Article

Not peer-reviewed version

# Circular Economy Development Metrics for E-waste Residuals and Attendant Economic Consequences

Jacob misiko Neyole *, Saad Minado Okwiri, Nelson Mapema

Posted Date: 25 June 2024

doi: 10.20944/preprints202406.1780.v1

Keywords: Circular Economy; Metrics; E-Waste Residuals; Economic Consequences

*Article*

# Circular Economy Development Metrics for E-Waste Residuals and Attendant Economic Consequences

**Saad Okwiri Minado [1], Nelson Mapema [2] and Neyole Misiko [3,*]**

[1] Umma University, Kajiado, Keya; sminado@umma.ac.ke
[2] Multimedia University of Kenya; nmapema@gmail.com
[3] Umma University TVET Institute, Thika, Kenya
* Correspondence: njacob@tvet.umma.ac.ke

**Abstract:** As the global overprovisioning of electronic devices continues to rise, the management of electronic waste (e-waste) has developed as a significant challenge. E-waste is comprised of hazardous materials; moreover, the toxic constituents in them can impact the environment and public health through improper disposal. On the beneficial side, this e-waste also contains some valuable materials. If the valuable materials are recovered, they can reduce the dependence on new, raw materials. Conventional linear models of production and consumption have led to a momentous buildup of e-waste, posing environmental and economic risks. This paper examines how the adoption of a circular economy approach can improve e-waste recycling in Nairobi by evaluating its economic recovery potential and e-waste residuals. It introduces metrics to assess the development of circular economy practices to help in the handling of e-waste residuals and examines the economic consequences associated with the adoption of circular strategies.

**Keywords:** circular economy; metrics; e-waste residuals; economic consequences

## 1. Introduction

Today, electronic devices are everywhere. According to Kenya Climate Innovation Center (2021), Kenya's annual electronic waste generation is 51,000 tons. The electronics industry has grown and developed exponentially over time, resulting in unprecedented levels of e-waste, characterized by discarded electronic devices and their components.

The conventional linear model of consumption, characterized by extraction, production, use, and disposal, has proven unsustainable. The circular economy offers an alternative paradigm, emphasizing resource efficiency, product life extension, and recycling. This paper aims to establish metrics frameworks for evaluating thresholds for e-waste residuals specifically tailored to the development of circular economy practices. Nairobi has a policy on the collection and recovery of obsolescent electronic devices which can be improved. A common, binding mechanism can be drawn from this paper.

Circular Economy principles aim to eliminate waste and pollution; they circulate resources and regenerate nature through improved design. In a Circular Economy, the life cycle of consumer electronic products is extended and kept in use for longer times. They are efficiently remanufactured for repairing, refurbishing, reusing, recovering, or recycling the valuable components.

There is such an extended producer responsibility in developed worlds, whose framework is also based on circular economy principles. It provides for a take-back coalition scheme; the producer takes back the waste products from the consumer for recovery and recycles the materials. It is a successful strategy to recover valuable metals from e-waste and to mitigate future environmental and economic risks.

E-waste is composed of a mix of materials like copper, silver, gold, aluminum, plastic, and heavy metals that can contaminate the environment when disposed of. For example, they produce dioxins, which are persistent organic pollutants that have been found to exist in human hair and breast milk in certain studies. Certainly, these are a threat to the well-being of mothers and children.

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 25 June 2024 doi:10.20944/preprints202406.1780.v1



E-waste management is an important item of various SDGs (Sustainable Development Goals) in the 2030 Agenda for Sustainable Development adopted by the UN and its member states in the year 2015.

### *1.1. Problem Statement*

Whereas we live in the information age and use of materials is inevitable in the manufacture of gadgets and equipment that facilitate the information economy; and whereas these products have a limited lifespan and are traditionally disposed resulting in adverse effects to the ecosystems, is there a way that they could be profitably adopted into circular economy with the resultant beneficial effect to the said ecosystem in Nairobi?

### *1.2. Objectives of the Study*

The general objective of the study was to explore measurements usable in the determination of electronic waste with the view to put qualities and quantities to potential absorption of the e-waste into circular economy, with attendant benefits.

Specific objectives were:

(i) To identify key metrics for e-waste characterization

(ii) To develop a framework for quantitative assessment of usable e-waste

(iii) To conduct case studies and empirical analyses

(iv) To evaluate economic and environmental impacts of e-waste

### *1.3. Justification of the Study*

(i) Environmental Impact and Sustainability Concerns:

Electronic waste poses significant environmental challenges due to its hazardous components and improper disposal methods.

