TALLINN UNIVERSITY OF TECHNOLOGY
SCHOOL OF ENGINEERING
Department of Civil Engineering and Architecture

# DEVELOPMENT OF A SUSTAINABLE E-WASTE MANAGEMENT SYSTEM IN ESTONIA

## JÄTKUSUUTLIKU ELEKTROONIKAJÄÄTMETE KÄITLUSSÜSTEEMI ARENDAMINE EESTIS

MASTER THESIS

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Tallinn 2022

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# THESIS TASK

**Student**: Seyi Rachel Dada, 201651EABM

Study programme: EABM03/18 Environmental Engineering and Management

Supervisor(s): Senior Lecturer, Viktoria Voronova

**Thesis topic**:

(in English) *Development of a sustainable e-waste management system in Estonia*

(in Estonian) *Jätkusuutliku elektroonikajäätmete käitlussüsteemi arendamine Eestis*

**Thesis main objectives**:

1. Assess the current state of e-waste management system in Estonia
2. Propose means of developing a sustainable e-waste management system in Estonia

**Thesis tasks and time schedule:**

| No | Task description | Deadline |
|---|---|---|
| 1. | Understanding of the subject matter i.e. e-waste and its management via literature | 01.2022 |
| 2. | Writing a master's thesis: Introduction, literature review | 02.2022 |
| 3. | Data Collection (including interviews), analysis of the results, etc. | 05.2022 |

**Language:** English **Deadline for submission of thesis:** 23rd May 2022

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# PREFACE

I'd like to thank my supervisor, Viktoria Voronova, for her help in comprehending the theory and providing suggestions for improvement, as well as for providing extremely detailed comments and advise.

I appreciate all my lecturers' efforts in providing me with the necessary knowledge.

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Finally, I am thankful to almighty God for His love in helping me till this moment.

Seyi Dada

# LIST OF ABBREVIATIONS AND SYMBOLS

| | |
|---|---|
| EEE | Electrical and Electronic Equipment |
| EEIA | Estonia Electronics Industry Association |
| EPA | Environmental Protection Agency |
| EPR | Extended Producer's Responsibility |
| EWRDS | Estonia Waste Reporting Data System |
| IEA | International Environmental Agreement |
| MSW | Municipal Solid Waste |
| MT | Million Tons |
| PVC | Polyvinyl Chloride |
| RoHS | Restriction on Hazardous Substances Directive |
| UEEE | Used Electrical and Electronic Equipment |
| WEEE | Waste Electrical and Electronics Equipment |

# 1. INTRODUCTION

Some human activities on planet Earth have led to a level of degradation of the planet, and the impact has increased the need to embrace sustainability (Gaidajis et al., 2010). Based on this in 2005, some studies such as Widmer et al. (2005) described electronic waste as an emerging problem that also offers business opportunities given the volumes of e-waste being generated. However, despite these findings being more than a decade, the business side of e-waste has still not been fully harnessed in 2022, and this has increased the level of risk posed by e-waste to the environment, making it a major concern in many countries around the world (Ahirwar & Tripathi, 2021). This, according to some reports, is due to the consistent change in the consumption habits of individuals regarding electrical and electronic equipment which has led to continuous development and mass production of equipment such as cell phones, computers, video recorders, televisions, coffee machines, and refrigerators, etc. Consequently, often, this results in an increasing level of e-waste year-in-year-out (due to the low life span of most of the equipment) with only a few of it being recycled.

According to Mmereki et al. (2016), e-waste makes up a small fraction (about 8 percent) of all global municipal waste; however, the growth rate is alarming, and it has forced governments of many countries to develop and implement environmentally sound management practices. As a matter of fact, Widmer et al. (2005) reported that an estimate of 20 million (approx. 7 million tons) PCs were considered obsolete in 1994 and by 2004, the figure had increased to 100 million PCs, which is almost 500 percent higher. Moreover, between 2010 and 2019, e-waste globally had increased from 33.8 million metric tons to 53.6 million metric tons, which is almost 140 percent (Tiseo, 2021). Meanwhile, out of the 53.6 million tons of its waste that was generated globally in 2019, only 13% of it was recycled while the rest ended up in landfills or incinerators, thus creating enormous environmental and health concerns (Andeobu, 2021).

With respect to this, researchers such as Abalansa et. al (2021) have found that most developed countries, despite their level of consumption of electric and electronic products, do not commit to the recycling of these products and this is due to the cost implication. Consequently, many of these countries prefer to collect these wastes and export to developing countries where proper recycling is not guaranteed (Abalansa et. Al., 2021). Regarding this, it will be surprising to know that despite the developmental level of the United State, it is also caught in this net, as the statistics of municipal waste recycling for 2019 as computed by Tiseo (2021), revealed that it only recycled 34% of its solid wastes when countries like Slovenia and Germany achieved 72% and 67% respectively.

Although Estonia has been consistent in its e-waste management practices, ensuring that a significant level (for instance 69% in 2017) of its e-waste is properly managed (Statista, 2022). However, it was observed that despite its commitment to the collection of this waste, it does not recycle a significant level of these within the country, but the majority are shipped abroad to be recycled (Rucevska, et al., 2015). This implies that despite its effort to ensure that e-waste is controlled in its immediate environment, it does not see it through to the recycling phase which is a stage that is crucial to e-waste management. Consequently, this is a concern, as the improper handling of the recycling stage of these wastes often result in the release of enormous dangerous toxins to the environment which can still indirectly affect the environment where this waste had been moved from. Hence, a system that will effectively manage this waste is important in protecting the world at large and this makes this study important at this time.

Therefore, the aim of this study is to assess the current state of e-waste management system in Estonia and propose means of developing a sustainable e-waste management system in Estonia. Consequently, this study will attempt to answer the following research questions:

1. What are the available e-waste management systems?
2. Which of these options will be effective in Estonia?
3. How can it be effectively implemented?

# 2. THEORETICAL FRAMEWORK

This section discussed relevant literature that were reviewed while carrying out the research. It considered e-waste from its definition to the method through which it is controlled, the processes involved and the benefits of e-waste recycling.

## 2.1 Electrical and electronic equipment

Electrical and electronics equipment (EEE) are devices that utilize electric currents and electromagnetic fields to execute the function for which they are intended or designed. According to European Union's definition these devices are (Shittu et al., 2020, 2):

> …an equipment that functions properly only on electrical currents or electromagnetic fields…for transfer, measurement, and creation of such currents and fields, and intended to be used with a voltage rate that is not more than 1500 Volts for direct current and 1000 Volts for alternating current (AC)

These terms cover a huge range of products, which are by weight categorized into small equipment, large equipment and temperature exchange equipment. Based on this classification the following are common products with respect to their classes (RTS, 2021):

a) Small equipment: This includes (but not limited to) vacuum cleaners, microwaves, toasters, scales, ventilation equipment, radio sets, GPS devices, electric shavers, routers, printers, modem, computers, electrical and electronic toys, electric kettles, small medical devices, video cameras, calculators, telephones, cell phones, small monitoring and control instruments, and small electrical and electronic tools.

b) Large equipment: This includes (but not limited to) clothes dryers, washing machines, electric stoves, copy equipment, solar panels, dish-washing machines and large printing machines.

c) Temperature exchange machine: This includes (but not limited to) air conditioners, refrigerators, heat pumps, and freezers.

### 2.1.1 Electrical and electronic equipment as a waste

Electrical and electronic products are referred to as being waste when these items begin to malfunction or fail to function optimally to meet its end users' needs, they become non effective which are otherwise referred to as Waste Electrical and Electronics Equipment (WEEE). Consequently, e-wastes are electrical and electronic devices that waste resources such as energy and release toxic gasses such as carbon dioxide when in use. At their end-of-life, these products are harmful to humans and the ecosystem which is why they should never be disposed-off with other wastes. Meanwhile, a report Ahsan et al. (2015) revealed that the rate of e-waste increases by 10% annually and this is a red flag as it contributes to an increase in the annual rate of the municipal solid waste. However, according Masud et al. (2019), there are a variety of reasons why this rate may not decrease and that is because:

a) Most electrical and electronics equipment are usually of low lifespan i.e., they are meant to work for a limited period after which they will cease to function optimally.
b) Decline in the product functionality due to damage to the equipment or the wear and tear of the moving parts.
c) Introduction of an upgraded version of the device, since human wants are insatiable.

### 2.1.2 Categories of WEEE

From the kitchen to the office, electrical and electronic equipment (EEE) has become a big part of human daily lives and they come in various levels of complexities, shapes, sizes, functionality, etc. (Abalansa et al., 2021). According to Williams (2016) they are usually heterogeneous in nature: formed by components and materials that are mixed in a complex way, which may contain numerous compounds and can be harmful. Over the years, many of these materials have changed in most of the devices to meet the specifications of the present era of technology; however, certain materials (such as chemicals) have remained unchanged. Consequently, based on the account of some researchers, this equipment and, by extension, its waste can be classified into five groups: Ferrous metals, Non-ferrous metals, Glass, Plastics, and other materials. (Baldé et al., 2015; Duan et al., 2016; Needhidasan et al., 2014; Tanskanen, 2013).

i. Ferrous Metals: These include iron and steel and are the most abundant source of metals in municipal solid waste (MSW) by weight. It is primarily available in durable products such as appliances, furniture, and tires, besides containers and packaging (EPA, 2021a). Ferrous metals are found in large numbers in construction materials as well as transportation parts and products like automobiles, trains, and ships. For example, in 2018, EPA (2021a) computed a report on the generation, composting, recycling, burning with energy recovery, and landfilling, and their data showed that 19.2 million tons of ferrous metals were produced in the United States and this forms about 6.6% of the total municipal solid waste that was generated over the year. Meanwhile, of this waste, an estimated 27.8% (4.7 million tons) of ferrous metals from durable items were captured as being recycled. Moreover, the report also showed that an estimated 70.9 percent of steel cans were recycled (1.1 million tons) and approximately 510,000 tons of additional steel packaging, including strapping, crowns, and barrels, were also recycled. Nevertheless, about 2.3 million tons of ferrous metals were combusted in the same year, an amount that is approximately equal to 6.7 percent of all MSW combusted with energy recovery in the previous year. Additionally, 10.5 million tons of steel was deposited in landfill in the same year, and this amounted to 7.2 percent of all MSW disposed-off on land. Consequently, Figure 2.1 depicts the management of ferrous metal waste between 1960 and 2018 in the United States (EPA, 2021a).

ii. Non-Ferrous Metal: These are metals that contain little, or no iron and they have less strength and shrinkage at high temperatures than ferrous metals (WeldingHandbook.com, 2022). They do not have magnetic properties and examples include aluminum, copper, lead, nickel, tin, zinc, and their alloys. According to EPA (2021b) they are found in durable products such as consumer electronics and appliances. For example, in 2018, EPA (2021b) reported that 2.5 million tons of it was generated in municipal solid waste, and approximately 1.7 million tons of it was due to lead in batteries, while others accounted for less than 1 percent of total generation. Meanwhile, the report noted that approximately 99 percent of the lead batteries were recovered, thus raising the recycled non-ferrous metal to a tune of 1.7 million tons in 2018. However, the report highlighted that 80,000 tons of nonferrous metal MSW were combusted in 2018 making the combustion with energy recovery in total MSW to amount to 0.2%. Additionally, landfills received 740,000 tons of MSW and nonferrous metals, and this amounted to 0.5 percent of all MSW disposed of in 2018. Consequently, Figure 2.2 depicts the management of non-ferrous metal waste between 1960 and 2018 in the United States (EPA, 2021b).

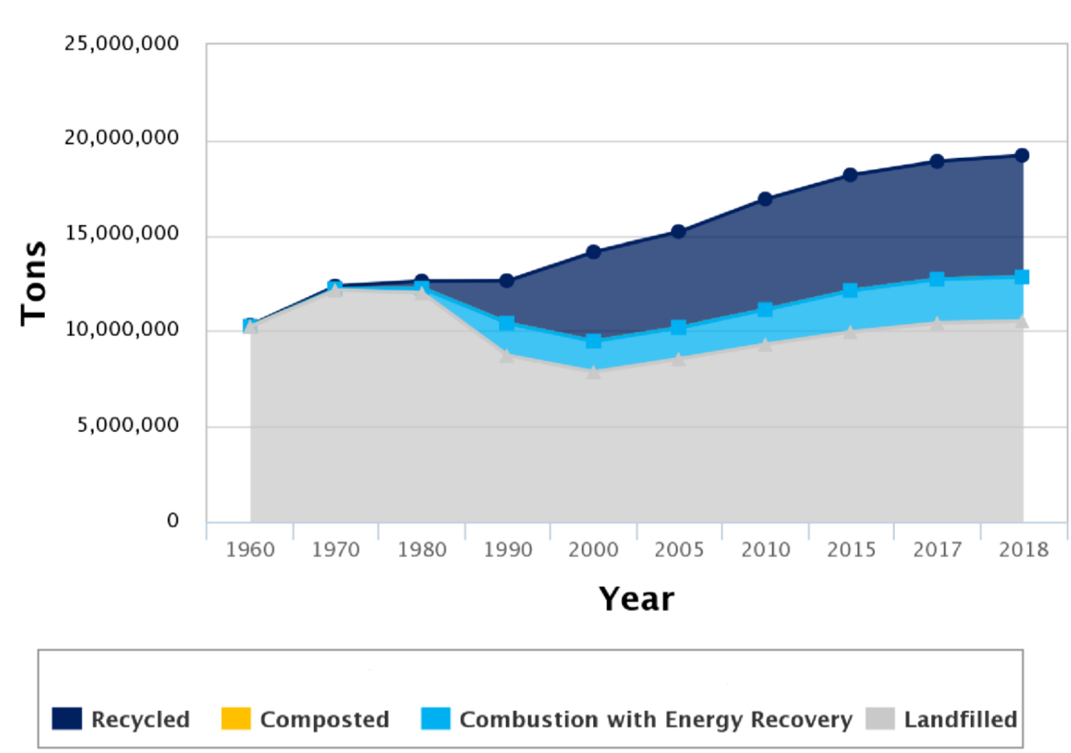


Figure 2.1: Ferrous metal waste management between 1960 and 2018 in the United States (EPA, 2021a).

