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Development of a sustainable e-waste management system in Estonia

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ABSTRACT

The growing problem of electronic waste (e-waste) has prompted the need for sustainable management practices. Since 2005, e-waste has been acknowledged as both a challenge and an opportunity, yet its full business potential remains largely unrealized. This study examines the current state of e-waste management in Estonia, aiming to identify pathways towards a more sustainable framework. The research examines global management systems and applies this knowledge to the unique context of Estonia, identifying both the obstacles and potential solutions to the country's e-waste issue. Although Estonia is praiseworthy for its e-waste management within the European Union, the practice of exporting e-waste for recycling raises questions about long-term sustainability and environmental responsibility. The study utilizes data from the Estonian waste which unveils inconsistencies in the electronic waste collection process and a significant deficit in the recycling stage, which highlights the necessity for extensive reforms. The findings have been obtained through a thorough analysis of relevant literature and interviews with key stakeholders. To effectively address these challenges, a paradigm shift is necessary towards centralized collection systems, while also fostering an entrepreneurial ecosystem that can harness the economic potential of e-waste. This study highlights the pressing need to establish a robust and sustainable e-waste management system in Estonia, as it is crucial for global environmental protection efforts.

Keywords: E-waste management, sustainable practices, recycling challenges, environmental responsibility, Estonia.

1. INTRODUCTION

According to Gaidajis et al., (2010), the degradation of the planet has resulted from certain human activities, leading to an increased need for sustainability. In 2005, Widmer et al., (2005) identified electronic waste as an emerging problem that presents both challenges and opportunities due to the large quantities of e-waste generated. Despite these findings having been published over a decade ago, the business potential of e-waste has yet to be fully realized in 2022, which has contributed to the increased environmental risks posed by e-waste, making it a significant global concern (Ahirwar and Tripathi, 2021). This, as some reports indicate, is purportedly due to the persistent alteration in the consumption patterns of individuals regarding electrical and electronic equipment, which has ostensibly resulted in continuous advancement and mass production of equipment, such as cell phones, computers, video recorders, televisions, coffee machines, and refrigerators, among others. Subsequently, there is an escalating amount of e-waste generated annually (due to the short lifespan of most equipment), with only a small proportion of it being recycled.

According to Mmereki et al., (2016), the amount of e-waste in global municipal waste is relatively small, accounting for approximately 8% of the total. Despite this, the rate of growth is cause for concern, leading many governments to establish and enforce environmentally responsible management practices. In fact, Widmer et al., (2005) reported that in 1994, an estimated 20 million personal computers (approximately 7 million tons) were considered obsolete. By 2004, this figure had risen to 100 million PCs, representing a nearly 500% increase. Additionally, during the period from 2010 to 2019, global e-waste grew from 33.8 million metric tons to 53.6 million metric tons, representing a rise of almost 140%. According to Andeobu et al., (2021), out of the 53.6 million metric tons of waste generated worldwide in 2019, only 13% was recycled, while the remaining portion was disposed of in landfills or incinerators, thereby posing significant environmental and health challenges.

Researchers, including Abalansa et al., (2021), have discovered that developed nations, despite their high consumption of electronic products, generally do not prioritize their recycling due to the associated costs. As a result, these countries often choose to collect and export these waste products to developing nations, where proper recycling procedures may not be in place (Abalansa et al., 2021). Surprisingly, even the United States, a highly developed nation, falls into this category. According to, the United States only recycled 34% of its solid waste in 2019, while countries like Slovenia and Germany achieved recycling rates of 72% and 67%, respectively. Although Estonia has demonstrated a consistent approach to the management of electronic waste, it is evident that a substantial portion of this waste is not being recycled within the country, but rather being exported for recycling purposes.

Despite its efforts to collect and control e-waste, the country has not been successful in ensuring that a significant level of this waste is recycled within its borders. This suggests that Estonia's efforts to control e-waste are not being carried through to the recycling phase, which is a critical aspect of effective e-waste management. Hence, handling the recycling stage of these wastes improperly can lead to the release of harmful toxins into the environment, which can still have an indirect impact on the environment from where the waste was originally generated. Therefore, it is essential to have an effective waste management system in place to protect the world at large. Given this context, this study is of utmost importance at this time. The primary objective of this study is to assess the current state of e-waste management in Estonia and propose ways to develop a sustainable e-waste management system in the country. To achieve this, the study will attempt to address the following research questions:

1. What are the various electronic waste management strategies that are currently available?
2. Which of these strategies would be most suitable for implementation in Estonia?
3. And what steps need to be taken to ensure effective implementation?

2. RESEARCH METHODOLOGY

Estonia Waste Reporting Data System (EWRDS)

The Waste Electrical and Electronic Equipment (WEEE) system in Estonia is organized in such a way that manufacturers, distributors, or importers of EEE are solely responsible for managing e-waste in the country. In accordance with this structure, the majority of e-waste is handled officially, and the data is made available through the Estonian Waste Reporting Data System, which serves as a centralized data hub. This arrangement facilitates access to the data and allows for a comprehensive assessment of the sector's state. The data covers information on e-waste management in Estonia from 2004 to 2019 and is presented on the website by category, including:

* Year
* Waste type, including subtype, code, and name
* Main group of waste substance, including subtype and name
* Hazardousness
* Export/import country

Additionally, the numerical data is organized under the following categories:

* Storage at the start of the year
* Total increase
* Import
* Recovery (R1 through R12)
* Disposal (including D1 through D14)
* To landfill
* Unspecified handling
* Export
*Storage at the end of the year.
The information on the definitions of these terms has been provided by WDMS (n.d).

Data collection

EWRDS contains diverse data related to waste management, but the focus of this study is limited to the e-waste management data that is available. The data spans a 15-year period, from 2004 to 2019, and provides an opportunity to analyze the sector. However, for the purposes of this study, the data range will be restricted to 2009 through 2019. This is because the data collection commenced in 2004, and the accuracy of the first year's data may be questionable. However, it is widely accepted that after a period of five years, the quality of the data used should have been improved, thereby reducing the likelihood of errors or inaccuracies.

With the coding of data complete, it has been determined that the majority of pertinent data can be found in the "wastes from electrical and electronic equipment and other equipment and apparatus" subgroup, identified as "16 02", and the "municipal wastes (household waste and similar commercial, industrial and institutional wastes) including separately collected fractions" subgroup, identified as "20 01". To facilitate the organization and sorting of data, the information tagged as "16 02" has been separately exported to a CSV file, while the data tagged as "20 01" has also been exported to a separate CSV file. The "20 01" dataset was sourced from various waste management sources and was subsequently sorted using the waste substance name criteria in Microsoft Excel software. The data deemed relevant for this study were those tagged with categories such as "wastes from electrical and electronic equipment and other equipment and apparatus", "other discarded electrical and electronic equipment", and "discarded major household equipment".

The following text includes the numerical data that is generally considered (RT, 2021; WDMS, n.d.):

a) The electronic waste at the beginning of the year, typically stored by the supplier awaiting referral or transfer for further processing.
b) The electronic waste generated from production or other operations, including those collected.
c) The electronic waste imported into Estonia from other countries.
d) The electronic waste put to good use after recovery operations.
e) The electronic waste not recovered, meaning incinerated without energy use.
f) The electronic waste disposed of at landfill sites.
g) The quantity of electronic waste handled by unaccountable entities.
h) The amount of electronic waste exported from Estonia to other countries.
i) The quantity of electronic waste at the end of the reporting year awaiting referral or transfer, which accounts for the data inventory for another reporting year.
j) The amount of electronic waste that was primarily utilized as fuel or in any other manner as an energy source (R1).
k) The quantity of organic substances that were recycled or recovered in electronic waste, excluding those used as solvents (R3).
l) The quantity of metals that were recycled or recovered in electronic waste (R4).
m) The quantity of inorganic substances that were recycled or recovered in electronic waste (R5).
n) The quantity of e-waste that was mechanically recycled (R5m).
o) The quantity of e-waste that was stockpiled as raw materials (R5f).
p) The quantity of e-waste that was prepared for reuse (R5k).
q) The quantity of e-waste that was prepared or regenerated for use in another manner (R9).
r) The quantity of e-waste that was exchanged or pre-treated for reuse in any of the recovery operations in R1 to R11 (R12).
s) The quantity of e-waste that was sorted prior to the recovery of certain components, which may involve mechanical treatment (R12s).
t) The quantity of e-waste that underwent pre-recovery or mixing (R12x).

u) The quantity of e-waste that underwent pre-repackaging (R12y).

Furthermore, this research will compare the findings from the data collected through the Estonia Waste Reporting Data System with other information obtained through interviews. The interviews were conducted with organizations that handle electronic waste in Estonia, and multiple organizations were contacted via email. None of the companies save for one (Base Metal) agreed to a physical interview, which is comprehensible given the need to reduce physical contact during the pandemic and others due to their schedules. As a result, the majority of the interview inquiries were addressed and returned via email. The face-to-face interview was documented and converted into written form.

The following organizations were included in the analysis: SWAPPIE, Weerec OÜ, Kat Metal Estonia OÜ, and Base Metal. SWAPPIE specializes in refurbishing phones, particularly iPhones, while Weerec OÜ focuses on electronics waste recycling. Kat Metal Estonia OÜ and Base Metal are both e-waste collection companies. Based on the sales data for the 2020 production year, the market shares of these organizations in Estonia were 16 percent, 24 percent, 30 percent, and 30 percent respectively, as reported by.

Data Analysis

The data was analyzed utilizing both qualitative and quantitative research techniques, as suggested by (Seaman, 2008). This approach is deemed suitable for many studies since it enables the quantification of specific aspects of a body of qualitative data. To comprehend the primary categories within a data set, quantification is essential, although it should be preceded by a preliminary qualitative analysis and followed by further qualitative analysis to interpret the quantitative results. In contrast, the quantitative research method entails the examination of an occurrence or circumstance through numerical measurements. While the quantitative research method entails examining an event or situation by utilizing numerical data obtained from surveys, experiments, and observations, the qualitative research method concentrates on analyzing subjective traits and viewpoints that cannot be quantified. The qualitative research method is typically employed to verify or confirm a hypothesis or to gain a deeper understanding of a topic that is particularly relevant to the present study.

In this study, a greater emphasis was placed on the qualitative research method in the interpretation of data, as compared to the quantitative research method. The data was analyzed comprehensively by evaluating the e-waste collected annually. Numerical data was utilized to quantify and qualify the information. An appropriate graphical tool was employed to illustrate the data being investigated for clarity, which helps to identify methods to enhance the existing e-waste management system in Estonia. In interpreting the data, the "Begin" value was informative. The primary analysis focused on other data points, such as recovery, disposal, unspecified handling, and so on.

For instance, if "import" is to be analyzed for 2019 based on Figure 1, the research examined each of the data in relation to one another, with a focus on the "End" data and excluding the "Begin" data. This constituted 9.7% of the data, compared to the 8% that could be physically observed. Additionally, a SWOT analysis was conducted to further analyze the data. SWOT, which stands for Strengths, Weaknesses, Opportunities, and Threats, is a management tool that is utilized to strategically identify and evaluate internal and external factors that impact the current and future operations of a business. It aids in the organization of information during the decision-making process, ultimately helping to develop strategic goals (Chaudhary and Vrat, 2015).

Data Validity

The data used in this study is the primary data, and thus, its validity must be defined. It has been observed that some numerical data for certain periods are missing, and it is automatically assumed that these values are equal to zero. However, since the data was obtained from a verified source, this paper assumes that all relevant data from the source are valid.

3. RESULTS AND DISCUSSION

Result (Data Collected from EWRDS website)

The categorization of e-waste management data available on the website can be based on 12 types of waste substances, including:

a) Other plastic waste,

b) Other aluminum waste,

c) Other mixed metallic waste,

d) Other metal wastes,

e) Other glass wastes,

f) Other discarded machines and equipment components,

g) Other discarded electrical and electronic equipment,

h) Ferrous metal waste and scrap,

i) Equipment containing or contaminated by PCBs,

j) discarded major household equipment,

k) Copper wastes, and

l) Lead wastes.

The data in Figure 1 demonstrates the management of e-waste in Estonia from 2009 to 2019. It is important to note that the amount of e-waste recorded at the end of each production year is not always the same as the beginning of the next year. This suggests that some of the waste may not have been captured in the previous year, or may have undergone operations such as recovery, export, or disposal without proper documentation. The information from 2010 to 2019 indicates inconsistency by various percentages, including -29.1%, -4.4%, 10%, -2.0%, 0.9%, 0.4%, -0.0%, 1.4%, 3.3%, and 2.7%, respectively. However, other data is thought to be accurate and is discussed below. Landfill, which was not previously considered for e-waste recovery, has become more commonly used over time. Between 2009 and 2019, the usage of landfill for e-waste recovery was negligible, ranging from 0% in 2009-2012 to 0.9-3.4% in 2013-2019.

This is attributable to the rise in the quantity of materials that cannot be recycled, such as glass and cathode ray tubes. Although the undefined management has not significantly decreased, it has remained relatively stable. Additionally, the importation of electronic waste into Estonia has been between 7 and 16% and is anticipated to continue as Estonia also exports its electrical and electronic equipment (EEE) products overseas. When these products reach their end-of-life under the extended producer responsibility, it is expected that manufacturers will take them back, which likely accounts for the increase observed over the past decade. Disposal of e-waste has been of minimal significance; however, it warrants attention as its contribution to the total waste in 2019 was 0.9 percent.

With regard to the export of e-waste, a substantial amount is being shipped from Estonia to other countries, and the data reveals that this figure has fluctuated between 14 and 37 percent from 2009 to 2019. This phenomenon is believed to be influenced by the EPR system in place, coupled with the fact that Estonia has fewer facilities for recycling electronic waste. Lastly, the data indicates that Estonia is making progress towards achieving its aim of recovering nearly all recoverable materials, with the recovery rate oscillating between 40 and 50 percent from 2009 to 2019. Estonia's dedication to shifting away from conventional landfill methods and towards energy recovery from waste, which involves the extraction of every recoverable component of waste, can be attributed to this initiative.

Moreover, Figure 2 depicts the e-waste recovery operations conducted between 2009 and 2019, as reported by EWRDS. These operations are classified into 12 categories, namely R1 to R12, and categories 5 and 12 are further sub-categorized into R5m, R5o, R5c, R5f, R5k, R5t, R12s, R12p, R12o, R12x, and R12y. The analysis of the e-waste recovery operations was limited to these categories for the 10-year period. According to the data, the most common e-waste recovery operations used were R1, R3, R4, R5 (R5m, R5f, and R5k), R9, and R12 (R12s, R12x, and R12y). This operation involves the pretreatment of products for the purpose of reuse. These wastes undergo mechanical processing, resulting in a recovery rate that fluctuates between 81.9% and 99.0% from 2009 to 2019. Additionally, a small portion of these wastes are processed as a raw material stockpile, with an unstable pattern that has a minimum of 0.2% and a peak value of 15.9% from 2009 to 2019.

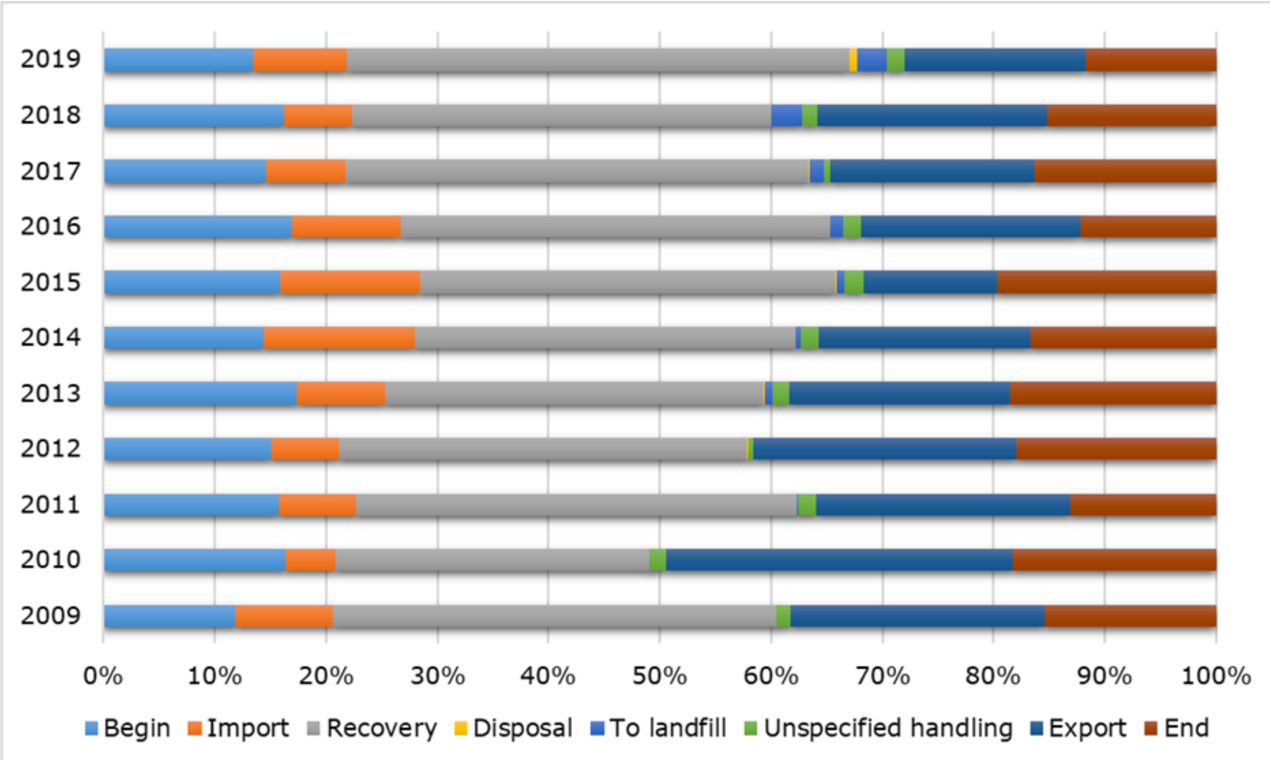

Figure 1 E-waste management in Estonia between 2009 and 2019 (author's calculation, 2022).

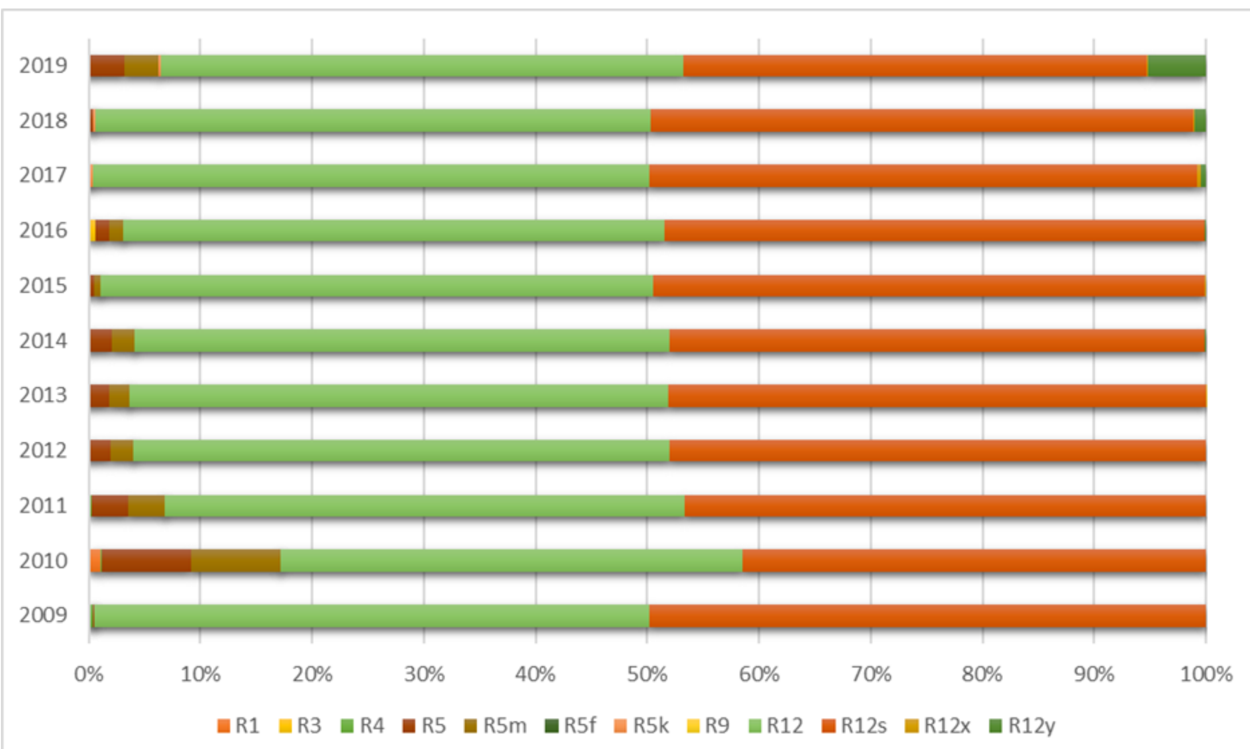

Figure 2 Recovery operations of e-waste in Estonia between 2009 and 2019 (author's calculation, 2022).

Result (Data obtained from the interview)

According to the information provided by SWAPPIE (Eippa WSOperations OÜ), this organization produces electronic waste during their electronics reuse operations. Specifically, the waste generated includes cables, iPhones, USB hubs, scanners, monitors, iPhone displays, rear cameras, iPhone processors, and motherboards. Some of these wastes are reused, while others are sent to buyback or recycling centers in countries such as China and Sweden. Prior to sending the waste to recycling centers, the organization manually sorts the waste. The study demonstrated that the percentage of electronic waste that cannot be recycled is minuscule, accounting for roughly one percent. Despite this, the organization highlighted the dearth of adequate recycling facilities and recommended that "Estonia needs to establish display and monitor recycling centers. These products are extensively used and their consumption is expected to increase significantly in the future. By establishing affordable recycling centers for these products, companies will be able to refurbish them, thus making a substantial contribution to a sustainable circular economy".

According to Weerec OÜ, the collection of electronic waste is the responsibility of the producer, and there are several collection networks available throughout the country. As a company that is directly involved in e-waste recycling, Weerec OÜ manually disassembles, sorts, and weighs the e-waste by category and type. This process is carried out to ensure a better outcome. After sorting the e-waste, more material can be sent for material recovery, while the company does not handle any material that cannot be recovered and will send it to a landfill or energy recovery facility. It holds the belief that electronic waste can be fully recycled for energy, albeit it exports items such as lead glass and cathode ray tubes to nations like the United Kingdom for recycling. Weerec OÜ is of the opinion that Estonia's e-waste management system is already in good condition and does not require further enhancement. It holds the belief that electronic waste can be fully recycled for energy, albeit it exports items such as lead glass and cathode ray tubes to nations like the United Kingdom for recycling.

Weerec OÜ is of the opinion that Estonia's e-waste management system is already in good condition and does not require further enhancement. Kat Metal Estonia OÜ procures electronic waste "globally" from a variety of sources, including manufacturers, e-waste companies, and telecommunications companies. The company manually disassembles and sorts the waste into different categories, such as metals (including aluminum, copper, and alloys), printed circuit boards (low grade, medium grade, etc.), cables, and plastics. However, Kat Metal Estonia OÜ does not handle the recycling of the waste itself; instead, it forwards the waste to specialized companies that focus on recycling specific types of materials. Please note that while Kat Metal Estonia OÜ did not provide explicit information about the proportion of electronic waste that is non-recyclable, the organization did acknowledge that the majority of electronic waste is, in fact, recyclable.

The company attributes the seemingly non-recyclable fraction to technological limitations, as these materials are either very inexpensive (with little or no value) or hazardous to human health. To emphasize the dynamic nature of the environment, Kat Metal Estonia OÜ recommended that the environment should be flexible vis-à-vis companies and that regulations must be periodically reviewed. This is undoubtedly a challenging endeavor for the state, and it is essential that it maintains close communication with entrepreneurs who encounter daily difficulties. Base Metal purchases electronic waste from Estonian citizens or residents and accepts all forms of EEE products, with the exception of refrigerators and other equipment containing hazardous gases.

It is important to note that Base Metal does not possess any machinery for crushing or processing the waste it collects; instead, it occasionally separates and collects electronic items, such as monitors and television sets. When it comes to recycling, Base Metal believes that Estonian companies that specialize in separating and shredding do not engage in chemical processing. The processing of electronic waste in Estonia is limited to mechanical recycling. Once this process is complete, the material is exported to Scandinavian countries. At present, Estonia does not have the necessary facilities to undertake final-cycle recycling of e-waste.

SWOT analysis of e-waste management in Estonia

Estonia has achieved noteworthy success in its management of electronic waste, as evidenced by the findings. However, as per the respondent from Weerec OÜ, there is always scope for enhancement. To this end, the data obtained from EWRDS and interviews will be subjected to a SWOT analysis.

Strength

One of the strengths of Estonia's e-waste management system is the presence of a comprehensive policy framework. After joining the European Union, Estonia's legal and policy framework for waste management was positively impacted. The Estonia's Waste Act of

2004, which serves as the central governing legal framework for e-waste management in the country, specifies obligations for major actors involved in the management process. The concept of Extended Producer Responsibility is central to this policy, with EEE producers or distributors being the main actors responsible for introducing electronic products into the Estonian market. The implementation of this policy has undoubtedly ensured the effective collection of e-waste. According to Abalansa et al., (2021) report, this policy has enabled Estonia and other EU countries such as Bulgaria and Croatia to achieve a 65 percent collection rate of the e-waste produced. Consequently, this has confirmed the enforcement as the primary solution to waste management. This perspective is shared by the respondent from Weerec OÜ, who stated that everything is in order and that no changes are necessary in the way Estonia manages its e-waste.

The increasing number of entrepreneurs and recyclers in Estonia is indicative of its status as one of the most entrepreneurial nations on Earth, as its startup ecosystem outperforms any other country. This is evidenced by Estonia's "country-as-a-service" scheme, which has lured numerous businesses and entrepreneurs from around the world, particularly in the realm of e-waste recycling (Baralla et al., 2023). Organizations such as Kat Metal Estonia OÜ's and Base Metal are not commonly found in other parts of the world. However, these companies have chosen Estonia as the base for their operations. This confirms the settlement of e-waste entrepreneurs who are potentially transforming the narrative about e-waste in the country from a mere liability to an asset that can generate revenue and improve the lifespan of certain e-waste materials. Additionally, these entrepreneurs are working to reduce the environmental pollution caused by e-waste. Estonians have reportedly shown a favorable response to the exchange of their end-of-life electrical and electronic equipment (EEE) for cash, as indicated by interviews with Base metal. This suggests that the introduction of incentives can facilitate the easy management of electronic waste, resulting in the majority of citizens becoming compliant. Consequently, this indicates that the presence of entrepreneurs who are interested in e-waste management can aid in the effective management of e-waste in the country.

Estonia's digital foundation, which has been driven by technology, has placed it in a distinguished position in the global ranking, according to. The country's prosperity has been greatly supported by technology. During the Coronavirus outbreak, Estonia achieved an impressive feat, as 99% of its public activities continued without interruption while most of the world's nations were under lockdown. Estonia has announced ambitious plans to become the first country in the world to implement a fully digitized real-time waste monitoring system. This system, which is expected to be implemented in 2021, is a testament to Estonia's commitment to waste management and its belief that technology can improve it further. This development underscores the potential of technology to revolutionize waste management and make it more efficient.

Weakness

E-waste management documentation: This is a crucial aspect of efficient waste management in a region or country. Accurate data is essential for determining planning and areas of improvement. However, a lack of available data can pose a significant challenge, such as in the case of Estonia. According to the EWRDS data, there is a notable gap in the "begin" and "end" data, which can hinder waste management efforts. The discrepancy in the annual e-waste recycling rate data for the year 2017, as presented by (69 percent) and the figure obtained from the Estonian Waste Reporting Data System (48.7 percent), is thus explained. Moreover, the feedback from Kat Metal Estonia OÜ and Base Metal indicated the potential for certain waste not to be officially captured, as these waste materials are sent to other countries. This justifies the discrepancies in the data that are accessible to the public on the EWRDS server.

Estonia suffers from a lack of e-waste recycling facilities, which are costly to establish and maintain. Despite efforts to optimize its recycling practices, data reveal that Estonia has fewer e-waste recycling centers than necessary. This limitation hinders the country's recycling capabilities, as it is unable to process e-waste into the reuse phase. Consequently, Estonia is restricted to the third stage of the recycling process, which involves manual sorting, dismantling, and shredding, as described by. As a result, Estonia is heavily reliant on exporting e-waste to other countries, such as Germany and Sweden.

Opportunities

Governments' partnership with entrepreneurs: Baralla et al., (2023) posited that businesses run by e-residents contributed approximately 51 million euros in taxes to Estonia's revenue in 2020. This is distinct from physical businesses and further emphasizes the crucial role that entrepreneurs play in Estonia's economy. Assessing the practices of the entrepreneurs reveals that all of them adhere to the best practices, as their preferred method for dismantling e-waste is manual, which is the most efficient approach according to (Lucier and Gareau 2019). The implication is that the entrepreneurs dealing with electronic waste in Estonia can make e-waste economically viable if the government collaborates with them. According to the respondent from Kat Metal Estonia OÜ, this is necessary because they are well-versed in the daily challenges. It is believed that the business potential of e-waste, which has not yet been fully exploited, can be unlocked in Estonia, allowing the country to once again take the lead, as it did during the Covid-19 pandemic.

Business opportunities related to electronic waste could potentially result in job creation, which is particularly significant in Estonia where unemployment rates, while gradually increasing, may pose a significant challenge if left unaddressed. Although the unemployment rate has consistently decreased over the past decade, the percentage rose by 2.01% in 2019, which represents a notable departure from previous trends. Consequently, it is essential to explore new avenues for job creation, and the business side of e-waste could potentially contribute to this effort. E-waste management has been shown to create job opportunities, as reported by (Kumar et al., 2017). It is estimated that this industry created 100,000 jobs in China for individuals working as recyclers in the informal sector, and it is projected to create approximately 30,000 jobs in the formal sector. This highlights the potential of the business side of e-waste to create employment opportunities and contribute to the country's revenue generation.

Threat

Health Hazard: A majority of electronic waste poses a threat to both human health and the environment when disposed of improperly. Furthermore, certain types of electronic waste are more harmful than others, such as refrigerators, which contain hazardous gases. However, while other electronic devices can be sold for a nominal fee, appliances containing these gases are considered a liability and are not accepted for disposal except through EPR programs. Due to the challenges associated with recycling these types of waste, they are often disposed of in landfills, which can lead to the release of hazardous gases into the environment, posing a risk of cancer, as well as developmental and neurological issues. Moreover, studies have shown that electronic waste contains elevated levels of hazardous materials, making reuse through recycling a critical method for protecting the environment (Kumar et al., 2017; Heacock et al., 2015).

The average life span of most EEE: According to recent reports, the global market for electronic and electrical equipment (EEE) has experienced significant growth over the past two decades; however, the lifespan of these products has correspondingly decreased. This emerging challenge has drawn the attention of both business and waste management authorities, and it is expected that the number of electrical devices worldwide will continue to rise. As a result, microprocessors are becoming increasingly prevalent in everyday products. The research conducted by also supports this conclusion.

Cost of managing e-waste: Entrepreneurs display a keen interest in e-waste management; however, recycling facilities pose obstacles. These facilities are typically expensive to construct and maintain, which could be the reason why the government of Estonia prefers to hold producers responsible for recycling the waste, rather than investing in a recycling facility.

Proposal on the development of Estonia E-waste management system.

Implementing the Swiss model of electronic waste management may render Estonia's e-waste management system more efficient. This involves integrating existing policies and implementing a centralized collection method, which would facilitate precise documentation of collected e-waste. Despite the potential benefits of new technologies like digital waste reporting, it is expected that this will improve the system. Nonetheless, the establishment of a central collection site for electronic waste has the potential to enhance efficiency and address potential fairness issues in Extended Producer Responsibility (EPR) practices, thereby ensuring that each producer is accountable only for a proportionate share of the waste generated by its products in Estonia.

In addition, the collaboration between the government and e-waste entrepreneurs has the potential to enhance the efficiency of e-waste management in Estonia. It has been observed that individuals prefer to receive a token for their e-waste instead of simply disposing of it. The entrepreneur's activities have the potential to facilitate the easy and efficient collection of these wastes, as individuals would value the token for their e-waste. This will encourage consumers to exhibit responsible behavior towards the end-of-life management of electrical and electronic products, which will result in the proper disposal of these items and increase the amount of recyclable materials in e-waste.

To encourage the utilization of electronic waste for business purposes, the government must assume some responsibility. One way to achieve this is by constructing recycling facilities with a focus on specific materials. For instance, recycling facilities that specialize in the processing of screens, which are widely used in the country, as suggested by the base metal industry. By doing so, these facilities will not only create direct jobs, but also indirect employment opportunities, ultimately contributing to the country's economic growth.

4. CONCLUSION AND RECOMMENDATIONS

This research investigated the creation of an electronic waste management system in Estonia. Information was gathered from the public inquiry section of the EWRDS website and through interviews with organizations that handle e-waste within the country. The collected data were assessed using a SWOT analysis. The results indicated that a key advantage of e-waste management in Estonia lies in the policies that have been established, the growing number of entrepreneurs and recyclers, and the existing digital infrastructure. The identified weaknesses include deficiencies in the documentation of electronic waste that is collected and processed, as well as a lack of recycling centers. Meanwhile, the identified opportunities include the government's collaboration with entrepreneurs and the business side of electronic waste, which could result in job creation. Lastly, the identified threats include health hazards, the average lifespan of most electronic equipment, and the cost of managing electronic waste.

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However, the inadequacies in the documentation are considered a significant obstacle to the effective management of these wastes, and the available facilities for recycling are insufficient. Nonetheless, e-waste presents opportunities for job creation in Estonia and improved management of e-waste through government partnerships with entrepreneurs. However, it also poses some threats, including health hazards if not properly handled, the financial burden of constructing facilities, and the escalating level of e-waste due to the short lifespan of these items. Consequently, the Swiss method, the Japanese method, and the EPR are examples of approaches that could be utilized. Amongst these methods, the Swiss approach is considered to be the most preferable and efficient solution for Estonia's challenge of e-waste management. To implement this approach, the Estonian government must concentrate on the business aspect, as it is the only factor that provides an incentive for companies to consider constructing a recycling facility. By doing so, not only will jobs be created, but the environment will also be protected, and the economy will benefit.

In summary, Estonia's performance in e-waste management is commendable, but there is room for improvement. This paper proposes potential improvements that could transform e-waste into a revenue stream, rather than a persistent threat. To achieve this, the government must demonstrate flexibility and a commitment to environmental improvement. The research highlighted the necessity for an enhancement in Estonia's e-waste management strategy. It emphasized the government's need to collaborate with business owners., it is strongly recommended to establish additional E-waste recycling facilities and promote the reuse of electronic devices instead of discarding them. The government could also implement initiatives or seminars to educate consumers on the benefits of e-waste recycling. Furthermore, future research should focus on addressing the issue of chemical processing of electronic waste in Estonia, as this could potentially yield valuable metals such as gold, silver, palladium, and others, thereby facilitating the final stage of e-waste recycling.

Informed consent

Not applicable.

Ethical approval

Not applicable.

Conflicts of interests

The authors declare that there are no conflicts of interests.

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Data and materials availability
All data associated with this study are present in the paper.

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