Louvain School of Management
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Technical and Economic Assessments on WEEE Management in São Tomé and Príncipe

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Abstract

Currently, São Tomé and Príncipe has been facing a serious problem related to the growing generation of WEEE in the country that is threatening not only the environment but also the health of its population, which demands an urgent response. In the scope of Output 3.1 of the ISLANDS Atlantic Project, the present Master's Thesis aims to propose a WEEE management system to ensure proper collection, storage, and treatment of this type of waste.

The methodology used to propose this WEEE management system encompasses five steps. First, the current WEEE scenario in São Tomé and Príncipe was analyzed, followed by a Material Flow Analysis, which aimed to find the biggest exporters of EEE to the country that are also responsible for its current state, as well as to estimate the quantity of WEEE to be generated in the upcoming years. Thirdly, the best practices were collected not only from literature but also from interviews with key entities in the WEEE sector. All this information was used in the development of the possible scenarios to be implemented in each phase of the proposed WEEE management system. From the possible scenarios, four were selected based on feedback from the country for an economic assessment.

From the assessment, it was shown that all scenarios present a negative Net Present Value (NPV), however, the need for a WEEE management system in the country encouraged the recommendation of the scenario whose NPV was the least negative: WEEE collection using collection bins and a door-to-door collection practice, storage in 20ft containers while waiting its exportation to Portugal, where WEEE will be subject to proper treatment.

From the work developed in this thesis, a proposal for a WEEE management system in São Tomé and Príncipe is delivered, which will improve the social and environmental conditions in the country. This study will also contribute to narrowing the gap in the literature on WEEE management systems in developing countries, particularly in SIDS (Small Islands Developing States).

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1. Introduction

Waste from Electric and Electronic Equipment (WEEE) includes all end-of-life devices that require electric current or batteries to operate. There is a wide range of equipment that falls into this definition, ranging from discarded household appliances, such as refrigerators, lamps, and washing machines, to personal items, like computers, mobile phones, and televisions (Lebbie, et al., 2021).

Of all the existing waste categories, WEEE is among the world's fastest-growing residues. In 2022, around 62 million tons of WEEE were generated worldwide, and it is estimated that this number will increase by an annual growth of over 2 million tons. This means that WEEE production may surpass 80 million tons by the end of 2030 (United Nations Institute for Training and Research, 2024). This constant and fast-paced growth can be explained by the rapid obsolescence of electric and electronic devices, alongside the insatiable desire of the market for new technologies and designs (Abdullah, et al., 2024).

In parallel, the environmental and social risks related to this growing waste stream are escalating, given that almost 80% of WEEE is not safely disposed of (Owusu-Sekyere, et al., 2022). WEEE contains toxic and harmful components, such as persistent organic pollutants and heavy metals that, upon their release into the environment, can contaminate the ecosystems, ending up having an impact on human health (He, et al., 2024). This is justified as these substances reach our body through the air we breathe, the food we eat, and the water we drink. Exposure of the human body to these substances can be manifested in health problems in the (not-so-distant) future, such as respiratory issues (Lebbie, et al., 2021), hormonal imbalances, Alzheimer's disease, and several types of cancer (Dutta, et al., 2023).

Furthermore, although WEEE is generated globally, approximately 80% of the total production is exported to developing countries (Lundgren, 2012), which puts these countries in an urgent and dangerous situation. It is in this scenario that the need for a safe WEEE disposal system arises.

In order to address this ongoing problem, the United Nations Environment Programme (UNEP) is leading the ISLANDS Project, which one of the goals is to tackle toxic waste and pollution, including WEEE, in 33 Small Island Developing States (SIDS) across the Atlantic, Caribbean, Indian, and Pacific regions (ISLANDS, 2025). In the Atlantic region, the project targets three specific SIDS, Cabo Verde, Guinea-Bissau, and São Tomé and Príncipe. These three Portuguese-speaking countries constitute heavy importers of electric and electronic equipment and do not possess any system to deal with it (ISLANDS, 2025). Therefore, the ISLANDS Atlantic Project intends to develop a WEEE management system that properly collects, stores, and treats this type of waste, decreasing its negative social and environmental consequences under Output 3.1. Using a new system to effectively manage WEEE not only contributes to environmental and social protection, but also to resource conservation, energy efficiency, and a sustainable circular economy (Lee, et al., 2024), given that by recycling this type of waste, there is a higher recovery rate for its components.

Additionally, it will also help achieve the Sustainable Development Goals (SDGs) adopted by all United Nations Member States to be accomplished by 2030, in particular, SDG 3 – Good Health and Well-being, SDG 6 – Clean Water and Sanitation, SDG 8 – Decent Work and Economic Growth, SDG 11 – Sustainable Cities and Communities, SDG 12 – Responsible Consumption and Production, and SDG 14 – Life Below Water (International Telecommunication Union, 2017).

Therefore, the present Master's Thesis will contribute to the response to this urgent claim by the proposal of a WEEE management system in São Tomé and Príncipe. From the three countries mentioned above, this was the country chosen to be focused on, as São Tomé and Príncipe was the country where data was more available to date.

2. Literature Review

This chapter is divided according to the activities required to manage WEEE (Dutta & Goel, 2021), as it encompasses collection (see section 2.1), storage (see section 2.2), and treatment of WEEE (see section 2.3). In addition, section 2.4 refers to the practices to be considered in all three previously mentioned stages. The literature review considered scientific articles, alongside grey literature, particularly from UNEP's official guidelines and insights developed in the Basel and Stockholm Conventions. In addition, insights from other ISLANDS Child Projects were reviewed to incorporate practical experiences and lessons learned.

2.1. Collection Practices

To have a successful collection phase, the consumers must be motivated to deliver their used electric and electronic equipment to the proper places. However, one of the factors that has contributed to the urgent WEEE situation is the lack of information and awareness among customers about the risks associated with the improper disposal of WEEE, and the proper ways to discard them (Wang, et al., 2017). This fact made people abandon and, mainly, store large quantities of WEEE at home (Guo, et al., 2018), instead of delivering them to the right places (Jian, et al., 2019).

Therefore, literature considers it imperative to spread knowledge about the importance of proper WEEE disposal and the possible ways to do it within communities, encouraging individual action toward responsible WEEE management (Muthukumari, et al., 2024). To achieve this outcome, green propaganda (Guo, et al., 2018) and information publicity (Muthukumari, et al., 2024) are recognized as practices to increase the inflow of collected WEEE in the first phase of the system.

In parallel, developing WEEE awareness campaigns across the territory is considered good practice. By doing these campaigns, it would be possible to inform the population about the dangers they are incurring when they do not deliver their WEEE in the right places and to enlighten them on how to properly behave in this matter (Guo, et al., 2018). It is also recommended that these public awareness initiatives occur regularly and locally (Akinrinade, et al., 2024).

For instance, in the state of Punjab, in India, awareness camps were organized across the state to make WEEE consumers aware of its dangers, alongside the spread of valuable information about this topic in various newspapers written in several languages to reach a broader audience - English, Punjabi, and Hindi (Dutta & Goel, 2021). Also, several countries, such as Canada and the USA, have been providing environmental education in schools since 1980, which has been a key practice in raising awareness among students (Qu, et al., 2013).

As mentioned above, the lack of information from customers about where to deliver their WEEE is causing them to store it in their homes, in the case of private customers, or at their offices and production sites, in the case of corporate institutions (Guo, et al., 2018). On the other hand, there are areas - also common in SIDS - where access to proper WEEE disposal sites is very difficult (Pereira, et al., 2021), leading to the same outcome. Consequently, implementing a procurement practice that reaches directly to businesses, households, and other establishments, going door by door to request and collect WEEE, would help address inappropriate disposal and home storage. In this sense, although it may be time-consuming and dependent on road conditions, door-to-door collection is a practice that does not rely on consumers' willingness to transport their waste to appropriate sites (Guo, et al., 2018) and would enhance the population's awareness of the importance of properly managing WEEE, while also contributing to the creation of local employment opportunities (Andeobu, et al., 2023).

Simultaneously, there are three types of collection channels: Municipal sites – where consumers can directly deposit their WEEE, In-Store Retailer Take-Back – which allows consumers to return their WEEE in retail stores, and Producer Take-Back – where producers collect WEEE directly on consumers' property. The last channel is mostly used to address B2B markets. In addition, other collection channels, such as centers specifically created for WEEE delivery, can also be considered (United Nations Environmental Programme, 2007).