(ii) Economic Opportunities and Resource Recovery Potential:

E-waste contains valuable resources, including metals, rare earth elements, and plastics, which can be recovered and reused in manufacturing processes.

(iii) Policy Imperatives and Regulatory Frameworks:

Governments and international organizations are increasingly prioritizing e-waste management and circular economy strategies through policy interventions and regulatory frameworks.

### *1.4. Limitations of the Study*

(i) Complexity of E-Waste Composition;

(ii) Data Availability and Reliability;

(iii) Technological Advancements and Innovation;

(iv) Regulatory and Policy Constraints;

(v) Resource and Infrastructure Constraints;

(vi) Social and Behavioral Factors.

Consumer behaviors, attitudes, and awareness regarding e-waste disposal and recycling practices influence the success of circular economy initiatives.

## 2. Literature Review

E-waste, composed of discarded electronic devices, poses significant environmental and health risks globally. However, it also presents opportunities for resource recovery and economic benefits within the framework of the circular economy. This literature review explores existing research on circular economy development metrics for e-waste residuals and the economic consequences associated with their management and utilization.

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 25 June 2024 doi:10.20944/preprints202406.1780.v1



Ellen McArthur Foundation states that a circular economy is a system where the economic growth is dissociated from the consumption of finite resources by utilizing the materials and components at their highest value and designing the waste out of the system. The following is a diagrammatic representation of the general scenario:

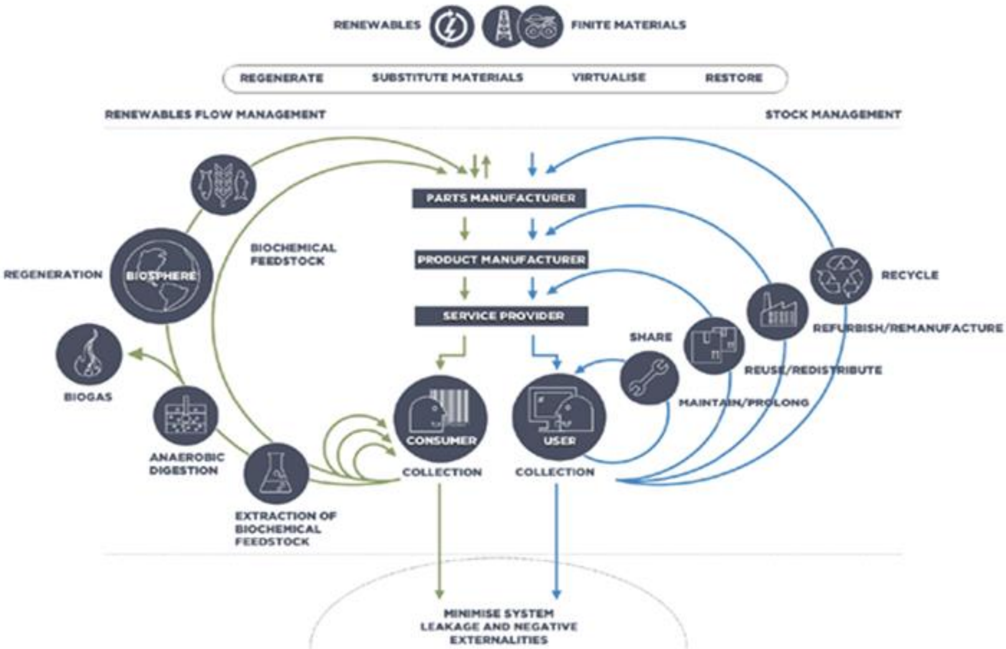


**Figure 1.** Showing Circular Economy (Meloni & Sturges, 2017).

## Circular Economy Development Metrics

### *2.1. Material Recovery Rate*

Research by M. Mathieux et al. (2019) emphasizes the importance of measuring material recovery rates from e-waste to assess the effectiveness of circular economy initiatives. Metrics such as the percentage of materials recovered from e-waste streams provide insights into resource efficiency and the potential for secondary material utilization.

### *2.2. Recycling Efficiency*

H. Hotta et al. (2020) propose metrics to evaluate the efficiency of e-waste recycling processes, considering factors such as energy consumption, material purity, and resource recovery yields. High recycling efficiency metrics indicate optimized resource utilization and reduced environmental impacts.

