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Assessing Strategic Management of E-Waste in Developing Countries

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Abstract: E-waste is one of the fastest growing waste streams in the world, paradoxically containing both hazardous components and substances which can adversely impact on both the environment and public health, as well as valuable secondary resources and raw materials that could be recovered if e-waste is processed properly. Developing countries not only lack the infrastructure and technology required to manage e-waste appropriately, they largely rely on a fragmented informal sector for the management of a large fraction of e-waste that is either recognized by the state, or is marginalized and suppressed. This article examines the current situation with e-waste management in the developing countries, and assesses these countries' challenges. The study highlights that there is an urgent need to design more better framework for e-waste that protect these countries from the problems caused by e-waste that are beyond repair and refurbishment, and to help these countries to advance their e-waste recycling and disposal facilities to prevent open burning on and dumping in the environment that can result in deleterious effects on communities at a local as well as at a global level.

Keywords: electronic waste; waste electrical and electronic equipment (WEEE); informal sector; environmental pollution

Citation: Awasthi, A.K.; Iacovidou, E.; Awasthi, M.K.; Johnson, M.; Parajuly, K.; Zhao, M.; Mishra, S.; Pandey, A.K. Assessing Strategic Management of E-Waste in Developing Countries. *Sustainability* **2023**, *15*, 7263. https://doi.org/10.3390/su15097263

Academic Editor: Agostina Chiavola

Received: 31 July 2022
Revised: 3 February 2023
Accepted: 11 February 2023
Published: 27 April 2023

1. Introduction

With the ever-increasing pace of technological development and growing consumer demand for electrical and electronic equipment (EEE), EEE is currently one of the largest international markets [1]. According to Perkins et al. [2], EEE can be categorized depending on its age, functionality and use—with all categories presented in Table 1. The problem with EEE is the continuously decreasing product lifetime and use phase, which result in large amounts of EEE reaching obsolescence considerably faster than before [3]. This has resulted in an ever-growing amount of- globally generated e-waste [4], with a large percentage of it being shipped abroad for processing, resulting in an increase in the transboundary movement of e-waste (Table 2) [5].

Table 1. Various categories of E-waste [2].

Type of Stream	*Description*
New electrical and electronic equipment (EEE) and functioning EEE	New components or products being delivered among different nations.
Used EEE and functioning EEE suitable for direct reuse	Equipment that is ready to use and requires no further refurbishment/repair/upgrading in terms of hardware. However, in several countries import/export restrictions apply.
Used EEE and non-functioning EEE suitable for repair	Equipment that can be repaired, and carry out all the essential functions. However, testing is necessary to decide the actual condition. (This type of waste stream classification is under discussion by Basel Parties).
Used EEE and non-functioning EEE that are non-repairable	Most commonly known as "e-waste." Some times also mislabeled as "used EEE."
Waste Electrical and Electronic Equipment (WEEE)	EEE determined as waste (also known as *e-waste*) under the Waste Framework Directive context, covering sub-assemblies and components.

Table 2. Initiatives towards addressing e-waste ([5,6] and http://www.basel.int/).

Regulation/Initiative	*Description*
Basel Convention	Ratified in 1992 to keep hazardous waste within producer countries. A total of 186 signatory countries, but not ratified by the US.
EU WEEE Directive	Adapted by all EU members by 2007. Creates collection and recycling systems based on producer take-back schemes, covering 10 categories of electrical goods.
RoSH [1]	Enacted along with EU WEEE, restricts amounts of lead, mercury, cadmium, hexavalent chromium and Polybrominated Diphenyl Ethers used in manufacturing.
StEP [2]	UN agencies formally established in 2007, StEP partners/cooperation with prominent academic and government organizations (e.g., MIT, USEPA, Tsinghua University) on encouraging the reuse and recycling of materials and preventing of e-waste pollutants.
BAN [3], *SVTC* [4], *ETBC* [5]	Promoting programs for collection and recycling of e-waste in countries.
US State laws and the Responsible Electronic Recycling Act (HR2284)	A total of 25 US states' laws for e-waste collection, some stipulating consumer payment. HR2284 is a proposed national law to control e-waste export and certify used electronic goods for export.

[1] Restriction of Hazardous Substances Directive; [2] Solving the E-waste Problem; [3] Basel Action Network; [4] Silicon Valley Toxic Coalition; [5] Electronics Take Back Coalition.

Therefore, the majority of e-waste collected for recycling in developed countries is shipped to developing countries for reuse and repair following the Basel Convention guidelines. Many developed countries are party to the Basel Convention and even have other forms of national regulations intended to control exports of EEE that are beyond reuse and repair (hence, e-waste). However, large numbers of e-waste are illegally exported from developed countries to developing, by mislabeling the e-waste as "used goods" [7].

The aim of this study is to preliminary examine e-waste management issues, challenges and opportunities in developing countries, looking specifically into the activities of the informal recycling sector. This study provides an overview of the pressing issues in achieving the circularity of EEE, to recognize aspects that could be improved in order to help developing countries reduce pollution and promote circularity. Sections 2 and 3 provides information on current initiatives and regulations that aim to control e-waste management and on the health and environmental concerns of e-waste processing and its mismanagement in developing countries. Section 4 presents a review of the method and keyword selections for e-waste management techniques in selected developing countries. Section 5 discusses the management of e-waste. Section 6 presents problems in transforming the informal e-waste sector in these countries. Section 7 discusses management handling options such as the circular economy and environmentally sound management in developing countries. Section 8 review the current strengths and weaknesses associated with e-waste management in these developing countries, with Section 9 concluding with a review and recap of the main points of the article.

2. Initiatives and Regulations

The rapid growth of e-waste is particularly problematic in developing countries with high population densities coupled with unavailable, unsuccessful or unenforced rules, regulations and policies concerning e-waste treatment. The lack of enforcement, monitoring and control measures at the borders of both developed and developing countries, and a failure to implement the legislation in developing countries have led to a high quantity of e-waste from domestic as well as imported sources (mainly from developed countries). A number of regulations and initiatives (Table 2) have been formulated over the past few years to control the movement of e-waste, yet the degree to which these are more better implemented remains uncertain.

3. Environmental and Human Health Concerns

In developing countries, e-waste recycling is an activity that is usually performed by the informal recycling sector [1]. With this sector being largely marginalized, resulting in a lack of access to suitable machinery and personal protection equipment (PPE), the processing of e-waste can result in many risks, both human-related as well as environmental [8,9]. The rudimentary recycling methods often used by informal workers can all too often be physically harmful to them. According to studies [10–12], the lack of proper PPE, as well as methods and procedures in the informal repair and recycling of e-waste illustrates the necessity of addressing this issue immediately, to prevent further human health risks.

In regards to the environmental pollution, the mixture of hazardous substances that is released into the environment via the informal processing of e-waste (i.e., improper treatment of e-waste), can lead to the contamination of air, soil and water [13]. In turn, this may then lead to bioaccumulation, contamination of the food chain and extensive environmental exposure [14]. Of greater concern are the negative effects on public health e.g., kidney damage, respiratory illness, gastroenteritis and liver disease, cardiovascular illness, urinary infection/disease and reproductive problems. These are not solely attributed to informal e-waste management processes, but also to the leakage and emission of high concentrations of pollutants and heavy metals from the e-waste components and products disposed of to landfills and dumpsites [15–18]. Rahman et al. [19] describe how significant amounts of heavy metals are transported through rainfall in addition to seepage to ponds in the rainy season. Yuan et al. [20] and Fujimori et al. [21] highlighted problems associated with soil contamination by such e-waste, whereas Fujimori and Takigami [22] stressed on the persistence of heavy metals to soil from e-waste dumping. Those studies, emphasised that plants or vegetable crop growth and development is severely impacted as a result of this pollution.

A solution to soil pollution due to e-waste may reside in the ground itself. Microorganisms are present in the soil which can help alleviate the hazardous side effects of e-waste processing. The soil is a well-known habitat for natural microbial diversity linked with plants. For example, those microbes which take part in phytoremediation e.g., stabilization, degradation in the rhizosphere and plants and accumulation inside tissue and volatilization [10,11]. In particular, soil indigenous fungi have higher tolerances for the effects of pollution such as metal adsorption on the cell wall surface (also known as bio-adsorption/biosorption), and bioaccumulation (transportation and cellular incorporation) [23,24]. Several studies have scientifically defined the positive response of arbuscular mycorrhizal fungi (AMF) to metals [25]. Rajkumar et al. [26] highlighted how microorganisms are able to produce numerous types of extracellular polymeric substances (EPS) that play a key role in toxic metal complexes, helping to slow down its mobility rate and penetration into the soil. Numerous research publications have demonstrated that the best solution is an integrated approach combining the use of potential microorganisms with plants for the effective remediation of polluted soil sites [27,28].

Finally, there are economic considerations that are worth considering at this point. From an economic perspective, e-waste offer potential economic opportunities as e-waste processing can also be leveraged to recycle valuable and critical raw materials from e-waste that help recoup some economic return [29]. This can help alleviate demand for primary resource-material ore mining [29,30].

4. Objective and Methods

This work focused on reviewing current practices related to the dismantling and recovery of components and materials (plastics, precious metals, glass) via heating, burning and leaching processing, as well as disposal practices. This work carried out an organized exploration of the literature available on Web of Science and Scopus by using the following keywords: “e-waste” or “electronic waste” or “waste electrical and electronic equipment” or “WEEE”, “informal recycling”, “primitive recycling”, “unorganized e-waste sector”, “backyard recycling”, “workshop recycling”. Only articles that included any of the keywords in either the article title, abstract or key words sections were selected.

This article mainly reviewed articles that focused on the strategies, regulations, management practices and policies of e-waste. Accordingly, the online search outcome was restricted to ensure that the strategy-related papers that would have been uncovered through adding other keywords, for example, “handling”, “management”, “policy”, along with “e-waste” or “electronic waste” or “waste electrical and electronic equipment” did not appear in the search results. Subsequently, the early screening of the strategy-related papers in general, then the additional screening carried out based on “country-wise” ensured that the results focused on the nations that were of note for this article.

5. E-Waste Management in Selected Developing Countries

Considering the current situation of e-waste management in developing countries, this section of the article categorizes e-waste management in Nigeria, Ghana, India and China, as these are some of the countries have received the most focus and attention in the literature to date. Examining the e-waste strategies of these nations shows that it is possible to impact the global strategic development across the world’s other developing countries.

In Asia-Pacific developing countries, nearly ~80% of e-waste is illegally imported from abroad [5,31]. Most e-waste undergoes rudimentary processing [32,33]. In China, a number of regulations on e-waste management have been issued [34]. For instance, the “Old-for-New” Measures implemented for Household Appliances (State Council) were initially piloted from 1 June 2009 to 31 May 2010 and extended until 31 December 2011 for waste collection, handling and treatment in appropriate recycling units. Soon after, the Chinese environmental authority issued e-waste guidelines that included 5 types of household appliances (televisions, washing machines, air conditioners, computers and refrigerators) which they further expanded to cover 14 types of WEEE [35]. The Chinese e-waste regulations are mainly based on the principle of the “polluter pays” and 3Rs (reduce, reuse, recycle), integrated with the EPR (for post-consumer recycling) principles in China [29,36]. In the meantime, other developing countries or regions need to update their e-waste regulations according to their own local situations, leveraging the lessons which can be learned from Chinese and Indian experiences [14].

Nigeria is one of the main destinations for e-waste from Europe. Attention was drawn to e-waste in Africa, specifically in Nigeria, through the e-waste documentary "The Digital Dump" in 2005 [5]. The issue of e-waste dumping and mismanagement in Africa was also previously highlighted at an international convention in Bamako, Mali in 1991. This led to the ''Bamako Convention", which formally came into force in 1998. Nigeria has to date introduced the Harmful Wastes Act, which generally describes banned materials by their effects as materials which subject a person to risk of public health. The Nigerian National Environmental Regulations clearly prohibits unusable electronic goods. However, there are still many incidents reported of illegal e-waste destined for Nigeria from developed countries [37].

Economically low-income countries are the ultimate first choice market for e-waste and it has been reported that almost 500 shipping containers of used EEE are imported into Lagos, Nigeria [38,39]. The authors estimated that each container could hold approximately 800 computer monitors or base units, or 350 large televisions. In fact, the majority of these electronic appliances will no longer be in working condition. This e-waste is normally dumped in open land outside Lagos, where they are picked over by human scavengers or waste merchants [5].

6. Transformation of the Informal E-Waste Sector in Developing Countries

One approach for addressing the shortcomings in the e-waste informal sector is through the establishment of cooperatives and associations via which informal workers can be organized and higher benefits, in terms of value recovery, can be achieved [14]. According to Awasthi et al. [3], China has 109 registered, formal recycling enterprises. About 133 million units of e-waste a year are recycled by these formal recycling enterprises. The total e-waste volume dismantled in 2014 was approximately 70.45 million units, with 35% of that volume being recycled [36]. The e-waste "informal sector" can play an important role in the management of e-waste in developing nations. Some countries have already begun to consider incorporating this addition into formal e-waste management systems. Such transformation can be seen in the latest e-waste management frameworks from countries such as China, where the Industrial Park model is a perfect example [14].

Policies and legal amendments can allow for the formalization of e-waste processing by dissolving the informal sector, who are key players in this area. Conversely, as an important stakeholder of e-waste handling and management systems in developing nations, the informal sector can play a significant role in the success of the formalization of such enterprises. Under this model, informal e-waste working groups can be organised into small-sized cooperatives or associations for carrying out the collection as well as the recycling of e-waste [14]. Similar approaches have been reported from developing countries in Asia, such as India, where the informal solid waste workers have been organised into small cooperative initiatives under their respective municipalities [40]. Academic institutions also have a key role to play here, providing better technical and scientific assistance to these cooperatives [14]. Such assistance can be in the form of pilot projects, helping to support informal e-waste manual workers; developing awareness of e-waste practices [41,42]; and eliminating potential exposure due to informal practices [10,11].

Generally, the community-based organizations or associations are formed when individual workers make themselves available for waste services in their societies. In this context, the local municipality plays a key role, providing rules and regulations, available infrastructure, equipment and events that raise awareness, etc. [14].

7. Management Handling and Circular Economy Considerations

The informal sector labors every day in handling e-waste in developing nations, collecting e-waste from consumer households or the local community, manually dismantling this collected e-waste using rudimentary methods at backyard family level workshops. Therefore, if the effects of these direct or indirect exposures to processing e-waste are not addressed, the related pollution, environmental issues and public health concerns will only continue to escalate. The introduction of suitable management handling schemes for e-waste processing in developing nations is one way to address this. Steps such as the introduction of appropriate e-waste dismantling practices, environmentally sound management (ESM) and regular environmental monitoring systems are just some examples that need to be introduced in developing nations in order to address these issues.

In order to solve the e-waste management problem in developing countries [43], such as India [10,11], the EPR system needs to be supported through better recycling infrastructure as well as advanced recycling technology. Additionally, the regular as well as appropriate monitoring of such a system is important to minimize the illegal movement of e-waste. To address the growing concern of securing valuable raw materials for the future from e-waste, an integrated strategy is needed that establishes targeted measures to secure and improve access to raw materials for developing countries. These are basically related to all industries throughout the supply chain. In this context, owing to a lack of innovation of e-waste in developing countries, it will be a challenging and difficult task to implement a more effective and efficient control scheme. Simultaneously, raw materials are needed for the manufacturing and production of the various goods and appliances used in everyday life. A circular economic system proposes an approach which sees us making products and services through the decrease in "new" raw materials, water and energy in the system, substituting them with ones that are recovered, re-used or re-integrated into the system [29]. To be able to adapt to environmentally friendly production, the overall system essentially needs to be re-designed in a "circular" fashion, with raw materials, components and residuals or waste all re-integrated into the system. In this setting, the product needs to be designed with consideration for the sequence of circular system design strategies, enabling the extension of a product's life span, disassembly, durability, repairability and as well as reliability (Table 3).

Table 3. Characterization of main challenges to formalization e-waste sector and facilitating actions for removal of informal sector (http://www.basel.int/).

Classification	*Challenges to Transforming Informal E-Waste Sector*	*Suggested Measures towards Formalization*
Social and environmental awareness	Lack of environmental awareness raising campaigns on the significance of establishing a sustainable waste management system and the active role of residents as waste creators in society [44].	• Promote regular awareness to provide latest information and training and education materials to workers in informal sectors in developing countries [16]. • Educate informal workers about the impact of their activities on their health, community and environment; • Improve the informal sectors' working and living conditions by giving them access to machinery and personal protection equipment to prevent social and environmental risks [45].

Table 3. *Cont.*

Classification	*Challenges to Transforming Informal E-Waste Sector*	*Suggested Measures towards Formalization*
Institutional/ organizational provisions	• Lack of shared responsibility, perceived trust, and competition between formal and informal stakeholders. • Interdisciplinary collaboration is lacking.	• Organize the informal sector into associations and cooperatives [14]. • Create partnerships and cooperation among various stakeholders of e-waste management schemes (Basel Convention).
Economic/financial instruments	• Lack of financial support through governmental schemes, as well as lack of economic planning [46,47].	• Microloan initiatives; • Financial incentives through Corporate Social Responsibility (CSR) company and industry and local and national banks [14].
Technical Support	• Absence of advanced technology; • Lack of technical expertise on Advance waste management; • Lack of country appropriated infrastructure-based technology, lacking in proper collection system, storage stations, collection vehicles, etc. [3].	• Collect basic data to assess the current state-of-the-art e-waste management system to identify where improvements are needed; • Launching pilot projects to demonstrate benefits of informal workers being organized; • Provide suitable sorting and storage places and setup, better-quality of secondary raw materials; • Obtain access to suitable advanced technology, both technical assistance and economic support through project scheme; • Provide regular capacity-building programs for those workers engaged in e-waste handling, storage, processing and management.
Policy and legal measures	Lack of policies, strong legislation as well as strong rules and regulations [3].	• Encourage the development of national e-waste policies, rules and regulations, government provision locally and nationally, and environmental law enforcement. • Practice a Waste Prevention approach that reduces reliance on packaging materials, and promotes an active producer responsibility [33,45].

8. An Evaluation of E-Waste Management

A number of studies [5,16,41,43] have evaluated the reasons inhibiting sustainable waste management systems in developing countries (Table 4). From these, strategies proposed include the formation of local associations (Table 3), initially to be supported through Corporate Social Responsibility activities, or through local and national bank [14]. Challenges identified include the need for regular monitoring, public awareness campaigns, collection system standardization, monitoring the proper implementation of the measures and proper transitioning from the informal to the formal sector without the loss of any job opportunities (Table 3). The means by which this can be achieved include the introduction of sustainable waste management techniques, income-based better livelihood options and social development within the formalized e-waste sector.

Table 4. E-waste management opportunities and threats in developing countries [21,22,48].

Opportunity/ Threat	*Costs*	*Gains*
Environmental	Pollution from releases of residual e-waste that damage air, soil and water quality which can contaminate the food chain. Ineffective recycling practices result in complete loss of recoverable resource material and then eventually there will be need for additional primary ore mining of resources.	Environmental protection in terms of soil, air and water pollution can be avoided, also subsequent secondary resource raw materials (gold, copper, etc.) recovery can also help avoid the unnecessary loss to landfills. Also effective processes can help to avoid remediation costs of contaminated sites; ore mining of raw material production can be avoided; and resource raw materials urban mining could be used as feedstock for manufacturing industries that give support to develop green industry.
Social	Informal recycling as a commonly existing practices cause direct social cost of less income, owing to incompetent, ineffective, poor and very hazardous practices as well as indirect social costs such as poor public health.	Formal recycling generates many green jobs with skilled workers as well as better social positions such as employees and entrepreneurs; and good public health as well as lesser occupational risks by the appropriate use of technologies, in addition to comparatively more consistent incomes for engaged workers with job security.
Economic	Informal recycling leads to lost significant value of e-waste, as a result an overall loss in revenues.	Formal sector recycling subsequent in value-added government funds by taxes, for e-waste treatment/disposal facility total technology and investment need to the particular city or region.

An evaluation of the main strengths and weaknesses/opportunities and threats facing e-waste management in developing countries (Table 4). Key strengths identified include an informal sector integration-based collection set-up that ensures the majority of e-waste is collected from the households as well as businesses at low cost [3,49,50]. Developing countries benefit from a very strong repair, refurbishing and reuse market for all kind of EEE, extending the useful life of a such products and appliances past their counterparts in developed countries [51,52]. Most developing countries offer a large market size and the huge volume creates potential opportunity to benefit from economies of scales; through setting up the manufacturing facilities, and a lot of downstream opportunities for further processing as well as material recovery (e.g., secondary smelters and secondary resource recovery) [3,53]. Weaknesses facing e-waste recycling in developing countries include the lack of mechanisms for proper training and skill development of recyclers and dismantler to identify risks; to avoid the associated health risk [10,11]. Furthermore, there is a very limited financial investment in e-waste recycling in these countries in terms of using of technologies and tools for recycling and recovery of valuable metals and resource materials. Developing countries usually suffer from a lack of proper knowledge and information of extended producer responsibility principles as well as mechanisms [54]. Through leveraging the inherent advantages of developing countries, these challenges can be converted into potential opportunities for development as opposed to remaining as extra cost loads [48,55].

9. Conclusions

The introduction of environmentally sound management practices at the local scale that consider specific characteristics and conditions pertaining countries that import e-waste are important to protecting the environment and human-health. Additionally, the development of decision and policy-making procedures that cater for the needs of informal workers, particularly the disadvantaged ones, by organizing them into associations and cooperations that operate based on circular economy principles is detrimental to preventing unintended consequences that span across health, social, economic and environmental impacts. E-waste laws and regulations within developing countries need to be little reformed to enable inclusivity and equity, including that of informal sector formalization. Many of the challenges facing developing countries in this regard generally result from a lack of strong environmental governance, that prioritizes the integration of the informal sector rather than the formal sector, and promotes environmental awareness and action towards the use of the best available e-waste management technologies and the coordination of the activities of all stakeholders involved in the e-waste management system. Such an indigenous, systematic and organized approach to e-waste management in developing countries will allow the e-waste problem be resolved systematically at both the global and national scale.

Author Contributions: Conceptualization, A.K.A.; methodology, A.K.A. and E.I.; Validation, M.J., K.P. and M.Z.; formal analysis, K.P.; investigation, M.Z.; resources, A.K.A. and A.K.P.; data curation, M.Z.; writing—original draft preparation, A.K.A.; writing—review and editing, E.I., M.K.A. and S.M.; visualization, K.P. and M.J.; supervision, A.K.P. All authors have read and agreed to the published version of the manuscript.

Funding: The authors disclosed no financial funding support for the research, authorship, and/or publication of this article.

Data Availability Statement: Data is contained within the article.

Acknowledgments: Author A.K.A is grateful to School of the Environment, Nanjing University, Nanjing China, for support and encouragement for international collaboration. We all the authors acknowledge the editor and anonymous reviewers for their valuable comments/suggestions/feedback on this contribution. The authors are thankful to all colleagues for encouragement and support.

Conflicts of Interest: The authors declare no conflict of interest.

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