Furthermore, applying a mechanism that combines reward and penalty for the collection of WEEE is also an object of study in scientific literature. It is concluded that raising the intensity of the reward/penalty can increase the collection rates, as well as it can decrease the overall environmental damage (Wang, et al., 2015). However, it is essential to think about the most appropriate types of reward and penalty to be applied to each case.

One option for this type of practice was the application of a "fee-upon-disposal" that was verified to motivate manufacturers to design for recyclability, along with motivating the customers to effectively recycle (Plambeck & Wang, 2009). In addition, applying a discount when purchasing a new electrical or electronic device by returning a used one (Wang, et al., 2017) is another option shared in the literature for this practice. This reward/penalty practice must be viewed as a continuous technique rather than a one-off event (Qu, et al., 2013).

Within the scope of the ISLANDS Pacific Ocean, in Suriname, partnerships with private companies were established to enhance the WEEE collection rates. In particular, the country collaborated with a telecommunications company, transforming it into a Retailer Take-Back collection channel, where consumers could deposit their WEEE at the company's stores (Duncan, et al., 2023).

In Guyana, one of the components of the project is to have a centralized location for the collection of WEEE, together with the other mentioned Pacific countries – Suriname and Trinidad and Tobago – aiming to promote and provide technical and financial support towards recyclers. In addition, regional collaboration and cooperation were also mentioned as important practices for WEEE collection (Duncan, et al., 2023).

In Trinidad and Tobago, to address the lack of awareness of the risks associated with WEEE and to motivate their collection, the RIDE – Reduction of Indiscriminate Dumping of E-waste - Program was developed. This program was launched as a club in secondary schools, involving young people from eleven to eighteen years old, where they were to be informed and trained on the collection and refurbishment of WEEE. The students' sense of belonging, energy, and enthusiasm about the project's mission facilitated the dissemination of information on WEEE matters, through their peers, families, and communities, whose substantial outcomes were the reason behind its expansion to other Pacific territories (Duncan, et al., 2023).

2.2. Storage Practices

Storage, as an intermediate step between collection and treatment processes, is substantial to allow entities to benefit from economies of scale related to the transportation of this type of waste to the proper treatment facilities. Therefore, to optimize this gain, it should be possible to store large quantities of WEEE (Dutta & Goel, 2021). However, this storage capacity should comply with legal regulations. In cases where those requirements are not available, facilities should consider that the maximum amount of WEEE stored should not overshoot the amount of WEEE that can be treated in six months (Akinrinade, et al., 2024).

Moreover, it is of extreme importance that after the collection of WEEE, the waste passes through a categorization process to segregate it into different categories (Agbim, et al., 2024). This fact is related to the different toxic components that are part of various types of products that should not be mixed. It is also important to mention that this categorization also allows a more efficient way to deal with WEEE in the steps ahead, having a significant economic impact (Agbim, et al., 2024). Regarding this practice, the European Union's Waste Electrical and Electronic Equipment Directive published a list with the UN-6 WEEE categories: (1) Temperature exchange equipment, (2) Screens and monitors, (3) Lamps, (4) Large equipment, (5) Small equipment, and (6) Small IT and telecommunication equipment (EU, 2012).

Overall, the storage of WEEE can happen in two distinct forms: either it occurs in the place where the waste is collected, or it is performed in a facility located in a different location from the collection site. If it is performed as described in the latter case, an optimal location for the storage site should be chosen, to ensure that the transportation of collected WEEE to the treatment facilities becomes easy and economical (Dutta & Goel, 2021), i.e., a central location.

2.3. Treatment Practices

Before discussing the best practices and levels regarding the WEEE treatment phase, it is substantially relevant to distinguish between the two distinct treatment concepts: i) the formal treatment sector and ii) the informal one.

The formal WEEE recycling sector is authorized by the government and includes authorized and registered recycling centers that have the knowledge to deal with WEEE, without causing damage to the environment. On the other hand, the informal WEEE recycling sector involves authorized facilities, and no laws or regulations are followed (Dutta & Goel, 2021).

Therefore, it is clear that the formal sector should be the only practice to be applied in terms of WEEE treatment processes. However, unfortunately, the informal sector is the most active in developing countries (Dutta & Goel, 2021), where São Tomé and Príncipe is included. Following the Global E-waste Flows Monitor 2024 (Baldé, et al., 2024), over 99% of the WEEE in

Africa was not subjected to proper ways of collection and recycling, which means that a substantial fraction of this type of waste was handled by informal collectors and subsequently processed by informal recyclers (Ilankoon, et al., 2024).

WEEE has valuable metals and minerals in its composition, such as gold, aluminum, and copper in high quantities, which should be safely recovered and recycled. However, informal workers – also known as waste pickers - go to dumpsites, landfills, or other sites where WEEE is not properly disposed of, and they manually extract these metals through open burning and acid leaching, for onward sales (Andeobu, et al., 2023).

Alternatively, within the formal WEEE recycling sector, a scientific article presents six techniques that can be applied. It takes into consideration the Mechanical, Pyrometallurgical, Hydrometallurgical, Biometallurgical, Electrometallurgical, and Thermometallurgical recycling methods (He, et al., 2024). As is possible to infer, these different formal techniques have distinctive characteristics, making each one more suitable for treating specific types of EEE. On the other hand, each technique also has its own environmental and operational costs, making some methods more sustainable and cost-effective than others (He, et al., 2024).

Yet, a different article from the scientific literature only refers to the Pyrometallurgy, Hydrometallurgy, and Biohydrometallurgy methods, which can be performed after a Pre-Treatment process, that segregates WEEE components in non-metals, ferrous-metals, and non-ferrous-metals (Vuppaladadiyam, et al., 2024).

Despite the technique used in the formal treatment of WEEE, this stage can be segregated into three different levels. The first level happens right upon WEEE collection and storage. At the end of this level, after the liquids and gases have been removed, it is possible to obtain segregated hazardous and non-hazardous materials (United Nations Environmental Programme, 2007).

The second level takes the segregated non-hazardous materials obtained in the first level, and after several unit operations and special treatment processes, it is possible to obtain several streams of metal scrap and plastic. While in the third level of treatment, various types of WEEE residues are received and transformed into recycled components, energy recovery, and materials for future reuse, through unit operations, and disposal and recycling techniques (United Nations Environmental Programme, 2007).

The Basel Convention also disclosed a WEEE treatment scheme that indirectly represents the three levels pursued when treating this type of waste (United Nations Environmental Programme, 2016).

An alternative practice to the formal WEEE recycling techniques mentioned above is the co-processing technique. This method consists of using mineral processing facilities to co-process WEEE with ore minerals, contributing to the improvement of recycling rates and the reduction of the substantial quantities processed by the informal recycling sector (Ilankoon, et al., 2024). However, it is stated that this specific method is suitable to be applied in countries where mining facilities are already in place, and may not be appropriate for developing countries, as local, social, technological, and economic considerations must be assessed (Ilankoon, et al., 2024).

Nowadays, there is an incredibly huge number of informal WEEE workers, which makes it extremely difficult to eliminate this sector over the formal one. A study conducted in Brazil presented a solution to reverse this problem by formalizing this type of workers, through the application of public policies and legal incentives. It is also stated that even though this study is focused on Brazil, it can be extrapolated to other developing countries (Ghisolfi, et al., 2017).

Moreover, to ensure that the WEEE reaches the proper treatment facilities, in the scope of the ISLANDS Pacific Ocean, the Moana Taka Partnership was established in the Pacific region, as a collaboration between Swire Shipping, the Secretariat of the Pacific Regional Environment Programme, and UNEP. This partnership utilizes Swire Shipping vessels to transport non-commercial waste, including WEEE, from the Pacific Islands by filling empty shipping containers. The waste is sent to countries with appropriate disposal sites, where it is treated, recycled, or disposed of in an environmentally responsible manner (SPREP, 2023).

Nevertheless, entities must come together and partner with one another. Industrial symbiosis must be the baseline in the design of a proper WEEE management system, where the waste of one entity must be the raw material of the others, building a zero-waste way of operating (Dutta & Goel, 2021). This has already been put into practice in some regions. For instance, in India, WEEE is already being exported by ship to Umicore, a Belgian entity that recovers base and precious metals, while plastics are transported to plastic industries, glass from monitors is exported to Videocon for recycling, and steel is sent and reused in steel facilities (Dutta & Goel, 2021). Also, Suriname's government partnered with two private companies, opening the way to start a pilot project, focusing on the WEEE dismantling process (Duncan, et al., 2023).