### *2.3. Circularity Index*

The circularity index, as discussed by S. Sprecher et al. (2021), quantifies the degree to which e-waste management practices adhere to circular economy principles. This metric integrates indicators related to material recovery, product lifespan extension, and end-of-life strategies, providing a comprehensive measure of circularity in e-waste management systems.

### *2.4. Value Retention*

J. J. P. de Kleijn et al. (2018) highlight the importance of measuring value retention in e-waste streams, which refers to the ability to preserve and recapture value from discarded electronic products. Metrics such as the economic value of recovered materials and components reflect the financial benefits of circular economy practices.

## Economic Consequences

 doi:10.20944/preprints202406.1780.v1



### *2.5. Resource Conservation*

A study by R. Cucchiella et al. (2018) underscores the economic benefits of e-waste recycling in terms of resource conservation. By recovering valuable materials such as precious metals and rare earth elements from e-waste, circular economy practices reduce the need for primary resource extraction, mitigating supply chain risks and enhancing resource security.

### *2.6. Job Creation*

Research by K. Madani et al. (2019) highlights the potential for e-waste recycling to generate employment opportunities and stimulate economic growth. Circular economy initiatives in e-waste management create jobs across the value chain, including collection, dismantling, refurbishment, and recycling activities, thereby contributing to local livelihoods and socioeconomic development.

### *2.7. Market Development*

The development of e-waste recycling markets is examined by A. J. Grainger et al. (2020), who emphasize the role of circular economy policies and incentives in driving market demand for recycled materials and products. By creating markets for secondary resources, circular economy practices stimulate innovation, investment, and entrepreneurship in the e-waste recycling sector, fostering economic diversification and competitiveness.

## **3. Conclusion**

The literature review highlights the importance of adopting comprehensive metrics to assess circular economy development in e-waste management and the significant economic consequences associated with sustainable resource utilization and recovery. By incorporating circular economy principles into e-waste management strategies, policymakers, businesses, and stakeholders can realize economic benefits while addressing environmental and social challenges posed by e-waste residuals. Further research is needed to refine measurement methodologies, evaluate policy effectiveness, and quantify the long-term economic impacts of circular economy initiatives in the e-waste sector.

### *3.1. Research Design*

This research adopted a mixed-methods approach, incorporating both quantitative and qualitative techniques to assess circular economy development metrics for e-waste residuals and their economic benefits/consequences. The study involved a combination of literature review, data analysis, case studies, and stakeholder interviews to gather comprehensive insights into the topic. The research analysis started with an overview of circular economy strategies applicable in the e-waste space. We sought to understand the current framework in e-waste management. We estimated e-waste generation, recycling, and economic potential of e-waste in Nairobi. This was done through Market Supply Method which included gathering the data from the Kenya National Bureau of Statistics to 2023. This assisted in estimating the e-waste generation rate in Nairobi. We then determine the economic potential of e-waste recovery.

A policy analysis of Nairobi's e-waste policies and regulations was done through Systems Analysis framework to understand the current progress and status of policy actions. This was followed by a Comparative Analysis to compare the policies and frameworks of the e-waste recycling program in Nairobi with UN-recommended standards.

### *3.2. Literature Review*

A thorough review of existing literature was conducted to identify relevant theories, concepts, methodologies, and empirical studies related to circular economy metrics for e-waste management and their economic implications. Key databases such as PubMed, Scopus, Web of Science, and Google Scholar were utilized to search for peer-reviewed articles, reports, conference papers, and policy documents.

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 25 June 2024 doi:10.20944/preprints202406.1780.v1



*3.3. Data Collection*

3.3.1. Quantitative Data

Data on e-waste generation, collection, recycling rates, and economic indicators were collected from the National Bureau of Statistics (KNBS), research institutes (KIRDI and IDDI), and industry reports. Economic data such as market value, employment figures, and revenue generated from e-waste recycling activities were obtained from relevant industries.

3.3.2. Qualitative Data

Semi-structured interviews were conducted with stakeholders involved in e-waste management, including policymakers, industry representatives, waste management experts, and community leaders. Case studies of successful circular economy initiatives in e-waste management were analyzed to understand the strategies, challenges, and economic outcomes associated with these practices.

## 4. Development of Measures and Metrics

Based on the findings from the literature review and stakeholder consultations, a set of circular economy development metrics for e-waste residuals were identified and refined. Metrics included material recovery rates, recycling efficiency, circularity index, value retention, job creation, market development, and environmental impact indicators.

