Qualitative Analysis of the E-Waste Management Practices and Policy Frameworks in Bangladesh and other South Asian Countries

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Abstract

Instantaneous shifts in the electronics industry are leading many electronic items to become obsolete early, creating huge volumes of waste electric and electronic equipment (WEEE/e-waste). The environmental and health effects of e-waste generated in developing countries are feared to be exacerbating, particularly in South Asia. Additional to issues with proper disposal and treatment of domestic waste, emerging market economies like Bangladesh are importing large amounts of e-waste from developed countries, to recover and re-use as raw materials, whilst handling their own increasing e-waste production. The scenario of e-waste generation, current policies and management practices are analysed and evaluated using comparative analysis of policies from four South Asian countries, document analysis and key informant interviews in Bangladesh. Findings show that even in countries like Sri Lanka and India where current policy framework is comprehensive enough to ensure sustainable e-waste management, implementation lags behind. Finally, recommendations are given for developing a sustainable e-waste management system focusing on the Bangladeshi context.

Keywords: electronic waste, e-waste management, e-waste management policies, e-waste management system, South Asia

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Introduction

Bangladesh has witnessed rapid economic growth in the past decade, with increasing demand for electric and electronic equipment, microchips, and automated machinery in various sectors such as transportation systems, office equipment, industrial tools, and household appliances (Mowla et al., 2021). Increased urbanization, industrialisation and increased household incomes means increased consumption and discarding of electric and electronic goods as e-waste. In 2009, Bangladesh generated an estimated total of 2.8 million tons of electronic waste (e-waste), with 2.5 million tons originating from imported electronic waste. Excluding this portion, the domestically generated e-waste amounted to 300 million kilograms (UNCRD, IGES, MoJ, 2018). In 2021, Bangladesh generated 600 million kilograms of electronic waste, with projections suggesting a potential increase to 10 billion kilograms by 2050 if current patterns persist (Roy et al., 2022). Between 20 to 35% is recycled in Dhaka and Chattogram and the remaining products get dumped into floodplains, rivers, open dumps and insanitary landfills (Islam & Emon, 2016).

Electric and electronic waste, also known as e-waste, denotes all electronic and electric items or their components, which have been discarded. They are also referred to as any secondary electronic goods that have been sold, donated, or discarded by their original owners. With technological innovation and fast phasing out of electronics, an unprecedented amount of e-waste is generated annually, worldwide. E-waste includes electric and electronic medical and dental equipment, household electrical appliances, office equipment, entertainment instruments/gadgets, sports equipment, telecommunications equipment, photovoltaic modules, commercial refrigerators, and batteries, etc. (Islam, 2016).

E-waste contains heavy metals such as cadmium, lead, chromium and mercury; organic hazardous materials such as polychlorinated biphenyls and brominated flame retardants; and metal-plastic mixtures. If handled illegally these can cause serious harm to human health and to the ecosystem (Zeng et al., 2016). At the same time, e-waste also contains large amounts of metals which are of high economic value such as iron, aluminium, copper, gold, silver, nickel, tin, and platinum group metals, as well as plastic, ceramics, and glass. In Bangladesh, while some electronic waste undergoes recycling, component dismantling, or disposal, a significant portion ultimately finds its way into landfills and water bodies (Roy et al., 2022). Improper handling and disposal of e-waste can cause toxic components to leach into the soil, water, and emit into air, resulting in death of aquatic plants and animals, cause air pollution; and cause harm to health of those who handle such waste, some of whom

are children (Ankit et al., 2021). Chemicals in batteries can also cause fires which leads to further leaching. Toxic chemicals from e-waste can harm people through the soil/water, crop/fish/livestock, human body pathway.

Toxicity, environmental degradation as well as the financial benefits of recovery of precious metals demands that a populous small country like Bangladesh requires a long-term e-waste management strategy with e-waste reduction, recycling, refurbishing and recovery of valuable materials inbuilt into legislation, regulation and management (Islam et al., 2020). Bangladesh has yet to formulate and implement exclusive guidelines for proper management of e-waste. Therefore, this study attempts to explore current gaps in e-waste management practices and policy regulations in Bangladesh. Based on e-waste management practices in three other South Asian countries, the paper also proposes guidelines to develop a comprehensive and sustainable e-waste management plan considering inadequate infrastructure, dominance of informal sector, and fragmented policy framework and weak implementation of waste electric and electronic equipment (WEEE) legislation in Bangladesh, and in the region.

Methodology

The study employed a qualitative research method to assess the current e-waste management practices and policy regulations in South Asia, using document analysis and interviews with key informants in Bangladesh. A comparative analysis on the e-waste management of Nepal, India, and Sri Lanka was conducted to identify the good practices which can be utilized in the context of Bangladesh, as these three countries have socio-economic, and cultural similarities to the Bangladeshi context studied.

Firstly, an extensive literature review was conducted to analyse the scenario of e-waste generation and its management practices in the four countries, in the past two decades, since the enactment of the Restriction of Hazardous Substances in electrical and electronic equipment (RoHS) Directive 2002/95/EC and the WEEE Directive 2002/96/EC by the European Commission. Relevant academic articles, reports, government publications, and policy documents were reviewed to gather comprehensive insights into the current state of e-waste management in each country. The articles were searched and screened for relevancy on concept of electronic waste, e-waste management and policy from a global perspective as well as from the perspective of research in Bangladesh, India, Nepal, and Sri Lanka.

Secondly, key informant interviews were conducted with six stakeholders involved in e-waste management in Bangladesh. These stakeholders included academics, government officials, representatives from non-governmental organizations (NGOs), and waste management professionals (Table 1). Semi-structured interviews were conducted to gather qualitative data on the existing policies, challenges, and practices related to e-waste management. Informed consent was obtained before conducting the interviews.

Table 1: Composition of Key Informants
Source: Author (2024)

Institutions	Designation	Number
Narayanganj City Corporation	Town Planner	1
Narayanganj City Corporation	Conservancy Officer	1
Savar Municipality	Town Planner	1
Waste Concern	Senior Environmental Specialist	1
Jahangirnagar University	Professor, department of Environmental Science	1
CCDB Climate Centre	Head, Climate Change Program	1

Data collected from the literature review and key informant interviews were analysed thematically. For this study, data were analysed under the themes e-waste management scenario, legal framework, major challenges, and scope of improving the management system. Based on the findings of the comparative study on the e-waste management of South Asian countries, and key informant interviews along with critical review of existing policy framework, a new e-waste management system is proposed for Bangladesh.

Electric and Electronic Waste (E-Waste) Scenario in Bangladesh

The primary contributors to electric and electronic waste in Bangladesh include televisions, mobile phones, computers, laptops, printers, scanners, CFL tubes, mercury bulbs, refrigerators, and medical and dental waste. The predominant source of e-waste originates from imported e-waste from ship breaking yards, constituting approximately 80.65% of the total, as indicated by the data (Ahirwar and Tripathi, 2021; Ananno et al., 2021; Masud et al., 2019). Following ship breaking, television sets contribute to 17.43% of the e-waste stream, while medical waste and computer accessories represent 0.86% and 0.80% respectively (Roy et al.2022).

The informal recycling sector involves private shop owners who buy e-waste at auction from shipyards, or from auction dealers who have bought e-waste as scrap. Useable products are cleaned, repaired, and sold to wholesale and retail markets. The remaining products such as metal and cable are sold as scrap. All remaining parts are thrown away as solid waste. The informal recycling shops use very basic tools, hence, most of the highly valuable metals may not get extracted. There is very little awareness among workers in the e-waste sector of the toxicity of the hazardous materials which they handle daily, and of their impact on human health and on the environment. Even though it is a lucrative business for shop owners, the pay to employees handling hazardous waste is not regulated, nor are they informed of the health risks. Munni et al. (2024) found that only 50% of workers in the e-waste recycling formal sector had any training, and 40% of the workers in the company they studied smoked, which is an indicator of occupational stress and low pay.

Data on adverse health impact on exposure to e-waste is only beginning to emerge in Bangladeshi context. Parvez et al. (2024a) identified elevated liver and renal impairment indicators among e-waste workers in Bangladesh, in comparison to the control group. Their study also showed higher levels of smoking and alcohol consumption among e-waste workers compared to the control group. In another study by Parvez et al. (2024 b), the researchers reported higher levels of exposure to lead among e-waste workers handling large amounts of e-waste, and higher levels of exposure to mercury among those who consumed fish, recommending that e-waste workplaces need to take measures to control exposure to lead and cadmium. Bangladesh as a whole is the most polluted country in the world, according to University of Chicago, Air Quality Life Index 2020, with a reduction of estimated life expectancy by approximately 7 years due to the level of air pollution.

Electric and Electronic Waste Management Policy Framework in Bangladesh

E-waste management encompasses the establishment of sorting, collecting, transporting, storing, disposal and recovery systems, the construction of recycling facilities, human resource development, and primarily, the implementation of legislative frameworks. Various developed nations have distinct approaches to e-waste management, such as export to developing nations where low cost of labour for recycling, and potential for illegal dumping exists (Ghulam & Abushammala, 2023). Regardless of the specific strategy employed, effective management of e-waste entails the allocation of roles and responsibilities among stakeholders in accordance with enforceable legal frameworks and regulations. While Bangladesh has in 2021 developed

legislation on Hazardous Waste (e-waste) Management Rules, infrastructure for collection of e-waste, recycling services monitoring and safeguarding, and training for recycling efficiency are not developed yet, despite the gap of ten years between this rule and the reduce, reuse and recycle policy of 2010, which indicates the necessity of training of legislators and policymakers on this emerging issue.

In Bangladesh, e-waste was first recognized as hazardous waste within the framework of medical waste management guidelines (Yousuf & Reza, 2011). The initial version of e-waste management guidelines was formulated by the government of Bangladesh in 2011, incorporating various legislations pertaining to e-waste, such as the Ship Breaking Rule of 1990, the Environment Protection Act of 1995, the Medical Waste Management Rules of 2008, and the Government 3R Rules (Mahbub & Khalid, 2015). In 2021, The Bangladesh Environmental Protection Act of 1995 was revised to coincide with introducing the first formal e-waste management regulation in Bangladesh. The Hazardous Waste (e-waste) Management Rules, 2021 apply to a wide range of electronic devices, including but not limited to automated machinery, medical equipment, control systems, home appliances, and information technology and communication devices. The categories of e-waste products covered under the categories, and threshold limits for use of certain hazardous substances are listed in detail in the rule. The following laws implemented by the Bangladesh government have led to significant legal advancements regarding the disposal of electronic waste within the broader context of solid waste management. The sequential development of these policies is illustrated in Table 2.

Table 2: Evolution of acts/policies regarding e-waste management in Bangladesh

Laws and Policies	Major Features
The Factory Act, 1965	Regulated the disposal of wastes and controlled factors within factory premises Lacks strict measures or policies for the safe disposal of waste Does not include incentives for recycling or waste reduction
The Ship Breaking Rule, 1990	To regulate the ship-breaking sector, involving the dismantlement of decommissioned ships to retrieve recyclable materials To ensure proper handling and disposal methods for hazardous substances
The Environment Policy, 1992	To control any actions leading to environmental pollution Prohibition of disposal of industrial, municipal, or agricultural wastes in any natural waterbody such as, ponds, rivers, and drains
Environment Protection Act, 1995	To prevent, control, and lessen pollution while also regulating, conserving, and improving the quality of the environment

Laws and Policies	Major Features
Environment Conservation Rule of 1997	Provision of specific legal framework for the management of diverse types of waste, including solid, hazardous, and industrial waste
The Labour Act (2006)	Occupational health and safety measures, mandatory for employers to implement Establishment of wastes and effluents disposal systems in recycling factories Protection of local environment from hazardous wastes
Medical Waste Management Rules, 2008	To ensure proper handling, collection, transportation, treatment, and disposal of medical waste from healthcare facilities
The National 3R (Reduce, Reuse, Recycle) Policy, 2010	Aims to mitigate environmental impact and foster resource conservation, sustainable practices, and circular economy principles. Encourages the establishment of infrastructure for waste collection, segregation, and recycling Contributes to the formalization of the waste management sector. Aims for a gradual shift towards more sustainable consumption patterns and increased public consciousness about waste reduction and recycling. Promotes awareness and education regarding waste management practices among the general population
National Occupational Health and Safety Policy, 2013	Ensures a safe and healthy work environment in both informal and formal work sectors
The Labour Rules, 2015	Minimum working age at 18, work hours, appointment, workers benefits, compensation, incident-accident investigation, record keeping for accidents, training of workers on health and safety
Hazardous Waste (e-waste) Management Rules, 2021	The first official legislation pertaining to e-waste management, to store and recycle waste in an organized manner Defines the responsibilities of all parties engaged in the product lifecycle, such as producers, sellers, buyers, and assemblers (collectors) Establishes penalties, including imprisonment, fines, or both, for non-compliance Prohibits importation of old or used electrical and electronic products, with limited exceptions Requires registration of various entities involved in e-waste management and facilitates nationwide monitoring of e-waste management activities

Challenges in Context of Bangladesh

In broad terms, Bangladesh lacks laws governing the management and trade of electronic waste. Bangladesh is a signatory to the Basel Convention, which prohibits the transboundary movement of hazardous waste. Accordingly, any importation of waste materials requires government authorization. The national Information and communication technology (ICT) policy mentions electronic waste (e-waste) in passing, but it does not yet have a comprehensive policy that addresses it.

The challenges identified in waste management in Bangladesh, as revealed through Key Informant Interviews (KII) in the research, encompass several critical areas. Firstly, the absence/inadequacy of source segregation practices at the source, it becomes challenging to separate recyclable materials from non-recyclable ones, leading to inefficient handling and disposal processes. Moreover, inadequate transfer facilities for electronic products to designated companies or transfer stations exacerbate the issue, hindering the smooth flow of waste from collection points to processing facilities. Additionally, at the local level, de-manufacturing facilities are found to be insufficient, limiting the capacity to dismantle and recycle electronic waste effectively. Another key challenge identified is the lack of skilled manpower in the recycling and recovery processes. The absence of trained personnel with expertise in handling electronic waste hampers the efficiency and safety of recycling operations, potentially leading to environmental and health hazards. Furthermore, disintegration within the policy framework exacerbates the challenges in waste management, as fragmented or inconsistent policies can impede coordinated efforts and hinder the implementation of effective waste management strategies.

Moreover, a critical challenge lies in the lack of public awareness and involvement in waste management practices. Insufficient awareness among the general population regarding the importance of proper waste disposal, recycling, and environmental conservation contributes to improper waste handling behaviours and practices. Without active participation and engagement from the public, efforts to improve waste management practices may face significant hurdles in achieving desired outcomes. Addressing these challenges requires coordinated efforts from various stakeholders, including policymakers, government agencies, industry players, and the general public, to develop and implement comprehensive waste management strategies that prioritize sustainability and environmental protection.

Electronic Waste Management Scenario in South Asia

The rising rate of e-waste generation, the use of potentially hazardous substances, and the environmental impacts of end-of-life (EOL) electronic products have drawn the interest of governments and the recycling industry worldwide in recent years (Parajuly et al., 2017). Table 3 presents e-waste generation in six South Asian countries. The data indicates that India produces the largest amount of e-waste daily, totalling 2752 metric tons, while Bhutan generates the lowest at 19 metric tons per day. However, despite India's much larger population of 1.32 billion compared to Sri Lanka's 20.8 million, Sri Lanka has e-waste generation at 3.57 kilogram per capita, whereas India's per

capita generation stands at 2.25 kilogram. This indicates that factors beyond population size, such as consumption patterns, recycling behaviours, and economic status, influence per capita e-waste production (Masud et al., 2019).

Table 3: e-waste generation in South Asian countries
Source: Masud et al. (2019)

Country name	Population (million)	EEE waste generation (metric ton per day)	Per capita e-waste production (kg)
India	1324.17	2752	2.25
Pakistan	193.2	300	1.68
Bangladesh	162.95	178	1.19
Sri Lanka	20.8	74	3.57
Nepal	28.98	24	0.76
Afghanistan	34.65	19	0.58
Bhutan	0.798	3	3.79
Maldives	0.428	2	5.11

The main approach to waste management in South Asia involves a basic process aimed at minimizing waste generation. E-waste is not separated at the source before collection. Disposal methods include incineration, and landfilling after useful materials are segregated after collection, and sold as scrap, sometimes to neighbouring Asian countries (Narasimha et al., 2019).

E-Waste Management in Nepal

Nepal lacks a dedicated legislation specifically addressing the management of e-waste. In 2011, the Nepalese Government initiated a regulation under the Solid Waste Management Act 2011 to address various waste categories, encompassing industrial, domestic, medical, chemical, and e-wastes. The legislation broadly defines “solid waste” to encompass various waste types such as domestic, industrial, chemical, medical, and electronic waste (e-waste). While it primarily focuses on municipal solid waste, it emphasizes the need for waste minimization, source segregation, and appropriate disposal without delving into technical details to promote resource recovery. There is a noticeable absence of specific requirements or guidelines for end-of-life (EoL) product processing, including collection and recycling. Furthermore, the predominance of informal recycling practices conducted by scavengers, scrap hawkers, and scrap dealers lack oversight and regulation, raising concerns about environmental and health implications. Inadequate waste management practices, particularly in rural areas, exacerbate the problem,

with open dumping and burning of non-biodegradable waste contributing to environmental degradation and health hazards (Giri & Adhikari, 2020).

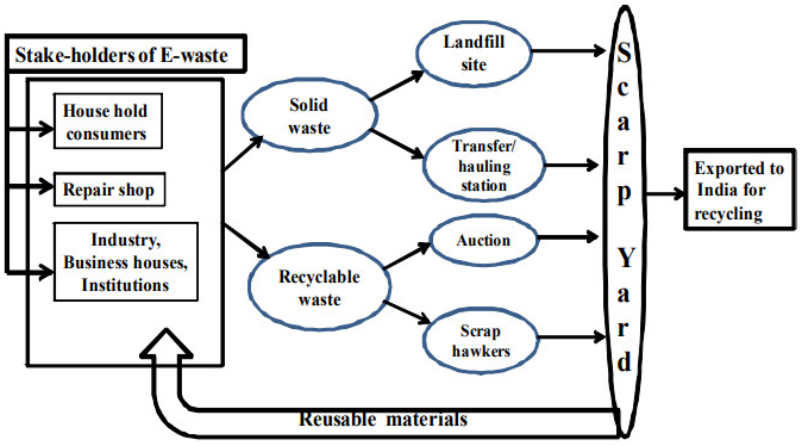

Figure 1: Waste disposal and recycling system in Kathmandu, Nepal

Source: Giri & Adhikari, 2020

Figure 1 illustrates the flow and management of e-waste in Nepal, from various stakeholders to its final destinations. E-waste is classified into solid and recyclable waste. Solid waste is directed towards landfill sites and transfer/ hauling stations, while recyclable waste is channelled through auctions and scrap hawkers. Both types of waste converge in a scrapyard. Recyclable waste from the scrapyard is exported to India for recycling, while reusable materials are redirected back to stakeholders, promoting resource recovery and waste reduction.

E-Waste Management in India

India is a significant generator of e-waste in Asia, with the majority of recycling activities occurring in the informal sector, which accounts for 90-95% of e-waste recycling in the country. This sector operates predominantly in urban slums, employing unskilled workers who utilize rudimentary methods to reduce costs. In India, e-waste originates primarily from domestic production and the importation of e-waste from other regions. Domestic e-waste is generated across various sectors, including individual households and small businesses, large corporations, institutions, government facilities, foreign embassies, PC manufacturers and retailers, and the secondary market for used PCs (Mundada et al., 2004). The informal sector primarily focuses on recovering precious

metals, with a recovery efficiency of around 28-30%. Despite the low income earned by workers, the informal e-waste sector remains lucrative, highlighting the need for improved regulation and worker protection (Ganguly, 2016).

The organized recycling of e-waste in India began in 2009. Formal recyclers prioritize environmentally friendly processes and serve clients like multinational companies concerned about product integrity. In contrast, informal recyclers prioritize profit, often refurbishing and selling electronics regardless of their e-waste classification. Overall, only about 10% of e-waste generated annually in India is recycled, with the rest being refurbished or discarded (Ganguly, 2016).

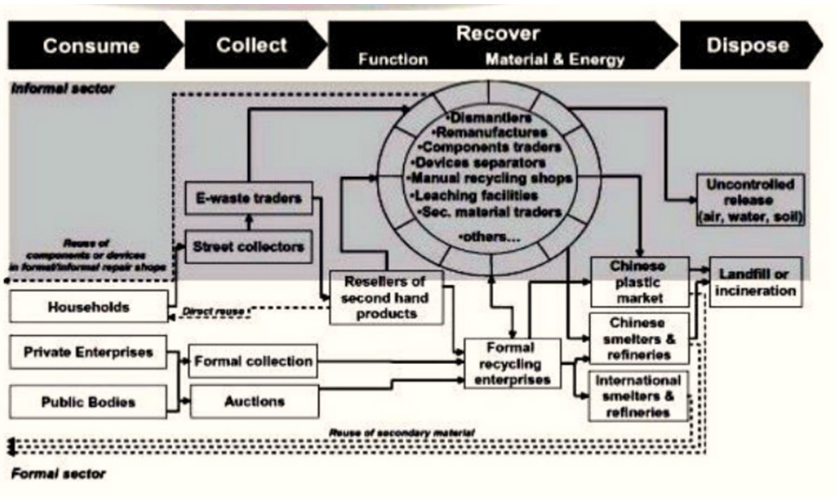

Figure 2: e-waste recycling system in organized sector in India.

Source: Ganguly (2016)

Figure 2 delineates the lifecycle of e-waste from consumption to disposal, highlighting the roles of both formal and informal sectors in India. E-wastes collected from both formal and informal channels are directed to recovery processes where components are dismantled, remanufactured, or processed by various facilities. These processes promote the reuse of components or materials, either directly through resellers of second-hand products or via formal recycling enterprises. The materials are subsequently sent to markets such as Chinese plastic markets or international smelters and refineries. Uncontrolled releases into the environment, as well as disposal in landfills or incineration, represent the final stages for non-recovered materials.

E-Waste Management in Sri Lanka

The current practices of e-waste management of the country emphasize collection, dismantling, reuse, recovery, and disposal, with a growing focus on minimizing e-waste generation through the introduction of energy-saving electrical and electronic equipment. Strategies such as the 3-R concept (Reduce, Reuse, and Recycle) are widely promoted as best practices. Reduction efforts involve purchasing new equipment only when necessary, opting for repairs instead of replacement whenever possible, and promoting the reuse of electronic devices. Recycling initiatives aim to divert recyclable materials such as glass and steel to relevant industries for processing. Moreover, energy-efficient technologies and sustainable development methods are advocated to further mitigate e-waste generation.

E-waste management and operational systems exhibit a notable reliance on informal sector stakeholders in the country, who handle a significant portion of electronic waste, particularly collected from large-scale electronic vendors through promotional take-back mechanisms. While formal sector initiatives such as drop-off events contribute to e-waste collection, much of the downstream management process involves informal sector participation. Despite efforts by regulatory bodies like the Central Environmental Authority (CEA), the informal sector dominates the handling of e-waste, with limited involvement in Extended Producer Responsibility (EPR) initiatives. However, the lack of technological know-how necessitates the export of sorted or pre-processed items overseas for end processing. Figure 3 illustrates the full e-waste management and operational system in Sri Lanka.

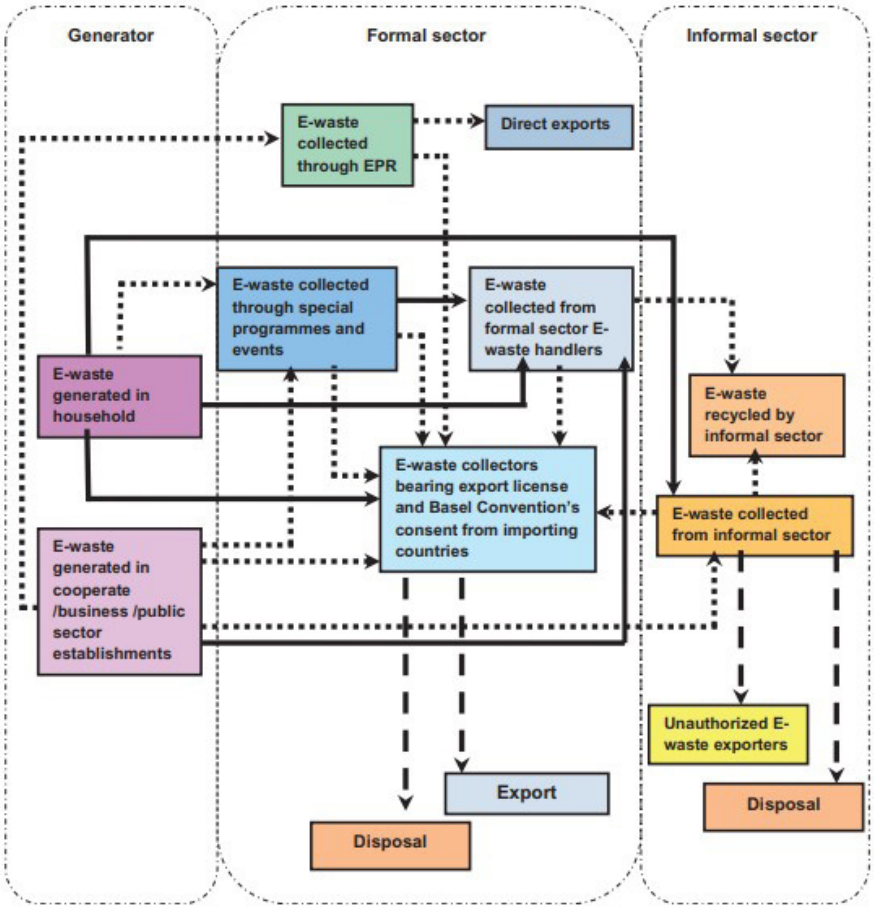

Figure 3: e-waste management and operational system in Sri Lanka.

Source: Ranasinghe and Athapattu (2019)

A Comparison of E-Waste Management System in Nepal, India, and Sri Lanka

E-waste management is a critical environmental and public health issue that varies significantly across different countries. Nepal, India, and Sri Lanka, despite their geographical proximity, exhibit diverse approaches and challenges in handling e-waste. Table 4 presents a comparative analysis highlighting the legislative frameworks, stakeholder involvement, challenges, strengths, collection and recycling practices, environmental and health impacts, technological and operational aspects, and public awareness initiatives in each country.

Table 4: Comparative analysis of e-waste management system in South Asian countries

Aspect	Nepal	India	Sri Lanka
Legislation	No specific e-waste regulation. Solid Waste Management Act 2011 encompasses e-waste, emphasizing waste minimization, source segregation, and appropriate disposal (Giri & Adhikari, 2020).	E-waste (Management) Rules, 2016, amended in 2018 and 2022. Detailed guidelines on the collection, dismantling, recycling, and disposal of e-waste (CPCB, 2022).	National e-waste Management Policy, 2019. Comprehensive policy addressing e-waste collection, recycling, and disposal (Ministry of Environment, 2019).
Stakeholders Involved	Producers, households, businesses, institutions, and electronic repair shops (Giri & Adhikari, 2020).	Formal recycling units, informal sector workers, aggregators, segregators, and recyclers (Ganguly, 2016).	Central Environmental Authority (CEA), large-scale electronic vendors, informal sector recyclers, and formal sector initiatives such as drop-off events (Ranasinghe & Athapattu, 2019). Willingness by households to pay for improved services (Thirumarpan & Dilsath, 2016)
Challenges	Lack of dedicated legislation specifically addressing e-waste; informal recycling practices by scavengers, scrap hawkers, and scrap dealers; inadequate practices in rural areas (Giri & Adhikari, 2020).	Inefficient take-back schemes; unsafe working conditions; child labour; auctions of e-waste to informal dismantlers; lack of rehabilitation plans for informal recyclers; poor infrastructure; insufficient awareness and incentives (Giri & Adhikari, 2020).	Technological know-how limitations necessitating export of pre-processed items; informal sector dominance; limited Extended Producer Responsibility (EPR) initiatives (Ranasinghe & Athapattu, 2019).
Strengths	Decentralized approach to waste management; regulatory efforts under the Solid Waste Management Act 2011 (Giri & Adhikari, 2020).	Formal recycling and reprocessing units create jobs; comprehensive technical guide on environmental management (Giri & Adhikari, 2020).	Emphasis on collection, dismantling, reuse, recovery, and disposal; energy-saving electrical and electronic equipment; public awareness initiatives; sustainable production and consumption strategies, successful recycling of glass, metal and paper (Ranasinghe & Athapattu, 2019).

Aspect	Nepal	India	Sri Lanka
e-waste Collection	Involvement of multiple stakeholders in e-waste collection (Giri & Adhikari, 2020).	Private and public sectors often auction e-waste to informal dismantlers (Giri & Adhikari, 2020).	Promotional take-back mechanisms from large-scale vendors; formal sector drop-off events (Ranasinghe & Athapattu, 2019).
Recycling Practices	Informal recycling practices by scavengers, scrap hawkers, and scrap dealers (Giri & Adhikari, 2020).	Only 10% of e-waste is recycled; informal dismantlers extract precious metals unsafely (Giri & Adhikari, 2020).	Recycling initiatives aim to divert recyclable materials to relevant industries; informal sector handles significant portion of e-waste (Ranasinghe & Athapattu, 2019).
Environmental and Health Impact	Concerns about environmental and health implications due to informal recycling practices and inadequate waste management, particularly in rural areas (Giri & Adhikari, 2020).	Unsafe conditions for workers; child labour; hazardous extraction processes by informal dismantlers (Giri & Adhikari, 2020).	Regulatory efforts to prevent negative environmental and health impacts; reliance on informal sector contributes to concerns (Ranasinghe & Athapattu, 2019).
Technological and Operational Aspects	No specific requirements or guidelines for end-of-life product processing (Giri & Adhikari, 2020).	Lack of efficient take-back schemes; poor infrastructure for recycling (Giri & Adhikari, 2020).	Technological limitations necessitating export for end processing; operational reliance on informal sector (Ranasinghe & Athapattu, 2019).
Awareness and Public Initiatives	Limited public awareness about the benefits of material recovery can lead to more effective e-waste management practices, reducing environmental pollution and health risks associated with improper disposal (Giri & Adhikari, 2020).	Insufficient awareness and financial incentives in promoting safer recycling practices, reduce the reliance on informal recycling sectors, and improve health outcomes by minimizing exposure to toxic substances (Giri & Adhikari, 2020).	Various public awareness initiatives like National e-waste Management Week; Corporate e-waste Management Program; drop-off events (Ranasinghe & Athapattu, 2019).

Proposals for E-Waste Management in Bangladesh

Based on the findings from the literature review, key informant interviews, and comparative analysis, the following recommendations are suggested to address the gaps and shortcomings identified in the current policy framework and practices, with the goal of promoting sustainable e-waste management in Bangladesh. The policy, guidelines, and infrastructures that support it must be arranged in a way that gives the highest priority to use the circular

economy concept of the Ten R strategy- Refuse, Rethink, Reduce, Reuse, Repair, Refurbish, Remanufacture, Repurpose, Recycle, and Recover (Pan, et al., 2022), and focus on ways to reduce landfill usage, and to reduce the number of incinerators. This will require a mechanism to ensure networking and goodwill between stakeholders including homeowners, non-governmental organizations, business enterprises, policy makers, and law enforcement. Kadir et al. (2024) recommends progressive formalisation of source segregation involving all stakeholders at all levels of the system within municipalities as key to achieving circular economy goals for e-waste management in Bangladesh.

Waste to Energy (WtE) generation through incineration, pyrolysis and gasification using agricultural and other bio-waste is practiced as a municipal solid waste management method in Bangladesh, and conversion of e-waste to electricity can be a way of achieving carbon neutrality (Shovon, et al., 2024). Burning plastic from e-waste may produce high calorific value. Combining recycling of plastic and recovery of precious metals with energy generation may be fruitful. However, the disposal of toxic slurry, prevention of air pollution and the health risks to workers and bystanders remains an issue in emerging economies like Bangladesh (Ahmed et al., 2022; Islam, et al., 2021).

E-Waste Policy and Regulation

To enhance e-waste management in Bangladesh, it is recommended to establish comprehensive policies and regulations addressing various aspects of the e-waste lifecycle. Specific measures include implementing product take-back obligations for industry, instituting financial responsibility for actions and schemes related to e-waste management, and placing greater emphasis on new product design to facilitate easier recycling and reduce environmental impact. Additionally, stringent restrictions on certain hazardous substances and increased scrutiny of cross-border movements of electrical and electronic products and e-waste are crucial steps toward effective regulation. Moreover, increasing public awareness through product labelling as environmental hazards can help educate consumers about the importance of responsible e-waste disposal.

Extended Producer Responsibility (EPR)

Incorporating Extended Producer Responsibility (EPR) into the e-waste management framework in Bangladesh is essential. EPR is a policy strategy that extends a producer's accountability for a product's environmental impacts throughout its entire life cycle, including its post-consumer stage and final

disposal. This approach involves assigning responsibility to all stakeholders in the product chain, including consumers, suppliers, and manufacturers. Consumers play a significant role by making environmentally conscious purchasing choices, maintaining products properly, and practicing responsible disposal methods such as recycling. Suppliers can contribute to reducing environmental impacts by providing manufacturers with eco-friendly materials and components. Manufacturers, in turn, can influence product design, material selection, manufacturing processes, and product support to mitigate environmental impacts.

E-Waste Recycling

It is necessary to establish specialized e-waste recycling facilities with cutting-edge technology for the secure and effective processing of e-waste. Establishing a robust collection infrastructure is crucial for effectively gathering e-waste from diverse sources. Countries like Japan and South Korea have implemented extensive collection networks, including designated collection centres, collection events, and producer responsibility schemes, which could serve as a model for Bangladesh (Kim, et al., 2013; Yoshida & Terazono, 2019). In South Korea, 100% of their e-waste is recycled and none of it is incinerated or goes into landfills. South Korea's model is based on the Waste Electrical and Electronic Equipment Directive (WEEE Directive), and the Restriction on Hazardous Substance Directive (RoHS Directive) developed by the European Union (Doan et al., 2019; Kim, et al., 2013). Moreover, implementing stringent regulations and standards for e-waste recycling facilities is essential to ensure environmental and worker safety.

Take Back Scheme

To take the advantage of the circular economy, the manufacturing companies should extend their take back policy. The manufacturing companies may declare incentives to their customers as they will be encouraged to return the obsolete electronic products. For example, the company may provide 1 new battery or bulb to the customer while returning 5-7 obsolete batteries or bulbs. Besides, companies may also offer discounted price for returning the old product when purchasing a replacement product. This can be an incentive for companies to find long-term solutions to reduce the huge volume of obsolete products.

Capacity Building, Training and Awareness Programs

Capacity building, training, and awareness programs are essential components of a robust e-waste management system. Capacity building programs can target various stakeholders, including government officials, industry professionals, waste management workers, and the general public, providing them with the necessary knowledge and skills to effectively manage e-waste. Furthermore, awareness campaigns can raise public consciousness about the environmental and health hazards associated with improper e-waste disposal and promote sustainable practices such as recycling and proper waste segregation. A philosophical movement should be introduced among the nation to buy an electronic product only when that is needed.

Proposed Model of E-Waste Management

Figure 4 highlights a comprehensive e-waste management model that incorporates both formal and informal sectors, emphasizing the importance of collaboration between various stakeholders and the implementation of effective policy instruments to ensure environmentally sound management of e-waste in Bangladesh. The system requires the involvement of both formal and informal sectors. Electronic devices that reach the end of their life cycle will undergo collection, facilitated by manufacturers' take-back programs, retailers' collection points, and informal waste pickers.

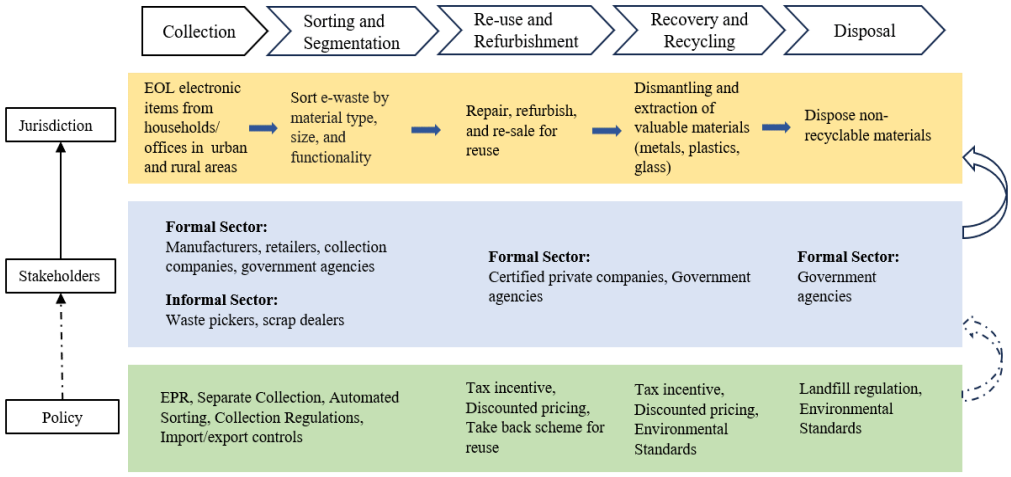

Figure 4: Proposed e-waste management system in Bangladesh.

Following collection, sorting and segregation will occur to categorize e-waste by material type and functionality. Introducing technological advancements such as automated sorting systems will make the process much efficient. After that functional devices may undergo reuse and refurbishment processes before pre-processing in the formal sector, where hazardous components are removed. The subsequent recycling phase extracts valuable materials like metals and plastics through physical and chemical processes, with non-recyclable residues disposed of in landfills under regulated conditions. In order to ensure responsible practices and sustainable management, the model places a strong emphasis on policy options like EPR, discounted pricing and tax incentives, in addition to relying on public awareness campaigns and technological advancements.

Conclusion

None of the four countries studied in this research has proper mechanisms for management of e-waste, to reduce, reuse, recycle nor to recover valuable materials from e-waste safely, compliant with a health and safety mechanism implementation. Burgeoning health problems such as cancer, birth defects and respiratory diseases from inhaling incinerated plastic fumes, and eating contaminated fish, livestock and crops, and unsightly open dumps and landfill sites cannot be afforded by a small country like Bangladesh with a dense population (Andeobu et al., 2023). While some progress has been made with the introduction of regulations, the existing policy framework in Bangladesh remains inadequate to address the multifaceted challenges associated with e-waste management comprehensively. Key challenges include the absence of proper source segregation practices, insufficient collection, storage, transportation, recycling, and disposal facilities, lack of skilled manpower, and policy fragmentation. Additionally, there is a crucial need to enhance public awareness and involvement in waste management practices. To address these challenges effectively, Bangladesh should consider implementing comprehensive policies and regulations; integrating extended producer responsibility (EPR); setting up of infrastructure for collection, transport, storage, and disposal; establishing specialized e-waste recycling facilities, and investing in capacity building and awareness programs. By adopting a circular economy approach to e-waste management and fostering collaboration among stakeholders, Bangladesh can mitigate the adverse impacts of e-waste on the environment, public health, and economy, paving the way for a more sustainable future.

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