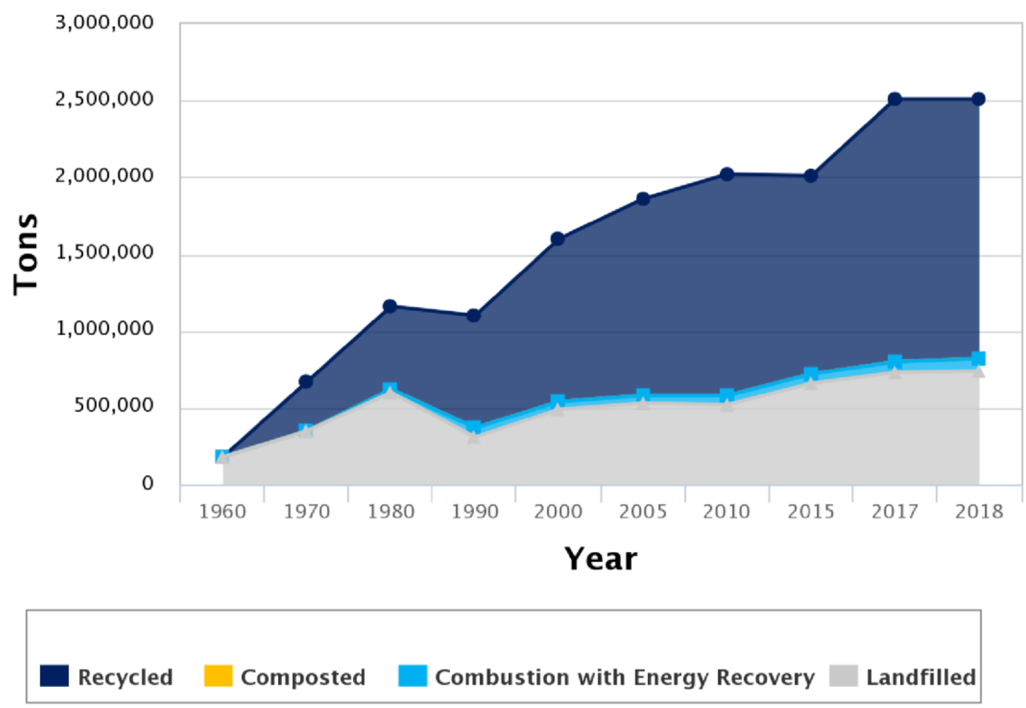


Figure 2.2: Non-ferrous metal waste management between 1960 and 2018 in the United States (EPA, 2021b).

iii. Glass: This is a fragile element which can be in the form of containers which includes food and cosmetics containers, liquor and wine containers, and many other product jars. Moreover, it is found in durable items such as furniture, appliances, and consumer electronics. For example, in 2018, the report from EPA showed that 12.3 million tons of its waste was generated in the United States alone. Meanwhile, reports showed that only 31.3 percent of its waste was recycled during this period, while 4.8 percent was combusted and 5.2 percent was landfilled. Consequently, Figure 2.3 depicts the management of glass waste between 1960 and 2018 in the United States. (EPA, 2021c).

iv. Plastic: The use of plastic around the world today has grown significantly and this has resulted in the increase in garbage production, which adds to the volume of waste that needs to be processed and/or disposed-off. According to Achilias et al. (2012), this is owing to the fact that plastic products have a very limited functional life - because approx. 40% percent of plastic products have an average lifespan of one month. Besides, most of the plastic waste produced today is not adequately collected, recovered, or disposed-off, thus leading to the growing accumulation of plastic debris in rivers and oceans, where it is easily consumed by animals (Ghosh & P, 2019). Plastic Solid waste (PSW) are therefore commonly found in MSWs since they are thrown and collected alongside other household wastes. Consequently, PSW is virtually always mixed with MSW in the form of polyethylene, polyethylene terephthalate, polystyrene, polypropylene, polyvinyl chloride (PVC), etc. (Ghosh & P, 2019). For example, a report by EPA (2021d) revealed that the United States generated 35.7 million tons of its waste in 2018 and this amounted to 12.2% of its total MSW. Of these volumes, the United States recycled 8.7%, combusted 16.3% and landfilled 18.5%. Consequently, Figure 2.4 depicts the management of plastic waste between 1960 and 2018 in the United States (EPA, 2021d)

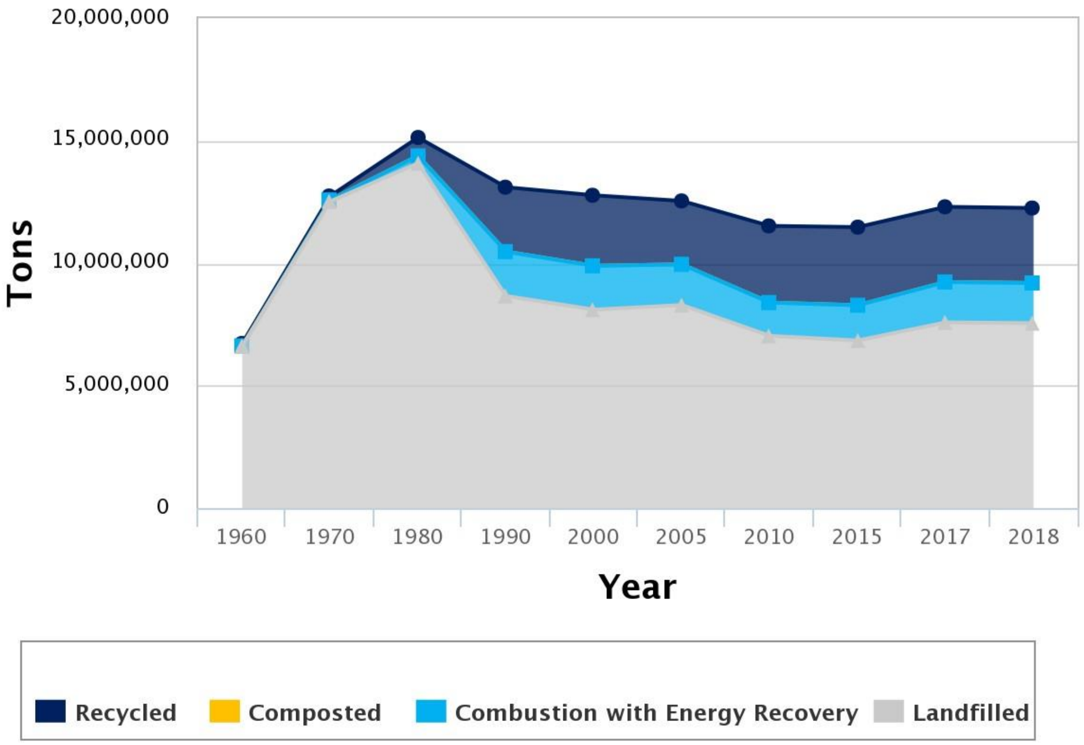


Figure 2.3: Glass waste management between 1960 and 2018 in the United States (EPA, 2021c).

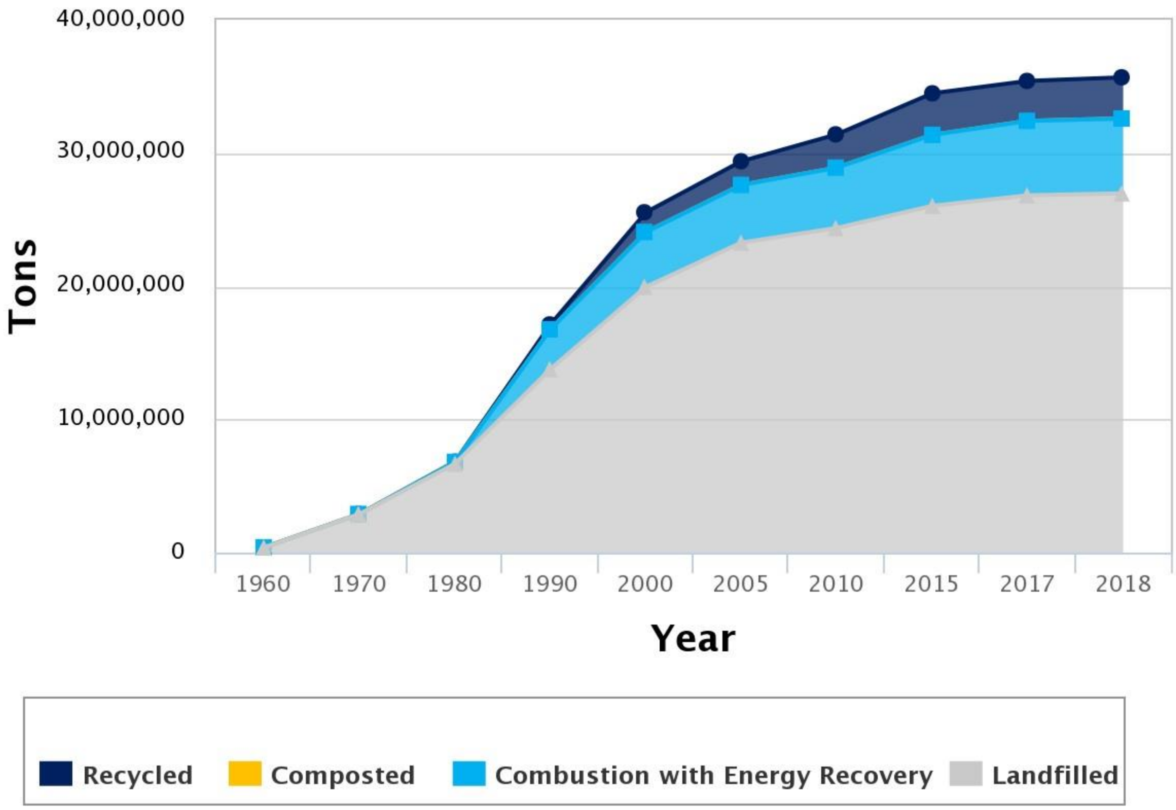


Figure 2.4: Plastic waste management between 1960 and 2018 in the United States (EPA, 2021d).

## 2.2 E-waste generation scenario around the world

The constant change in human daily lifestyle has increased waste generation and this applies to WEEE too. In the last few decades, waste from electrical and electronic appliances has therefore become a major concern in both the developed and developing countries around the globe. According to some reports, WEEE has contributed to a five percent increase in municipal solid wastes in affluent countries (Ahsan et al., 2016).

In the United States, a report by USEPA has it that 438 million tons of new electronic goods were sold in 2009; around 5 million tons of electronic products were stored; and approximately 2.37 million tons of electronic products reached their end-of-life in the same year. Moreover, in 2008, an estimated one billion computers and accessories that were produced were not utilized (abandoned), and another one billion gadgets were discarded over the course of a five years' period (Thavalingam & Karunasena, 2016). However, in all of these, only 25% of these electronic debris that were collected for recycling was recycled (Awasthi & Li, 2017).

The improper disposal of e-waste is therefore becoming one of the most alarming environmental crimes in the world today. This according to Golev et al. (2016) is because it is generated globally within the range of 20 million to 50 million metric tons per year, with about 75 to 80 percent of it being transferred to poor nations, particularly Africa and Asia, for recycling and disposal. Although, the primary importing countries are China and India; however, other countries such as Pakistan, Nigeria, Ghana, Bangladesh, and Kenya are among other major importers of e-waste for recycling. Nevertheless, most of these countries' practices are not legal under the Basel Convention of 1992 or any other existing national environmental legislation, and that is because of the absence of regulated handling and recycling of these wastes. (Garlapati, 2016).

Figure 2.5 thus depicts the relationship between continents in terms of total e-waste generation, creation per capita and collection rate according to Baldé et al. (2017)'s data. The data implies that Asia leads with 18.2 Mt of total e-waste generation and a primary reason is because China is the most sophisticated country in the world and it employs the most technical equipment which invariably result in the huge production of e-waste. Moreover, their waste generation is also affected by the activities of the Southern Asia countries who engage in the importation of electronic waste. Furthermore, Europe is the second leading continent on this chart with a production rate of 12.3 Mt; then America, which produces 11.3 Mt; Africa, which produces 2.2 Mt, and Oceania, which produces 0.7 Mt. Despite the generation rate, Oceania ranks first in e-waste per capital generation, with an average of 17.3 kg per inhabitant, due to its low population; then Europe, America, Asia, and Africa, with an average of 16.6, 11.6, 4.2, and 2.2 kg per individual, respectively. Regarding collection rate, Europe ranks first with a 35 percent e-waste collection rate. America ranks second with a 17 percent collection rate. Others such as Asia, Oceania, and Africa collect their e-waste at 15 percent, 6 percent and 0 percent respectively. (Masud et al., 2019)

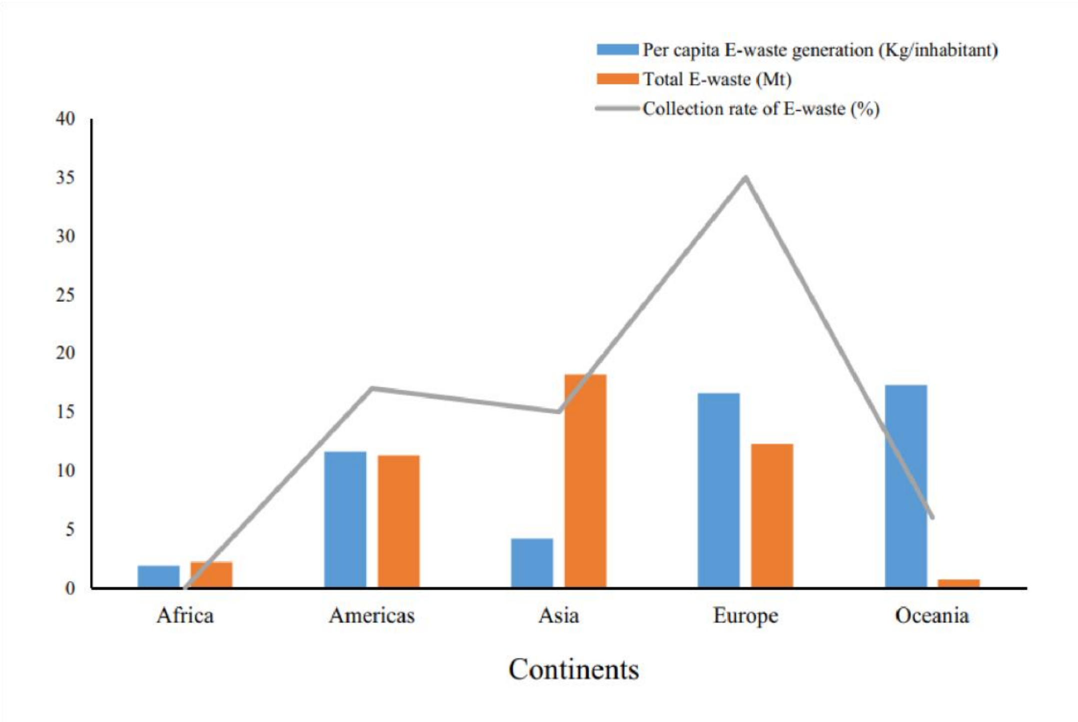


Figure 2.5: Continents and their level of e-waste generation (Masud et al., 2019)

In recent decades, the globe has seen a considerable increase in e-waste. According to the USEPA, the global yearly generation of e-waste is increasing at a rate of 5 to 10% per year, with a recovery rate of only 5%. (de Souza et al., 2016; Ahsan et al., 2016). The World Health Organization forecasts that the rise rate of e-waste generation will be significant due to many interconnected factors. This problem has two major causes. First, the frequency of acquiring needless EEE goods is high (Namias, 2013), and second, the electrical equipment has a limited lifespan (Althaf et al., 2020). According to the International Association of Electronics Recyclers (2006 cited by Awasthi et al., 2016), an average of 400 million units of e-waste are trashed each year. E-waste accounts for 8 percent of the total volume of existing municipal solid waste (MSW). Waste electronic devices are fast filling landfills throughout the world. In a single year, about 60 million metric tons of e-waste is deposited in landfills, according to a USEPA report. According to research by the Environmental Protection Agency (EPA), the amount of electronic waste which is being recycled, and with some ending in landfills would amount to 15-20 percent in approximate. E-waste output grew from 1% to 2% of total solid waste by 2010, and it continues to grow at an alarming rate as one of the fastest rising waste components. It is predicted to increase by up to 6%, with a range of 0.01 to 1% for underdeveloped countries producing less than 1 kg per year. (Masud et al., 2019)

The global volume of wasted refrigerators, televisions, cell phones, computers, monitors, and other electronic waste weighed about 200 Empire State Buildings in 2017 (Awasthi et al. 2016). Figure 2.6 depicts the top e-waste producing countries, as well as the total amount of E-waste they generate, with the European Union being the top on the table, followed by the United States, followed by China, down to Mexico, which is the least on the table. Based on e-waste generation data from 19 countries in Asia, Africa, Europe, North America, and South America, the following two box and whisker plots were created. The first box and whisker plot in Figure 2.7a depicts the distribution of annual e-waste generation in kilograms per year, while the second box and whisker plot in Figure 2.7b summarizes the spread of per capita e-waste generation data in kilograms per inhabitant (Masud et al., 2019). It is clear from Figure 2.7a that Asia and North America are the leading producers of e-waste. China in Asia and the United States of America in North America produce massive amounts of E-waste compared to other countries on their respective continents. The median result for Asia and North America reveals that the majority of countries produce half of the total e-waste, with only a few countries producing the other half. This is worrying because, despite their attempts to limit e-waste generation, the environmental damage would be shared equally by all counties.

Kumar et al. (2017) offer a summary of per capita e-waste creation from five continents. South America, followed by Africa, has the lowest per capita E-waste creation rate, as seen in Figure 2.7a. Except for North America, all continents have an even distribution of per capita E-waste generation. This is owing to the United States' contribution, which shows that Americans generate more E-waste on average than citizens of any other North American country. Furthermore, because China generates a lot of E-waste on an annual basis, its E-waste creation per capita is significantly higher. However, it is evident from the whisker and box chart that Asia generates more E-waste per capita than the majority of other continents. This is owing to the fact that most developing and least developing Asian countries have limited recycling capacities. Finally, despite Europe's low annual e-waste creation, it has the largest per capita E-waste generation of the five continents.

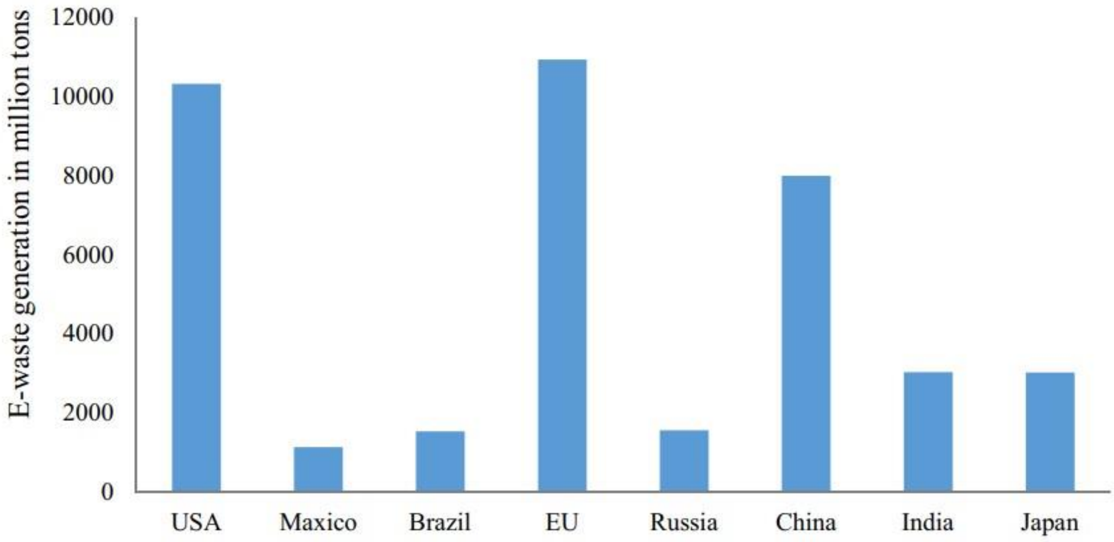


Figure 2.6: E-waste producing quantity and the volume they generate (Masud et al., 2019)

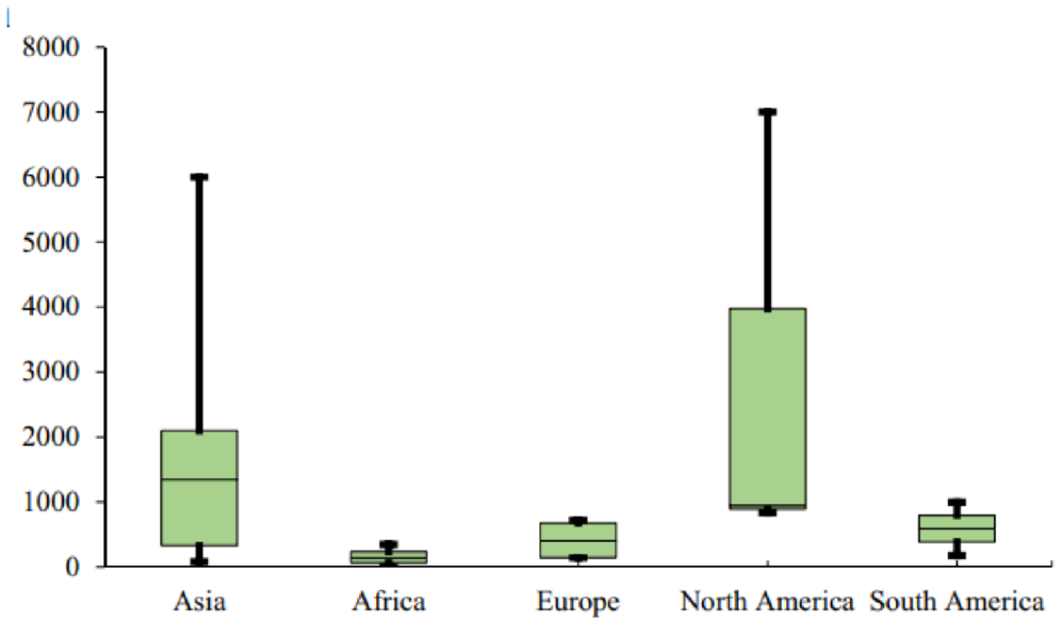


Figure 2.7a: Distribution of annual e-waste generation in kilograms per year (Masud et al., 2019)

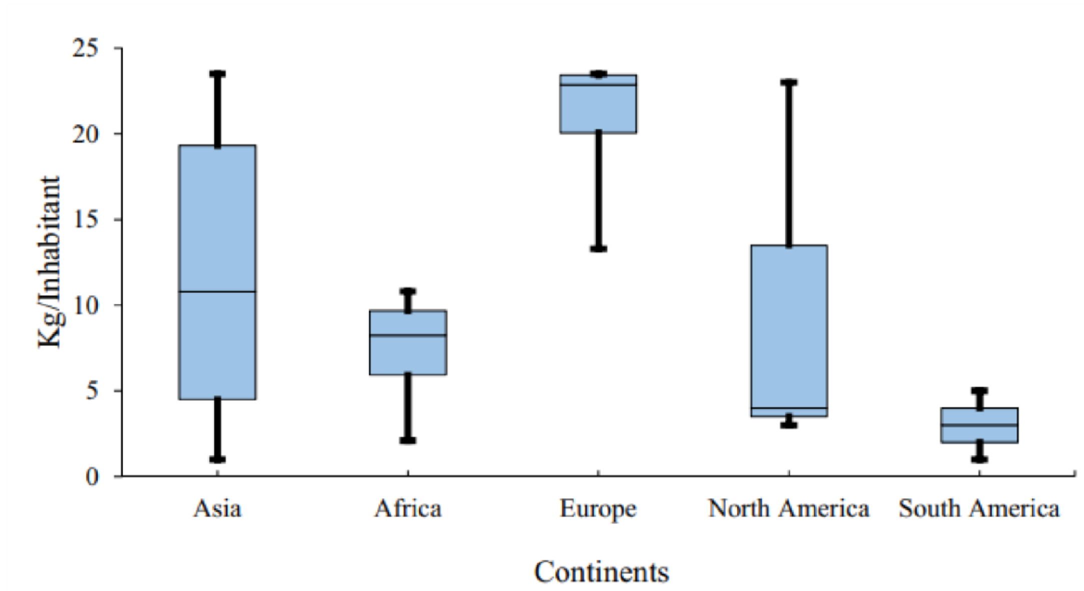

Figure 2.7b: Spread of per capita e-waste generation data in kilograms per inhabitant (Masud et al., 2019)

## 2.3 Global e-waste management

Global Waste Electric and Electronic Equipment (WEEE) generation reached 54 million tons (MT) in 2019 (Forti et al., 2020), with a global average of 7.3 kg/person/year (Baldé et al., 2017). According to projections shown in Figure 2.5, Over the next few years, this generation rate is predicted to skyrocket, with total volume generated expected to reach 75 MT by 2030. (Forti et al., 2020).

However, developing ways to successfully manage e-waste on a worldwide basis is proving extremely difficult (Williams, 2016). Different e-waste management strategies and scenarios exist all across the world, with regional differences. E-waste flows and movement can be complicated and intertwined, with many uncounted flows (Peagram et al., 2014). Four common management scenarios, however, have been identified and classified (Shittu et al., 2020):

i. The first involves WEEE that has been legally documented and collected in compliance with existing WEEE/WEEE-related legislation. In this scenario WEEE is typically collected by municipal collection stations, which could be electrical and electronic equipment manufacturers and retailers, or through dedicated pick-up arrangements in this case. WEEE is collected and transferred to specialized treatment facilities, where it is processed (including physical disassembly, shredding, and materials recycling) under strict criteria to ensure that it is treated in an environmentally sound manner.

ii. The second scenario has to do with the direct dumping of WEEE among mixed household waste. WEEE is disposed of with non-segregated household waste by consumers. Depending on the prevailing disposal procedures, the mixed waste may be sent to landfill or incinerated.

iii. The third scenario involves the collecting of WEEE in an unauthorized manner. These activities may involve waste brokers and dealers. Recycling of collected WEEE at specialist facilities, refurbishment, or shipment to developing countries are some of the outcomes. In contrast to scenario 1, collected WEEE in this scenario is not properly documented, that makes auditing and tracking generation and collected amounts hard; this could be due to a lack of legal requirements or a WEEE management system. As a result, the treatment of WEEE gathered may be harmful to the environment, or WEEE may be destined for illicit export.

iv. The fourth scenario is more common in developing countries and it involves waste brokers and scrappers collecting WEEE from consumers informally. These operations are unregulated because of the lack of enforcement of WEEE management legislation. As a result, treatment procedures are frequently simple and rudimentary; typically, collectors look for metal elements in WEEE and use open burning and acid leaching to recover metals. Meanwhile, William (2016) reported that this scenario, in which WEEE is reused, repaired, and cannibalized for parts, also occurs in Europe.