**The table below gives typical results over years:**

**Table 1.** Reabsorption of e-waste by year and category.

| Year | Recycling (%) | Refurbishment (%) | Reuse (%) | Resource Recovery (%) |
|---|---|---|---|---|
| 2014 | 30 | 20 | 15 | 35 |
| 2015 | 32 | 22 | 16 | 30 |
| 2016 | 35 | 25 | 14 | 26 |
| 2017 | 38 | 27 | 13 | 22 |
| 2018 | 40 | 28 | 12 | 20 |
| 2019 | 42 | 30 | 11 | 17 |
| 2020 | 45 | 32 | 10 | 13 |
| 2021 | 48 | 34 | 9 | 11 |
| 2022 | 50 | 36 | 8 | 10 |
| 2023 | 52 | 38 | 7 | 8 |

*4.1. Circular Economy Development Metrics*

Circular economy development metrics play a crucial role in assessing the effectiveness of strategies aimed at managing e-waste residuals sustainably. This section outlines key metrics utilized to measure the progress and impact of circular economy initiatives in the context of e-waste management.

4.1.1. Material Recovery Rate

Material recovery rate refers to the percentage of materials recovered from e-waste streams through recycling, refurbishment, or resource recovery processes. It serves as a fundamental metric

 doi:10.20944/preprints202406.1780.v1



for evaluating the efficiency of circular economy practices in retaining and reutilizing valuable resources.

4.1.2. Recycling Efficiency

Recycling efficiency metrics assess the effectiveness of e-waste recycling processes in terms of energy consumption, material purity, and resource recovery yields. Higher recycling efficiency indicates optimized resource utilization and reduced environmental impacts associated with e-waste management.

4.1.3. Circularity Index

The circularity index quantifies the degree to which e-waste management practices adhere to circular economy principles. It integrates indicators related to material recovery, product lifespan extension, and end-of-life strategies, providing a comprehensive measure of circularity in e-waste management systems.

4.1.4. Value Retention

Value retention metrics assess the ability to preserve and recapture value from discarded electronic products. They include indicators such as the economic value of recovered materials and components, reflecting the financial benefits of circular economy practices in e-waste management.

*4.2. Economic Consequences*

The economic consequences of e-waste residuals and circular economy development metrics are multifaceted, encompassing both direct and indirect impacts on various stakeholders and the broader economy. This section examined the economic implications associated with sustainable e-waste management practices.

4.2.1. Resource Conservation

Circular economy practices in e-waste management contribute to resource conservation by recovering valuable materials such as precious metals and rare earth elements from electronic devices. This reduces the need for primary resource extraction, mitigating supply chain risks and enhancing resource security.

4.2.2. Job Creation

The adoption of circular economy initiatives in e-waste management creates employment opportunities across the value chain, including collection, dismantling, refurbishment, and recycling activities. This stimulates economic growth, enhances local livelihoods, and fosters skill development in the e-waste recycling sector.

4.2.3. Market Development

Circular economy practices promote the development of e-waste recycling markets by creating demand for recycled materials and products. This stimulates innovation, investment, and entrepreneurship in the e-waste recycling sector, fostering economic diversification and competitiveness.

*4.3. Case Studies and Examples*

This section presents case studies and examples of successful circular economy initiatives in e-waste management, highlighting the application of circular economy development metrics and the attendant economic consequences in real-world contexts.

4.3.1. Case Studies and Best Practices

**Case I: Agbogbloshie E-Waste Management Program - Ghana**

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 25 June 2024 doi:10.20944/preprints202406.1780.v1



**Overview:** Agbogbloshie, located in Accra, Ghana, gained fame as one of the largest e-waste dumping sites globally. Lately, Agbogbloshie has transformed into a hub for sustainable e-waste management through circular economy initiatives.

**Key Metrics:**

- **E-Waste Collection:** The program involves the systematic collection of e-waste from various sources, including households, businesses, and informal collectors, to prevent improper disposal.
- **Material Recovery:** Advanced recycling techniques are employed to recover valuable materials such as copper, gold, and aluminum from e-waste items.
- **Job Creation:** The initiative has created employment opportunities for local residents, including waste pickers, technicians, and entrepreneurs involved in e-waste recycling and refurbishment activities.

**Economic Outcomes:**

- **Revenue Generation:** The recovered materials are sold to local and international markets, generating revenue for the participants in the e-waste management program.
- **Cost Savings:** By reclaiming valuable materials from e-waste, the program reduces the need for raw material extraction, leading to cost savings for manufacturers and resource conservation.
- **Community Development:** The program contributes to the socio-economic development of the surrounding community by providing stable employment and fostering entrepreneurship in the e-waste recycling sector.