2.4. Transversal Practices

An important part of the WEEE system is the establishment of policies, laws, and regulations. The "Extended Producer Responsibility" is the baseline policy in developed countries, which governments use to encourage proper recycling schemes (United Nations Environmental Programme, 2016). Moreover, the WEEE Directives present a regulatory framework for the collection, recovery, and recycling/reuse targets within the EU (United Nations Environmental Programme, 2007).

On top of that, the lack of laws, regulations, and legislative frameworks addressing WEEE matters in Africa is seen as a key obstacle to the effective management of this type of waste in the region (Andeobu, et al., 2023). In that sense, having policies, legislation, and a compliance structure to be followed in a WEEE management system is also important. However, for this practice to be effective, it should be aligned with a set of strategies such as education and assistance programs, compliance incentives, monitoring and inspections, and fair and differentiated non-compliance responses (United Nations Environmental Programme, 2016). To set effective policies, legislation, and regulations, it is essential to have competent authorities and trained inspectors to supervise the entities involved in the system (Ghisolfi, et al., 2017), which also require financial, physical, and technical resources (United Nations Environmental Programme, 2016).

On the other hand, to guarantee that the WEEE stream is being managed in an environmentally sound manner, the entities involved in the process should hold a license, a permit, or other authorization to certify their ability to pursue their operations. This practice should be applied to all involved parties, except those whose impacts on both the environment and human health are negligible (United Nations Environmental Programme, 2016).

Moreover, the Basel Convention enforced the idea that transboundary movements of waste should be minimized as much as possible, to substantially decrease the amount of WEEE that is exported to other countries. To meet this goal, it is crucial to build sufficient domestic infrastructure and capacity that can engage in waste management processes in an environmentally proper manner (United Nations Environmental Programme, 2016). The transboundary movements of waste should only be authorized if the exporter country possesses neither the facilities nor the technical capacity to manage WEEE in an environmentally sound way, and it must be ensured that the importing country is able to do so (United Nations Environmental Programme, 2016).

Furthermore, regarding the infrastructure of those different facilities, where WEEE is collected, stored, and treated, it must comply with specific requirements. For all stages, it must feature impermeable surfaces, spillage collection facilities, and weatherproof covering, and it must be according to the defined standards of contamination (United Nations Environmental Programme, 2007).

Finally, the E-waste Manual Volume II, developed by UNEP, discloses the official guidance procedure to build a formal and efficient WEEE management system, which encompasses nine general steps, presented in Table 1, from WEEE collection to its treatment (United Nations Environmental Programme, 2007).

Table 1 - UNEP's Guidance Procedure to build a formal WEEE management system

Steps	Overall Guidance Procedure
1st	Determine the collection and transportation system.
2nd	Determine the **area** of the collection point/storage facility.
3rd	Determine the **number** of collection points/storage facilities.
4th	Determine the **location** of collection points/storage facilities and transportation.
5th	Determine the layout for the **1st level** WEEE treatment facility.
6th	Determine the layout and equipment for the **2nd level** WEEE treatment facility.
7th	Identify and fix the **3rd level** WEEE treatment options.
8th	Identify and determine hazardous and non-recyclable WEEE fractions disposal options.
9th	Follow general guidelines for WEEE treatment facilities.

In the second step, to determine the area of each collection point/storage facility, the WEEE capture rate for the geographical area served, in a given time frame, must be calculated. Then, based on the previous total capture rate, the volume of each WEEE item must be calculated to compute the bin/container/cage/Gaylord container size required and their necessary quantities. After obtaining the area of each site, this number should be fixed, as well as the container size and quantities.

In the third step, the number of collection points/storage facilities must be calculated based on the population served and the WEEE capture rate per inhabitant per year. This value must be at least 4kg of WEEE per inhabitant per year. The final number must be set only after analyzing the area, land use, and geography of the region.

In the fourth step, to determine the locations of each collection point/storage facility, not only must the consumer behavior be analyzed, but also the transportation must be taken into consideration. In this step, it is relevant to examine the WEEE haulage capacity, the number of trucks or trailers required for transportation, the optimized routes, and the frequency of collection.

In the fifth and sixth steps, determining the facilities' layout involves calculating their capacity, productivity, number of workers, and shifts, as well as the specific areas in which the different steps of the treatment phase will take place. Specifically, in the sixth step, it is also required to define some metrics related to the processes that are going to be conducted and the equipment necessary to operate.

For the seventh step, different recyclers are assessed to choose the ones that are going to use the output of the previous treatment level in their recycling process. On top of that, in the eighth step, the hazardous waste landfill sites and incineration facilities closest to the WEEE treatment facility are identified and assessed to determine whether they could support the disposal of WEEE fractions.

Finally, there are formal and bureaucratic guidelines to be followed when a WEEE treatment facility is established. The last step of the official Guidance Procedure for building a proper WEEE management system aims to ensure that these guidelines are followed and complied with.

In conclusion, despite all the practices gathered from the studies presented in the literature, it is important to mention that a few gaps were acknowledged to exist. This fact is justified as neither was any study found under the topic of WEEE performed in São Tomé and Príncipe, or even in the island context; nor a study which gives an overview of the development of the three phases of the WEEE management system in a developing country. A great part of the studies found are focusing on China, due to the substantial growth of its WEEE treatment sector over the past years, however, the conditions present in this country are much different from the ones observed in São Tomé and Príncipe.

Therefore, this thesis will contribute to bridging the gap in the literature on the development of WEEE management systems in small developing countries, particularly in small island developing states (SIDS).

3. Methodology

The methodology used to design the WEEE management system in São Tomé and Príncipe encompassed five steps and is presented in Figure 1.

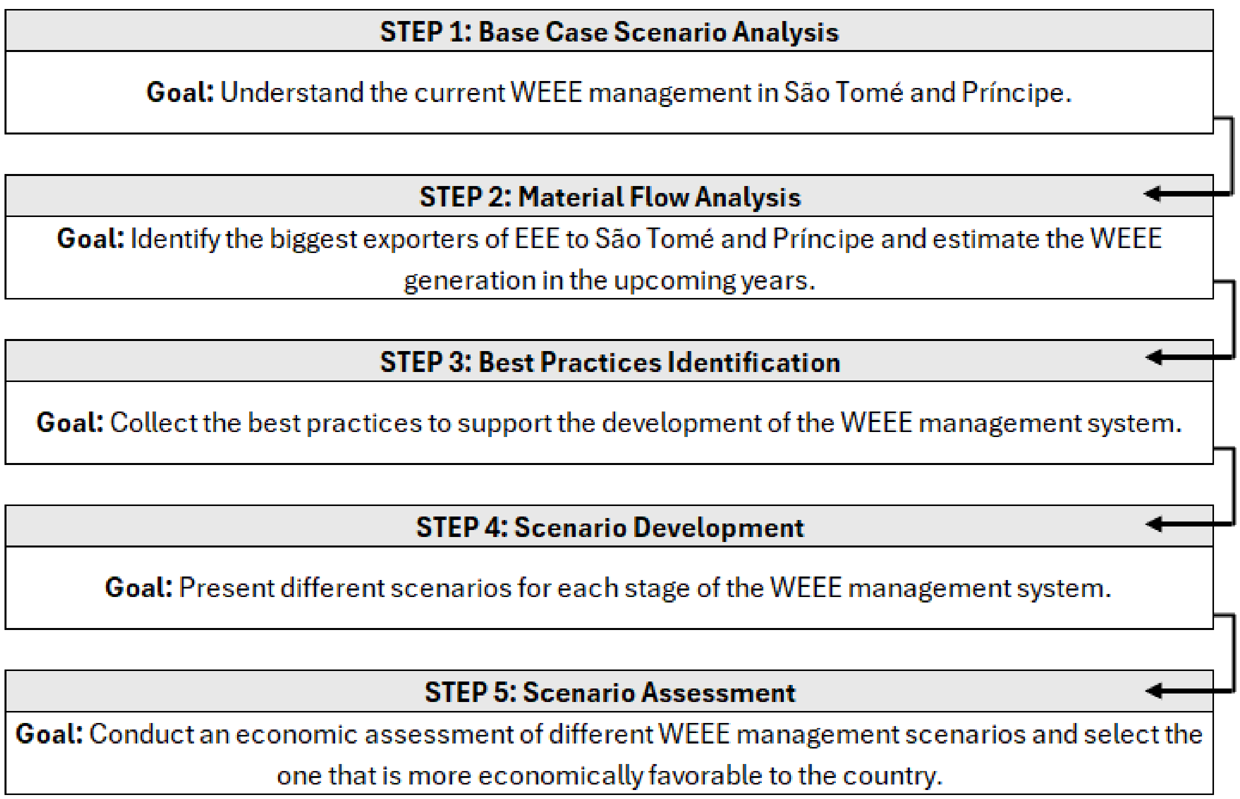


Figure 1 - Methodology proposed for the development of a WEEE management system in São Tomé and Príncipe

3.1. Base Case Scenario Analysis

The first step consists of analyzing the current WEEE management situation in the country. For this step, Pereira et al. (2021), a previous study conducted in the field, was used to gather information about the way WEEE is being managed in São Tomé and Príncipe, the practices that are currently being performed, the type of infrastructure that is already in place, and the stakeholders involved.

3.2. Material Flow Analysis

In the second step, to find which countries are the biggest exporters of EEE to São Tomé and Príncipe, and for this reason, have part of the responsibility for the WEEE generated, alongside estimating the WEEE generated in the country from 2014 to 2030, a Material Flow Analysis was developed. The method followed in this analysis encompassed three stages, each one divided into several steps, as is possible to observe in Figure 2.

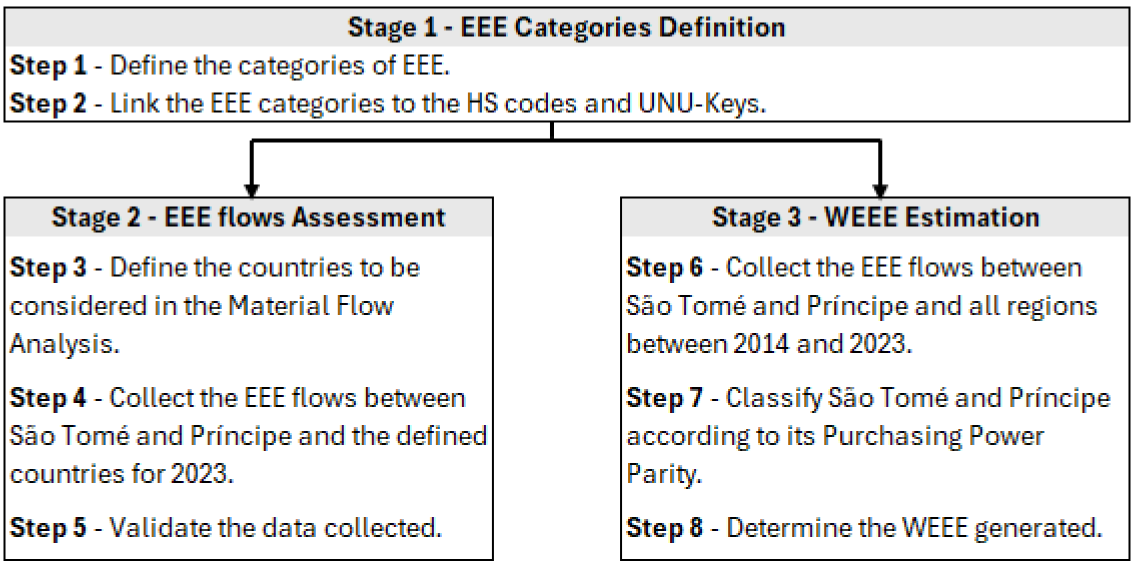


Figure 2 - Methodology applied in the Material Flow Analysis

The first stage, which involves steps 1 and 2, focuses on defining the EEE categories, whose flows will be tracked in the analysis. These EEE categories, defined as the UN-6 Categories (EU, 2012), are then linked to HS ("Harmonized System") codes and UNU-Keys. This stage must be performed, given that the Trade Map (International Trade Map, 2023), which was the data source used to track the flows of the EEE, is organized into HS codes.

In the second stage, the flows of EEE between São Tomé and Príncipe and other countries in 2023 are assessed. As mentioned, this stage involves the usage of the Trade Map data source (International Trade Map, 2023). In step 3, the four chapters of HS codes tracked are Chapters 84, 85, 90, and 91, given that these chapters encompass most of the EEE; and the non-African countries that contribute to less than 1% of the imports from/exports to São Tomé and Príncipe, in these four chapters, are removed from the analysis. In steps 4 and 5, the data regarding the EEE flows from importations and exportations between the country under analysis and the considered countries are collected from the Trade Map for 2023 (International Trade Map, 2023), and validated by São Tomé and Príncipe's customs officials, using a questionnaire.

The third and final stage allows the assessment of the quantity and types of WEEE estimated to have been generated between 2014 and 2024, as well as predicted to be generated from 2025 to 2030 in São Tomé and Príncipe. In this sense, to quantify the WEEE generated between 2014 and 2023, in step 6, the search for EEE flows of step 4 is extended to all years between 2014 and 2023.

In step 7, as it is aimed to estimate the quantity of WEEE generated between 2014 and 2030, the Purchasing Power Parity (PPP) of São Tomé and Príncipe is studied to establish an annual growth rate for the consumption of EEE in the country. Notably, given that there is no domestic production of EEE in São Tomé and Príncipe (Pereira, et al., 2021) and since the country's exports of EEE are negligible, it is considered that this annual EEE consumption rate is only due to EEE importations to the country, and encompasses a value of 23% since São Tomé and Príncipe fall under the Low PPP category (Forti, et al., 2020).

Finally, in step 8, the quantity of WEEE generated in year *n*, from 2014 to 2030, is computed using Equation 1:

$$WEEE\ generated\ (n) = \sum_{t=t_0}^{n} POM(t) \times L^{(p)}(t, n) \tag{1}$$

In this case, $POM(t)$ is the quantity of EEE "put on the market" in the years *t* before year *n*, starting from t_0, which is the initial year that a product was sold. As mentioned before, given that there is no domestic production and since the exports of EEE from São Tomé and Príncipe are negligible, this parameter corresponds to the quantity of EEE imported in the same year *t*:

$$POM\ (t) = EEE\ imports\ (t) \tag{2}$$

Additionally, the parameter $L^{(p)}(t, n)$ corresponds to the lifespan distribution of an EEE sold in year *t*, and reflects the probable obsolescence rate in year *n*. This parameter was determined by a Weibull density function, defined by a time-varying shape parameter (β) and a scale parameter (α), as observed in Equation 3. The life-time profiles of the wide range of EEE were taken from Forti, et al. (2018) for non-European countries.

$$L^{(p)}(t,n) = \frac{\alpha}{\beta^{\alpha}}(n-t)^{(\alpha-1)}e^{-\left(\frac{n-t}{\beta}\right)^{\alpha}} \quad (3)$$

This quantification of WEEE is relevant to estimate the number of containers and shipments required, and the dimension of the infrastructure needed to accommodate all the e-waste generated.

3.3. Best Practices Identification

The third step consists of collecting the best practices implemented in the field, particularly in Africa. To achieve it, several sources were reached: the current practices available in the literature, alongside relevant entities in the sector, with whom contact was established and interviews were conducted.

Interviews were scheduled with two companies in the WEEE management field - Close The Gap and Umicore – as well as with Ecosteryl, a leading company in the sustainable treatment of the medical waste sector, also present in Africa. Moreover, two additional interviews were scheduled with two WEEE experts: Mrs. Aysha Lotter, an environmental and mineral law consultant and researcher on WEEE management in Africa, at the University of Cape Town; and Mrs. Joanna Bingham, the founder and former CEO of Footprints Africa.

The meetings happened during March 2025, through the Teams platform, except the one with Umicore that included a visit to the company's facility. The interviews focused on acquiring information about how waste collection, storage, and treatment is or should be performed, and understanding the main challenges regarding this type of system. The guide encompassing the specific questions asked in the semi-structured interviews is presented in Annex A.

3.4. Scenario Development

In this fourth step, taking into consideration information gathered in the previous steps, scenarios were developed for each of the three stages of WEEE management. These scenarios are based on the best practices identified in the previous step, on the infrastructure available and companies settled in the country, and on the information about the exporting countries of EEE to São Tomé and Príncipe.

After the development of the scenarios for each phase of the WEEE management system, some were selected based on feedback from the country to undergo the economic assessment.

3.5. Scenario Assessment

The last step is an economic assessment to enlighten about the viability of the scenarios chosen. To quantify the economic impact of each option, the evaluation encompasses a collection of quantitative data, such as costs, revenues, and relevant parameters. Furthermore, the calculation of the Net Present Value (NPV) is performed for each scenario chosen, via Equation (4), taking into consideration the Cash Flows (CF_t) for all the years t within the period of T years under analysis, the investment, and the discount rate, r. The scenario with the best value for the NPV will be selected as the WEEE management system to be adopted in São Tomé and Príncipe.

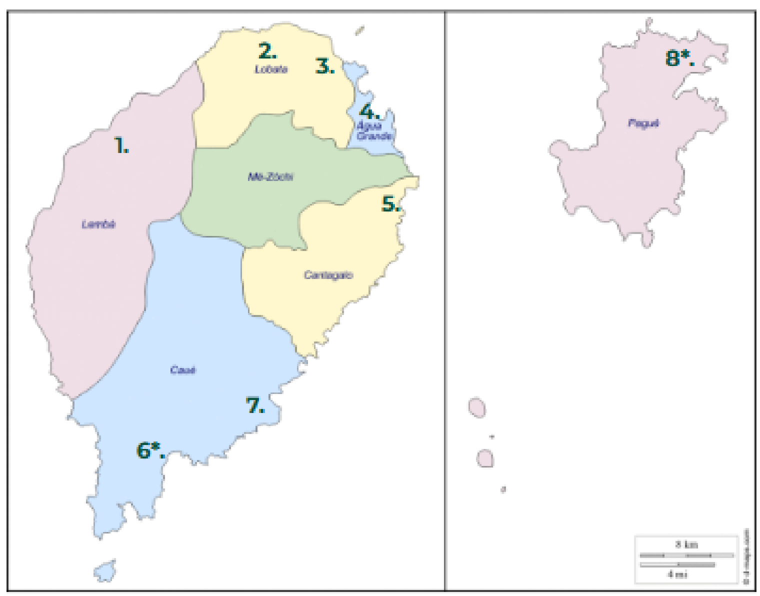
$$NPV = -\,Investment + \sum_{t=1}^{T} \frac{CF_t}{(1+r)^t} \tag{4}$$

4. Results

4.1. Base Case Scenario Analysis

According to Pereira et al. (2021), nothing is being done to selectively collect, store, and treat WEEE in São Tomé and Príncipe. WEEE ends up in open dumpsites all over the country, mixed up with other types of waste. Frequently, open burning is performed directly at the dumpsite (Pereira, et al., 2021).

There are eight main open dumpsites in the country: seven on the island of São Tomé — Cadão,



1. Cadão
2. Guadalupe
3. Fernão Dias
4. Penha
5. Almoxairife
6. Estrada N2
7. Fraternidade
8. Picantê

*This is not its precise location, as it was not possible to determine it.

Figure 3 - Open dumpsites in São Tomé and Príncipe

Guadalupe, Fernão Dias, Penha, Almoxairife, Estrada N2, and Fraternidade — and one on Príncipe Island—Picantê (Pereira, et al., 2021). Figure 3 presents the accurate geographical location of each dumpsite, except for the dumpsites of Estrada N2 and Picantê for which their accurate location was not possible to find.

Currently, Penha is the biggest dumpsite in the country, and it is run by the Água Grande district. As it is in an area surrounded by houses, the City Council found it necessary to rent a backhoe to remove waste (Pereira, et al., 2021), as its volume could potentially affect the households. In this dumpsite, similarly to what happens to the others, there is no type of control over the waste that is deposited there – anyone can go to this dumpsite and freely deposit their waste (Pereira, et al., 2021), regardless of its type, amount, or condition.

Even though there are no tangible actions to deal with WEEE in the country, some efforts have been seen in São Tomé and Príncipe to manage other types of waste. Regarding collection, vans were being used for waste management, particularly to collect some medical waste on São Tomé Island, such as needles and other dangerous materials. These vans were offered by TESE, an association that operates towards development, however, some of them were being used for other purposes rather than waste management, including recreational activities and public works (Pereira, et al., 2021).

On the other hand, door-to-door collection was being carried out in areas where it was not possible to have a dumpsite, making the task of depositing waste more difficult for the nearby population. This practice was being performed using a single truck that would reach these areas three times per week. Furthermore, it was expected that a REDES project would offer not only more trucks but also containers, to enhance the waste collection (Pereira, et al., 2021).

Additionally, to deepen the population's knowledge regarding waste practices, a collaboration between UNESCO and the Biosphere Reserve of the Island of Príncipe aimed to put into action awareness campaigns on Príncipe Island (Pereira, et al., 2021).

Concerning storage, it was acknowledged that there were null to very basic temporary storage facilities (Pereira, et al., 2021). The Waste Processing Centre, in Lobata, was used to store many batteries that were collected under a TESE collection project, which sought their exportation for proper treatment (Pereira, et al., 2021). This center was built with funds from the

European Union and the Camões I.P. – a Portuguese international organization aiming to promote the Portuguese language worldwide – and was receiving recyclable waste, mainly from Água Grande, Caué, and Lemba districts (Pereira, et al., 2021). Currently, battery storage does not exist.

There is another warehouse at Mouro Carregado that was used to store around 10 tons of chemicals, aimed to be exported to the United Kingdom, with the collaboration of UNIDO. Furthermore, the General Directorate for the Environment (DGA) – the entity responsible for managing hazardous waste in the country – requested to use private industrial facilities as a storage space for certain types of waste, until a solution is found to properly manage them (Pereira, et al., 2021). This was the case of a beer production company in São Tomé and Príncipe. Additionally, at Príncipe Island, the HDB Private Group was carrying out a waste segregation process to increase the efficiency of waste management on the island.

On top of that, it is acknowledged that there are no proper waste treatment facilities of any kind in São Tomé and Príncipe. General waste is burned at dumpsites and in private households (Pereira, et al., 2021).

4.2. Material Flow Analysis

According to the results collected from the Trade Map database, 629.86 tons of EEE were imported to São Tomé and Príncipe in 2023. From this value, 44.6% and 39.7% came from China and Portugal, respectively, which make these two countries the major exporting countries of EEE to São Tomé and Príncipe. These countries are followed by Angola and Egypt, which account for 9.0% and 2.5% of the total EEE imports, respectively. There are other countries from which the EEE exports to São Tomé and Príncipe also exist, however, they were not considered in the subsequent analysis, as the percentage of their respective exports to the country, in 2023, was less than 1%. These flows of EEE to São Tomé and Príncipe are presented in Figure 4.

In contrast to the results on EEE imports to the country under analysis, it was realized that there are no exports of EEE from São Tomé and Príncipe to other countries in 2023. This means that all the equipment that enters the country is kept within the borders until the point when it is considered waste. Annex B presents the figures depicting the results obtained on the EEE imports and exports.

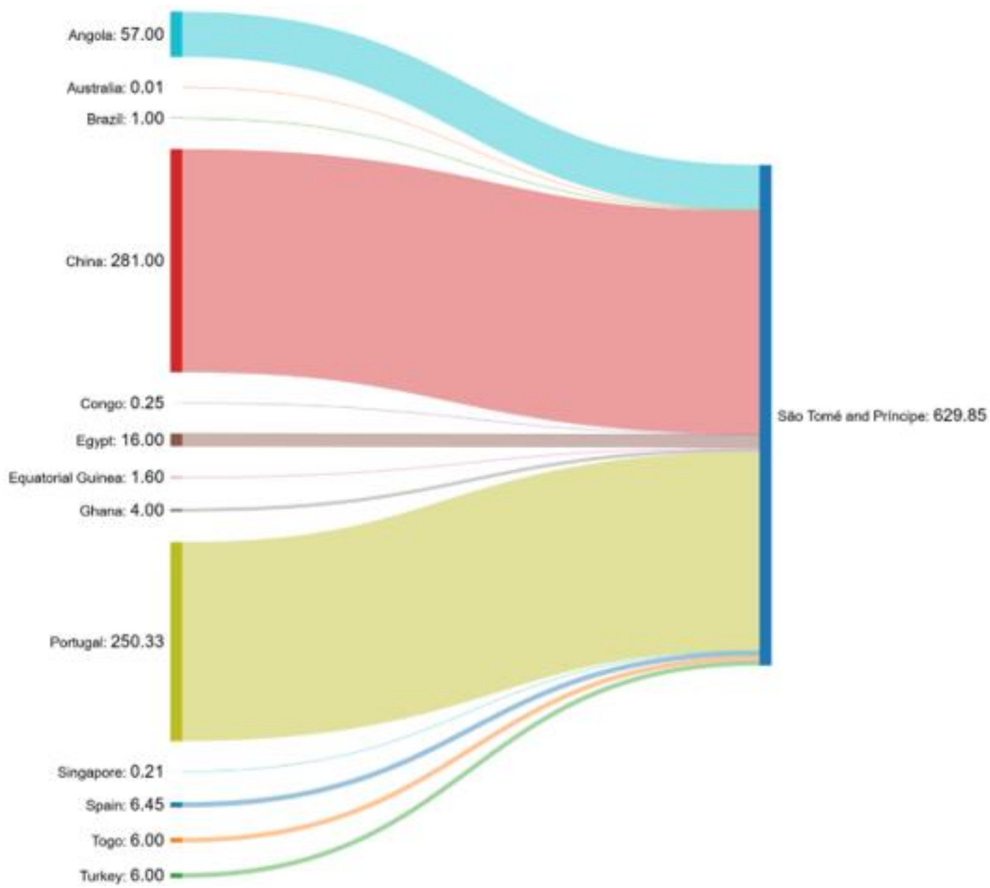


Figure 4 - EEE flows, in tons, between São Tomé and Príncipe and other nations in 2023

Following the methodology explained in the previous chapter and considering the amount of EEE entering the country between 2014 and 2023, and the lifespan of these materials, it was possible to obtain the expected WEEE quantities to be generated in São Tomé and Príncipe from 2014 to 2030, shown in Table 2, alongside with the WEEE generation trend in Figure 5.

Table 2 -Values for the WEEE estimated to have been generated between 2014 and 2024 and projected to be generated from 2025 to 2030 in São Tomé and Príncipe

Year	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
WEEE Generation (tons)	0	30.5	64.57	101.79	141.96	179.07	220.07	257.16	296.41	335.24	369.96	411.24	460.23	519.56	592.3	682.13	793.47

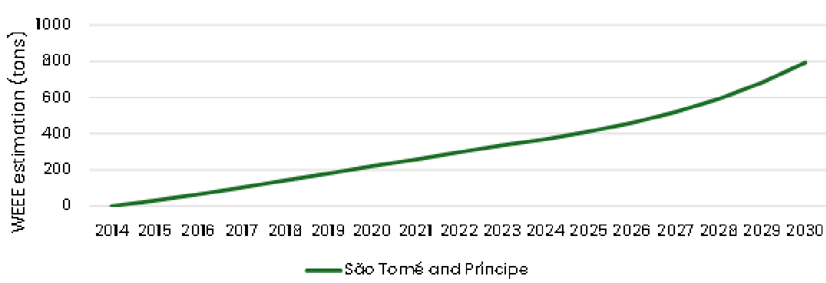


Figure 5 - WEEE estimated to have been generated between 2014 and 2024 and projected to be generated from 2025 to 2030 in São Tomé and Príncipe

Moreover, it was possible to discriminate the contribution of each EEE category to the total amount of WEEE estimated to have been generated and to be generated from 2014 to 2030 in São Tomé and Príncipe, as presented in Figure 6.

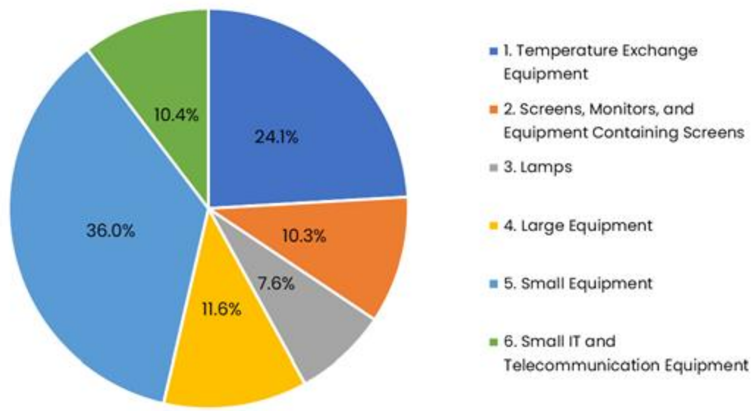


Figure 6 - Relative contribution of each EEE category to the total amount of WEEE estimated to have been generated between 2014 and 2024 and projected to be generated from 2025 to 2030 in São Tomé and Príncipe

4.3. Best Practices Identification

From the literature review, it was possible to identify the current best practices used in WEEE management, which are presented in Table 3.

Table 3 - Summary of the best practices on WEEE management

	Best Practices
Collection	Develop green propaganda and awareness campaigns on WEEE; Adopt a procurement practice for WEEE, through a door-to-door channel; Consider a Drop-off and/or Take-back collection channels; Use public sites, such as schools, as collection points; Establish partnerships with private companies; Increase regional collaboration and cooperation.
Storage	Categorize the WEEE; Have storage facilities in central locations; Ensure sufficient domestic infrastructure and capacity.
Treatment	Ensure formal WEEE treatment; Establish partnerships with private companies; Consider exportation through the use of shipping containers; Minimize transboundary movements; Ensure sufficient domestic infrastructure and capacity; Engage with informal WEEE workers.

Additionally, from the semi-structured interviews with the key entities contacted, the most relevant insights were collected and are presented in Table 4.

Table 4 - Relevant insights taken from the meetings

	Collection	Storage	Treatment
Close The Gap	Supermarkets and local stores are used as collection sites. Partner with community-based organizations to engage with the informal sector.	-	After being dismantled, components go from Kenya to Europe for treatment.
Umicore	Paying a small amount to the informal pickers for the WEEE collected could potentially increase collection rates.	Inside the plant, materials are stored in containers.	Umicore is receiving dismantled components from Angola and Nigeria. Umicore's facility in Hoboken can be a solution to treat dismantled equipment containing precious metals from São Tomé and Príncipe. Umicore offers dedicated training courses to employees.
Ecosteryl	Municipal sites are a collection channel used by the company. Centralized locations are better to efficiently manage flows.	Color-codes are used in the categorization process of the materials.	Training records are available online, facilitating the training process of new employees. Ecosteryl cannot be a solution to treat the WEEE from São Tomé and Príncipe.
Mrs. Aysha Lotter	Collection points in communities to collect WEEE from households. Door-to-door collection to collect large household appliances. WEEE collection from businesses should be performed through a B2B contract. Informal sector as an important part of the system. Recognize the work of informal pickers by giving them a financial incentive. E-Waste Day as an event to raise public awareness on WEEE.	Storing WEEE in containers is seen as a good solution.	Exporting WEEE for treatment must be considered. WEEE should reach treatment facilities without being dismantled.
Mrs. Joanna Bingham	Raise awareness among the population for WEEE matters. Informal pickers seen as "a gold mine of wisdom". Partner with organizations to integrate the informal sector in the collection phase.	-	Reach nearby countries to treat the WEEE of São Tomé and Príncipe.

The practices gathered, both from the literature and the interviews, were considered to develop the scenarios for each phase of WEEE management to be implemented in São Tomé and Príncipe.

4.4. Scenarios Development

From the information obtained in the previous steps, it was possible to identify possible scenarios in each stage of the future WEEE management system.

4.4.1. Collection

Regarding collection, as it is possible to observe in Figure 7, the possible channels are the door-to-door collection, drop-off collection, and take-back collection.

Regarding the drop-off collection, the population can deliver their WEEE in public places, such as schools, supermarkets and local stores; in municipal sites, including public containers distributed throughout the country, and bins located in city councils; or even in organizations' sites, such as Santa Casa da Misericórdia – an organization with substantial impact in the country.

Moreover, the "Take-back" collection mechanism can be set up with Retailers and Producers of electric and electronic equipment. Concerning the retailers, a range of entities that operate in the EEE sector and could be key players in this channel was identified. Regarding producers, this mechanism is directed at B2B markets and should be based on a contract between the EEE producer and the organization that possesses the equipment.

Figure 7 - Scenarios for the Collection Phase

Additionally, in this stage of the system, even though it is not considered a collection channel, it is important to mention that green propaganda could be a good practice to implement to increase the collection rates, which are crucial to the success of the system. Green propaganda can be performed through awareness campaigns developed in public places, such as schools, community centers, and companies, but also by distributing informative materials to the population. At the same time, establishing collection incentives would also be considered to achieve the same goal.

4.4.2. Storage

To store the WEEE collected in the previous phase, the options available encompass the building of new warehouses, using existing warehouses, using containers, and taking advantage of storage sites at industry facilities, as presented in Figure 8.

Figure 8 – Scenarios for the Storage Phase

As mentioned in the Base Case Scenario, there are three warehouses in São Tomé and Príncipe: the Waste Processing Centre, the Waste Recovery Centre, and a Warehouse at Mouro Carregado. Therefore, these three facilities could also be considered for this stage of the system. Additionally, the possibility of using facilities belonging to industrial companies to store WEEE was previously used in the country, as a temporary solution, and it is also being considered for this phase.

4.4.3. Treatment

As it was seen in the Literature Review, the treatment phase can be divided into three levels (United Nations Environmental Programme, 2007), in which the first level of treatment encompasses the dismantlement and segregation of WEEE components. At this first level, São Tomé and Príncipe has two options that can be considered for its completion: either the country builds a dismantling operation line, or it exports the WEEE to another country, where the waste will be under the responsibility of a certified company.

If the first option is chosen, after being dismantled, the components must proceed to the second and third levels of the treatment process. As acknowledged in the Base Case Scenario, São Tomé and Príncipe does not have any infrastructure capable of performing the sequential levels of the process; therefore, it either builds a proper treatment facility or it resorts to transboundary movements to proceed with a proper WEEE treatment elsewhere.

Whether exporting WEEE as a whole or its dismantled components, from all the countries where the WEEE treatment can be performed, it is logical to consider the countries that are exporting EEE to São Tomé and Príncipe, and which are also responsible for the waste generated, when they reach their end-of-life. In this sense, according to the Material Flow Analysis, the four countries that should be taken into consideration are China, Portugal, Angola, and Egypt (see Figure 4).

Portugal not only shares the same language with São Tomé and Príncipe but also has provided the country with helpful solutions in the past to properly manage this type of waste. In fact, Portugal also has good treatment facilities, and the distance between the country and São Tomé and Príncipe is reasonable, when compared to China, for instance. All these facts make Portugal an important country to have in mind when considering the option of exporting WEEE for proper treatment.

Additionally, it seems clear that countries such as Ghana and Nigeria, which are relatively close to São Tomé and Príncipe and have a developed WEEE treatment sector, should also be considered. Similarly, Kenya, where Close The Gap is originally from, is seen as a reference country in matters of WEEE management.

After knowing the countries to have in consideration in case of performing transboundary movements – Angola, China, Egypt, Ghana, Kenya, Nigeria, and Portugal – entities and organizations present in these countries aiming to treat WEEE were researched, which could make sense having a partnership with, to treat the WEEE generated in São Tomé and Príncipe.

It is important to highlight that, except for Umicore, most of these entities prefer to start the treatment featuring the WEEE as a whole and not dealing with its previously dismantled parts. Therefore, this is an important issue to have in mind in this scenario, and a fact that would probably favor the exportation of WEEE at the first level of the treatment stage. Also, even when building a dismantling facility to perform the first treatment level in São Tomé and Príncipe, this would not take away the possibility of having exports of the dismantled components anyway.

Nevertheless, whether the WEEE is exported as a whole or dismantled into its components to other countries, it is crucial to ensure the legal performance of these Transboundary Movements (United Nations Environment Programme, 2023).

Figure 9 presents all the possible options considered for WEEE treatment, encompassing the three levels of this phase.

Treatment

1st Level	2nd & 3rd Levels		
Build a WEEE dismantling line	Build a treatment facility		
	Export dismantled components	Angola	Partner with Narisrec
			Partner with Umicore's suppliers
		China	Partner with Veolia
		Egypt	Partner with Egyptian Electronics Recycling Co.
			Partner with Triple RE
		Ghana	Partner with Electro Recycling Ghana Limited
			Partner with Neweco
		Kenya	Partner with Close The Gap
			Partner with WEEE Centre
		Nigeria	Partner with Epron
			Partner with E-Terra Technologies
			Partner with Hinckley
			Partner with Umicore's suppliers
		Portugal	Partner with Ambicare
			Partner with Ambigroup Reciclagem
			Partner with BGR
			Partner with Veolia

1st, 2nd & 3rd Levels		
Export WEEE	Angola	Partner with Narisrec
	China	Partner with Veolia
	Egypt	Partner with Egyptian Electronics Recycling Co.
		Partner with Triple RE
	Ghana	Partner with Electro Recycling Ghana Limited
		Partner with Neweco
	Kenya	Partner with Close The Gap
		Partner with WEEE Centre
	Nigeria	Partner with Epron
		Partner with E-Terra Technologies
		Partner with Hinckley
	Portugal	Partner with Ambicare
		Partner with Ambigroup Reciclagem
		Partner with BGR
		Partner with Veolia

Figure 9 - Scenarios for the Treatment Phase

4.5. Scenario Assessment

Based on feedback from São Tomé and Príncipe regarding the scenarios developed for each phase of the WEEE management system, four scenarios were selected to be assessed.

The following assessment of the scenarios proposed by the country will be focused only on São Tomé Island, as this island encompasses 95.82% of the total population of the country (City Population, 2025). Additionally, this assumption will ease the logistics of implementing the recommended scenario, and later, this study could be extended to Príncipe Island as well.

4.5.1 Scenarios in assessment

For the **collection phase**, the scenario proposed for São Tomé and Príncipe was the following – Scenario C1:

- Perform drop-off collection through collection bins, collecting WEEE from the UN-Categories 2, 3, 5, and 6;
- Perform door-to-door collection by truck, during a WEEE Collection Period of 10 days per year, to collect WEEE from the UN-Categories 1 and 4;
- Implement Radio Awareness Campaigns throughout the year.

For the **storage phase**, two options are considered for evaluation:

- Using 20ft containers to store the WEEE upon collection – Scenario S1;
- Build a storage facility – Scenario S2.

Regarding the **treatment phase**, two options were also selected:

- Export to Portugal the WEEE for proper treatment – Scenario T1;
- Build a treatment facility in São Tomé and Príncipe – Scenario T2.

Since two alternative ways for the storage and treatment phases of the system were selected, there are four different scenarios encompassing the entire system to be considered:

- Scenario C1+S1+T1;
- Scenario C1+S2+T1;
- Scenario C1+S1+T2;
- Scenario C1+S2+T2.

4.5.2 Assumptions

To perform the economic assessment and analyze the viability of each scenario, the assumptions presented below were considered.

Regarding the **investment** required for the implementation of the scenarios, the following data is presented:

<u>Collection Bins:</u>

- 6 collection bins (one placed in the City Council of each district);
- 1,060€ of acquisition cost per bin (Securr, 2017);
- 15 years of effective life (depreciation rate of 6.67% per year) (ATO, 2023).

<u>Trucks:</u>

- 1 truck (the reasoning behind this value is presented in Annex C);
- 17,109.88€ of acquisition cost (Focus Technology, 2025);
- 15 years of effective life (depreciation rate of 6.67% per year) (ATO, 2023).

<u>20ft Containers:</u>

- 25 tons of capacity per container (OZBOX Containers, 2023);
- 975€ of acquisition cost per container (CBOX Containers, 2025);
- 15 years of effective life (depreciation rate of 6.67% per year) (ATO, 2023).

<u>Storage Facility:</u>

- Estimated for a medium-sized warehouse (30 m x 40 m) (Jacobs, 2025);
- 21,936€ of initial investment (Jacobs, 2025);
- 40 years of effective life (depreciation rate of 2.50% per year) (ATO, 2023).

<u>Treatment facility:</u>

- Capacity estimated for the maximum yearly amount of WEEE collected during the period under analysis – the estimated values for WEEE collection are presented further below;
- 81,388€ of initial investment in the dismantling infrastructure (Schluep & Spitzbart, 2015);
- 113,446€ of initial investment in the treatment infrastructure (Reuter, et al., 2013);
- 40 years of effective life for infrastructure (depreciation rate of 2.50% per year) (ATO, 2023);
- 374,299€ of initial investment in equipment (Reuter, et al., 2013);
- 20 years of effective life for equipment (depreciation rate of 5.00% per year) (ATO, 2023).

The **direct costs** considered encompass the labor costs incurred in the different stages of the system, as well as the transportation, loading, and shipping costs:

Labor Costs:

- 2 workers per truck performing the door-to-door collection, for 10 days per year;
- 1 worker responsible for the storage containers throughout the year;
- Number of workers in the storage facility given by the rounded value of the linear regression (5) (the reasoning behind this regression is presented in Annex C):

$$No.\, of\ workers\ in\ Storage\ Facility = 0.0227 * WEEE\ captured(tons) + 3.2885 \quad (5)$$

- 22 working days per month, for 12 months;
- 4.74€ of daily wage per worker (the reasoning behind this value is presented in Annex C);
- 55% of total operational costs in the treatment facility correspond to direct labor costs (Hart, 2024).

