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Review Article

SUSTAINABLE ELECTRONIC SOLID WASTE MANAGEMENT: A CASE OF UGANDA

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ABSTRACT

With growing civilization and the widespread advancement of information technology, electronic waste (e-waste) management has become a significant concern globally. E-waste is generated in large quantities globally and Uganda is not spared. There is an increase in the importation of electronic goods and the implementation of information and communication technologies. Due to the lack of enough infrastructure to manage e-waste, alarming volumes of e-waste have been accumulated in the environment leading to the release of toxic hazardous substances that contaminate the environment and threaten human health. On the contrary, e-waste provides opportunities if handled well such as the recovery of precious metals for reuse and employment opportunities for the handlers thus improving their livelihoods. A literature review is conducted to identify the key drivers to sustainable development management of e-waste. Additionally, the review provides sustainable practices for managing e-waste such as reduction, repurposing, refurbishment, remanufacturing, repair, recovery, reuse and recycling. Several factors from environmental, social and economic aspects are key drivers that contribute to the sustainable management of e-waste. E-waste management is still a huge challenge in Uganda and the need for strategies and a clear action plan is key for appropriate management of e-waste. The review underscores the need for a converted approach involving the government, industries and communities to tackle these challenges and affect the adoption of effective e-waste sustainable management practices. Overall, this review suggests a comprehensive overview of e-waste management in Uganda and mentions the importance of adopting sustainable practices to address the rising volumes of e-waste.

INTRODUCTION

The rise in widespread technological advancement and civilization in developing world economies has led to overdependency on electronic devices (Anam et al., 2023). Certainly, it is undeniable that in the present era, it is inconceivable for anyone to live a life without electronics. Electronics often lead to a more dynamic lifestyle and have become an integral part of our lives (Anam et al., 2023). The rapid increase in the number of electrical and electronic equipment along with their brief lifespans has led to a significant accumulation of electronic waste (e-waste) (Nyeko et al., 2022). A study conducted by the United Nations University found that the world produces approximately 40 million tonnes of waste electrical and electronic equipment annually (Davis et al., 2010). E-waste encompasses all electrical and electronic devices intended for reuse, resale, salvage, recycling, or disposal (Anuardo et al., 2023).

Most existing research has primarily focused on the motivations behind participating in the e-waste chain and recycling in developed economies (Ismail et al., 2020; Awasthi et al., 2023) however, these studies lack a suitable framework to discuss the important barriers that lead to customer reluctance in e-waste recycling efforts (Asante et al., 2019). Limited studies identified the drivers in the implementation of sustainable e-waste management (Bhutta et al., 2011; Nandan et al., 2023). Noted that the end user's unwillingness to recycle e-waste was one of the

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main challenges requiring scholar's urgent attention in research. Ananno suggested that there is a need to study and analyze consumer behavior on e-waste management methods (Ananno et al., 2021). A study by Davis and Herat identified access to reprocessing facilities and limited public awareness as key barriers experienced by local councils in the management of e-waste (Davis, et al., 2010).

Although there are numerous societal and environmental advantages to proper management of e-waste, consumers often resort to illegal and openly dumping e-waste residues and non-functional parts (Davis, et al., 2010; Awasthi et al., 2023; Asante et al., 2019; Ananno et al., 2021). The rampant and illegal disposal of e-waste was attributed to a combination of factors, including insufficient awareness, absence of financial incentives ineffective enforcement of laws, inadequate regulations, limited access to recycling and disposal facilities, and the convenience of such actions (Jangre et al., 2022; Bhutta et al., 2011; Lowe et al., 2013). Therefore, it is important to understand consumer behavioral perspectives related to the recycling and disposal of e-waste to ensure sustainable management of e-waste. There is still a lack of public awareness and insufficient infrastructure are a few of many hindrances that need to be overcome. These stakeholders play a key role in recycling e-waste, formulation of policy and resource mobilization (Anam, et al., 2023; Nyeko et al., 2022; Ismail et al., 2020; Awasthi et al., 2023).

This review is aimed at identifying drivers that can enhance the development of sustainable systems for managing and recycling e-waste in economic, environmental, and social aspects. More so, the review identifies where future improvements are needed to explore the drivers identified for sustainable implementation of e-waste management in Uganda.

LITERATURE REVIEW

Methodology

In this review, we modified the data sources used by to obtain information from original peer-reviewed articles published in legitimate scientific journals, especially focusing on the sustainable management of solid electronic waste (Nandan, et al., 2023). We carefully searched through electronic literature databases including science direct, and google scholar for relevant records for the period of 2000 to 2023. The following key search terms were used "e-waste", "sustainable e-waste management" and "e-waste management", the selection of publications was limited to journal articles written in english. The data obtained were verified independently for their accuracy and any discrepancies were resolved through collaborative discussions among authors. The final data obtained were summarized, analyzed, compared and conclusions were made accordingly.

Categories of e-waste

E-waste arises from different sources including but not limited to industries, businesses, households and offices (United Nations Industrial Development Organization, 2013). E-waste can be grouped into different categories including Information and Communications Technology (ICT) equipment, personal electronics, and domestic appliances. ICT equipment including laptops, printers, scanners, mobile phones and cable wires are contributors to e-waste (Jangre et al., 2022) as shown in Figure 1. Domestic appliances such as fridges, microwaves, washing machines, air conditioners, and ovens significantly contribute to e-waste (Anuardo et al., 2023). Generally, e-waste includes ferrous and non-ferrous metals, as well as plastics, glass, wood and plywood, Printed Circuit Boards (PCB), concrete and ceramics, rubber and other products. E-waste contains about 50% iron and steel, then plastics (21%), non-ferrous metals (13%) and other components (Garlapati, 2016).

Fig. 1 Some of the e-waste in an electronic repair store in Kampala.

Status of e-waste in Uganda

In Uganda, electrical and electronic goods are recognized as necessary for the country's economic advancement. Consequently, there's a growing emphasis on infrastructure projects and development plans that integrate electronic devices, especially Information and Communications Technology (ICT), which are being actively encouraged and implemented nationwide. Uganda being one of the economically low-income countries, is one of the destinations for e-waste from Europe and Asia. Particularly in Uganda, the collection amount of e-waste from 2013 to 2018 was estimated at 17,000 tonnes. According to the data from the Uganda Revenue Authority (URA) for 2021, a total of 32,803.57 tonnes of electrical and electronic goods were on the market comprising 99.388% as new and 0.612% as second-hand (Ssekajja et al., 2023).

The data indicated batteries and solar equipment were the highest on the market as shown in Figure 2 below.

Fig. 2 Composition of imported Electronic equipment in 2021. **Note:** ( ) Consumer equipment 22%; ( ) Solar and batteries 32%; ( ) Household appliances 22%; ( ) Lighting equipment's 17%; ( ) Electrical tools 5%; ( ) ICT 2% and ( ) Medical 0%.

Uganda faces the challenge of e-waste management that is increased by weak systems of electronic device importation quality control, resulting in a high percentage of sub-standard and counterfeit devices being imported into the country (Uganda Communications Commission, 2023). Without an adequate system for managing e-waste, it is anticipated that these electronics will contribute to the overflow of the waste stream. However, the management of the e-waste has not been sufficiently incorporated into plans aimed at safely utilizing electronic devices. One notable initiative is the establishment of an e-waste management center by the National Environment Management Authority (NEMA) and the National Enterprise Corporation in 2021. This center aims to streamline the collection of all e-waste and repurpose it into valuable resources while safeguarding the environment from harmful waste materials.

Households and offices represent the initial stage of the value chain, but the government has not implemented any restrictions on them to curb the percentage of e-waste generated.

Impact of e-waste

The surge in electronic waste due to the advancement poses a growing concern and calls for serious international deliberation on methods to tackle the challenge. Many people remain uninformed about the potential adverse consequences resulting from the increased utilization of phones, computers, monitors, and televisions. E-waste has become a serious threat to the environment and human health. When e-waste is disposed of without controls, it leads to negative effects on the environment and human health. The components of electronic products contain toxic substances and hazardous materials such as nickel, beryllium, lead, mercury, zinc and cadmium. These toxic materials can pollute the air, water, and soil when e-waste is improperly disposed of causing ecological pollution and health risks like reproductive system diseases, cancer and nervous system illnesses. In addition, e-waste leads to the production of greenhouse gases when disposed of (United Nations Industrial Development Organization, 2013). The poor disposal and handling of e-waste lead to major health problems for the people in their surroundings (Asante et al., 2019). With a surge in e-waste accumulation in landfills, the likelihood of increased exposure to environmental pollutants rises, potentially leading to increased risks of cancer, as well as developmental and neurological disorders (Bhutta et al., 2011). This necessitates proper management of e-waste.

Approaches of e-waste management

Sustainable e-waste management is more difficult to achieve than traditional e-waste management (Awasthi et al., 2023). There are several approaches related to sustainable e-waste management. Faulty electrical equipment and electronics are repaired and either returned to the owner or sold off as secondhand. In case the faulty equipment and electronics cannot be repaired, repair shops just obtain useful spare parts and dismantle the rest to obtain base metals and useful components that are sold to scrap dealers (Ssekajja et al., 2023). Most studies indicate that recycling is one of the strategies for end-of-life waste management of electronics and electrical products (Anam et al., 2023; Ismail et al., 2020). The most applied method of handling e-waste was storage in Uganda in 2021 as shown in Figure 3 below.

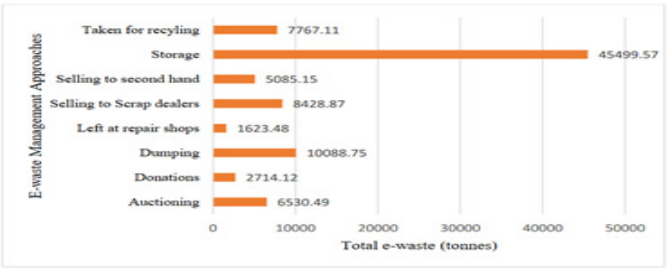

Fig. 3 The distribution of e-waste along the different management approaches in Uganda in 2021.

Recycling is considered one of the best options in the electronic solid waste management hierarchy to reduce the impacts presented by end-of-life and end-of-use post-consumer utilization. Recycling provides an opportunity to use recovered e-waste to manufacture a new product hence contributing to sustainable manufacturing and environmental benefits. Recycling is also considered the second most environmentally beneficial approach for managing e-waste preceded only by the preventive strategies of source reduction and reuse. Other mechanisms to deal with e-waste include reusing and refurbishing the devices to reduce e-waste volume disposed into the environment (Ananno et al., 2021).

Though there is a struggle to manage e-waste properly, especially among the local communities, there are several drivers that can influence proper e-waste management through recycling to drive sustainability. Despite several studies having been conducted on the recycling of e-waste, a majority of these have used life cycle assessments to evaluate the environmental, economic, and social impacts of the processing and recycling chain (Asante et al., 2019). Other studies have compared the environmental and economic impacts of different recycling technologies of e-waste (Bhutta et al., 2011). The studies are useful in suggesting sustainable technologies for recycling e-waste (Madkhali et al., 2022). E-waste recycling can be considered an aspect of sustainable manufacturing because it involves utilizing recovered plastic waste to create new products that would otherwise be made from virgin materials (Gaur, et al., 2023). identified the most common practices leading to effective sustainable e-waste management (Table 1).

Table 1. Common practices that promote effective sustainable e-waste management.

Sustainable practice	Impact of the practice
Reduction	This increases the efficiency of manufactured products by using fewer virgin materials
Repurpose	This uses e-waste items for a completely different function to serve another purpose from the original goal
Refurbishment	This aims at repairing, cleaning, lubricating, cleaning, replacing, or upgrading the e-waste item for resale
Remanufacturing	This involves the use of a combination of reused, repaired and new parts to produce or rebuild a product to its specification. This minimizes its products' environmental footprint by using fewer resources
Repair	This involves fixing a product by putting something together to bring it back to its original state
Recovery	This involves the process of extracting valuable materials from waste and incineration of materials with energy recovery
Reuse	This involves repurposing the item for its original or different purpose. This significantly reduces waste and pollution
Recycling	This involves converting the waste generated to produce other products

Drivers of sustainable e-waste management

Drivers in this review are mechanisms that can significantly impact development in the sustainable recycling of e-waste. These drivers lay a foundation for establishing an e-waste management system, garner the attention of all stakeholders, and inspire the general populace to enhance their awareness of e-waste management as a component of achieving sustainable recycling. Consequently, there is a pressing need to address the proper management and disposal of this waste, especially in developing economies. Therefore, understanding the key factors driving e-waste management, particularly within the context of Uganda, is significant. Without addressing these pivotal drivers, challenges in e-waste management are likely to persist, regardless of ongoing research efforts and the adoption of new technologies in developing economies. Various research approaches have extensively examined the imperative of identifying the factors or drivers affecting the sustainable development of e-waste recycling and management systems. The reviewed work was analyzed to classify the drivers into three aspects of sustainability. These aspects include economic, environmental and social.

Environmental drivers: Environmental concerns such as climate change, global warming and the need for environmental protection play key roles in managing e-waste. Suggest that there is a need for producer companies to have an environment management system that sets standards and guidelines in the supply chain for environmental monitoring (Zhou et al., 2017). Environmental regulations and policies on e-waste management encourage electronic companies to incorporate sustainable practices into their operational and business activities (Xu et al., 2018). Investment in research and development, along with the development of digital capabilities, are essential for the advancement of eco-design and green manufacturing technologies, aiding in the management of e-waste (Zhou et al., 2017). The adverse impact of post-consumer waste on the environment underscores the importance of educating communities and households about the effects of e-waste, which is essential for the sustainable development of systems. These factors are pivotal in influencing and mobilizing the informal sector to actively engage in and

enhance sustainable recycling systems.

Economic drivers: From the economic aspect of sustainability, e-waste is considered a valuable resource in sustainable e-waste management implementation (Aarti et al., 2017). However, there is a huge investment required for the recycling of e-waste (Awasthi et al., 2023). There is a need for governments to consider formulating policies to encourage electronic manufacturers to adopt green practices such as tax incentives, to minimize hazardous emissions (Anam et al., 2023; Aarti et al., 2017). Asserted that material and energy recovery from e-waste recycling provide an investment benefit by reducing the use of virgin material and easy extraction of rare earth material (Coban et al., 2018). Advance recycling fee is a key economic enabler that adds an extra fee to consumers to pay an extra tax that covers future recycling and disposal costs (Zhou et al., 2017). Therefore, municipalities and local governments must perceive e-waste as a valuable resource. At the community level (informal sector), people need to be educated and sensitized to be aware of e-waste as a resource. When the local community and households perceive e-waste as a resource, even the introduction, adoption and implementation of recycling strategies for sustainable development can be progressive.

Social drivers: Social factors, including public awareness, the widespread use of electronics, population growth and education, have played a significant role in driving informal e-waste management (Davis et al., 2010). As the global population expands, so does the consumption of electronics, leading to an increase in waste generation (Abalansa et al., 2021). To effectively manage this growing issue, it is imperative to consider the impact of human behavior on electronic consumption and its subsequent waste.

Community awareness and involvement regarding environmental protection from e-waste contamination are key social drivers to attain sustainable e-waste management (Xu et al., 2018). Suggested that the idea of green collaboration revolves around reducing e-waste by establishing a shared environmental objective and offering necessary support through technology exchange, information dissemination and training for recycling personnel (Gupta et al., 2016). This approach aims to reduce hazardous waste, thereby making a positive contribution to the social aspect. However, without adequate education and awareness, achieving sustainable development in e-waste management remains unattainable. It is essential to educate local communities and households about recycling strategies to foster a culture of sustainability.

From the literature, producer and consumer responsibilities, along with policies and regulations, emerge as key catalysts for fostering the sustainable development of e-waste management systems across economic, social and environmental dimensions. Producers and importers of electronics and e-waste must assume accountability for its management. Despite the existence of recycling systems, sustainable e-waste recycling hinges on the proactive engagement of both producers and consumers.

DISCUSSION

This review intends to identify drivers that influence the development of sustainable systems for managing e-waste. Upon further examination of the existing research studies, it becomes apparent that the data currently available does not offer all the avenues for improving sustainable practices in managing e-waste in Uganda. To address this gap, the following findings are presented within various contexts related to the identified factors, aiming to suggest potential actions that could enhance the acceptance of e-waste recycling moving forward.

Need to participate the informal sector

There is an inherent component of invisibility and unlawfulness associated with the informal sector (Asante et al., 2019). The first step would be to recognize the informal sector more explicitly as a critical stakeholder in any future e-waste regime. Addressing the problem of informal sector e-waste practices requires a greater understanding of the sector itself in terms of its incentives and challenges (Abalansa et al., 2021). Participated with the informal sector workers and the groups, in a manner that recognizes their right to livelihoods, builds trust and develops a shared understanding of the problems along with potential solutions, is a critical initial step (Garlapati et al., 2016).

Need to have manufactures responsibility come into implemented

Economic instruments such as advanced recycling fees or advanced disposal fees on every unit of the product sold in the market would relieve the manufacturers of the physical responsibility of collection and the revenues generated could be used to develop markets for the end-of-the-life products (Davis et al., 2010).

Promote public awareness of e-waste

One of the critical reasons for the failure in the implementation of the current regulation can be attributed to low levels of awareness among consumers and waste generators (United Nations Industrial Development Organization, 2013). There is very little understanding of the stakeholders and their role in e-waste management (Garlapati et al., 2016). Most consumers are unaware of the end-of-life management of electronic products. Citizens, if sensitized can help strengthen the informal networks by passing on waste to them and stopping them from undertaking some of the most toxic processes (Asante et al., 2019).

Proper regulation on E-waste imports

Under the existing regulation, e-waste is not allowed

to be imported for final disposal but can be imported for reuse and recycling (United Nations Industrial Development Organization, 2013). With the absence of adequate infrastructure in the country for recycling, we should affect the resolutions of the 15th meeting of the basel convention Conference of the Parties (COP 15) to ban all kinds of illegal e-waste imports, similar to what China did in recent years. We should develop accurate estimates of e-waste data on imports and integrate them with the e-waste inventory (Bahers et al., 2016).

Promote efficient recycling processes

Poor recycling and recovery processes mean lower revenues from the materials, creating larger financing gaps and the likelihood of environmental effects (Xu, et al., 2018). The weakest link in the chain determines overall efficiency (Garg, 2021). A highly efficient system with a good collection and recovery rate can capture a higher share of the intrinsic value than a system with a high collection rate but a low recovery rate. Programs to upgrade the skill sets and build capacities of the sector in dismantling and segregating various kinds of e-waste are imperative (Sharma et al., 2020). Training and skill set upgradation of the informal sector to understand good environmental, safety and health practices will also create environment-friendly e-waste recycling practices (Zeng et al., 2017).

CONCLUSION

The explosion of electronic products over the last decade or so, and the corresponding rapid rise in e-waste pose a significant environmental challenge to governments, particularly in developing countries like Uganda. The limited impact that current regulations have had is an indication of the challenges that the country faces as far as e-waste management is concerned. This review identifies informal sector e-waste practices, poor regulatory design and enforcement and low awareness as some of the challenges that Uganda faces. The meaningful way forward is how to engage all the stakeholders to make e-waste an economic resource, environmentally friendly and socially acceptable.

LIMITATIONS

This review has some limitations. First, during our review process, we included information in reports that are locally published hence our findings could be affected by publication bias. Second, we might have missed studies or vital information published on other sites other than those we focused on. Nevertheless, this review is very significant in sustainable e-waste management in Uganda.

DECLARATION OF COMPETING INTEREST

The authors affirm that they do not possess any conflicting financial interests or personal relationships that might have been perceived to influence the findings presented in this paper.

AUTHORS' CONTRIBUTIONS

A. Tumwebaze is the author of the review. T. Dennis, E. Baluku and O. S. Francis reviewed and edited the work. R. Komakech as a corresponding author.

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