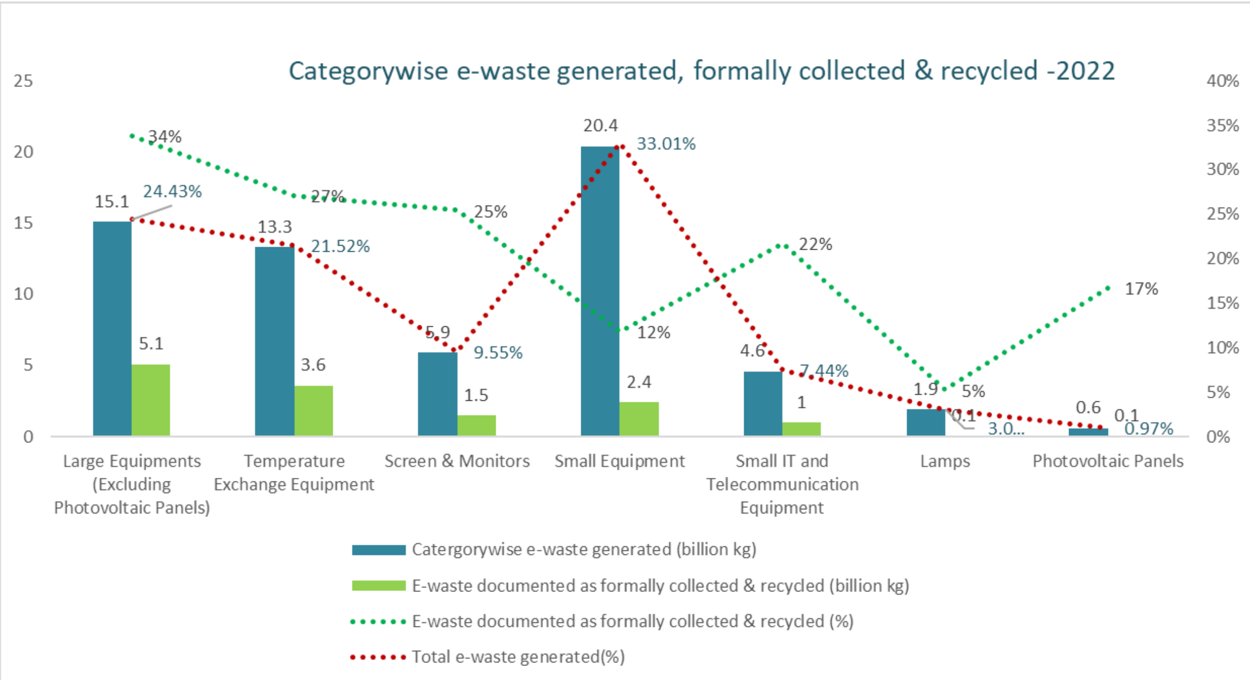


Figure 3

Source: Global E-waste Monitor 2024. The Figure shows the category wise of e-waste generated, formally collected, and recycled amount and percentage in 2022. We can notice here that small equipment e-waste was generated in the largest amount but formally collected and recycled very lower amount.

The Global E-waste Monitor 2024 found that 62 billion kg of e-waste has a composition of 31 billion kg metals, 17 billion kg plastics, and 14 billion kg other materials such as alloys, composite materials, glass, and concrete. The most used metal is iron/steel (Fe, approximately 24 billion kg), followed by copper (Cu, 2.1 billion kg) and aluminum (Al, 3.9 billion kg). Of the 31 billion kilograms of metals, an estimated 19 billion kilograms may be recovered economically using the methods currently used for e-waste management. This indicates that 12 billion kg of metals were lost, either as a result of them ending up in non-compliant management plans or disposal sites with generally poorer efficiency or during the compliant recycling process. Consequently, the losses were not viable for recovery. The study assessed that 500 million kilogram of copper was present in temperature exchange equipment from compressors and cables, whereas 1 billion kg of copper was present in printed circuit boards and cables in the small equipment category. Along with hazardous materials like lead (Pb, 70 million kilogram) and the crucial metal cobalt (Co, 34 million kilogram), there were also trace amounts of other extremely valuable precious metals (1.6 million kg), including gold (Au), palladium (Pd), and silver (Ag).

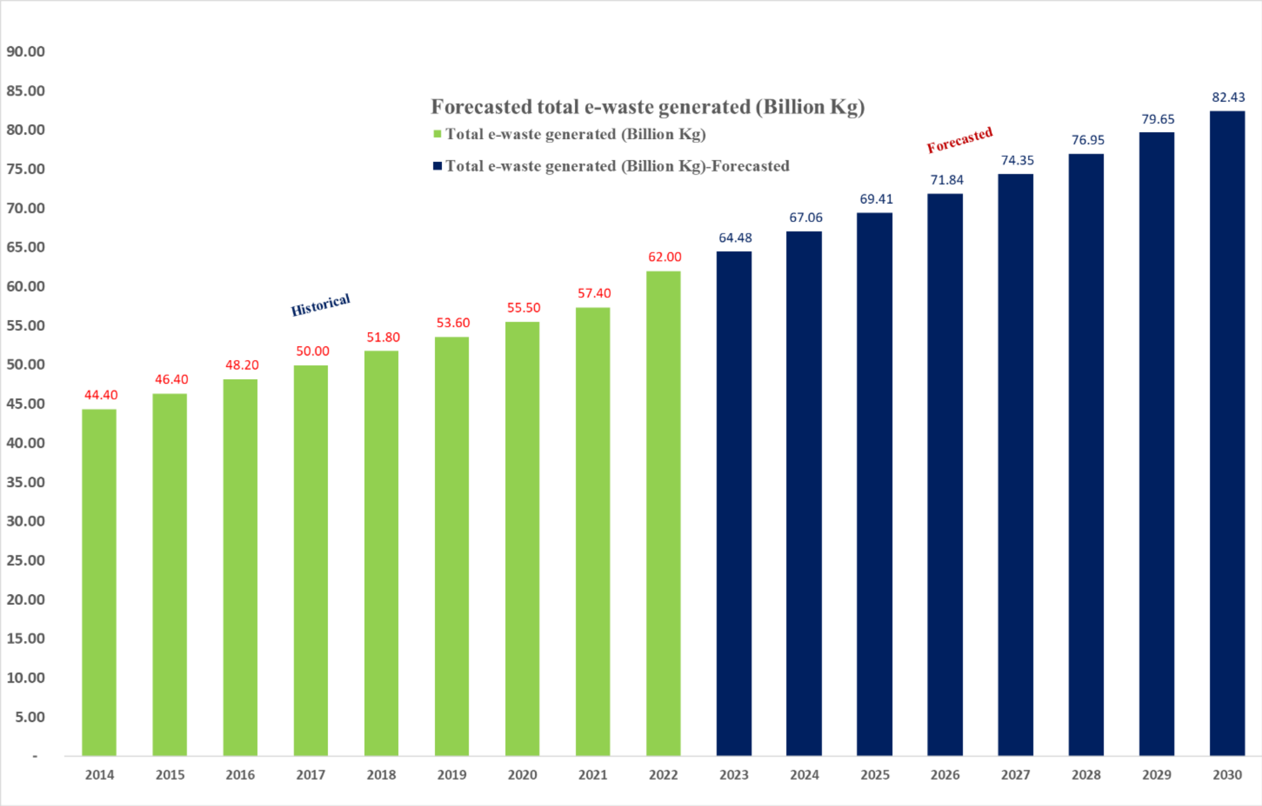


Figure 4

Source: Global E-waste Monitor 2024 (Liu et al., 2023; Roy, Islam, Haque, & Riyad, 2022).

The Global E-waste Monitor 2024 developed four distinct scenarios, including business-as-usual, progressive, ambitious, and aspirational scenarios, for the projection of e-waste scenarios in the future to achieve SDGs targets. Research projects indicate that 82 billion kilograms of e-waste will be produced worldwide in 2030. According to the projection, formally documented to be collected and recycled by 2030, as follows:

Table 2.

Overview of e-waste flows for 2030 scenarios and viable recovery of metals

SCENARIO	E-WASTE DOCUMENTED AS FORMALLY COLLECTED AND RECYCLED (SDG INDICATOR 12.5.1)	E-WASTE DOCUMENTED AS FORMALLY COLLECTED AND RECYCLED (SDG 12.5.1)	ESTIMATED E-WASTE IN WASTE BIN	ESTIMATED E-WASTE IN SCRAP METAL	INFORMAL SECTOR	TOTAL	IRON	COPPER	GOLD	NICKEL	ALUMINIUM
Unit	*per cent*	*billion kg*	*billion kg*	*billion kg*	*billion kg*	*billion kg*	*billion kg*	*billion kg*	*thousand kg*	*million kg*	*billion kg*
2022 - current practice	22	14	14	16	18	19	16	1.1	47	1.9	1.1
2030 - business as usual	20	16	20	22	24	25	21	1.4	50	2.1	1.4
2030 - progressive	38	31	13	14	24	28	24	1.6	78	4.3	2.2
2030 - ambitious	44	37	12	13	21	29	24	1.6	79	4.5	2.4
2030 - aspirational	66	50	10	10	13	30	25	1.7	79	4.9	2.9

Source: Global E-waste Monitor 2024. The figure shows the e-waste flows of 2022 and the projected scenario and viable recovery of different useful metals in 2030.

Metal recovery and contributions to climate change were used to assess the economic benefits of e-waste management.

Table 3.

Overview of environmental/economic impact of the 2030 scenarios

SCENARIO	AVOIDED MERCURY EMISSIONS	MERCURY EMISSIONS	AVOIDED GREENHOUSE GAS EMISSIONS (DIRECT AND INDIRECT)	GREENHOUSE GAS EMISSIONS CAUSED BY ENVIRONMENTALLY UNSOUND MANAGEMENT OF REFRIGERANTS	OVERALL ECONOMIC COST	VALUE OF RECOVERED METALS E-WASTE	VALUE OF AVOIDED GREENHOUSEGAS EMISSIONS	TREATMENT COSTS	EXTERNALIZED COSTS ARISING FROM LEAD/ MERCURY EMISSIONS, PLASTIC LEAKAGES AND GLOBAL WARMING CONTRIBUTION
Unit	*1000 kg*	*1000 kg*	*Mt CO_2 equivalent*	*Mt CO_2 equivalent*	*billion USD*	*billion USD*	*billion USD*	*billion USD*	*billion USD*
2022 - current practice			94	145	-36	28	23	-10	-78
2030 - business as usual	11	46	105	149	-40	42	26	-15	-93
2030 - progressive	21	36	155	116	-4	52	39	-20	-75
2030 - ambitious	25	32	171	103	9	54	43	-21	-66
2030 - aspirational	34	23	209	74	38	57	52	-24	-47

Source: Global E-waste Monitor 2024. The Figure shows the environmental and economic impact, including associated costs related to e-waste treatment, in the scenario of 2022 and projected 2030.

Table 4 shows the overall annual economic monetary impact of e-waste management globally in different projected scenarios by 2030, controlling the environmental impact through formally documented e-waste collection and managed and efficient resource recovery.

Table 4

Scenario 1: Business as Usual by 2030	Scenario 2: Progressive by 2030	Scenario 3: Progressive by 2030	Scenario 3: Progressive by 2030
Key e-waste statistics	***Key e-waste statistics***	***Key e-waste statistics***	***Key e-waste statistics***
16 billion kg | **20%** e-waste projected to be formally collected and managed by 2030.	**31** billion kg |**38%** e-waste projected to be formally collected and managed by 2030.	**37** billion kg |**44%** e-waste projected to be formally collected and managed by 2030.	**54** billion kg |**60%** e-waste projected to be formally collected and managed by 2030.
Metals	***Metals***	***Metals***	***Metals***
25 billion kg metal resources are viably recovered. 17 billion kg metal resources are lost.	**28** billion kg metal resources are viably recovered. **14** billion kg metal resources are lost.	**29** billion kg metal resources are viably recovered. **13** billion kg metal resources are lost.	**30** billion kg metal resources are viably recovered. **12** billion kg metal resources are lost.
Environmental Impact	***Environmental Impact***	***Environmental Impact***	***Environmental Impact***
46 thousand kg emissions of mercury released. **11** thousand kg mercury emissions avoided.	**36** thousand kg emissions of mercury released. **21** thousand kg mercury emissions avoided.	**32** thousand kg emissions of mercury released. **25** thousand kg mercury emissions avoided.	**23** thousand kg emissions of mercury released. **34** thousand kg mercury emissions avoided.
149 billion kg CO2-eq. contributing to global warming. **105** billion kg CO2-eq. emissions	**116** billion kg CO2-eq. emissions released **155** billion kg CO2-eq. emissions	**103** billion kg CO2-eq. emissions released **171** billion kg CO2-eq. emissions	**73** billion kg CO2-eq. emissions released **209** billion kg CO2-eq. emissions
Overall Economic Impact of e-waste management	**Overall Economic Impact of e-waste management**	**Overall Economic Impact of e-waste management**	**Overall Economic Impact of e-waste management**
Benefits	***Benefits***	***Benefits***	***Benefits***
26 billion USD value of avoided greenhouse emissions.	**39 billion USD** value of avoided greenhouse emissions.	**43 billion USD** value of avoided greenhouse emissions.	**52 billion USD** value of avoided greenhouse emissions.
42 billion USD value in viable recovery of metals.	**52 billion USD** value in viable recovery of metals.	**54 billion USD** value in viable recovery of metals.	**57 billion USD** value in viable recovery of metals.
Costs	***Costs***	***Costs***	***Costs***
15 billion USD Value of compliant recycling costs.	**20 billion USD** Value of compliant recycling costs.	**21 billion USD** Value of compliant recycling costs.	**24 billion USD** Value of compliant recycling costs.
93 billion USD Value of externalized costs to the population and the environment.	**75 billion USD** Value of externalized costs to the population and the environment.	**66 billion USD** Value of externalized costs to the population and the environment.	**47 billion USD** Value of externalized costs to the population and the environment.
Projected annual economic monetary impact of e-waste management globally.	***Projected annual economic monetary impact of e-waste management globally.***	***Projected annual economic monetary impact of e-waste management globally.***	***Projected annual economic monetary impact of e-waste management globally.***
- 40 billion USD	**- 4 billion USD**	**10 billion USD**	**38 billion USD**

Source: Global E-waste Monitor 2024

The extent to which e-waste management technologies, laws, and infrastructure are expected is the main difference between scenarios. These scenarios seem doable, considering that e-waste management technology is already available and mostly necessitates capital expenditure in infrastructure development and regulatory initiatives. In Scenerio 2, international action is implemented through volunteer collection programs in areas without existing laws. Formal collection rates rose to 85% in areas with adequate e-waste management infrastructure and existing laws. It is anticipated that waste circuit boards will be disassembled and treated in the best possible way to maximize their value. In Scenario 3, governments concentrate on improving the source separation of e-waste in conventional waste management systems, while international action takes the shape of efficient voluntary collection programs. A percentage of imported used EEE goods in low- and middle-income countries will be collected through formal collection systems, and efforts will be made to legalize the informal sector. High- and upper-middle-income nations with laws will achieve a formal collection rate of 85% in Scenario 4. More imported EEE goods will be treated as a result of cooperative efforts between high- and low-income nations. A total of 54 billion kilograms of e-waste will be managed sustainably, and the worldwide e-waste collection rate will increase to 60%. The majority of the gains in this scenario occur in low- and middle-income nations.

4.2. E-waste Generation Scenario in Bangladesh

In the past 50 years, Bangladesh has experienced tremendous socio-economic changes, such as rapid industrialization and urbanization, which have directly influenced its electronic equipment and demand. Televisions, freezers, cellphones, and other gadgets have evolved into necessities of modern life; such advancement signifies the evolution of a technology-based lifestyle in both urban and rural areas of the country. Bangladesh is experiencing challenges in the safe management of mobile phones, compact fluorescent lamps, computers, laptops, televisions, refrigerators, household appliances, and office equipment. The lack of assessment of how much e-waste is generated annually in the country and the absence of a legal mechanism for its efficient management has further contributed to the challenge. The main objective of this study is to assess the alternative use of e-waste and its business opportunities in our country.

As one of the largest e-waste-generating countries in Asia, Bangladesh generated about 367 million kilogram annually in 2022 at a rate of 2.2 kg per capita (Unitar, 2024), out of which 0% of the e-waste was formally collected and documented. The population of Bangladesh is 169.83 million, according to the 2022 census. As of 2024, Dhaka, the capital of Bangladesh, is a megacity home to 10.2 million people, according to Wikipedia. The majority of e-waste generated in Bangladesh is dumped into open soil, open land, or open sources of water bodies without knowledge of the harmful effects of such dumping, endangering human health, the environment, and the ecosystem (Awasthi, Zeng, & Li, 2016). Although this change is a landmark development, it has also generated the terrifying issue of electronic waste. Millions of gadgets reach the end of their lives each year, creating an unparalleled amount of e-waste for the nation to handle. Owing to its high nodule density and reliance on technology, the capital city of Dhaka contributes a huge amount of e-waste to the national e-waste stream every year.

Table 5. Estimated e-waste generation (estimated) per 500 people based on device data collected from interviews in the City of Dhaka.

Item for Dhaka City	Number of Devices per 500 People	Average Life Span (Years)	Average weight of E-Waste per Device (kg)	Total weight of E-Waste (kg) per 500 People	Average Annual E-waste (Kg)
Television	170	15	4	680	45.33
Refrigerator	160	20	30	4,800	240.00
Air Conditioner	100	10	35	3,500	350.00
Washing Machine	90	10	25	2,250	225.00
Microwave Oven	90	5	10	900	180.00
Laptop/Computer	80	5	2	160	32.00
Smartphone	850	3	0.2	170	56.67
Tablet	95	3	0.5	48	15.83
Printer	65	3	7	455	151.67
Ceiling Fan	600	8	5	3,000	375.00
Total				15,963	1,671.50

Table 5 shows the interview result of e-waste generation (estimated) per 500 people based on device data, which is an average of 2.88 kg per person in Dhaka city as in comparison with other parts of Bangladesh, people of Dhaka city use a greater amount of electronic equipment for their lifestyle. Few people living in rural areas of Bangladesh use air conditioners, washing machines, microwave ovens, laptops, etc. However, a huge number of people living in Dhaka and other cities use these appliances. Again, offices, factories, and industries use different types of electronic and electrical equipment in the country.

Waste Management has become an enormous problem for municipalities. Two city corporations in Dhaka, Dhaka North City Corporation (DNCC) and Dhaka South City Corporation (DSCC), are responsible for the management of all waste. Due to a lack of proper planning and successful execution, most e-waste is not recycled or reused and is dumped in landfills. For this reason, proper management of e-waste makes the economic value of resources in all electrical and electronic rubbish. In this study, a business model of e-waste materials is proposed and its prospects and challenges are demonstrated.

In Bangladesh, stakeholders in the e-waste business can be divided into two sectors, formal and informal, for the collection, treatment, and disposal of e-waste. The informal sector gathers e-waste from various home and industrial sources and then supplies it to the formal sector, which is involved in industrial-scale scientific recycling and the creation of new products after obtaining approval and informing law enforcement and monitoring committees/agencies about the classification of e-waste (i.e., hazardous and non-hazardous) before further processing, recycling, and trading (Akter & Hossain, 2025). In Bangladesh, the informal sector collects and manages e-waste.

4.3. Prospects and Opportunities of E-Waste Management Related Business

According to Shahabuddin et al. (2023), there are great prospects and opportunities for e-wastes if they are recycled properly. E-waste containing precious metals can generate a significant amount of profit by applying appropriate business models. The e-waste industry has enormous economic potential, owing to the growing volume of electronic garbage created globally. E-waste is a global issue. Therefore, opportunities exist for collaboration and global trade in recycling projects. E-waste contains recyclable materials and precious metals such as palladium, silver, gold, and rare earth elements. Businesses may arise from these product offerings to include services such as collecting, electronics refurbishing, and retailing refurbished items to generate other revenue streams. Profit from these businesses can be lucrative. Many nations have laws governing the proper disposal of e-waste, which can open up commercial prospects for authorized recyclers and trash management companies. Raising consumer awareness of e-waste recycling can promote efficient disposal methods, which can enhance economic potential. It is possible to raise awareness and establish a consistent flow of electronic waste for disposal by collaborating with manufacturers, retailers, and municipal governments. Considering the significance of sustainability, companies that focus on environmentally friendly e-waste solutions may draw attention to eco-aware customers. Selecting and processing e-waste with cutting-edge technologies, such as robotics and artificial intelligence, can boost productivity and profitability. The growth of Bangladesh's e-waste sector has both social and environmental benefits.

The e-trash recycling process involves disassembling and dissecting electronic equipment into constituent pieces. Materials such as copper, aluminum, glass, and plastic are removed and transformed to create new goods, and hazardous materials such as lead, cadmium, and mercury are disposed safely. The largest amount of e-waste is collected informally and is unregulated in underdeveloped and developing countries. Bangladesh still lacks legislation to control the risks to workers' health and the environment associated with e-waste management. The recycling industry in Bangladesh is dominated by the informal sector. Only 3% of all e-waste is recycled in this country, which is substantially less than that in other poor nations. Therefore, unrecycled e-waste harms ecosystems in different waterways, landfills, and drains (Bhattacharjee et al., 2023).

4.3.1. Prospects of E-waste business in Bangladesh

Recycling of e-waste, particularly collecting, sorting, and processing of e-waste, might generate many employment opportunities. This may help many people in both rural and urban areas find employment. By considering exporting recycled goods, Bangladesh might be able to benefit the global market for resources that originate from e-waste. Appropriate e-waste management can reduce the need to import raw materials by promoting resource recovery. The sustainability efforts of the e-waste management sector in Bangladesh might be further strengthened by better management of e-waste. This saves money and supports the preservation of national resources.

Using cutting-edge technologies from developed nations will assist Bangladesh's e-waste recycling facilities in running more effectively and productively. Working together with reputed, international e-waste management companies can bring best practices, knowledge, and technology to Bangladesh. These collaborations may help build a more robust framework for e-waste management. This transfer of knowledge can significantly enhance local capacity. The establishment of e-waste companies and e-waste management initiatives can be encouraged through international funding and grants, providing the sector with support for sustainable growth.

4.3.2. Opportunities of E-waste Management Related Business

Bangladesh's rapid technological advancement is causing a noticeable increase in electronic waste, or "e-waste." Over the past few decades, Bangladesh has seen a notable increase in the use of electronic components, microchips, and automated machinery in various industries, including office supplies, industrial tools, domestic appliances, and transportation (Roy et al., 2022). It is anticipated that this percentage will rise in tandem with the nation's digital transformation. There are many business prospects in e-waste management in Bangladesh and around the world as a result of the growth in e-waste. The formation of social enterprises or Non-Governmental Organizations (NGOs) may be centered on teaching local populations about recycling and e-waste management techniques. Partnerships with companies for improved waste management solutions can result from favorable attitudes toward e-waste management. In 2021, the Bangladeshi Ministry of Environment, Forests, and Climate Change established the E-waste Management Rules (moef.portal.gov.bd, 2025) to regulate disposal through formal channels and recycling through recycling industries, emphasizing environmental sustainability and public health. The Bangladesh Telecommunication Regulatory Commission (BTRC, n.d.) has approved a Guideline on E-waste Management and Recycling Systems for the purpose of regulating import, installation, and use of telecom equipment properly, supporting formal recycling of E-waste, reducing environmental pollution, and encouraging the adoption of E-waste management by both consumers and manufacturers. As per the report of the Global E-waste Monitor 2024, some development partners are interested in co-operating Bangladesh in establishing an effective e-waste management system. According to The Global E-waste Monitor 2024, the World Bank initiative (Worldbank, n.d.) has given a commitment for financing USD 71 million to support the piloting and effective private-public partnership for attracting private investment in e-waste management, ensuring environmental sustainability.

4.4 Challenges for effective e-waste management

Lack of appropriate legislation, policies, and infrastructure for e-waste collection, sorting, and recycling are the most important challenges in e-waste management. The unregulated informal sector, which generally lacks safety requirements, handles a significant amount of e-waste. This dominance hampers the implementation of safe and standardized e-waste processing methods. According to the Global E-waste Monitor 2024, the number of countries with e-waste management legislation rose little from 78 to 81 between 2019 and 2023. Out of the 81 countries (42 percent of total countries worldwide and 72 percent of total population), 67 had e-waste management laws with clauses supporting the extended producer responsibility (EPR) environmental policy principle, 37 countries have provision of e-waste recycling target rates, and 48 countries have formal collection target rates.

Although a policy for e-waste management was introduced in Bangladesh in 2021, no target was set for formal collection and recycling. Consequently, e-waste is not collected through formal channels in Bangladesh. There are very few e-waste recycling companies in Bangladesh, out of which we interviewed the top five reputed recycling companies according to Business Inspection BD (businessinspection.com.bd, 2023) and analyzed their business prospects through recycling processing. The companies mainly collect e-waste from different offices through online or phone calls through their own formal channels. However, they are facing problems in the collection of e-waste from households due to the lack of awareness of the people of Bangladesh. The companies informed us that there is a big prospect of recycling business if it can be done using advanced technology, and the full amount of e-waste generated in Bangladesh can be collected through formal channels. It should be noted that in Bangladesh, starting a recycling business necessitates obtaining certain licenses from the government and other independent, capable authorities. Obtaining these licenses can deter investors and business owners from starting recycling facilities. Businesses may find it difficult to navigate a regulatory environment. It could be challenging for new businesses to enter the market, given the need for constant monitoring and adherence to current laws and regulations.

4.5. Recommendation

An integrated e-waste facility must have an effective collection system and facilities, sufficient storage space, a suitable disassembly and segregation section, a recycling plant or unit, treatment, and a disposal unit (Rautela et al., 2021). A combination of community involvement, local government involvement, commercial sector participation, and national and regional initiatives is necessary for effective e-waste management (Mor, Sangwan, Singh, Singh, & Kharub, 2021). It is necessary to create a formal collecting mechanism to decrease the stream of e-waste (Ádám et al., 2021).

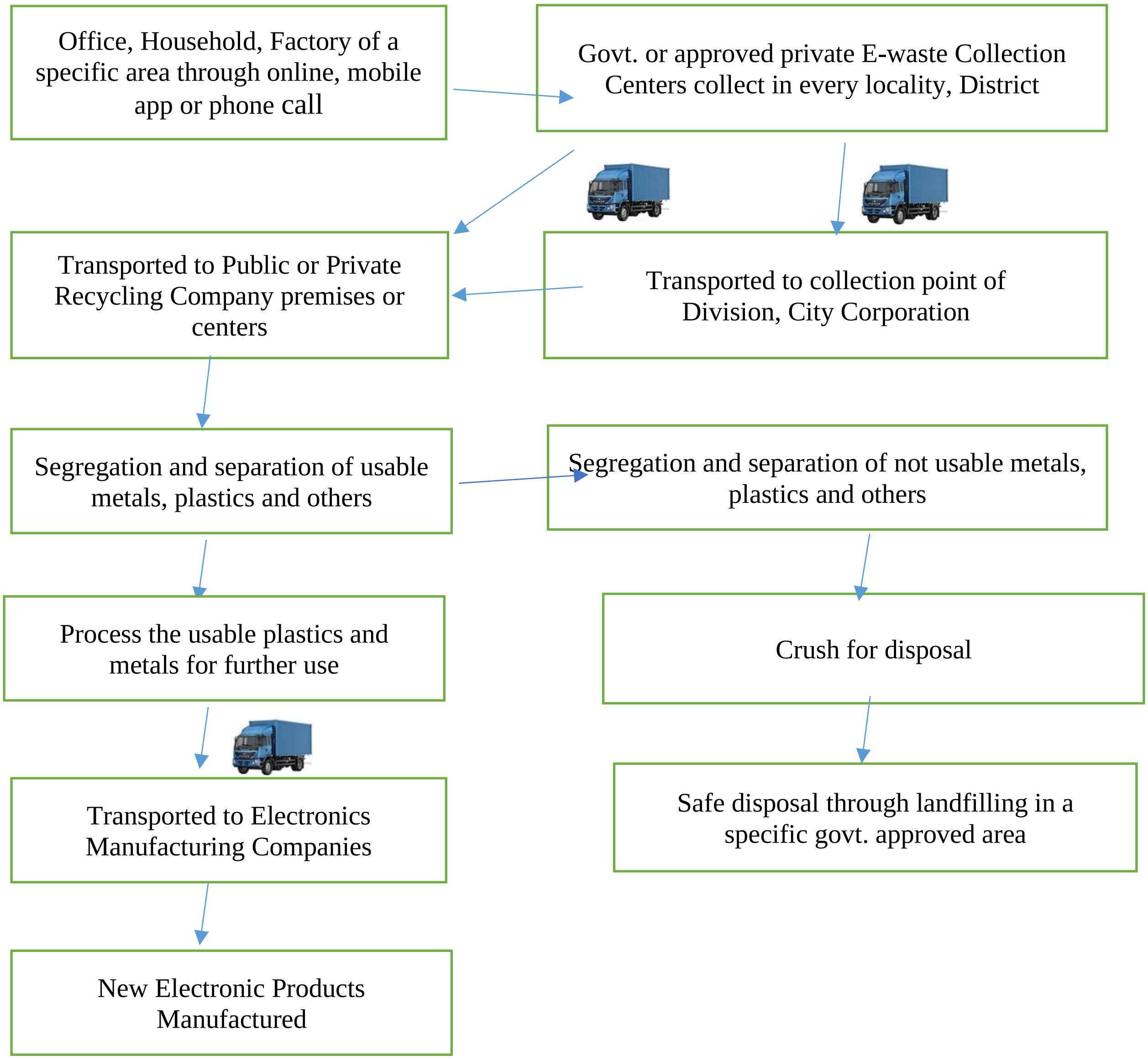
The World Health Organization (WHO, 2024) suggested some preventive measures to reduce health hazards for e-waste management, which include approving and upholding important international agreements, creating and implementing national e-waste management laws that safeguard the public's health, adding provisions for health protection to national laws, keeping an eye on e-waste locations and nearby neighborhoods, and implementing and monitoring interventions that improve informal e-waste recycling activities.

Awareness and proper knowledge are important for efficient e-waste management. People associated with this work can be educated on the dangers of improper e-waste disposal through strong public awareness campaigns. Increasing knowledge can lead to more responsible consumer behavior and increased participation in recycling initiatives. By participating in educational programs, people can gain the knowledge they need to make decisions about their technological devices. People need to be taught the proper methods to dispose of electronic waste by community organizations and schools. By putting corporate social responsibility initiatives, businesses can assist with e-waste management initiatives. By supporting sustainable practices and community education programs, businesses can promote an environmentally conscious culture. Investing in advanced recycling facilities is essential to solve this problem.

Emphasis should be placed on reuse, repair, efficient maintenance, and refurbishing to reduce the amount of e-waste. E-waste management is to be considered a global concern for the sake of saving the environment and reducing health hazards. International organizations for monitoring and assisting e-waste management need to play a stronger role in every e-waste generating country for implementing proper and formal e-waste management. Investors and business entities may come forward to invest in the e-waste management sector worldwide with advanced technology and effective plans. Global and collective measures are necessary to make e-waste management available in all countries.

Technology is necessary to boost production and reduce reliance on manual systems. Significant investment and robust regulatory backing are necessary for the effective deployment of automation technology (Susanti, Reniati, & Altin, 2025). The policy makers of Bangladesh need to develop the existing e-waste management policy by fixing the formal collection target and recycling target, as in developed countries. E-waste management needs to be strictly regulated and monitored by concerned authorities to ensure that all e-waste is formally managed and recycled in environmentally sound ways. The government should encourage private companies to invest more funds in recycling industries and arrange incentives for complying with recycling companies.

A proposed E-waste Management Model



5. Conclusion

E-waste management is a great concern for the whole world, including Bangladesh, with the increased use of electronics and electrical equipment day by day. Therefore, proper e-waste management is necessary to protect the environment and prevent health hazards. The e-waste management procedure needs to be turned into an economic benefit by applying efficient techniques, technology, and effective business models to contribute to the national and global economy. Many people need e-waste management procedures such as recycling, refurbishing, repair, and maintenance. There are multiple opportunities for these people to benefit financially from employment generation. Stakeholders, including concerned government authorities, must take proper steps to introduce and enforce the right to e-waste management with advanced technology.

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Competing interests

The authors declare that they have no conflicts of interest.

Ethical Approval

None of the authors of this article have conducted any experiments on humans or animals. Until the editorial process is completed, the manuscript, in whole or in part, has not been submitted or published anywhere and will not be published.

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