### 2.3.1 E-waste management in Europe

E-waste management in the European continent can be analyzed from two different perspectives which include the European Union (EU) countries and the non-EU countries (Shittu et al., 2020). 2019 WEEE figures revealed that 12 million tons (MT) of WEEE was produced (Forti et al., 2020). To manage this, some legislative instrument is put in place and they include: WEEE directive and RoHS directive.

i. WEEE directive:

The Waste Electrical and Electronic Equipment Directive (WEEE Directive) is a legislative instrument of the European Union that enables environmentally sound WEEE management. It has been in force since 2003 and sets collection and recycling targets for all Member States (MS) (Eurostat, 2022). The WEEE Directive's main goal is to reduce WEEE creation by promoting and improving environmental performance through reuse, recycling, and material recovery (Ongondo et al., 2011a; Ongondo et al., 2011b; Yla-Mella et al., 2015). Each EU Member State is compelled to build various systems as a result of an EU Directive and methods in order to meet the Directive's collection and recycling requirements. The Directive divides EEE into ten main categories (Annex 1), but as of 2018, all EEE is divided into six categories (European Union, 2014 cited by Shittu et al., 2020). The WEEE Directive (Directive 2002/96/EC) was founded on the principle of extended producer accountability (EPR), which mandates EEE producers (importers, manufacturers) to gather and treat end-of-use and end-of-life EEE from consumers in an environmentally friendly manner. (Shittu et al., 2020; Widmer et al., 2005). When the Directive was first implemented, it set a minimum collection goal of 4 kilograms per person per year. The WEEE Directive posed considerable obstacles for Member States to implement, particularly in terms of legal and technical foundations for collection and treatment (Ylä-Mella et al., 2014). In 2012, the WEEE Directive was revised to address some of these concerns. The recast Directive (2012/19/EU) aimed to clarify the Directive's scope and set new collection goals based on WEEE creation in each Member State. (Yla-Mella et al., 2015; Shittu et al., 2020). Under the Recast WEEE Directive, each Member State has been supposed to furnish, collect a minimum of 45 percent of the average weight of EEE put on market (POM) in the previous three years since 2016 (Directive 2012/19/EU), In 2014, it was replaced by Directive 2002/96/EC (Yla-Mella et al., 2015). Starting in 2019, each Member State's minimum collection rate will be 65 percent of the average EEE placed on the market in the last three years, or 85 percent of the yearly generated WEEE. (European Union, 2012 cited by Shittu et al., 2020).

ii. RoHS directive:

The Restriction on Hazardous Substances Directive (RoHS Directive). The directive went into effect in 2004 with the primary purpose of reducing the use of harmful compounds in the manufacturing of EEE, including as lead, mercury, polybrominated diphenyl ether (PBDE), and other persistent organic pollutants (POPs) (Shittu et al., 2020).

### 2.3.2 E-waste management in Africa

In 2019, Africa created an estimated 2.9 MT of WEEE, with Western Africa producing the largest amounts (Forti et al., 2020). In addition, several countries get considerable volumes of WEEE exported by developed countries. (Ongondo et al., 2011a; Ongondo et al., 2011b; Baldé et al., 2015; Snyman et al., 2015). Before being exported, the shipments are typically not subjected to rigorous functioning assessments and are largely imported as used electrical and electronic equipment (UEEE) (Ongondo et al., 2011a; Ongondo et al., 2011b). This trend, along with a lack of WEEE management infrastructure and insufficient or non-existent WEEE regulation, has exacerbated Africa's WEEE management problem. While many African countries lack WEEE-specific legislation or have inadequate enforcement, international agreements such as the Basel and Bamako Conventions (as explained in 2.6.1 and 2.6.2) govern and control the movement of hazardous waste across international borders (including WEEE) (Li et al., 2013; Snyman et al., 2015).

i. The Basel convention:

The Basel Convention is an International Environmental Agreement (IEA) that regulates the trans-boundary movement of hazardous waste and went into effect in 1992. There are presently 53 signatures. It aims to reduce the transfer of toxic waste from developed to developing and less developed nations (LDNs) (Andrews, 2009; Li et al., 2013). The Basel Convention has no influence on how WEEE is managed or moved. WEEE, on the other hand, is known to contain trace levels of dangerous substances, thus it is covered by the agreement when it travels across borders.

The Basel Convention arose from high-profile transboundary hazardous waste flows, most notably an Italian transport of toxic trash to Nigeria in 1988. (Amanze, 2013). The Convention allows hazardous waste to be transported as long as there is a bilateral or multilateral agreement in place for its' safe treatment within the importing countries (Lepawsky & McNabb, 2010). The success of IEAs like the Basel Convention is difficult to judge, because to a paucity of data on activities previous to their passage is making comparison and analysis difficult. On the other hand, the Basel Convention has been criticized for failing to achieve its goal of reducing toxic waste trafficking. (Andrews, 2009; Daum et al., 2017); The Convention permits garbage to be transferred between nations who are members (as stipulated in Article 4 of the Convention3). Furthermore, the Convention makes no provision for ensuring that adequate treatment techniques are accessible in the importing country. The Bamako Convention was formed in reaction to the Basel Convention's inability to prevent toxic waste dumping in Africa (UNEP, 2018).

ii. Bamako convention: The Bamako Convention is an African treaty that went into effect in 1998 after being signed in 1991. It, like the Basel Convention, restricts the importation and movement of hazardous waste into and within Africa. The Bamako Convention seeks to complete the work begun by the Basel Convention in preventing toxic waste from crossing borders into African countries (UNEP, 2018). The Convention aims to safeguard African communities from the environmental and human health threats caused by indiscriminate garbage dumping and uncontrolled incineration, as well as develop a framework for environmentally sound toxic waste management (UNEP, 2018).

    The success of the Bamako Convention in limiting cross-border trafficking of toxic waste has been a source of significant debate (UN Environment, 2018). It has been suggested that the Convention's inability to carry out its mandate is due to the lack of an enforcement arm (Daum et al., 2017). High-profile dumping incidents, such as the Probo Koala disaster in Ivory Coast, and the net inward flow of e-waste to countries like Ghana and Nigeria, despite the fact that both are members to the Convention, illustrate this. The Bamako Convention, like the Basel Convention, is primarily consultative in nature, and member countries are not obligated to follow its mandate (UNEP, 2018).

### 2.3.3 E-waste management in Asia

In the previous several decades, a vast number of Asian countries have witnessed economic growth, resulting in a rise in the amount of WEEE generated. (Ongondo et al., 2011a; Ongondo et al., 2011b; Baldé et al., 2017, Forti et al., 2020). Baldé et al. (2015) estimated that 16 million tons of WEEE were generated in 2014, with China alone generating around 6 million tons (38 percent). In 2019, the amount for Asia grew to 24.9 MT, accounting for over half of all WEEE produced globally. As a result, Asia is the world's greatest generator of WEEE (Forti et al., 2020)

### 2.3.4 E-waste management in some selected countries

An official report for e-waste collection and recycling showed that less than 20 percent (17.4%) were recycled in 2019. This implies that in spite of the continuous increase in the rate of e-waste which has risen to about 1.8 million tons annually since 2014, only few countries are committed to this task of recycling. Nevertheless, it is believed that these few are doing something differently, and this is the reason for assessing their e-waste management. (Forti, 2020). Consequently, based on the data from Statista (2021a) regarding Germany e-waste management, the chart in Figure 2.8 depicts that Germany has been consistent in its practices, with its stats being 37.8% in 2009, 33.9% in 2015 (which is its' low), 39% in 2016 (which is its' peak) and 36.9% in 2018 which signifies a little drop from its peak. (Statista, 2021a)

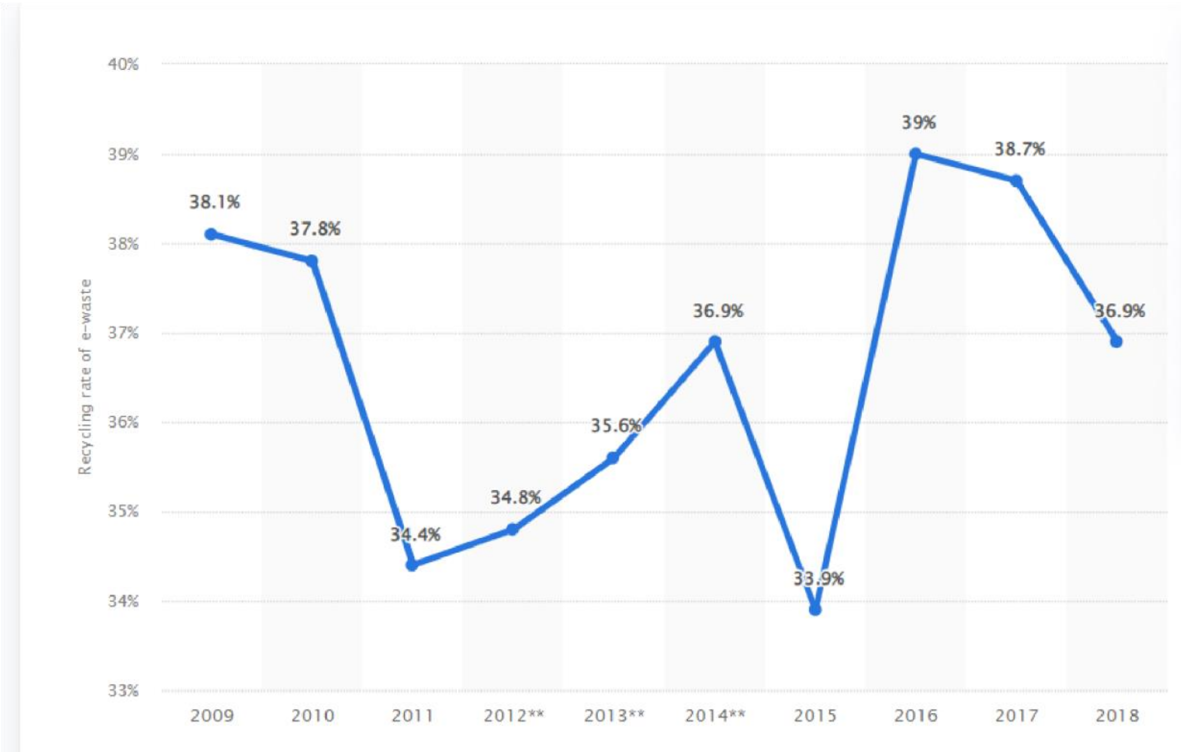


Figure 2.8: Germany e-waste management between 2009 and 2018 (Statista, 2021a)

i. Germany: This is one of the countries who have found a way around recycling its electronic waste. Its achievement is primarily due to the implementation of strict policies at all levels of government such as the "ElektroG" which has helped in the appropriate deposit, collection and treatment of these wastes (Deubzer, 2011). These wastes, just like every other waste in Germany, are collected by the public waste management agency (PuWaMa) and the collection is either done directly from the consumer (on demand or periodically) or from the municipal collection point. After collection, treatment is handed over majorly to the private organizations (who are electronic producers or end-of-life service providers) from the clearing house which is meant to ensure even distribution for treatment. Sometimes, the likes of PuWaMa and nonprofit organizations also participate in the treatment/recycling of these wastes (Deubzer, 2011).

ii. Switzerland: this is the country where an e-waste management system was officially established and operated. For its effectiveness, it introduced legislation in 1998 and based on the available data, it manages two-different e-waste recycling systems (Gaidajis et al., 2010). Its legislation allows for the proper collection of the waste which is then transferred to the recycling facility to be disassembled, disinfected (such that it is not toxic to the environment) thus limiting the non-recoverable part of each items to about 2%, as others are sent to factories or foundries for recovery. In 2016, it produced 184 kilotons of e-waste and this makes it one of the biggest producers of e-waste; however, about 75% of these were recycled. In 2018, the country scaled up its recycling rate to 95% of digital e-waste generated and this places it at the top of the list (ITUNews, 2019; Islam et al., 2018). Meanwhile, its success has not been through its collection process only, but also legislation which include the responsibility levied on electrical and electronic equipment manufacturers with managing the recycling based on the charge which has been included during the device purchase. (Wath et al., 2010)

iii. Japan: More like Switzerland and Germany, Japan employs the use of legislation too, with strict penalties for non-compliance (Gaidajis et al., 2010). It established a withdrawal system whose focus is on four products: air conditioners, televisions, washing machines and refrigerators. It imposes the incorporation of e-waste management into the manufacturer's production plan and as such almost all of the companies have their e-waste management system (Gaidajis et al., 2010). Meanwhile, it has some partially funded e-waste management system, but the handling of its e-waste is done in such a way that what will turn out to be a waste is greatly attenuated: with its central collection hub and its procedural distribution system (Gaidajis et al., 2010). Consequently, Japan recycled around 8.4 million tons of waste in 2019 and in the 2020 fiscal year, it recycled 87% of its electronic waste which is up from its 82% rate in 2011 (Klein, 2021).

iv. Slovenia: This is another country that has gotten a grip of its e-waste management system. The country achieved this by creating sufficient public awareness and enhancing its waste collection method (Petek, 2016). This country imposed a pay-as-you- throw system to attenuate the level of waste generation in the country and also introduced a collection center where most of e-wastes are given a new chance of life through repairs (Petek, 2016). In 2009, it recycled 17.6% of its e-waste and in 2015 it achieves a rate of 47.7% which is its peak till date; although there has been a significant drop in its rate, but it still maintained a 33.4% in 2017 as depicted in Figure 2.9 (Statista, 2021b). Although, its practices to have achieved the number is not explicitly stated, but information from some reports, presentations and the likes suggested that it employs the use of policies too and has good waste collection practices in place.

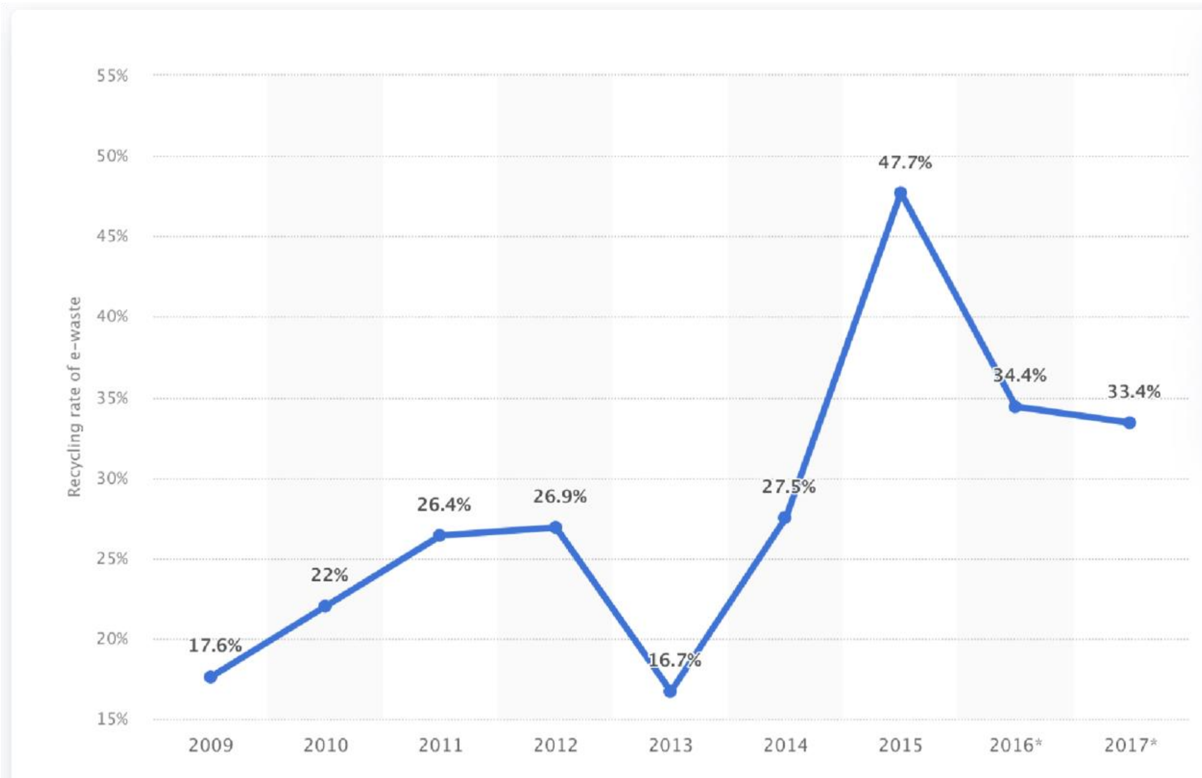

Figure 2.9: Slovenia e-waste management between 2009 and 2017 (Statista, 2021b)

### 2.3.5 E-waste management in Estonia

Estonia is a consumer and also a producer of electronics and electrical equipment, and this makes it fit into the category of countries like Japan in terms of e-waste generation. According to ITA (2020), the electronic and electrical equipment manufacturing sector has become the fastest growing sector in the country, and based on EEIA (2018) assessment, this has significantly contributed to Estonia's GDP. Consequently, since the emergence of a new market for its EEE products in Germany and the United States, the rate of production has increased, to make up for its export while still serving the Swedish and the Finnish market. However, this action is not without its consequence, and that is the increased rate of the total e-waste generation in the country, which is a concern.

On e-waste management, Estonia adopted the extended producer's responsibility method, which implies that producers or importers are responsible for such products when it reaches its end-of-life. To make this effective, Estonia put in place some legislation to hold these sets of people responsible for the management of the e-waste in the country. Consequently, this makes the producers accountable for the collection, recovery or disposal, treatment and recycling of the e-waste. (MoE, 2021)

Meanwhile, based on the waste act, there are other expectations from the producer with regards to sufficient guarantee for the obligation, and this includes its participation in the collective schemes, recycling insurance or "closed bank account'' (MoE, 2021). Moreover, the producer is expected to provide the following information (in a legible, indelible and visible manner) on any goods that are meant for distribution: the producer identifier data, a separate collection mark by standard EVS-EN 50419 and CE-Marking. Furthermore, the producer is expected to provide other information such as; return facilities (with the requirement being data such as location, telephone numbers for ease), the potential effect of the product on the environment and human health due to the hazardous substance it may contain, and the meaning of the separate collection mark for sensitization. In addition, producers are also required to begin the preparation for the management of each new product they introduce to the market after one year of introducing it, and this is to enhance the preparation for the reuse and processing of such products. (MoE, 2021)

On the collection of the waste, EEE waste is collected separately from other waste, and as for WEEE of products placed on the market after August 13th 2005, these are also collected separately. The collection is done through collection centers established by each manufacturer within the local territory of most households. Moreover, collection is done through take-back programs, especially by the distributor, and this is expected to be free of charge and without restriction. (MoE, 2021)

## 2.4 E-waste recycling methods

Generally, the recycling of waste on a large scale involves a number of processes for an optimal result. This in the case of e-waste is not an exception and according to RTS (2021) as illustrated in Figure 2.10, this process is in five stages: collection; storage; manual sorting, dismantling and shredding; mechanical separation; and recovery.

i Collection: This is regarded as the first stage of the process, and it involves the collection of electronic products through collection centers, recycle bins, on-demand collection services or take-back programs. It is pivotal to the process and as best practice the wastes at this stage are expected to be separated by type. This is because some of these products require special treatment due to their constituents such as batteries which are highly flammable and can be damaging when mixed with other products. (RTS, 2021)

ii Storage: This stage just as the name implies ensures the safe storage of the e-waste collected whether for a short while or for an extended period of time. This stage is considered critical and as well important for the process as it helps to safely keep some of the components which can be reused as in the case of cathode ray tube which used to be recycled into new computer monitors, back in the days when this technology was still embraced. However, despite the advancement, this stage ensures the storage of those glass indefinitely. (RTS, 2021)

iii Manual sorting, dismantling and shredding: This is the third stage of the process and in this stage, the wastes are first sorted or dismantled for "components, reuse, or the recovery of valuable materials". In this sorting phase, which is best done manually, each waste electronic device is separated into constituents such that various items including batteries, screens, etc., are removed for their own processing. Furthermore, the e-waste is then shredded into small pieces for accurate sorting of the material, which is an important part of the process. (RTS, 2021)

iv Mechanical separation: This stage consists of several processes, and it is important to the recycling process. This is because most electronic products have been found to contain a mixture of materials which can be mechanically separated, having been broken down into pieces which are within a few centimeter radii. Consequently, in this stage, the magnetic separation and water separation have been identified as the key steps. (RTS, 2021)

   a. Magnetic separation: This involves the use of a giant magnet to pull ferrous metals (such as iron and steel) from the shredded waste mixture. Due to the non-magnetic property of the non-ferrous metals, an eddy current is used to separate them from other constituents of the waste. Usually, waste separated in this stage is diverted to dedicated recycling plants for smelting. (RTS, 2021)
   b. Water separation: Pot-separation of the ferrous and non-ferrous metals, the waste mixture will now consist of plastic and glass (majorly). Due to the density of these two constituents, water is used for the separation. (RTS, 2021)

v Recovery: This is the final stage of the recycling process and in this stage, materials that have been separated are prepared for sale and reuse. (RTS, 2021)


Figure 2.10: The e-waste recycling process flowchart (RTS, 2021)

Meanwhile, this process is usually implemented in form of methods, and the following are some of the methods:

i The Swiss method: This is coined the Swiss method because it emulates MSW management that is employed in Switzerland. The method is such in which the government sets policies to make the waste management practices effective. Apart from the policies, the Swiss government also invested in recycling facilities which it manages. Furthermore, the EEE manufacturers within the country were saddled with the responsibility of recycling their own products when it has reached its end of life. Hence, the Swiss MSW management method involves the consumers, the government and EEE manufacturers within the country. (Gaidajis et al., 2010)

ii The Japanese method: This method is coined the Japanese method because it emulates the e-waste management that is employed in Japan. Japan is the home to several electronics manufacturing companies and as such a slack in its policies could be disastrous. This method is more stringent compared to the Swiss method, as there is a penalty for non-compliance. The Japanese government also developed a policy which enforces withdrawal of EEE goods at their end of life. Japan imposes the incorporation of the EEE recycling strategy into manufacturers' production plan. Consequently, the government has a central hub which it partially funds and this has been the reason for its success in terms of e-waste management. (Gaidajis et al., 2010) iii Extended Producer's Responsibility (EPR) method: This can be considered as one of the most widely used methods for recycling e-waste around the globe. It places the responsibility of the management of EEE products at their end-of-life in the hands of the importers or manufacturers. This method shifts part of the burden of waste management from the governments to the upstream producers. Moreover, it forces the internalization of the external costs of disposal which is meant to incentivize producers to take environmental considerations into their product design. Consequently, the producers would design their products using materials that are more recyclable or less toxic if EPR makes them internalize the social costs of disposal after the useful life. Nevertheless, EPR can be done in four different ways: firstly, economic-wise, the producers can be required to typically pay a tax for the collection recycling and disposal of e-waste; secondly, physically, the producers can be required to collect their products that has reached their end of life from consumers at a specific rate; thirdly, the producers can be required to provide information about the attributes of the product such as its toxicity, recyclability, etc.; lastly, some financial liability may be levied on producers for environmental damages and clean-up. (Tagara et al., 2019)

iv The use of state-of-art recycling technologies: This is another e-waste recycling strategy and it involves a number of processes such as hydrometallurgical, bio-metallurgical and pyro metallurgical processes (Yong et al., 2019).

a. Pyro metallurgical process: this method is applied to recover precious and nonferrous metals from e-waste. The process involves "conflagrating, incineration, and smelting in a plasma arc furnace, crossing, sintering and melting at high temperatures" (Murugappan & Karthikeyan, 2021). In this method, the scrap or e-waste is first crushed and liquefied in a furnace or in a molten bath to separate the plastic constituents. This process has been rated as being economically efficient in that it recovers a sufficient amount of metals present in the e-waste. However, it has been noted that it requires high operation energy, high investment and it releases toxic fumes into the environment. (Murugappan & Karthikeyan, 2021)
b. Hydrometallurgical process: This method is used to extract precious metals such as (but not limited to) gold, silver and selenium. It consists of three different stages which include the pretreatment stage (disassembly), where hazardous and valuable components are removed for special treatment in preparation for other stages; concentrating stage, where the concentration of desirable materials are increased through metallurgical and/or mechanical processing; and the refining stage, where desirable materials are made to undergo

purification and metallurgical treatment using acidic solutions (Kamberović et al., 2009). It is considered better than pyro metallurgical processes since it does not release toxic emission to the environment; however, it is said to require high operation cost and besides, the difficulty in treating its wastewater makes it less perfect (Qi, 2018).

c. Bio-metallurgical process: This process is considered an emerging and very promising method of processing e-waste. It is considered one of the most of the eco-friendly technologies for the treatment of e-waste and can be classified into two sections: Bio-sorption and Bioleaching. While bio-sorption involves "adsorption of metals by means of adsorbents prepared from waste biomass or abundant biomass", bioleaching is "the mobilization of metal cations from often almost insoluble materials by biological oxidation and complexation" (Debnath et al., 2018, 4). However, despite how promising this process is, it is still in the phase of researching as there are quite a number of limitations to its use (Debnath et al., 2018).

## 2.5 The benefits of e-waste recycling

The benefits of e-waste recycling are numerous but it can be categorized into three: economic benefits, environmental benefits and public health and safety benefits (Kumar et al., 2017).

i Economic benefits: The economic benefit of e-waste is quantifiable and in 2014, its value based on some metals such as silver, gold, copper, aluminum, and iron was estimated to be 48 billion euros Kumar et al., (2017). Electronic waste contains up to 60 different metals and according to Kumar et al., (2017) between 2005 and 2014, the global demand for metals such as copper, silver and tin has been on the increase; while the demand for gold on the other hand became relatively stable.

Meanwhile, the most valuable component of e-waste is the printed circuit board (PCB), and it accounts for more than 40% of the overall metal value of e-waste (Golev et al., 2016). According to Bullion Street (2012 cited by Kumar et al., 2017), the electronic sector consumes 320 tons of gold and 7500 tons of silver per year. Due to the existence of a higher concentration of precious and crucial metals, Cucchiella et al. (2015) found that laptops, smartphones and tablets, are the most valuable categories for the e-waste stream. Moreover, Golev et al. (2016) also found that screens, monitors, and tiny IT devices contain over 80% of gold, over 70% of silver, as well as Platinum Group Metals (PGMs). Printed circuit boards therefore

contain a high amount of precious metals such as gold, silver, gold and palladium, which is said to account for almost 3–6% of total e-waste (Kumar et al., 2017).
In the same vein, the metal concentration in e-waste is far higher than in traditional mining operations and this is because the global ore grade is declining. However, studies have shown that the global taste for quality metal around the globe is high and this is compelling mines to extract more complicated and fine-grained ore deposits (Lèbre and Corder, 2015). A comparison done by Electronics TakeBack Coalition (2014 cited by Kumar et. al., 2017) between various metals recovered from e-waste recycling and the run of mine ore showed that to get a 24 kg of gold, 250 kg of silver, 9 kg palladium and 9000 kg of copper, only 1,000,000 units of mobile phones which weighs approximately 148.4 tons is required; but for the run of mine ore, 23,762.4 tons of gold ore, 1160.1 tons of silver ore, 3333.3 tons of palladium ore and 1500.0 tons of copper ore is required.

Furthermore, e-waste is said to provide better opportunities for natural elements that are already scarce such as gallium and indium, who currently have an estimated life of less than 20 years. Consequently, the economic benefit of e-waste is numerous, and primarily, it aids job creation, as in China, where 100,000 people work as recyclers for informal e-waste recycling and the projection of about 30,000 jobs in the formal sector. (Kumar et. al., 2017)

ii Environmental benefits: The e-waste contains substances such as Mercury, lead, cadmium, chromium, ozone depleting compounds like CFC, and other dangerous pollutants which are hazardous to our environment (Balde et al., 2015). By keeping these hazardous waste out of landfills, e-waste recycling decreases the dangers associated with disposal, thus revealing its importance in environmental conservation. Although landfill and incineration with strict controls and regulations may provide a temporary solution to the global e-waste problem; however, they are not sustainable in the long run, especially in countries with limited landmasses, such as Japan and Europe, and they also reduce the possibility of resource recovery. (Kumar et. al., 2017)

Moreover, the recycling of e-waste reduces the world need for new metal manufacturing, which helps to decrease greenhouse gas emissions. According to the Electronics TakeBack Coalition (2014 cited by Kumar et. al., 2017), one computer with a monitor needs 240 kg of fossil fuels, 22 kg of chemicals, and 1.5 tons of water to manufacture. But with the practice of reusing some of these parts, this need to manufacture new ones will be greatly attenuated, thus making the environment safer.

iii Public health and safety benefit: Relative to the fact that e-waste contains a stream of hazardous substances, this makes it dangerous to human health. According to Balde et al. (2015), some of these substances are capable of impairing human mental health, and causing liver, lung or kidney damage. Moreover, the improper handling of the recycling process which often leads to more e-waste ending up in landfill, often produces harmful effects and sometimes releases chemicals to the environment thus causing pollution of the air, water and land (Heacock, et al., 2015). Besides, study showed that e-waste contains elevated levels of these hazardous materials, thus making reuse though recycling one of the methods to keep the environment safe (Kumar et al., 2017).

# 3. METHODOLOGY

This section describes the method through which the highlighted aim for this study is fulfilled. It explains the research design in detail, as well as how the data used for the study was collected and analyzed.

## 3.1 Estonia Waste Reporting Data System (EWRDS)

The WEEE system in Estonia is structured such that EEE manufacturers or distributors or importers are solely responsible for the e-waste management in the country. As such, the majority of these wastes are handled officially such that the data is made available at a data hub recognized as the Estonian Waste Reporting Data System. Consequently, this makes it easier to access the data and to assess the state of the sector.

The data consists of information about how e-waste in Estonia has been managed from 2004 to 2019. The website groups the waste in terms of:

- year
- waste type (including waste subgroup, waste code and waste type name)
- waste substance main group (including waste substance subgroup and waste substance name)
- Hazardousness
- Export/import country.

  Furthermore, the numerical data is grouped under the following headings:

- Storage at the beginning 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

To understand each of these terms, Appendix 1 provides information about the definition of the terms.

## 3.2 Data collection

EWRDS hosts varieties of waste management data; however, this study is only focused on e-waste management data that is available. The data available gives the opportunity to study the sector for a 15-year period, but for the purpose of this study, the data to be considered will be limited to the following range: 2009 through 2019. This is because the website showed that data collection commenced in 2004, which could be significantly inaccurate being in the first year. However, it is believed that over a period of five years this should have been improved, thus limiting the chances for error/inaccuracies in the data used.

With the data being coded, most of the relevant data are found in the waste subgroup "16 02" which is defined as the "wastes from electrical and electronic equipment and other equipment and apparatus" and "20 01" which is defined as the "municipal wastes (household waste and similar commercial, industrial and institutional wastes) including separately collected fractions". To ease data sorting, the data tagged "16 02" was exported separately to a csv file and the "20 01" was also exported separately to another csv file. The "20 01" contains data from other sources of waste management and as such this was sorted using the waste substance name criteria, using the Microsoft Excel software filter before being considered fit for the study. Consequently, the data that are relevant to this study are those tagged "wastes from electrical and electronic equipment and other equipment and apparatus", "other discarded electrical and electronic equipment" and others like "discarded major household equipment".

The numerical data considered include (RT, 2021; WDMS, n.d.):

a) the amounts of e-waste at the start of the reporting year which is usually waste stored by the supplier awaiting referral or transfer for further processing.
b) The amount of e-waste from production or other operations including those that were collected.
c) The amount of e-waste that is imported into Estonia from other countries.
d) The amount of e-waste that was put into good use after recovery operation.
e) The amount of e-waste that were not recovered i.e., incinerated without energy use
f) The amount of e-waste that were disposed at landfill sites
g) The amount of e-waste handled by unaccountable operators
h) The amount of e-waste exported from Estonia to other countries
i) The amount of e-waste at the end of the reporting year awaiting referral or transfer, which account for the data inventory for another reporting year

j) The amount of e-waste that was "mainly as fuel or as an energy source in any other way" (R1)
k) The amount of organic substance that was recycled or reclaimed in e-waste other than that used as solvent (R3)
l) The amount of metals that were recycled or reclaimed in e-waste (R4)
m) The amount of inorganic substance that was recycled or reclaimed in e-waste (R5)
n) The amount of e-waste that were recycled mechanically (R5m)
o) The amount of e-waste that were recycled as stockpile of raw materials (R5f)
p) The amount of e-waste that were prepared for reuse (R5k)
q) The amount of e-waste that were prepared or regenerated to be used in another manner (R9)
r) The amount of e-waste that were exchanged or pre-treated for reuse in any of the recovery operation in R1 to R11 (R12)
s) The amount of e-waste that were sorted prior to recovery of certain components which may involve mechanical treatment (R12s)
t) The amount of e-waste that undergone pre-recovery or mixing (R12x)
u) The amount of e-waste that undergone pre-repackaging (R12y)

Moreover, this study will juxtapose its findings from the data collected from the Estonia Waste Reporting Data System with other data obtained from interviews. The interview was targeted at organizations that deal with e-waste in Estonia and as many as possible were contacted via emails. None but one (Base Metal) of these companies contacted granted physical interview and this is understandable given the need to minimize physical contact due to the pandemic and others based on their schedule. Consequently, most of the interview questions were answered and returned via email. The physical interview was recorded and transcribed. Consequently, all the data obtained from the interview are present in Appendix 2.

The organization that participated include: SWAPPIE, Weerec OÜ, Kat Metal Estonia OÜ and Base Metal. While SWAPPIE is an organization that refurbishes phones especially iPhone; Weerec OÜ is an electronics waste recycling company and both Kat Metal Estonia OÜ and Base Metal, are e-waste collection companies. Based on the data for their sales for the 2020 production year, the market shares of SWAPPIE, Weerec OÜ, Kat Metal Estonia OÜ and Base Metal in Estonia is 16 percent, 24 percent, 30 percent and 30 percent respectively (inforegister.ee, 2022).

## 3.3 Data Analysis

The data will be analyzed using both qualitative and quantitative research methods. This approach according to Seaman (2008) is appropriate in many studies and that is because there are “several ways to quantify some parts of a body of qualitative data”. Hence, to make sense of the main categories of a set of data, quantification of these data is necessary; although with it being preceded by a preliminary qualitative analysis and also being followed by further qualitative analysis, to make sense of the quantitative findings.

While the quantitative research method involves analyzing an event or circumstance using hard data or numbers, with these being collected from surveys, experiments, and observations; qualitative research method focuses more on the subjective characteristics and opinions, which cannot be expressed by numbers. Qualitative analysis is used to test or confirm something and sometimes adopted to understand something which is more applicable to this study. Consequently, this study will use more of a qualitative research method in interpreting the data to quantitative research method.

The data will be analyzed holistically by considering what happened to the e-waste collected for each year. The numerical data will be used to both quantify and qualify it. An appropriate graphical tool will be employed to illustrate the data being investigated for clarity. This will help to identify ways to further improve on the existing e-waste management system in Estonia.

In interpreting the data, the “Begin” value will only be informational. The main analysis will be done with respect to other data such as recovery, disposal, unspecified handling, etc. That is, if “import” is to be analyzed for 2019 based on Figure 4.1, the study will analyze each of those data with respect to others including “End” but excluding the “Begin” data such it will represent 9.7 percent of the data compared to about 8 percent that can be physically observed.

Moreover, SWOT analysis will be employed to further analyze the data. SWOT which represent Strength, Weakness, Opportunities and Threats, is a management tool that is used to strategically identify and assess internal and external factors that affects the current and the future of an operation. It helps to organize innumerable bits of information during the decision-making process to aid the development of strategic goals. (Chaudhary & Vrat, 2015; Kenton, 2021).

## 3.4 Data Validity

The data employed for this study can be considered as primary data, and for that reason, it is important to define its validity. Meanwhile, it was noticed that some numerical data for some periods are not filled in, and this is automatically assumed to be zero ton. However, because the data was collected from a verified source, this paper assumes that all data relevant to the study from the source is valid.

# 4. RESULTS AND DISCUSSION

This section contains graphical representation of processed data from the website which has undergone filtering and some mathematical operations (such as addition) for ease of representation. It analyzes and discusses the data.

## 4.1 Result (data collected from EWRDS website)

The e-waste management data as made available on the website can be categorized into 12 based on the waste substance name and they include:

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.

All of these are summed together for each period being considered and are considered as a whole for recovery, disposal, export, etc.

Figure 4.1 represents the management of e-waste in Estonia between 2009 and 2019. The data revealed that the record for most of the e-waste at the end of each production year is not always the same with the beginning of the next production year, which implies that some of these wastes may not have been captured in the previous year, or otherwise undergone operations such as recovery, export, disposal, etc. without proper documentation. Regarding this, the data from 2010 through 2019 showed that there is an inconsistency by -29.1 percent, -4.4 percent, 10 percent, -2.0 percent, 0.9 percent, 0.4 percent -0.0 percent, 1.4 percent, 3.3 percent, 2.7 percent respectively. Nevertheless, other data are believed to be accurate, and they are discussed below.

Landfill which was not considered as an option for e-waste recovery in the early part of the selected period is gradually becoming significantly used. The data between 2009 and 2019 showed that this was almost 0 percent from 2009-2012 and since 2013-2019, the percentage has been fluctuating between 0.9-3.4. This can be ascribed to the increase in the number of material that are non-recyclable such as glass, cathode ray tube, etc. Regarding the unspecified handling, despite this not significantly reducing, it has been relatively constant. Furthermore, on the import of e-waste into Estonia, this has been between 7 and 16 percent and it is expected, as Estonia also exports its EEE products overseas. When these products reach their end-of-life under extended producers' responsibility, it is expected that the manufacturers have these items back and this invariably explains the increase over the 10 years' period. On disposal, this has remained very insignificant; however, it needs attention as its value in 2019 was 0.9 percent. Regarding the export, a significant amount of e-waste is being exported from Estonia to other countries and based on the data, this fluctuates between 14 and 37 percent since 2009-2019. It is believed that this has something to do with the EPR in place; besides, Estonia has fewer recycling facilities for e-waste. Lastly on recovery practices, data showed that Estonia is getting closer to its aim of recovering almost everything that is recoverable. The pattern from 2009 through 2019 is relatively stable between 40-50 percent. This can be ascribed to Estonia commitment to transition from heavy dependence on landfill practices to energy recovery from the waste i.e. recovering every recoverable part of waste.

Moreover, Figure 4.2 represents the e-waste recovery operation carried out between 2009 and 2019. According to EWRDS. the recovery operations are categorized into 12 i.e., R1 - R12 and the category 5 and category 12 are sub-categorized into R5m, R5o, R5c, R5f, R5k, R5t, R12s, R12p, R12o, R12x, and R12y. For the 10 years' period, it was determined that the recovery type used for e-waste so far are R1, R3, R4, R5 (R5m, R5f and R5k), R9, R12 (R12s, R12x and R12y), and as such the recovery operation analysis is limited to these. The data showed that most of the e-waste is being recovered using R12 recovery operation. This operation sees the pretreatment of the product for reuse purposes. These wastes go through the mechanical processing and it fluctuates between 81.9 and 99.0 percent recovery rate since 2009-2019. Meanwhile, a minority of these wastes are processed as a stockpile of raw material, with the pattern being highly unstable, 0.2 percent minimum and a peak value of 15.9 percent since 2009-2019.

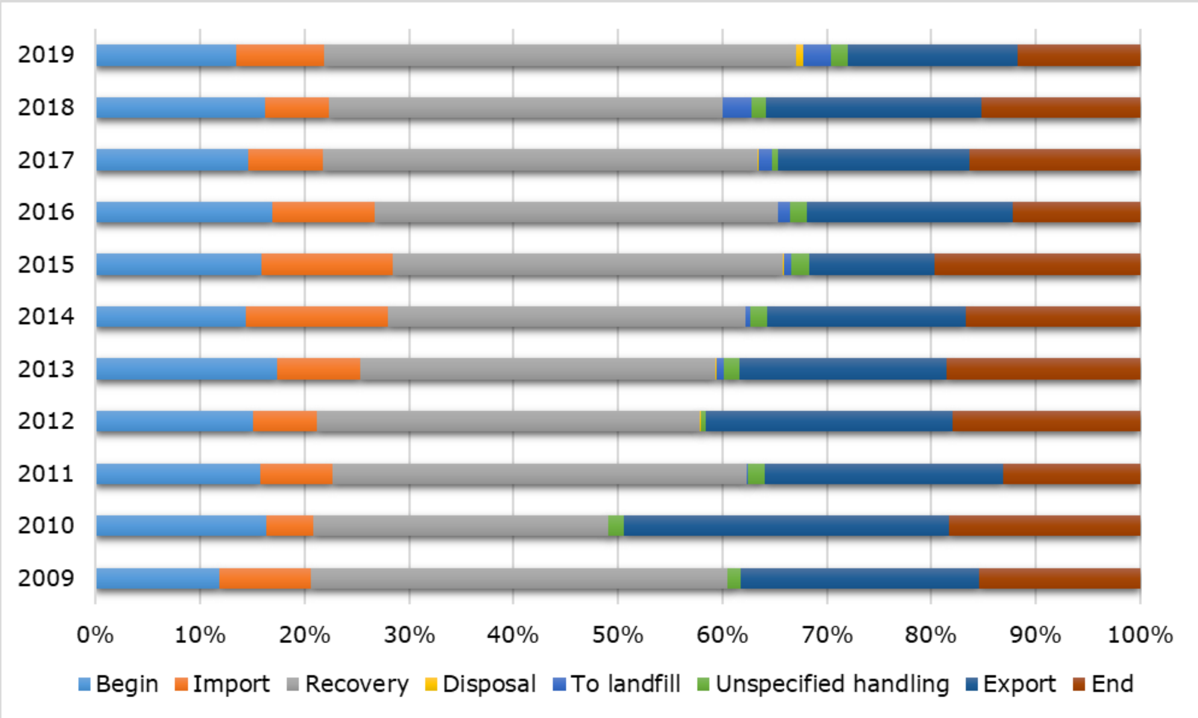


Figure 4.1: e-waste management in Estonia between 2009 and 2019 (author's calculation, 2022)

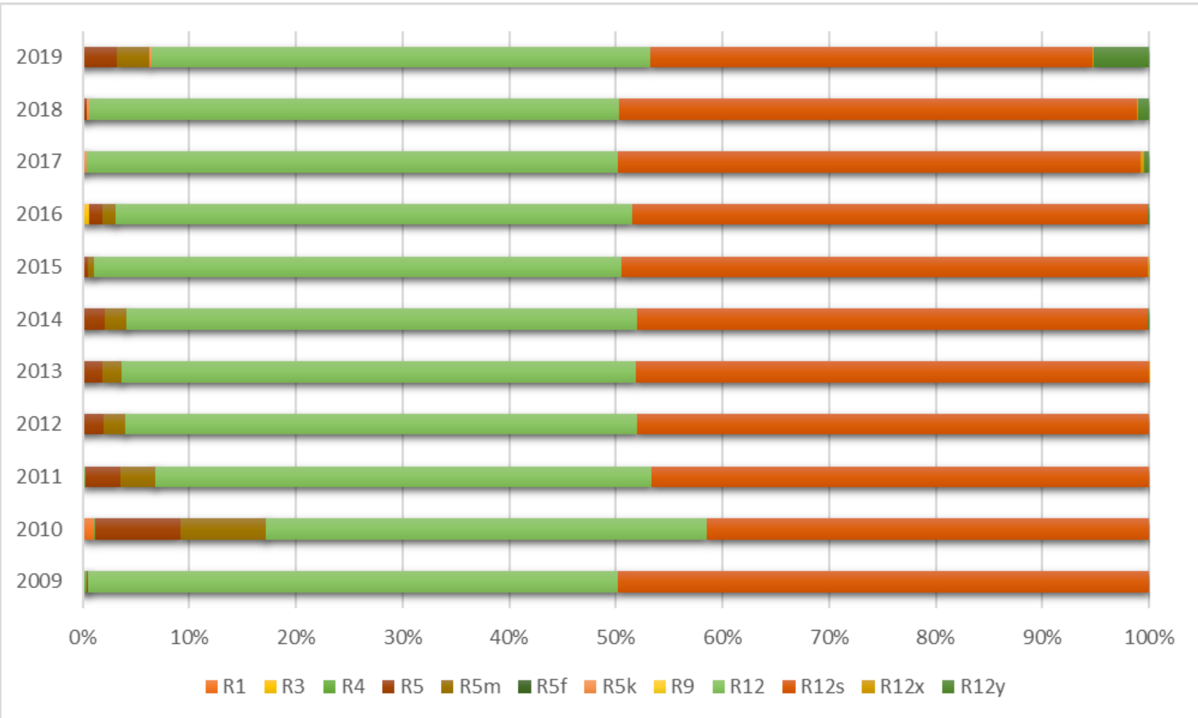


Figure 4.2: Recovery operations of e-waste in Estonia between 2009 and 2019 (author's calculation, 2022)

## 4.2 Result (data obtained from the interview)

Based on the response received from SWAPPIE (Eippa WSOperations OÜ), this organization generates e-waste during their electronics reuse operation. These wastes include: "cables, iPhone, USB hubs, Scanners, monitors, iPhone displays, rear cameras, iPhone flexes and motherboards". Some of these wastes are reused, while others are sent to buyback or recycling centers in places like China and Sweden. Meanwhile, before this waste is sent to recycling centers, the organization does the sorting of the wastes, and this is done manually. On the fraction of e-waste generated that are not recyclable, the response showed that this is infinitesimally small (about 1 percent). The organization however pointed out the lack of sufficient recycling center and suggested that "Estonia should have displays, monitors recycling centers. As these products are consumed very largely and are expected to consume significantly more in future. Having affordable recycling centers for these products will allow companies to refurbish their products and will provide a significant contribution to a sustainable circular economy".

According to Weerec OÜ, the collection of e-waste is producer's responsibility, and there exist several collection networks across the country. Since it is directly involved in e-waste recycling, it dismantles, sort, weigh by category and type in processing the e-waste; and their method is manual (for better outcome). After sorting the waste, "more material can be sent to material recovery; what we do not handle we will send to landfill or energy". It believes all e-waste can be recycled as energy, but as for lead glass and cathode ray tube (CRT), those are exported to countries like the United Kingdom for recycling. Weerec OÜ, believes that the e-waste management system of Estonia is in good shape and does not need improvement.

Kat Metal Estonia OÜ buys e-waste "globally: from manufacturers, e-waste companies, telecom companies, etc.". It dismantles (where and when necessary) manually and sort the outcome to "different categories: metals (aluminum, copper, alloys etc.), PCB (Low grade, medium grade, etc.) cables, plastics, etc.". It however does not handle the recycling of the waste as it forward to other companies that specialize in the recycling of certain groups of materials. While Kat Metal Estonia OÜ is not explicit about the fraction of the e-waste that are non-recyclable, it did state that most e-wastes are recyclable, and the fraction that may seem to be non-recyclable is due to technological limitation, as most of these materials are either very cheap (with little/no value) or hazardous to human health. Therefore, the organization highlighted the dynamic nature of the environment and recommended that "environment must be flexible vis-à-vis companies and, on the other hand, that regulations must be kept under review. This is certainly not an easy task for the state, and for this it must be in direct contact with entrepreneurs who see everyday problems".

Base metal buys e-waste from Estonia citizens or residents. It purchases all forms of EEE products except refrigerators and other equipment that contain hazardous gases. Meanwhile, it does not process any of the waste as they "don't have any machine for crushing or processing… just collecting and separating sometimes, electronics like monitors and TVs". On recycling, it is of the opinion that "Companies that separate and shred in Estonia doesn't do chemical processing. They only do mechanical processing of the E-waste. They finally send the material out of Estonia, to some Scandinavian countries. In Estonia, there is no provision of any final cycle of e-waste recycling".

## 4.3 SWOT analysis of e-waste management in Estonia

Estonia can be rated high in the handling of its e-waste based on the results, but contrary to Weerec OÜ respondent, there is always a need for improvement. Consequently, the data collected from EWRDS and interviews will be analyzed using SWOT analysis.

a) Strength:

  i. The presence of e-waste management policy: The onboarding of Estonia into the European Union changed its legal and policy framework positively for waste management (OECD, 2017). This policy which is the Estonia's Waste Act of 2004 became the central piece of legal governing of e-waste management in the country, as it specifies obligation for major actors involved in the management. This with respect to e-waste is the Extended producers' responsibility where the main actors are EEE producers or distributor that in a way introduce an electronic product into the Estonian market. The implementation of this policy has notably ensures the effective collection of e-waste, and according to Abalansa (2021) report, this policy has helped Estonia and other countries in the EU such as Bulgaria and Croatia achieve a 65 percent collection rate of the e-waste produced. Consequently, this has justified enforcement as the key solution to waste management and this explains the perspective of the Weerec OÜ respondent who said everything is fine and that nothing needs to change in the way the Estonia manages its e-wastes

ii. Growing number of entrepreneurs and recyclers

Estonia "is regarded as one of the most entrepreneurial nations on Earth", and its startup thrives more than any country in the world (Gaskell, 2021). It's country-as-a-service scheme has attracted several businesses and entrepreneurs across the world, and this can also be seen in the area of e-waste recycling (Flinders, 2021). Organizations like Kat Metal Estonia OÜ's and Base metal are rare to find in other parts of the world, but these have considered Estonia as base for their operations. This confirms the settlement of e-waste entrepreneurs who are potentially changing the narrative about e-waste in the country from a mere liability to an asset that can earn the owner a token, help to improve the lifespan of certain e-waste material and reduce the pollution of the environment by these wastes. Estonians are responding positively to the exchange of their EEE products at their end-of life for cash based on the interview with Base metal and this imply that with the introduction of incentive, e-waste management will become easy, and majority of the citizens will be compliant. Hence, this justifies that the presence of entrepreneurs, that are interested in e-waste management, can aid the effective management of e-waste in the country.

iii. Estonia digital foundation: A technology driven approach has put Estonia in a distinguished place in the world ranking, and according to Lenz et al. (2021), technology has been the backbone of Estonia's prosperity. During the outbreak of Coronavirus, Estonia achieved some assumed impossible feat, as 99 percent of its public activities continued without interruption when the majority of the nations of the world was under lockdown (Silaškova, 2021). Estonia has planned to be the first country in the world to have a completely digitized real-time waste monitoring system, and this from its history is achievable and should make waste management more seamless (e-Estonia, 2021). Hence, this justifies that technology can further improve waste management

b) Weakness:

i. E-waste management documentation: Waste management documentation generally helps in the efficient management of waste in a region/country. The accuracy of the data helps to determine the subsequent planning and areas of improvement for efficient management. However, this could be a major drawback in waste management when there is a gap in the available data, and such is the case of Estonia. Based on the data from EWRDS, it was observed that there is a significant gap in the "begin" and "end" data. This therefore justifies the disparity in the annual e-waste recycling rate data presented by Statista (2022) for year 2017 (i.e., 69 percent) and that which was obtained from the Estonian Waste Reporting Data System (i.e., 48.7 percent). Moreover, the responses from Kat Metal Estonia OÜ's and Base metal highlighted the possibility of some waste not being officially captured, as these waste are sent to some other countries. Hence, this justifies the gap that exist in the data available for public query on EWRDS server

ii. Availability of fewer e-waste recycling centers in Estonia: The management of e-waste requires recycling facilities which are usually cost intensive. Despite Estonia's plan to optimize its recovery practices, data showed that it has fewer e-waste recycling centers. Consequently, this is limiting its recycling practices, as data from both sources of the study showed that it could not process this waste to the reuse phase, and as such, it is limited to the third stage of the recycling process, which is the manual sorting, dismantling and shredding as described by RTS (2021). Hence, this limits its recycling ability, making its dependence on e-waste exportation to other countries such as Germany, Sweden, etc. a primary choice.

c) Opportunities:

i. Governments' partnership with entrepreneurs: According to Flinders (2021), businesses owned by e-residents added 51 million euros in tax to Estonia revenue in 2020. This is different from physical businesses, and as such further buttressed that entrepreneur play an important role in Estonia and are important in the sustenance of the country's economy. Assessing the practice of the entrepreneurs shows that all of them believe in best practices as their preferred method for dismantling of the e-waste is manual which is the most efficient practice according to Lucier & Gareau (2019). This implies that the e-waste entrepreneurs in Estonia could make e-waste become economical if governments work closely with them. This according to Kat Metal Estonia OÜ's respondent is necessary because they "…see everyday problems". It is believed that the business side of e-waste which has not been fully harnessed till date can be unlocked in Estonia, and Estonia could once again lead the world like it did during Covid-19 pandemic.

ii. Business side of e-waste could lead to job creation: Unemployment in Estonia, though increasing slowly, but could become significant if a means to close up the gap is not devised. The rate has continuously decreased in the last one decade, but in 2019, this increased by 2.01 percent which is a significant change compared to the trend in the last 10 years (Macrotrends, 2021). This implies that job creation is a need in the country and harnessing the business side of e-waste could provide some jobs. According to Kumar et al. (2017), e-waste management created a 100,000 job in China for people work as recyclers for informal e-waste recycling, with the projection of it creating about 30,000 jobs in the formal sector. Hence, the business side of e-waste can create jobs and assist the country to even generate more revenue.

d) Threat:

i Health Hazard: Most electronic wastes are harmful to human health and the environment if improperly disposed; besides, some are even more harmful than others and example is refrigerator. While other devices can be sold for a token, refrigerators and appliances containing harmful gases are considered a complete liability and are not accepted at all except through EPR. Due to the difficulty in recycling these kind of wastes, most of them end up in landfills, which may lead to the release of harmful gases to the environment, raising the risk of cancer as well as developmental and neurological issues. Besides, study showed that e-waste contains elevated levels of these hazardous materials, thus making reuse though recycling one of the methods to keep the environment safe (Kumar et al., 2017; Heacock, et al., 2015).

ii The average life span of most EEE: Report has it that over the last two decades, the worldwide market for (EEE) has grown tremendously, but product lifespans have become shorter. As a result, business and waste management authorities are confronting a new dilemma, and e-Waste is gaining a lot of attention from policymakers. Predictably, the worldwide number of electrical devices will continue to grow, and microprocessors will be utilized in an increasing number of everyday products. (Khurrum & Bhutta, 2010)

iii Cost of managing e-waste: As much as the entrepreneurs are interested in the e-waste management, they still consider some things as roadblocks and that is recycling factories. Recycling facilities are usually capital intensive both to build and to manage and this may be the reason why a government such as Estonian may prefer to have the producers completely responsible for the recycling of these waste instead of building a facility.

## 4.4 Proposal on the development of Estonia E-waste management system

The employment of the Swiss method of e-waste management could make Estonia e-waste management system flawless. This involves the combination of policies, which Estonia already have in place and the use of a centralized collection method. This will ensure that all e-waste that is collected can be account for and this will aid an efficient documentation. Although, with new technology such as the proposed digital waste reporting, it is believed that this should get better (Lenz et al., 2021). Nevertheless, the central collection of e-waste has the potential of improving the efficiency and also solve some potential issue of fairness in EPR's practice, ensuring that each producer is only responsible for a fair share of the waste generated by its product in Estonia.

Moreover, the partnership of the government with e-waste entrepreneurs could further improve the efficiency of e-waste management in Estonia. This is because it has been observed that people prefer to get a token for their e-waste instead of just dumping it. The activities of the entrepreneur have the potential to aid easy and efficient collection of these waste as people would value the token for their e-waste. This will encourage good consumer behavior, which will see them care for the electrical and electronic products even at their end end-of-life, and this will invariably improve the recyclable parts of most e-wastes.

Harnessing the business side of e-waste will require government to take on some responsibility and example include the construction of recycling facilities. This facility may not be a general purpose facility, but can focus on the recycling of specific materials such as screens which are consumed in large quantity (in the country) as proposed by Base metal respondents. This will eventually create jobs directly and indirectly, and consequently improve the economy of the country.

# 5. CONCLUSIONS AND RECOMMENDATIONS

This study considered the development of the e-waste management system in Estonia. It collected data from the public query section of the EWRDS website and interviews with some organizations that deals with e-waste in the country. These data were analyzed using SWOT analysis. It was determined that the key strength of e-waste management is the policy in place, the growing number of entrepreneurs and recyclers and the digital foundation that Estonia already have. The Weaknesses identified are the lapses in the documentation of the e-waste that is collected/processed and the availability of fewer recycling centers. The Opportunities identified include the government's partnership with entrepreneurs and the business side of e-waste that could lead to job creation. Lastly, the threats were identified to be health hazard, the average lifespan of most EEE and the cost of managing e-waste.

From the analysis, Estonia waste management policy has helped it with the collection of over 65 percent of its e-waste. There has been an increasing number of e-waste entrepreneurs in the country and this invariably suggest that harnessing the business side of e-waste in the country is something that could be achieved. The Estonia's digital foundation is noted to make easy switching to any form of technology that could help this management easy, as the majority are used to the digital world which is the country's backbone. However, the lapses in the documentation is considered a major challenge to the efficient management of these waste and so is the available facilities for recycling which is insufficient. Nevertheless, e-waste present opportunities of job creation in Estonia and an improved management of the e-waste through governments partnership with the entrepreneurs. Meanwhile, it also presents some threats which include health hazard if not properly handled, the cost implication in building the facility and the increasing level of e-waste due to short life span of those items.

Consequently, the Swiss method, the Japanese method the EPR, are example of methods that could be employed. Of all these methods, the Swiss will be preferable and will efficiently solve Estonia challenge with e-waste management efficiency. To implement, Estonian government need to focus on the business side, as it remains the only encouragement to want to consider building a recycling facility and as such this will not only create jobs, but will also keep the environment safe, and contribute to the economy.

In conclusion, Estonia is performing well in term of its e-waste management, but there is a need for improvement. This improvement as described in this paper could just be a way of making e-waste another stream of income generation instead of it being a continuous threat. This therefore requires that the government be willing and see a need for flexibility to better improve the environment.

The study identified the need for a development in Estonia e-waste management approach. It found the need of the government to partner with entrepreneurs. And it is highly suggested to build more E-waste recycling center and create more awareness on reusing electronics instead of disposal, government could also create programs or seminars on the usefulness of recycling e-waste to its’ consumers. However, in future research there is a need to consider dealing with the chemical processing of E-waste in Estonia, which can in turn bring precious metals like gold, silver, or palladium and so on to give room for a final cycle of e-waste recycling.

# SUMMARY

Some human activities on planet Earth have led to a level of degradation of the planet, and the impact has increased the need to embrace sustainability (Gaidajis et al., 2010). Based on this in 2005, some studies such as Widmer et al. (2005) described electronic waste as an emerging problem that also offers business opportunities given the volumes of e-waste being generated. But over the decades, the business side has not been fully harnessed and this makes the study important at this time. The study considered several literatures to fully comprehend the issue associated with e-waste around the globe. Also it considered other subtopics such as the recycling processes, some e-waste management policies, global management of e-waste and how some selected countries manage their e-waste. It also considered the current situation of e-waste management system in Estonia, which the study aims to develop. The study found that Estonia has been performing very well in terms of its e-waste management, especially among the European union countries, but it did notice that majority of its e-waste are exported to other countries. The study data obtained from the public query section of the EWRDS website and interviews with some organizations that deals with e-waste formed the foundation of this study. The result showed that Estonia method of collection is not accurate, thus affecting the data available on its e-waste management system. Furthermore, it found that of the five stages of the recycling process, Estonia limits itself to the third process which is the reason for the significant level of e-waste export to other countries. However, the assessment of the first challenge showed that Estonia could improve the efficiency of its e-waste management data at this time by taking on the responsibility of collecting the e-waste just as the likes of Germany, such that the collection is centralized. Moreover, with the entrepreneurs who deal with e-waste settling in Estonia, there is a possibility of changing the narrative of e-waste in Estonia, as they see more closely what the issue is and possible ways to address it. This implies that e-waste could become economical instead of the threat it appears to be.

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# APPENDICES

## Appendix 1: Definition of terms

| | | |
|---|---|---|
| Waste type | - | the main group of waste according to the list of types of waste and hazardous waste. For example, code 20 - municipal waste |
| Waste substance subgroup | - | waste subgroup according to the list of types of waste and hazardous waste. For example, code 20 01 - waste extracted from municipal waste or collected separately |
| Waste code | - | type of waste according to the list of types of waste and hazardous waste. For example, 20 01 08 - biodegradable kitchen and canteen waste |
| Waste substance main group | - | the main group of waste in accordance with the material-based waste management (EWC-stat in accordance with regulation on waste statistics of the European Parliament and of the Council (EC) No 2150/2002). For example, 07 - non-metal waste |
| Waste Substance subgroup | - | subgroup of waste according to material-based waste management (EWC-stat). For example, 07.1 - Glass waste |
| Waste substance name | - | waste material according to material-based waste management (EWC-stat). For example, 07.11 - glass packaging; 07.12 - other glass waste |
| Hazardousnes s | - | waste is classified as hazardous and non-hazardous waste according to the list of types of waste and hazardous waste. Hazardous waste is waste that, due to its harmful effects, can be hazardous to health, property or the environment |

| | | |
|---|---|---|
| Export/import country | - | Country of destination or country of origin of waste exported out of estonia or imported into Estonia |
| Storage at the begining of the year | - | quantities of waste held by the supplier (enterprise/installation) in the so-called intermediate warehouses, waiting to be directed or transferred to further handling, the quantities of waste at the beginning of the reporting period (year) |

| | | |
|---|---|---|
| Total increase | - | waste arising from production or other activities in the enterprise (installation) during the reporting period, including waste collected from other persons |
| Import | - | Quantities of waste imported to Estonia from other countries |
| Recovery | - | waste or a substance or material contained therein which, as a result of a waste management operation, is put into use in the manufacture of products, work or energy production, or preparatory activities |
| Disposal | - | waste disposed of as a result of disposal operations, such as incineration without energy use or other equivalent operation other than recovery, including preparation of waste for disposal (disposal operations D2, D3, D6, D7, D8, D9, D10, D11 and D13) |
| To landfill | - | quantities of waste deposited in landfill (disposal operations D1, D4, D5, and D12). A landfill is a waste disposal site where waste is deposited on or underground, including a waste disposal site where the waste producer deposits the waste at source (an in-installation landfill) and a waste disposal site used permanently for intermediate storage of waste for at least a year |
| Unspecified handling | - | quantities of waste given to unaccountable operators for handling or quantities where the definition of a partner company has been mistaken in the transfer/receipt of waste. A large part of this waste has actually been recycled, but there is no documentary confirmation of this in the form of the receiver's report |
| Export | - | quantities of waste exported to other countries from Estonia |

| | | |
|---|---|---|
| Storage at the end of the year | - | quantities of waste that are in the possession of the rapporteur (enterprise/installation) in the so-called intermediate warehouses, the quantities of waste awaiting referral or transfer to further handling at the end of the reporting period (year). These quantities will be reflected as inventory at the beginning of the year in the next reporting period |
| R1 - R12 | - | recovery operations in accordance with the list of waste recovery operations established by Regulation No. 148 of the Government of the Republic of 8.12.2011 (RT I, 14.12.2011, 4) |
| D1 - D14 | - | disposal operations in accordance with the list of waste disposal operations established by Regulation No. 148 of the Government of the Republic of 8.12.2011 (RT I, 14.12.2011, 4) |

Source: WDMS (n.d.)

## Appendix 2: Interview Data

| Questions | Response |
|---|---|
| Company: | SWAPPIE |
| How does your organization collect e-waste? | There are different kinds of e-waste that are being produced from our swappie operations such as cables, iphones, USB hubs, Scanners, motinors, iphone displays, rear cameras, iphone flexes and motherboards.<br>Faulty cables are collected in a separate box which has a label e-waste.<br>Scrapped phones are collected in the scrapped box in the warehouse.<br>Scanners, hubs and monitors are also collected in separate boxes.<br>Broken displays are collected in separate boxes which are specific to models in the warehouse.<br>Rear cameras, iphone flexes and motherboards are also collected in separate boxes in the warehouse. |
| How does your organization process the e-waste collected? | Faulty cables and motherboards are sent to recycling centers. However, some motherboards are kept in a warehouse for further micro soldering works.<br>Scrapped phones are either sold through internal auction or disassembled for spare parts reuse in the repair.<br>Scanners, hubs and monitors are either sent for warranty or sent to e-waste recycling centers.<br>Iphone flexes, displays and rear cameras are either sent to buyback or for refurbishment or recycling to China or Sweden. |
| How does your organization handle the recyclable and non-recyclable components of e-waste? | Recyclable components are further used in our operations. For example, iPhones are disassembled to obtain parts which are further used to repair the phones. Non-recycling components are sent to recycling centers for either refurbishment, buyback or recycling. |
| Is the process manual or automated? | The recycling process is manual. |
| What fraction of e-waste is usually unrecyclable on average and why? | Based on our observation, less than 1% of e-waste is not recyclable compared to all the e-waste we produce. Only some iphone flexes which either cannot be refurbished or reused. |
| How would you describe a self-sufficient Estonia in the area of e-waste management? | Again based on my observation, there are not many recycling centers for E-waste in Estonia. Most of the companies buy the recyclable e-waste and ship it to third countries for recycling. |
| What is your thought on how Estonia can achieve this? | Opening affordable recycling centers which all the companies can afford can be the best way to achieve proper e-waste recycling. |
| What would be your recommendation to the government on sustainable e-waste management? | Estonia should have displays, monitors recycling centers. As these products are consumed very largely and are expected to consume significantly more in future. Having affordable recycling centers for these products will allow companies to refurbish their products and will provide a significant contribution to a sustainable circular economy. |

Source: Dada (2022). InterviewData

| **Questions** | **Response** |
|---|---|
| Company: | Weerec OÜ |
| How does your organization collect e-waste? | Responsible for collection are Producer responsibility organizations. For them there are several minimum requirements for collection in Estonia. Special collection network all over country, shops, etc… |
| How does your organization process the e-waste collected? | we sort them, weight them by catorgories and by type. Dismantling is manual! |
| How does your organization handle the recyclable and non-recyclable components of e-waste? | Always manual – better outcome (pure) and more material can be sent to material recovery! What we do not hanlde we will sendi t to landfill or energy |
| Is the process manual or automated? | The recycling process is manual. |
| What fraction of e-waste is usually unrecyclable on average and why? | All material can be recycled as energy, but what we do not handle is Leaded glass from CRT (actually in can be recycled in UK). Laminated glass, and some PCB. |
| How would you describe a self-sufficient Estonia in the area of e-waste management? | All is fine and Under control, as responsibility goes to producers!. |
| What is your thought on how Estonia can achieve this? | Achieve what? All is achieved! |
| What would be your recommendation to the government on sustainable e-waste management? | Nothing, because producers are responsible! |

Source: Dada (2022). InterviewData

| Questions | Response |
|---|---|
| Company: | Kat Metal Estonia OÜ |
| How does your organization collect e-waste? | We are buying material globally: from manufacturers, e-waste companies, telecom companies, etc. |
| How does your organization process the e-waste collected? | We are sorting it, then in case of need dismantling manual and outcome will be sorted to different categories. Metals (aluminum, copper, alloys etc.), PCB (Low grade, medium grade, etc.) cables, plastics, etc. |
| How does your organization handle the recyclable and non-recyclable components of e-waste? | Recyclable components of e-waste will be handed over to different companies that are specialized in certain groups of materials. For example from plastic will be used to do plastic building material or used to do flower pots. |
| Is the process manual or automated? | |
| What fraction of e-waste is usually unrecyclable on average and why? | The reason is that the material is very cheap or there is no technology yet to recycle it. The reason is that the material is very cheap or there is no technology yet to recycle it. Secondly, the material is hazardous to health and must be disposed of |
| How would you describe a self-sufficient Estonia in the area of e-waste management? | |
| What is your thought on how Estonia can achieve this? | |
| What would be your recommendation to the government on sustainable e-waste management? | Waste management is constantly changing very fast. On the one hand, this means that the environment must be flexible vis-à-vis companies and, on the other hand, that regulations must be kept under review. This is certainly not an easy task for the state, and for this it must be in direct contact with entrepreneurs who see everyday problems. |

Source: Dada (2022). InterviewData

| Questions | Response |
|---|---|
| Company: | Base Metal |
| How does your organization collect e-waste? | We are just collecting point; in Estonia we have a collection point for citizens to bring electronics free of charge |
| How does your organization process the e-waste collected? | We don't crush, we don't make some recycling processes |
| How does your organization handle the recyclable and non-recyclable components of e-waste? | We collect consumer electronics (pc, pc board, etc.) and electrical devices (excluding refrigerators due to hazardous gas that they contain); our aim is to collect, make them in batches and send to factories |
| Is the process manual or automated? | We don't have any machine for crushing or processing here, just collecting and separating sometimes, electronics like monitors and TVs |
| What fraction of e-waste is usually unrecyclable on average and why? | |
| How would you describe a self-sufficient Estonia in the area of e-waste management? | |
| What is your thought on how Estonia can achieve this? | My thinking is that it requires a very big investment, will probably quite take a lot of time for local entrepreneurs. It is faster to find reliable partners who have a bigger market like Germany, Poland, France and especially Italy to send the e-waste. SO, they have a reliable system of how it works, you send, they recycle it, gives some result because they are getting some metal and getting paid |
| What would be your recommendation to the government on sustainable e-waste management? | Companies that separate and shred in Estonia doesn't do chemical processing. They only do mechanical processing of the E-waste. They finally send the material out of Estonia, to some Scandinavian countries. In Estonia, there is no provision of any final cycle of e-waste recycling. |

Source: Dada (2022). InterviewData