4.3.2. Case Studies and Best Practices

**Case II: WEEE Centre - Kenya:**

**Overview:** The Waste Electrical and Electronic Equipment (WEEE) Centre in Nairobi, Kenya, is a pioneering initiative aimed at promoting responsible e-waste management and recycling in East Africa. It operates based on circular economy principles, emphasizing the recovery and reuse of electronic components and materials.

**Key Metrics:**

- **E-Waste Collection:** The WEEE Centre facilitates the collection of e-waste from various sources, including households, businesses, and government agencies, through its network of collection points and partnerships.
- **Resource Recovery:** Advanced recycling technologies are employed to dismantle, refurbish, and recycle e-waste items, with a focus on maximizing the recovery of valuable materials such as metals, plastics, and glass.
- **Capacity Building:** The WEEE Centre provides training and capacity-building programs for local technicians and entrepreneurs involved in e-waste recycling and refurbishment activities, thereby promoting skill development and job creation.

**Economic Outcomes:**

- **Market Development:** The WEEE Centre creates market opportunities for recycled electronic components and materials, fostering the growth of a circular economy ecosystem in the region.
- **Value Addition:** By refurbishing and recycling e-waste items, the initiative adds value to discarded electronics, thereby contributing to the local economy and reducing the reliance on imported goods.
- **Environmental Benefits:** The WEEE Centre helps mitigate the environmental impacts of e-waste by promoting responsible recycling practices and reducing the accumulation of electronic waste in landfills and informal dumping sites.

 doi:10.20944/preprints202406.1780.v1



In summary, these examples demonstrate how circular economy initiatives in e-waste management can generate economic value, create employment opportunities, and promote sustainable development in Africa. By adopting innovative approaches and leveraging local resources, countries across the continent can address the challenges of e-waste while harnessing the economic potential of circular economy practices.

The Waste Electrical and Electronic Equipment (WEEE) Centre in Nairobi, Kenya, serves as a pioneering example of circular economy initiatives in e-waste management. Through the utilization of circularity index and value retention metrics, the WEEE Centre has contributed to economic development, market expansion, and environmental sustainability.

## 5. Conclusions

The study identified and established key metrics and indicators for characterizing e-waste, including aspects such as material composition, recyclability, toxicity, and resource recovery potential. These metrics provide a comprehensive understanding of the qualities and quantities of e-waste suitable for circular economy integration. It developed a quantitative assessment framework to evaluate e-waste suitability for circular economy initiatives. This framework incorporates selected metrics and measurement criteria to facilitate consistent and comparable assessment across different e-waste streams and types of electronic devices.

Through empirical analysis and case studies, the study provided insights into the circular economy potential of e-waste, including its capacity for resource recovery, material reuse, and sustainable disposal.

Based on the findings, the study offers recommendations for policymakers, industry stakeholders, and environmental practitioners to optimize e-waste management practices and maximize the benefits of circular economy approaches. These recommendations include policy interventions, industry standards, and best practices for promoting e-waste recycling and resource recovery. It recommends advocacy for awareness creation of the potential both negative and positive, of e-waste to the population.

Importance of Collaboration and Innovation should be emphasized in addressing e-waste challenges and advancing circular economy objectives. This could involve partnerships between government agencies, businesses, non-profit organizations, and research institutions to develop and implement sustainable e-waste management solutions.

Finally, the study highlights the need for ongoing monitoring and evaluation of e-waste management efforts to track progress, identify emerging trends, and address evolving challenges. Continuous improvement in measurement methodologies, recycling technologies, and policy frameworks is essential for achieving long-term sustainability in e-waste management and circular economy implementation.

Overall, the importance of integrating e-waste into circular economy strategies to promote resource efficiency, reduce environmental impact, and create economic value from waste materials should be emphasized.

## References


1. Achilias, D. S., et al. (2020). Circular Economy in Electronic Waste Management and the Role of Extended Producer Responsibility: A Review of Key Issues.
2. Wang, F., et al. (2019). E-Waste Management and Circular Economy in China: Policy, Legislation, and their Implications.
3. United Nations Environment Programme. (2019). Global E-Waste Monitor 2019: Quantities, Flows, and the Circular Economy Potential.
4. Otieno, F. A., & Adkins, E. (2018). Informal E-Waste Recycling in Nairobi, Kenya: