Strategies for Transitioning to Sustainable E-waste Management Systems Globally, Regionally and Nationally

Shanomae Oneka Eastman

Department of Civil Engineering, Faculty of Engineering and Technology, University of Guyana, Guyana.

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Abstract

The quantity of electronic waste generated globally is rising rapidly as a result of advanced technology, over reliance, and the use of electrical and electronic equipment (EEE) beyond comprehension. The rapid technological advancements has resulted in a reduced lifespan of EEE resulting in enormous amounts of waste electrical and electronic equipment (WEEE). It is well recognized that EEE contains complex metallic and non-metallic components that, if improperly managed, can seriously disrupt the environment and endanger the survival of life. The majority of industrialized nations possess advanced methods for managing e-waste, well-defined system boundaries, technological expertise, strict legislation, appropriate recycling facilities, and trade with emerging and impoverished countries. However, because of a number of issues and a dearth of pertinent policies, the situation in emerging nations is different. WEEE are handled in developing nations by using a variety of low-end methods, including product reuse, traditional landfill disposal, open burning, and rudimentary "backyard" recycling. The bulk of developing and less developed countries lack the necessary legislation, gaps in policy formulation, socioeconomic and cultural hurdles, technology, and treatment facilities. The main issues affecting Guyana's management include absence of legislation, safe options for treatment and disposal, and inadequate inventory of data. The strategic interventions that are essential for sustainable e-waste management include urban mining, embracing the concept of a circular economy, fortifying existing laws and regulations, investing in adequate facilities for handling all waste streams and coordination and cooperation among all of the key stakeholders.

Keywords: E-waste, E-waste Generation, E-waste Management, Sustainable Management

1. Introduction

Humans rely heavily on electrical and electronic devices (EEEs) to lead lavish lives (Arya and Kumar, 2020) and the subject of whether humans might survive without EEEs is now urgent (Manomaivibool, 2011 as cited in Gollakota et al., 2020). Increased demand and consumption have led to the creation of the Electronic-Web (E-Web) globally and increased trade potential for EEE's (ITU 2017 as reported in Arya & Kumar, 2020). Customers' needs are primarily evolving at a relatively short period (Arya & Kumar, 2020; see also Shekarabi et al., 2019; Huang et al., 2009), which may be a result of the product's shortened lifespan (Arya & Kumar, 2020; Gharaei et al., 2019b; Singh et al., 2017; Oh et al. 2003 as cited as cited in Osibanjo & Nnorom, 2007) and reduced price (Arya & Kumar, 2020; see also Zhang et al., 2012 & Yu et al., 2010). There are serious concerns about the increasing gaps in the use of EEE, the buildup of electronic waste at the end of its life (EOL), and the storage, handling, and disposal of this garbage (Kahhat & Williams, 2009 as cited in Gollakota et al., 2020). Another factor that contributes to the growing amount of e-waste is predetermined obsolescence, which is closely linked to consumer purchasing power. However, a market research conducted between 2013 and 2015 indicates that the average period between smartphone replacements is gradually increasing (Kantar, 2016 as mentioned in Kasim, 2021). After being rejected by the owner Ari (2016, as cited in Arya & Kumar, 2020), noted that obsolete EEE is converted to waste electrical and electronic equipment (WEEE), also known as electronic waste or E-waste. Kang & Schoenung (2004, as cited in Osibanjo & Nnorom, 2007) stated that this rapid depletion of waste disposal capacity poses a threat to the environment. Madkhali et al. (2023) remarked that because of the negative impacts that electronic devices have on the environment and public health, their composition, including the presence of hazardous materials have become a major issue. As per their statement, the U.N. E-waste monitor categorizes E-waste as an assortment of surplus devices that include circuitry components and need electricity to operate. Under these broad categories, there are six fundamental types of electronic waste as depicted in Figure 1.

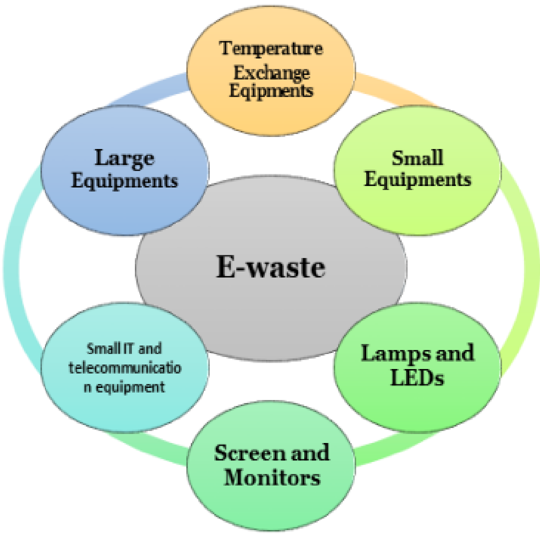

Figure 1: Composition of E-Waste (Adopted from Madkhali et al., 2023)

Potential e-waste management technologies, technological competence, and well-defined system boundaries are present in the majority of developed nations. However, because of a number of issues and a dearth of pertinent policies, the situation in emerging nations is different. WEEE are managed in poor nations using a variety of low-end methods, including product reuse, traditional landfill disposal, open burning, and rudimentary "backyard" recycling (Hakami, 2018 as cited in Madkhali et al., 2023; Munoz et al., 2009 as cited in Gollakota et al., 2020). With the entire value of e-waste created in 2019 anticipated to be US $57 billion, the recoverable material in e-waste provides a substantial financial benefit (Van Yken et al., 2021). Nonetheless according to reports from the United States Environmental Protection Agency (U.S. Environmental Protection Agency, 2016), only 15%–20% of electronic waste is documented and recycled, with the remaining 80% ending up in landfills (Vats and Singh, 2015 as cited in Gollakota et al., 2020) and open incineration facilities (Lu et al., 2014a as cited in Gollakota et al., 2020). These activities raised a lot of questions, worries, and potential risks. Developed countries were the first to see the necessity for an efficient management system, while poorer countries caught on later. There are several efforts available, however only 41 countries had particular e-waste data and laws in place, and 16 additional countries out of 195 were about to implement legislation by the end of 2019

(Baldé et al., 2017). The take-back system, Basel convention, European Union (EU) regulation, extended producer responsibility (EPR), and organization for economic cooperation and development (OCED) were among the most well-liked legal enactments. As stated by Sharma et al. (2023 as referenced in Madkhali et al., 2023), the goal of these directives and revisions is to handle significant increases in e-waste in a sustainable and environmentally beneficial way while maintaining ecological parity. Countries that are members of the European Union are required to abide with the e-waste Directive (2012/19/EU). Legislation has been passed in several nations to improve e-waste collection and recycling rates and build suitable e-waste management systems. Japan began enacting WEEE management laws at the beginning of the twenty-first century. In order to make operational the e-waste reverse logistics, a sectoral agreement was adopted in Brazil in 2019 following the release of the National Solid Waste Policy (no 12.305/10). But not every nation has passed legislation pertaining to the handling of e-waste (Castro et al., 2023). It is necessary to manage and handle E-waste in a safe, economical, ecologically responsible, and sustainable manner. This includes appropriate recycling, metal recovery, transportation, and E-waste disposal. This will ultimately assist in reducing environmental risks and achieving a more equitable distribution of natural resources (Sharma et al., 2023 as cited in Madkhali et al., 2023).

At the national and international levels, collection, separation, and consumption or recovery depend on an appropriate framework and ecosystem strategy for addressing e-waste. To combat improper practices in disposing e-waste, the system in place at the national level has to include local management (E-waste Monitor, 2021 as reported in Madkhali et al., 2023). The ecosystem model is recommended as a viable and eco-friendly method of organizing the recovery of noble metals and discarding of e-waste (Rene et al., 2021 as mentioned in Madkhali et al., 2023). For example, during informal metal recovery, consuming pure concentrated acids, cyanide, and nitrox poses serious risks to human health and the environment (Joshi et al., 2022 as cited in Madkhali et al., 2023). Hence while processing e-waste today, low-cost, safe, and environmentally friendly recycling and recovery techniques are essential. Proper management of the EoL of electronics requires sound EoL management practices using value-added product recovery (repair and remanufacturing), material recovery (recycling), energy recovery (incineration), and, as a last resort, disposal in landfill by employing suitable landfill technology (Osibanjo & Nnorom, 2007). This research aims to highlight the E-waste generation, issues associated with E- Waste management and strategies for transitioning to a more sustainable e-waste management systems globally, regionally and nationally.

2. Methodology

A thorough review of the literature was done using reliable sources including Science Direct, Research Gate, Pub Med, Google Scholar and Google General, newspapers, and websites of government bodies. The Google search results comprised both peer-reviewed papers and grey literature. All searches were not limited to any particular time frame. The review were carried out to determine the following globally, regionally and nationally: (A) E-waste generation (B) Issues associated with e-waste management (C) Strategies for transitioning to a more sustainable e-waste management systems.

3. E-Waste Generation

3.1. Global aspect of E-Waste Generation

As per the Global E-waste monitoring program, 53.6 million metric tons of e-waste were produced worldwide in 2021, with a mean rate of increase of 2.5 Mt per year (Ismail & Hanafiah, 2020 as cited in

Madkhali et al., 2023) growing at an average annual rate of 3-5% (Arya & Kumar, 2020; see also Ilankoon et al., 2018; European Parliament Briefing, 2015). The amount of E-waste created in 2014 was measured at 44.4 Mt, indicating a 20% increase from the previous year; this is very concerning (Ismail & Hanafiah, 2020 as cited in Madkhali et al., 2023). Waste generation is expected to increase significantly over the next ten years, reaching 121% between 2020 and 2030 (Sharma et al., 2023 as cited in Madkhali et al., 2023). By 2030, this amount is projected to reach 74.7 million metric tons (Forti et al., 2020). Figure 2 shows the projected values. The correlation between G.D.P. and E-waste generation accounts for the high projection and non-linear behavior. It indicates that the saturation of E-waste generation is associated with the transition from a lower to a higher economic status country (Madkhali et al., 2023). The United States of America generates 13.1 Mt of e-waste yearly, or 13.3 kg per person. Unfortunately, according to Madkhali et al. (2023), only around 1.2 Mt of all the e-waste is effectively handled, that is, formally gathered, monitored/acknowledged, and recycled in accordance with USEPA guidelines. Europe produces the most e-waste globally per person (16.2 kg). Europe has demonstrated that it has the most structured and sustainable e-waste management, accounting for 42.3% (5.1 Mt) of the total e-waste produced (12 Mt). With 24 Mt of E-waste created Asia has the greatest E-waste production rate and recycled just 2.9 Mt; China being one of the top producers with 10.1 Mt followed by India with 3.2 Mt. (Madkhali et al., 2023).

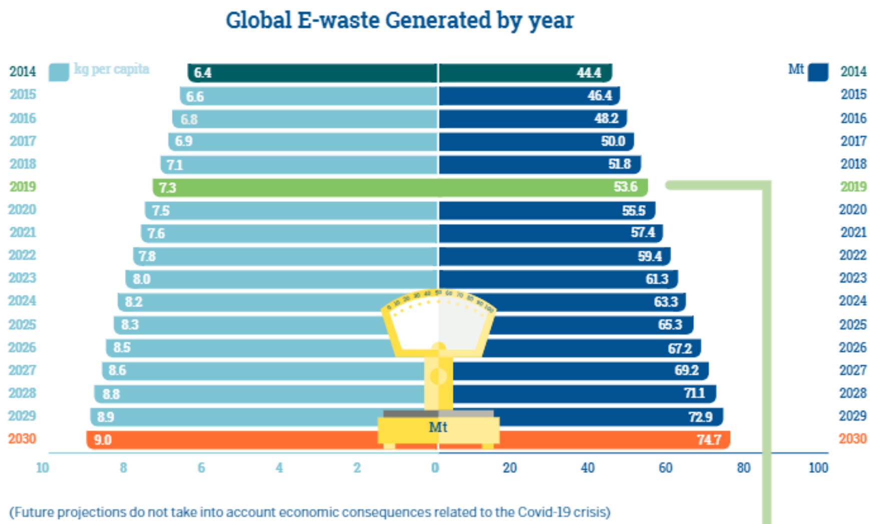

Figure 2: Projected E-waste Generation up to 2030 (Adopted from Forti et al., 2020)

Low recycling rates are frequently caused by an absence of infrastructure to process e-waste and legislations to control collecting, processing, and the recovery of materials from e-waste (Van Yken, 2021; see also Baldé et al., 2020; Forti, et al., 2020). This is noted in the Waste Electrical and Electronic Equipment (WEEE) directive of the European Union, which establishes guidelines for the recycling of e-waste and applies to the whole population; this is one of the reasons the European Union has the greatest recycling rate in the world in 2019 (Baldé et al., 2020 as stated in Van Yken, 2021).

Large income-producing nations ship the majority of their e-waste to developing or lower-income nations (Sharma et al., 2023 as cited in Madkhali et al., 2023). Approximately 75–80% of the WEEE generated in developed countries ends up in Asian countries and African countries in spite of the ban on the transboundary movement of hazardous waste (Shamim et al., 2015 as cited in Arya & Kumar, 2020). The majority of household electronic devices are disposed of in the garbage, which also serves as the main justification for not including e-waste in official records. Garbage receptacles receive 0.6 Mt of E-waste, according to records (Sharma et al., 2023 as mentioned in Madkhali et al., 2023). According to reports, consumer electronics account for 40% of Pb and 70% of Hg and Cd found in US landfills (O'Connell Kim, 2002 as cited in Arya & Kumar, 2020). Tue et al. (2016, as referenced in Arya & Kumar, 2020) noted that when e-waste is recycled without adhering to scientific procedures, mixtures of the composite dioxin-related compounds (DRCs) are released. There have been reports of heavy concentrations of DRCs, such as bromine, chlorine, and mixed halogenated dibenzo-p dioxin and dioxin-like (PCBs), in the surface soil of Agbogbloshie, Ghana's largest informal recycling hub (Kyere et al., 2018 as cited in Arya & Kumar, 2020). Residents in the surrounding areas may be subjected to elevated concentrations of harmful substances (Kyere et al., 2018 as cited in Arya & Kumar, 2020) and soil contamination in the Guiyu area (Lu et al., 2015 as mentioned in Arya & Kumar, 2020). It has been discovered that local water pools have Pb concentrations 2400 times higher than permissible levels, and the soil in the surrounding regions has the greatest amounts of heavy metals and dioxin (Arya & Kumar, 2020).

3.2. E-Waste Generation in the Caribbean Region

Mohammadi et al. (2021a) examined whether e-waste presents a threat to the environment and if there a chance to implement a circular economy. They concentrated on five Small Island Developing States (SIDS) in the Caribbean: Trinidad and Tobago, Grenada, Aruba, Jamaica, and Barbados. They pointed out that islands are constrained systems that frequently face a number of sustainability barriers, including insufficient land and resource accessibility along with urgent waste management problems. SIDS have several challenges, including a lack of opportunity for recycling and resale, insufficient legislation, and obstacles to exporting waste to other nations (Mohammadi et al., 2021b; see also Camilleri-Fenech et al., 2018; Fuldauer et al., 2019), consequently, innovative approaches are needed (UNEP, 2019 as cited in Mohammadi et al., 2021b). Forty percent of the world's biodiversity is found in the Caribbean, along with Latin America and if not properly handled, the e-waste that is kept in the region might pose a serious hazard to these hotspots, according to Mohammadi et al. (2021b). Despite these well-known issues, there is a dearth of research aimed at assisting small island nations in creating effective e-waste management systems, as noted by Mohammadi et al. (2021a). Their study offered the first thorough analysis of e-waste generation patterns in an island setting and looks into the variables influencing those trends. For the five island examples, they analyzed the flows of Electrical and Electronic Equipment (EEE) over a 60-year period (1965–2025). They estimated these fluxes and stocks for 206 products using a dynamic material flow analysis (MFA) approach. In the field of industrial-ecology, material flow analysis (MFA) is one of the most well recognized and applied techniques. It evaluates the input-output materials and the flux and paths of each material flow across the entire system (Islam & Huda, 2019). According to Mohammadi et al. (2021b), the five Caribbean islands generated twice as much e-waste annually per person, or 13 kg/cap/year, as the world average in 2016, which was 6.1 kg/cap/year. The total e-waste produced annually on these five islands appears to be increasing significantly in the future, from 27,500 tonnes in 2010 to a projected 59,000 tonnes in 2025. When this e-waste production fails to be adequately handled, it not merely poses a threat to the local ecosystem but also results in significant health effects and the loss of important resources. According to their analysis, small islands should think about transitioning from a linear to a circular economy in order to reduce waste production and their dependency on outside suppliers of virgin resources.

The circular economy potential of e-waste from the same five Caribbean islands was investigated by Mohammadi et al. (2021b). The findings show that approximately 317.4 kt of secondary materials, including a sizable proportion of base and precious metals like copper, silver, gold, palladium, and aluminum, would be recoverable from e-waste stockpiled on the islands from 2001 to 2019. These materials are thought to have an estimated commercial worth of over $546 million. Nevertheless, the sensitivity analysis indicates that if these islands had begun resource recovery in early 2001, this value would have roughly tripled to $1,430 million, or nearly 30% of the GDP from mining and quarrying in the Caribbean region as a whole, from only the five mentioned islands. In order to transition to a CE, regional collaboration and industrial partnership would be crucial due to economies of scale that constrain smaller governments.

3.3. E-waste Generation in Guyana

According to research done on urban mining and e-waste management in South America (StEP (2014), GSMA (2015), and Baldé et al. (2017), as cited in Kasim (2021), Guyana generated 5Kton of e-waste annually in 2014 and 2016 respectively, and 6.1 kg of e-waste per resident in the year 2014 and 2016. According to BRC Caribbean (2022b), e-waste generation rates for Guyana were anticipated to be 8, 9, and 10 kg per inhabitant in 2019, 2020, and 2021, respectively. The World Bank's worldwide population statistics was used to calculate Guyana's population for 2019 and 2020, and a 0.5% growth rate from 2020 was used to estimate the country's population for 2021. Moreover, it was noted that relying solely on local data to estimate e-waste generation was very challenging due to Guyana's inadequate data management systems, especially with regard to maintaining records of EEE utilized and e-waste produced. In spite of this, the Put On Market (POM) was used to estimate e-waste creation. Even though Guyana's predicted per capita e-waste output is greater than the worldwide average for 2019 (7.3 kg per capita), only a small fraction of this gets exported for ecologically sound management (ESM). According to DeFreitas (2018), no study is conducted by the EPA to track the disposal practices of Guyanese.

In both the formal and informal sectors in Guyana, waste pickers, scrap metal merchants, and waste management facilities do prerecycling tasks, which mostly involve disassembling and sorting. Waste pickers work at the dumpsites in Lusignan, Esplanade, New Amsterdam, as well as the Haags Bosch Sanitary Landfill Site in Guyana. Recyclers that operate outside of official regulations are often referred to as operating in the "informal recycling sector." One of the main buyers of the e-waste produced at the Haags Bosch Landfill Site was noted to be N&S Enterprise which has been identified as one of the providers of electronic waste to Eternity Investment Inc., which is currently authorized to export electronic waste (BRCB Caribbean, 2022b). According to DeFreitas (2018), Eternity Investment is the first company to export e-waste and was founded in 2018. As stated in the BRCB Caribbean (2022b) report, the company facilitates trading of useful resources that are obtained during disassembly; government organizations, the University of Guyana (UG), and the GRA are among their e-waste providers. Exportation is the primary means by which ecologically responsible handling of electronic waste takes place in Guyana. Since there is no market for products like plastics and rubber that are recovered from the dismantling process, garbage is generated from the operation are disposed of at the Haags Bosch Landfill Site. For recycling or recovery, all of the e-waste recovered from end-of-life EEE is transported to nations including South Korea, Pakistan, Thailand, Taiwan, and India. But the e-waste is typically heaped up until enough has amassed to fulfill the quantities that the importer and exporter have legally agreed upon. Given that the e-waste buyers are typically third parties in the importing nations, Eternity Investment does not receive a certificate of destruction or recovery attesting to the environmentally sound disposal of the e-waste. Though it might seem that just under 1% of Guyana's E-waste was exported in general, the amounts shipped primarily include the valuable parts of end-of-life EEE, not the complete equipment (BRCB Caribbean, 2022b).

4. Issues associated with E-waste Management

4.1. Global Issues

The ICT sector is expanding and evolving rapidly which presents a number of risks to sustainable development. The life cycle of ICT goods utilizes a lot of natural resources and produces a considerable amount of hazardous waste. The quantity of outdated, discarded, broken, or rejected products that society has to cope with has unavoidably increased due to the rising demand for consumer electronics and electric products as well as the rapid rate at which technology is developing (Hula et al., 2003 as cited in Osibanjo & Nnorom, 2007). ICT equipment has significantly decreased in weight and size, but its total quantity has grown, significantly increasing the amount of resources used and producing hazardous waste (Plepys, 2002 as mentioned in Osibanjo & Nnorom, 2007). Consumer electrical and electronic equipment is especially problematic because of its high manufacturing volume and propensity for short-term technological scales which results in the large-scale landfilling of abandoned goods. This issue is made worse by the fact that parts of these items usually have to fit into a small space, making it difficult to disassemble and retrieve parts (Hula et al. 2003 as cited in Osibanjo & Nnorom, 2007). The extremely high complexity and heterogeneity of e-waste is a significant challenge to recycling since it complicates processing when combined with regular household garbage (Kaya, 2017 as cited in Van Yken et al. 2021). EEE have expanded to include wearables like smartwatches and medical monitoring devices, as well as crossover items like electronically connected clothes (Parajuly et al. 2019 as mentioned in Van Yken et al. 2021). Beyond a product's inherent longevity, factors that impact its potential for reuse encompass compatibility and software updates, copyright protection, manufacturers' maintenance policies, and product maintenance procedures (Thomas 2003 as cited in Osibanjo & Nnorom, 2007).

According to Gollakota et al. (2020), there is an urgent need to tackle efficient e-waste management solutions from both developed and developing countries. E-waste contributes significantly to toxicity and is one of the most rapidly growing waste streams globally in terms of quantity (Chen et al., 2011; Kiddee et al., 2013 as cited in Mohammadi et al., 2021b). Needhidasan et al. (2014 as cited in Arya & Kumar,2020) noted that specifically, heavy metals like barium (Ba), selenium (Se), beryllium (Be), cadmium (Cd), lead (Pb), arsenic (As), mercury (Hg), hexavalent chromium [Cr(VI)], polyvinyl chloride (PVC), polychlorinated biphenyl (PCBs), and brominated flame retardants (BFR) that are present in e-waste and beyond permissible limits are deemed hazardous to human health and the environment. The most frequent cause of e-waste-related environmental pollution is improper handling of the waste. Some instances involve dust released during mechanical treatment (Tue et al., 2013 as cited in Van Yken, 2021), open disposal (Rautela et al., 2021 as cited in Van Yken, 2021), dumping that is not permitted (Singh et al., 2018 as cited in Van Yken, 2021), and crude recycling processes (Ha et al., 2009 as cited in Van Yken, 2021). As a result, pollutants may contaminate the air, soil, and water, and they may bioaccumulate in the food chain (Van Yken, 2021; see also Rautela et al., 2021; Luo et al., 2011). There is evidence on the impact of this contamination on human health (Grant et al., 2013 as mentioned in Van Yken, 2021). Several studies indicates that this involves having an effect on lung function, health of the reproductive system, thyroid function and mental health (Van Yken, 2021). Employing inappropriate landfilling and water treatment and landfilling techniques results in ion leaching and pollution of natural resources (Hakami, 2018 as cited in Madkhali et al., 2023). Discarding electronics will have long-term repercussions on our planet due to the pollution that results from both artisanal recycling and the massive and growing volume of electronics that are disposed of in landfills (Chen et al., 2015 as stated in Mohammadi et al., 2021a). Artisanal recycling, according to Ilankoon et al. (2018 as mentioned in Mohammadi et al., 2021a), is an unauthorized recycling method in which e-waste is manually sorted, disassembled, and burned outdoors largely in the absence of safety precautions. The leaching and recovery of costly metals using highly concentrated acids and cyanide raises serious health risks (Madkhali et al., 2023; see also Sharma et al., 2022; Baniasadi et al., 2019). The neurological, digestive, respiratory, and cardiovascular systems of humans may be seriously impacted by these harmful compounds (Madkhali et al., 2023; see also Kumar et al., 2017; Joshi, 2023).

A study conducted in China on e-waste recycling areas revealed that between 35 and 39% of the children living there had blood lead levels at dangerous levels beyond of 10 µg/ L (Wang et al., 2012 as cited in Mohammadi et al., 2021a), which is set by the World Health Organization (World Health Organization, 2010 as reported by Mohammadi et al., 2021a). An elevated level of environmental contamination from crude recycling operations were found in Guiyu, China, according to studies (Osibanjo & Nnorom, 2007). Guiyu's drinking water has been supplied from a nearby town due to excessive levels of heavy metal contamination in the town's surface and ground water due to the presence of WEEE industry (Hicks et al. 2005 as cited in Osibanjo & Nnorom, 2007). For the people in developing countries working in these recycling facilities and being exposed to health hazards might be the distinction between earning a livelihood and staying jobless, according to Gattuso (2005 as cited in Osibanjo & Nnorom, 2007). Additionally, the public and government are unaware of the possible risks to human health and the environment posed by the current EoL handling of WEEE in developing countries. Individuals engaged in hazardous crude recycling operations are either unaware of the consequences of their actions or feel compelled choose between "poverty and poison."

While developing nations are compensated for receiving e- waste, Davis et al. (2019 as cited in Abalansa et al., 2021) noted that the Pollution Haven Hypothesis (PHH) implies that polluting industries are moved—or located—to areas with the laxest environmental laws, especially developing nations. PHH and the Environmental Kuznets Curve (EKC) have been linked in several research (Abalansa et al., 2021; see also Sadik-Zada & Loewenstein, 2020; Sadik-Zada & Gatto, 2020). According to the EKC, a country's pollution concentrations rise as it develops and becomes more industrialized up to a certain point, at which point they fall as the country uses its growing economic prosperity to lower pollution concentrations (Jbara, 2007 as cited in Abalansa et al., 2021). This suggests that the achievement of a cleaner environment in industrialized countries comes at the expense of a dirtier environment in emerging countries. As a result, the EKC and PHH are similar in that the import of garbage from post-industrial countries is linked to an increase in environmental deterioration in pre-industrial economies.

Studies like the BAN/SVTC research on e-waste recycling in poor nations, according to Osibanjo & Nnorom (2007), have sparked a worldwide push to prevent more e-waste exports to poor countries and to compel manufacturers to retrieve and recycle their goods. According to Gattuso (2005, as cited in Osibanjo & Nnorom, 2007), the 'push' to prohibit desktop computers and other electronics from US landfills is directly responsible for the hundreds of tons of computers and other devices that are exported from the US to developing nations. According to some, the US computer recycling market is not adequate to accommodate the volume of e-waste produced, which is increasingly prohibited from being disposed at municipal landfills. They pointed out that this isn't the situation in developing nations like

India, where there is a strong need for labor and where markets for recyclables and electronic components flourish. In the US, recycling a home computer costs $20, while in poor nations like India, it only costs $4. The study also noted that, in contrast to landfilling, which costs just $40, recycling one ton of electronic garbage in the US can cost as much as $500.

According to Osibanjo & Nnorom (2007) and Gollakota et al., (2020) developing nations face several obstacles when it comes to managing e-waste, such as inadequate infrastructure for proper waste management, a lack of legislation that targets e-waste, and the lack of a framework to take-back or implementation of end-of-life (EoL) products or adoption of extended producer responsibility (EPR). Osibanjo & Nnorom (2007) noted that furthermore, laws and regulations pertaining to the management of hazardous waste and recyclables crossing international borders and adhering to sustainable consumption and development principles are either almost nonexistent or poorly implemented. Furthermore, it is uncommon for used EEE imported into developing countries to undergo functional testing. Therefore, a sizable portion of old EEE imports—roughly 25–75%—consist of useless waste (also known as e-scrap). Gollakota et al. (2020) identified additional significant obstacles for efficient e-waste management, particularly in developing and underdeveloped countries. These include the failure to integrate the formal and informal sectors, the requirement for network registration, strict enforcement of the law, controlled cross-border movements, manufacturers' accountability, consumer awareness, and better eco-designs. The solution lies in investing in efficient recycling facilities and better disposal facilities. Moreover, e-waste management's present obstacles that will be significantly overcome by substituting the antiquated, conventional methods with cutting-edge, environmentally friendly ones like chelation, ionic liquid induction, integrated processes or hybrid technologies, microfactories, photo catalysis, and green adsorption. Hicks et al. (2005) as cited in Osibanjo & Nnorom (2007), pointed out that insufficient capital and investment exist to support financially viable enhancements in e-scrap recycling. The crude "backyard" recycling efforts are causing resource loss, energy waste, and environmental contamination, they stated. Incentives for environmentally friendly habits and technologies should also be provided financially. It is costly to construct formal e-waste recycling since it requires cutting edge equipment to securely recover salvageable components (Perkins et al., 2014 as cited in Abalansa, 2021).

Data and statistics on the amount of e-waste generated are needed to manage this hazardous waste stream, which is growing at a rapid pace, yet just 20% of countries worldwide gather data on e-waste, while only Europe maintains consistent, standardized data (Mohammadi et al., 2021). Awasthi et al. (2015, as cited in Xavier et al. 2018) mentioned that developing nations need broad regulations, financial and technical backing, and social guarantees in order to more effectively tackle the foundation of waste management namely the collection and disposal of post-consume material. In contrast, the majority European and North American countries have centralized regulations and infrastructure support.

4.2. Issues in the Caribbean

It was reported in the Basel Convention Regional Centre (BCRC) in 2016 that poor e-waste disposal and processing in the Caribbean islands leads to a serious deterioration of the ecosystem, a loss of biodiversity, and a reduction in the natural population. In spite of this claim, no country in the Caribbean has e-waste-related rules or regulations (BCRC, 2016 & Balde et al., 2017 as cited in Mohammadi et al., 2021a). The International Telecommunications Union (ITU) and the Caribbean Regional Council are two examples of the very few non-governmental players who have taken up the e-waste challenge and are tackling associated issues (Riquelme et al., 2016 as cited in Mohammadi et al., 2021a). The amount of e-waste generated in this region is still only partially known (BCRC, 2016 as stated in Mohammadi et al., 2021a), and there is no comprehensive analysis of the issue or suggested solutions. They pointed out that little research on e-waste in SIDS exist. There is a dearth of information regarding the Caribbean countries, and recent reports from the ITU 2017 indicated that the region lacks any specific legislation (Rodan, 2017 as cited in Gollakota et al., 2020). They further noted that only certain areas of Trinidad and Tobago, Jamaica have local policies covering the management of e-waste and solid waste. With a few notable exceptions, the majority of countries in the Caribbean and Latin America have data or regulations (Gollakota et al., 2020). According to Hill et al. (2022), there are no institutional incentives in place to encourage society to send their electronic waste to recyclers, nor are there any national rules governing how it should be disposed of or stored in Trinidad. Because there is no official structure in place, people store and/or dispose of e-waste at their own discretion. It has been reported that certain business and institutional have e-waste policies that specify how to dispose of e-waste in an environmentally responsible way. It appears that corporations choose responsible disposal in light of sensitive data, global standards, and awareness of inappropriate handling of electronic waste.

It is reported in BRCB Caribbean (2022b) that the methods now employed to extract valuable metals are especially concerning since they cause unintentional persistent organic pollutants (UPOPs) to be released. Furthermore, wastes containing mercury, such as primary batteries and energy-efficient lighting, are included in the e-waste stream and are subject to regulations under the Minamata Convention on Mercury. Regretfully, the Caribbean Region has relatively little capacity for the treatment and disposal of products that contains mercury.

4.3. Issues in Guyana

In Guyana, legislation addressing the management of e-waste continues to be inadequate to lessen the detrimental effects on human health and the environment (BCRC Caribbean, 2022a; St. Hill, 2022). The BRCB Caribbean (2022b) study indicates that merely 5% of Guyana's households are engaged in source segregation of household food waste. It is noteworthy that the majority of domestic e-waste is presumably mixed with municipal waste and transported to the Haags Bosch Landfill Site for disposal. Although there is some information about Guyana's domestic capacity to address issues related to E-waste management, the majority of these activities come from interpreting regulations, according to the BRC Caribbean (2022a). The following are the laws and policies that St. Hill (2022) and BCRC Caribbean (2022a) highlighted:

- Low Carbon Development Strategy
- Environmental Protection Act (EPA Act)
- Public Health Act
- Old Metal Dealers Act & Old Metal Dealers (Amendment) Act 2006
- Guyana National Bureau of Standards Act (1984)
- Municipal and District Councils Act
- Customs Act
- Draft Solid Waste Management Bill 2014
- Draft National Solid Waste Strategy 2014-2034

Table 1: Institutional Framework (Source: BCRC Caribbean, 2022a)

Stakeholder	Institution	Justification for Inclusion
Environmental Protection Agency (EPA)	State Agency	Agency responsible for overseeing waste management regulations and protection of the environment.
Ministry of Local Government and Regional Development (MLGRD)	Government/Waste Management	Ministry that oversees the operational aspect of waste management, that includes sorting, transporting, disposing, and, when appropriate, treatment.
Guyana Revenue Authority	Taxation, Customs and Excise	Authority responsible for handling import and export administration into and out of Guyana
Ministry of Tourism, Industry and Commerce – Scrap Metal Unit	Government/ Technical Unit	Unit responsible for issuing permits for the export of obsolete metals (together with magisterial authorities)

The requirement for guidance especially to stakeholders, in order to implement any such laws or policies would constitute a hurdle with reference to the institutional framework. A variety incentives might be required to increase the involvement of private waste disposal services in the process (Acosta and Corallo, 2020, p. 5 as stated in St. Hill, 2022). Furthermore, it is important to have more precise prerequisites for distinguishing between e-waste that is deemed harmful and harmless. Additionally, there is a lack of a regional strategy for managing e-waste, specifically in relation to exporting and transporting under the Basel Convention's Prior Informed Consent (PIC) procedure; the institutional and regulatory structure that promotes the development of e-waste management in Guyana lacks regional synergy. Another obvious gap pertains to whether the Basel Convention would forbid, for instance, the export of E-waste from Guyana to a different nation in the subregion for additional treatment, so offering a greater economy of scale as opposed to one country at a time.

Environmentally safe recycling and recovery of metals and hazardous compounds present in e-waste is not carried out by any facility in Guyana. Recycling e-waste can be a profitable endeavor, but the health risks connected to incorrect or illegal e-waste management, particularly in the informal sector, remain concerning because of the direct and indirect health risks as well as the environmental impacts. The ability to appropriately manage, treat, and dispose of this waste stream is essentially nonexistent in the country at large. The methods currently used to extract valuable metals are particularly concerning and it is extremely difficult to deal with these toxins effectively after they are released. It is reasonable to anticipate significant negative effects on the environment and human health, as well as a comparatively large social and economic cost as a result of inappropriate e-waste treatment (BRCB Caribbean, 2022b).

Relying on local data for determining the amount of e-waste generation is practically impossible due to Guyana's inadequate data management systems, especially with regard to keeping track of EEE consumed and e-waste generated (BRCB Caribbean, 2022b).

5. Strategies for Transitioning to a More Sustainable E-waste Management Systems

5.1. Global Strategies

Urban mining is a term commonly used to describe the process of recovering resources from e-waste, since the metals found in this waste have a substantial monetary value that is lost permanently from the market (Baldé et al., 2020 as cited in Van Yken, 2021). Waste can be converted into a resource and assist in achieving sustainability goals by means of urban mining (Xavier et al., 2018). In order to achieve the Sustainable Development Goals (SDGs) agenda 2030, particularly for Goal 3 (Water and Sanitation Health), Goal 8 (Decent Work & Economic Growth), Goal 11 (Sustainable cities and Communities), and Goal 12 (Responsible Consumption and Production), as well as a circular economy and resource efficiency, sustainable urban mining of e-waste has become a global concern and of extreme importance (ASSOCHAM, 2015 as cited in Arya & Kumar, 2020). Urban mining when used for e-waste recovery and recycling is acknowledged as a significant source of vital and valuable resources for Europe's circular economy strategy. An intuitive understanding of the relationships between economic status and the development of e-waste is provided by this pattern. E-waste is thought to contain up to 60 different elements from the periodic table (Baldé et al., 2017 as cited in Kasim et al., 2021). It is an appealing secondary source of valuable elements which include base metals (like Cu), precious metals (like Au, Ag, Pd), and crucial elements (like lanthanides, Li) that are highlighted as raw materials (Zhuang et al., 2015 as cited in Kasim et al., 2021). It is possible to recover important and valuable components from electrical and electronic equipment, which can then be reintegrated into a number of supply chains along with mitigating or eliminating negative environmental impacts (Kasim, 2021). As a result of the high concentration of base and precious metals, printed circuit boards (PCBs) are considered to be the most expensive type of e-waste; nonetheless, they only make up around 3-6% of all e-waste (Pinho et al. 2018 as cited in Van Yken et al. 2021). PCBs are quite diverse, with their composition varying according to their initial use, much like the majority of e-waste. A mixture of 40% metals, 30% polymers, and 30% ceramics make up PCBs (Sum, 1991 as referenced in Van Yken et al. 2021). Van Yken et al. (2021) observed that copper (10–27%), nickel (0.3–2%), zinc (0.03–0.42%), tin (0.08–0.9%), aluminum (2–19%), and iron (8–38%) make up the majority of PCBs based on multiple research. High-grade PCBs may also include valuable metals like palladium (40–4000 ppm), silver (110–4500 ppm), and gold (250–2050 ppm).

Energy saving also makes recycling electronic waste crucial. In addition to saving a significant amount of energy, using recycled materials from e-waste to augment virgin resources can help reduce the environmental impact of mining and refining raw materials. As much as 95% of aluminum, 85% of copper, and 74% of lead and steel might be saved in terms of energy as a result of this (Van Yken et al. 2021; see also Widmer et al., 2005; Cui & Forssberg, 2003). As demonstrated in 2019, e-waste recycling decreased world CO_2 by an equivalent of 15 Mt by offering an alternative to mining and processing virgin minerals (Baldé, et al., 2020 as cited in Van Yken, 2021). Additionally, it was projected that an extra 83 Mt of CO_2 emissions could have been avoided by recycling all of the e-waste produced in 2019 (Baldé, et al., 2020 as referenced in Van Yken, 2021). It is crucial to emphasize that making or importing EEE increases the availability of resources and elements. In addition, when e-waste ages and accumulates in urban areas, it adds to the stock of e-waste (Kasim et al., 2021). According to Gollakota et al. 2020, Xavier et al. (2018) and Kasim et al. (2021), the primary benefits of recycling e-waste include a reduced reliance on foreign material supply and rare-earth metals and Binnemans et al. (2013) noted, results in the absence of radioactive wastes during secondary processing. It alleviates the strain on virgin assets and creates opportunity for employment (Arya & Kumar, 2020; see also Zeng et al., 2017; Kumar & Holuszko, 2017).

The inclusion of persistent organic pollutants (POPs) and brominated flame retardants (BFRs) in e-waste makes recycling plastics more difficult (Ma et al., 2016 as mentioned in Van Yken et al. 2021). BFRs and POPs are classified as regulated wastes under the Stockholm Convention, therefore recycling plastics containing these components must be done in an environmentally responsible way (Van Yken et al. 2021). The development of technologies capable of securely recycling the plastic component of e-waste is imperative, considering the exponential expansion of e-waste globally. While it is ideal to recover the chemical components from the polymers in plastic e-waste (Sahajwalla & Gaikwad, 2018 as cited in Van Yken et al. 2021), recycling e-waste is made more difficult due to the presence of BFRs and POPs (Imai et al., 2003 as mentioned in Van Yken et al. 2021). Before being processed, BFRs and plastic e-waste can be separated using technology such as the CREASolv method which utilizes a blend of solvents to isolate BFRs from polymers. As fresh materials, the polymers are extracted and re-extruded (Schlummer et al., 2016 as cited in Van Yken et al. 2021). The circular economy and the waste hierarchy both support the idea that reusing plastics to create new products is preferable to using virgin plastic products.

Another significant composition of e-waste is glass, and account for as much as 12% of the waste produced globally (Baldé et al., 2020 as noted in Van Yken et al., 2021). CRT, which was formerly utilized in televisions and monitors, is especially concerning. The presence of lead in CRTs makes them hazardous waste, and increased concern about the possibility of harmful metals leaching from CRTs has led to a rise in possible recycling routes (Van Yken et al. 2021; see also Townsend et al., 2003, Spalvins et al., 2008). The need for CRT monitors has decreased considerably due to the development of LEDs and OLEDs, which are safer and more efficient. As a result, manufacturers of CRTs have gradually reduced or stopped (Van Yken et al. 2021; see also Mueller et al., 2020; Mostaghel & Samuelsson, 2010). According to Yao et al. (2018) and Van Yken et al. (2021), one route that might be pursued is the utilization of CRT glass in the building sector for the creation of foam glass (Mucsi et al., 2013 as mentioned in Van Yken et al. 2021) and ceramic glazes (Mucsi et al., 2013 as as cited in Van Yken et al. 2021), glass tiles (Van Yken et al. 2021; see also Minay & Desbois, 2003; Raimondo et al., 2007) and concrete (Romero et al., 2013 as cited in Van Yken et al. 2021).

According to Madkhali et al. (2023), achieving sustainable development necessitates significant additional work, mostly in the area of E-waste management. This can only be accomplished through the establishment of a formal collection system, early forecasting, and precise estimation. According to Arya and Kumar (2020), developing nations such as India are realizing the urgency of elucidating suitable management systems and treatment alternatives in addition to the safe disposal of used electronics. The authors observed that India has implemented a number of progressive measures in the field of Municipal Solid Waste Management (MSWM) which includes: "door-to-door collection, source segregation at the source and at landfills, waste transportation, processing, and treatment". It is necessary to find new waste management solutions in order to keep EOL electronics out of landfills. Nonetheless, there are a number of considerations to take into account when creating an effective diversion strategy. This strategy must be based on its economic sustainability, eco-efficiency, technical feasibility, and a realistic level of social support for the programme. One aspect of the strategy should include recycling and re-use of end-of-life electronic products (Kang & Schoenung 2004 as cited in Osibanjo & Nnorom, 2007). Efficient e-waste recycling can be either stimulated by the economic benefits or controlled by strict regulations (ECOFLASH 2003 as reported in as cited in Osibanjo & Nnorom, 2007).

Australia is the only country in Oceania with an e-waste management policy. This policy is known as the Product Stewardship Act and was established in 2011 (Australian Government Product Stewardship Act 2011 as reported in Van Yken, 2021). The policy is a form of extended producer responsibility (EPR), which aims "to effectively manage the environmental, health and safety impacts of products, and in particular, those impacts associated with the disposal of products and their associated waste" (Australian Government Product Stewardship Act 2011 as reported in Van Yken, 2021). According to Van Yken (2021), the Australian Government Product Stewardship Act of 2011 states that the policy is a type of extended producer responsibility (EPR), with the goal of "effectively managing the environmental, health and safety impacts of products, and in particular, those impacts associated with the disposal of products and their associated waste." In line with this policy, the National Television and Computer Recycling Scheme (NTCRS) was launched in 2012 (Islam & Huda, 2020 as cited in Van Yken, 2021). It mandates that all importers and manufacturers with an EEE import volume exceeding 5,000 products or 15,000 peripherals be culpable partners and contribute to the funding of the NTCRS as well as the recovery and recycling of materials from computer and television wastes (Islam & Huda, 2020 as cited in Van Yken, 2021). According to Abalansa et al. (2021), there are a number of management strategies that can be used to lessen the negative effects in developing nations such as urban mining, adopting the idea of a circular economy, closing gaps, strengthening current policies and regulations, and minimizing the income gap between the top and bottom of the management hierarchy for the disposal of e-waste. Therefore, wealthy nations should support developing nations in combating e-waste instead of sending their environmental issues to these less developed regions.

Furthermore, understanding the details behind the developed world's accomplishments in managing e-waste gives emerging countries perspective and enables them to fortify their deficiencies. When it comes to developing and implementing e-waste legislation, the Europeans and the Japanese are at the forefront. It is admirable that Switzerland was the first country to implement a complete e-waste management system (Gollakota et al., 2020). The majority of North American and European nations already possess specialized knowledge in waste management, which may be shared and utilized to enhance learning and boost implementation effectiveness for e-waste management improvements. The integration of e-waste with standard feed material into existing metallurgical processes has been achieved in several countries, including Belgium (Hagelüken, 2006 as cited in Van Yken, 2021), Germany (Aurubis Environmental Protection at Lünene, 2021 as cited in Van Yken, 2021), Canada (Tesfaye et al, 2017 as cited in Van Yken, 2021), Sweden (Kaya, 2019 as cited in Van Yken, 2021), and Japan (DOWA, 2016 as cited in Van Yken, 2021). All of these countries have done so with barely any extra infrastructure investments (Kaya, 2018 as cited in Van Yken, 2021). "A knowledge partnership in e-waste management in the form of an International WEEE Conference Center" was proposed by Widmer et al. (2005), as cited in Osibanjo & Nnorom (2007). Through this collaboration between rich and poor nations, new e-waste management models that benefits consumers, producers, and recyclers worldwide may be created. In their research, de Oliveira Neto (2023) noted that there aren't many studies that concentrate on the WEEE management hierarchy's top priorities—preventing or reducing WEEE generation. de Oliveira Neto noted that from previous research, the way that WEEE is currently managed may be harmful to long-term sustainability because it places more emphasis on developing end-of-pipe technological solutions, which are primarily related to material recovery, than it does on deterring generation.

5.2. Strategies for the Caribbean

Creating a plan to optimize the reduction of EEE consumption, repurposing electronics, and recycling end-of-life items in an environmentally and financially sustainable way should all be part of the region's e-waste management strategy. It is mandatory that the strategy consist of guiding principles and action plans for policy creation, financial systems, technology, and skill sets. Recycling is a labor- and capital-intensive sector that requires significant investment as well as a wide range of expertise for undertakings which include gathering, sorting, and processing materials. Notwithstanding SIDS's budgetary constraints, recycling could offer a medium-to long-term, commercially and environmentally sound strategy for managing e-waste. The recovery of rare and precious metals from e-waste can lead to the development of a lucrative regional industry. These islands will need to prepare for the possibility that the recycling sector will offer prospective employment by establishing human resource development and training programs (Mohammadi et al., 2020 as cited in Mohammadi et al., 2021a). National governments must develop strong data and information systems in order to make the transition to more environmentally friendly e-waste management systems. Different stakeholders are unclear about their roles and the format in which they should report data. Harmonizing data sources and reporting methods is essential for improved and transparent resource flow monitoring. Setting goals and improving overall planning and resource recovery from e-waste will be made easier with clear documentation and classification of data on EEE sales and flows, volume of electronic waste produced, and import and export of used EEE and electronic waste flows. The encouragement of manufacturers and businesses to start take-back initiatives is another way to lessen the quantity of abandoned EEE that ends up in landfills. Furthermore, it is imperative that various stakeholders take the lead in raising local community awareness on the problem of e-waste. It is critical to raise public awareness about e-waste in order to effectively modify behavior. Taking into account all of these factors, implementing appropriate e-waste management systems will eventually contribute significantly to a reduction in environmental loads and the ensuing public health issues term (Mohammadi et al., 2021a).

According to Mohammadi et al. (2021b), CE has a number of positive social, environmental, and economic advantages in addition to helping islands maintain resource self-sufficiency. New strategies like CE could assist countries in enhancing resource security and minimizing negative effects on the environment and public health. Islands can act as living laboratories and centers of innovation for a transition to resource circularity; a strategy that could lessen pollution of both land and ocean and lessen the concerning pattern of rising global material consumption (Schaffartzik et al., 2014 as cited in Mohammadi et al., 2021b). They added that the research examined the feasibility of a CE on islands and questioned if it may be a viable way for islands to address their e-waste problem by using Aruba, Barbados, Grenada, Jamaica, and Trinidad and Tobago as cases. They pointed out that recycling e-waste can be a major milestone in the direction a CE for the Caribbean region and that e-waste can be thought of as a resource mine.

5.3. Strategies for Guyana

Guyana is obligated to make sure ESM techniques are applied nationwide as a Party to the Basel Convention on the Transboundary Movement of Hazardous Wastes and their Disposal (BCRB Caribbean, 2022b). Legislation and policy must be updated to reflect global best practices in this field especially the technical guidelines and the practical guides, while also taking into account Guyana's distinctive requirements. Solving the E-waste Problem (StEP) White Paper - Developing Legislative Principles for e-waste policy in poor and developing nations recommends the use of the building block principles in the legislative framework (BCRC Caribbean, 2022a). The following, according to Acosta and Corallo (2020) as reported in BCRB Caribbean (2022b) would be required for the promotion of proper management of e-waste: coordination and cooperation between the major stakeholders; standardized collection system; citizen behavior that favors recycling efforts; regulations and rewards for recycling or reuse; and sufficient facilities to treat all waste streams. BRCB Caribbean (2022b) recommends the creation of interagency committee, establishment of a nationwide data gathering system, setting up of public-private partnerships, information sharing to raise public knowledge of the ESM of e-waste and a thorough analysis of the informal sector's involvement. Furthermore, the e-waste sector can increase its contribution to the GDP of the country by bolstering institutional and technical capacity for managing e-waste, establishing local programs for material recovery, marketing, and disposal, and creating financial incentives for effective e-waste management. Gharaei et al. (2018 as cited in Arya & Kumar, 2020) noted that resource recovery workers need to possess the necessary skills, knowledge of product design and structure, decision-making abilities, supply chain knowledge, and estimates of replenishment life cycle costs. Moreover, companies in these fields have to adhere to quality control and environmental rules as part of their managerial structure.

6. Conclusion

53.6 million metric tons of e-waste were created globally in 2021, with an average annual growth rate of 2.5 Mt, according to the Global E-waste Monitoring Program. Over the next ten years, the amount of e-waste generated is predicted to rise dramatically. Demand and consumer growth have resulted in the global establishment of the Electronic-Web (E-Web) and enhanced trade opportunities for EEEs (ITU 2017 as stated in Arya & Kumar 2020). Mohammadi et al. (2021b) reported that in 2016, the five Caribbean islands (Trinidad & Tobago, Grenada, Aruba, Jamaica, and Barbados) produced twice as much e-waste per person yearly, or 13 kg/cap/year, than the global average of 6.1 kg/cap/year. The overall amount of e-waste produced on these five islands is expected to increase dramatically from 2010 and 2025. As per BRC Caribbean (2022b), the estimated e-waste generation rates for Guyana in 2019, 2020 and 2021 were 8 kg, 9 kg, and 10 kg per resident respectively. Due to Guyana's poor data management systems, particularly with regard to keeping track of the EEE used and the e-waste generated, an estimate of the generation of e-waste was made using the Put On Market (POM).

The growing gaps in the use of EEE, the accumulation of electronic waste at the end of its life (EOL), and the treatment, storage, and disposal of this waste are all major causes for concern (Kahhat and Williams, 2009 as cited in Gollakota et al., 2020). According to Needhidasan et al. (2014, cited in Arya & Kumar, 2020), certain heavy metals, such as those found in e-waste are exceeding permissible limits and are considered hazardous to human health and the environment. Gollakota et al. (2020) asserted that it is imperative to address effective e-waste management strategies for both developed and developing nations. Most developed countries have potential e-waste management technology, technological expertise, and clearly defined system boundaries. However, the situation in emerging nations differs due to several factors including a lack of relevant policies. Osibanjo & Nnorom (2007) & Gollakota et al., (2020) stated that developing countries encounter a number of challenges in managing e-waste, including insufficient infrastructure for appropriate waste management, a dearth of legislation specifically addressing e-waste, and the absence of a framework for the return or adoption of end-of-life (EoL) products or extended producer responsibility (EPR). Furthermore, laws and regulations governing the handling of hazardous waste and recyclables across international borders while upholding the concepts of sustainable consumption and development are either missing or inadequately enforced, according to Osibanjo & Nnorom (2007). Innovative solutions are required because SIDS in the Caribbean face a number of difficulties, such as limited opportunities for recycling and resale, inadequate legislation, and barriers to exporting e-waste to other countries (Camilleri-Fenech et al., 2018; Fuldauer et al., 2019 as cited in Mohammadi et al. 2021b). Furthermore, according to Mohammadi et al. (2021b), the amount of e-waste generated in the Caribbean region is still only partially known (BCRC, 2016). Moreover, no thorough study of the problem or recommendations for solutions have been provided. It was noted that in order to mitigate the negative effects on human health and the environment, Guyana's e-waste management laws are still insufficient (BCRC Caribbean 2022a as reported in St. Hill, 2022). In the country as a whole, there is virtually no capacity to manage, treat, and dispose of this waste stream. Guyana's data management systems are so poor that it is nearly impossible to rely on local data to estimate the amount of e-waste generated, particularly when it comes to tracking the amount of EEE consumed and e-waste generated (BRCB Caribbean, 2022b).

E-waste must be handled and managed in a sustainable, cost-effective, environmentally conscious, and safe manner. According to Sharma et al. (2023 as referenced in Madkhali et al., 2023), this covers proper recycling, metal recovery, transportation, and the disposal of e-waste. Madkhali et al. (2023) noted that urban mining is recognized as a major source of essential and valuable resources for the circular economy approach, particularly it comes to e-waste recovery and recycling. Furthermore, additional works required to achieve sustainable development includes establishing a formal collection system, predicting ahead of time, and performing precise estimations. Abalansa et al. (2021) state that a variety of management techniques, including urban mining, embracing the concept of a circular economy, closing gaps, fortifying existing laws and regulations, and reducing the income disparity between the top and bottom of the management hierarchy for the disposal of e-waste, can be employed to mitigate the adverse effects in developing countries. Developed nations should thus aid developing countries in their fight against e-waste rather than shifting their environmental problems on these underdeveloped areas. According to Widmer et al. (2005 as cited in Osibanjo & Nnorom, 2007), "a knowledge partnership in e-waste management in the form of an International WEEE Conference Center" could be adopted. It may be possible to develop new e-waste management models that benefit producers, recyclers, and consumers globally through this cooperation between wealthy and developing countries.

Despite SIDS's financial limitations, recycling may provide a medium-to long-term, economically and environmentally sound approach to manage e-waste. A profitable regional industry may emerge as a result of the recovery of rare and valuable metals from e-waste (Mohammadi et al., 2020 as cited in Mohammadi et al., 2021a). To shift to more ecologically friendly e-waste management systems, national governments need to build robust data and information systems. To reduce the amount of abandoned EEE that ends up in landfills, manufacturers and businesses should be encouraged to launch take-back efforts. Additionally, it is critical that different stakeholders take the initiative to educate the local community about the issue of e-waste. To effectively change behavior, it is imperative to increase public knowledge of e-waste (Mohammadi et al., 2021a). In Guyana, Laws and policies need to be modified to take into consideration the unique needs of Guyana and to reflect international best practices in this area, particularly the technical and practical guidelines (BCRC, 2022a). Acosta and Corallo (2020) as reported in BCRB Caribbean (2022b) noted that additional requirements for the promotion of appropriate e-waste management include: citizen behavior that supports recycling efforts; regulations and incentives for recycling or reuse; adequate facilities for handling all waste streams; and coordination and cooperation among all of the key stakeholders. Workers in resource recovery must also have the requisite skills, including decision-making skills, knowledge of supply chain, product design and structure knowledge, and estimations of replenishment life cycle costs. Furthermore, as part of their management structure, businesses in these sectors must be required to follow environmental regulations and quality control standards.

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