Truck Transportation Costs:

- 7 working hours per day;
- 30 km/h is the average truck speed considered in São Tomé Island;
- 0.38 liters of fuel consumed per 1 km travelled (Wise, 2024);
- 0.61€ per liter of fuel (Nevzorov, 2022).

Container Loading Costs:

- 175.50€ per container shipped (Manhart, et al., 2015).

Container Shipping costs:

- 2,981€ per container shipped (the reasoning behind this value is presented in Annex C).

The **operating expenses** encompass the operational costs incurred by the storage and treatment facilities, alongside the costs incurred by the implementation of the Radio Awareness Campaigns:

Radio Awareness Campaigns:

- 52 weeks per year;
- 4 advertisements per week (Radio Centre, 2025);
- 32.25€ per advertisement (the reasoning behind this value is presented in Annex C).

Storage Facility:

- 55% of the total operational cost corresponds to the direct labor costs (Hart, 2024), which means that the remaining 45% corresponds to this operating expense.

Treatment Facility:

- 247.33€ of operational costs per 1 ton of WEEE treated (Schluep & Spitzbart, 2015);
- 55% of the total operational cost corresponds to the direct labor costs (Hart, 2024), which means that the remaining 45% corresponds to this operating expense.

The **revenue** is obtained only in the treatment phase. While in Scenario T1 it comes from selling the WEEE inside the shipped container to the treatment company in Portugal, in Scenario T2, the revenue is obtained from the sales of the components recovered after the treatment. The following values were taken into consideration:

Revenue from Exporting to Portugal:

- 900€ per container received at a Portuguese certified treatment entity (Ambigroup, 2025);

Revenue from the Treatment Facility:

- 0.02033 tons of aluminum recovered per 1 ton of WEEE treated (Schluep & Spitzbart, 2015);
- 0.00467 tons of copper recovered per 1 ton of WEEE treated (Schluep & Spitzbart, 2015);
- 0.2033 tons of ferrous metals recovered per 1 ton of WEEE treated (Schluep & Spitzbart, 2015);
- 250€ of revenue per 1 ton of aluminum and copper recovered (Reuter, et al., 2013);
- 120€ of revenue per 1 ton of ferrous metals recovered (Reuter, et al., 2013).

For this economic analysis, a period of **15 years** is considered, as it is aligned with the effective life of most of the investment assets required for the proposed system. Although the effective life associated with the infrastructure of the storage and treatment facilities encompasses a larger period, extending this time window would increase the uncertainty associated with the analysis, discrediting the results obtained. Therefore, the implementation of the scenarios will occur between 2026 (Year 1) and 2040 (Year 15), being 2025 the investment year (Year 0).

To dimension the problem in these 15 years, the quantity of WEEE generated in the São Tomé Island was estimated, as presented in Table 5. For this purpose, the following was assumed:

<u>WEEE Generation in São Tomé:</u>

- Estimated WEEE generation from 2025 to 2030 obtained from the Material Flow Analysis (see Table 2);
- 16.32% is the growth rate of WEEE generated from 2029 to 2030 and assumed to remain constant for the following years;
- 95.82% is considered the share of WEEE generated in São Tomé Island (City Population, 2025);
- 22.30% is considered the WEEE capture rate, which is the average value worldwide (Baldé, et al., 2024)
- 35.7% of the WEEE captured is collected from the door-to-door collection, corresponding to the waste from UN-1 and UN-4 Categories (see Figure 6);
- 64.3% of the WEEE captured is collected from the bins located in the City Councils, corresponding to the WEEE from the remaining four UN-Categories (see Figure 6).

Table 5 - Estimation of the WEEE generated and captured from 2025 to 2040

	Year	Expected WEEE Generated in the country (tons)	Expected WEEE Generated in São Tomé (tons)	Expected WEEE Captured (tons)
Annual Growth Rate	2025	411.24	394.06	87.88
(starting in 2030)	2026	460.23	441.01	98.34
16.32%	2027	519.56	497.86	111.02
Share of São Tomé	2028	592.30	567.56	126.57
Island	2029	682.13	653.64	145.76
95.82%	2030	793.47	760.33	169.55
Capture Rate	2031	922.98	884.43	197.23
22.30%	2032	1073.64	1028.79	229.42
	2033	1248.88	1196.71	266.87
	2034	1452.73	1392.05	310.43
	2035	1689.85	1619.26	361.10
	2036	1965.67	1883.56	420.03
	2037	2286.51	2191.01	488.59
	2038	2659.73	2548.63	568.35
	2039	3093.86	2964.63	661.11
	2040	3598.85	3448.53	769.02

Accordingly, Table 6 shows the number of containers needed per year, alongside the number of containers shipped, i.e. number of shipments. The latter takes into consideration the total quantity of WEEE collected per year and the capacity of each container. The reasoning behind the number of containers is presented in Annex C.

Table 6 - Number of containers and shipments per year

Year	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
No.of containers	1	1	1	1	1	1	2	2	2	2	3	3	3	4	4	5
No. of shipments	4	4	5	6	6	7	8	10	11	13	15	17	20	23	27	31

The economic analysis performed in this section encompasses the computation of the Net Present Value (NPV) for each of the four scenarios, which combine the different options available for each phase. The discount rate used was **14.557%** and represents the risk of the project. This rate results from the combination of a Risk-Free rate of 1.207%, seen as a Risk-Free rate in Africa (South African Reserve Bank, 2025), with a Risk Premium of 13.350% (Damodaran, 2025). Given that the Country's Risk Premium of São Tomé and Príncipe was not found, the same rate was used from Myanmar, as the latter was the closest country to São Tomé and Príncipe, measured by the Human Development Index (HDI), whose Risk Premium rate was found (Conceição, et al., 2024).

The economic assumptions used to compute the NPV of each scenario are presented below:

<u>Economic assumptions:</u>

- Time period: 15 years;
- Year 0: 2025;
- Discount rate: 14.557%;
- Tax rate: 15% (Caragher, 2023);
- Interest rate: 0%, it is assumed that the project will be financed by the government.

Tables 7 to 10 show that, in all scenarios, the NPV is substantially below 0. The fact that the treatment revenues are always substantially inferior to the direct costs, for all the years of the study, is the reason behind the fact that all cash flows are negative, which will lead to a negative NPV in all cases. From this result, it is possible to conclude that, despite the scenario chosen, the system to be implemented will not be profitable to the country, or even allow the achievement of the breakeven point, at least for the next 15 years.

Table 7 - Economic results for Scenario C1+S1+T1

SCENARIO C1+S1+T1

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
Investment	**24,445 €**	**0 €**	**0 €**	**0 €**	**0 €**	**0 €**	**975 €**	**0 €**	**0 €**	**0 €**	**975 €**	**0 €**	**0 €**	**975 €**	**0 €**	**975 €**
Revenues		3,600.00 €	4,500.00 €	5,400.00 €	5,400.00 €	6,300.00 €	7,200.00 €	9,000.00 €	9,900.00 €	11,700.00 €	13,500.00 €	15,300.00 €	18,000.00 €	20,700.00 €	24,300.00 €	27,900.00 €
Direct Costs		14,457.48 €	17,613.62 €	20,769.75 €	20,769.75 €	23,925.89 €	27,082.02 €	33,394.29 €	36,550.43 €	42,862.70 €	49,174.97 €	55,487.24 €	64,955.64 €	74,424.05 €	87,048.59 €	99,673.13 €
Gross Profit		**- 10,857.48 €**	**- 13,113.62 €**	**- 15,369.75 €**	**- 15,369.75 €**	**- 17,625.89 €**	**- 19,882.02 €**	**- 24,394.29 €**	**- 26,650.43 €**	**- 31,162.70 €**	**- 35,674.97 €**	**- 40,187.24 €**	**- 46,955.64 €**	**- 53,724.05 €**	**- 62,748.59 €**	**- 71,773.13 €**
Operating Expenses		6,708 €	6,708 €	6,708 €	6,708 €	6,708 €	6,708 €	6,708 €	6,708 €	6,708 €	6,708 €	6,708 €	6,708 €	6,708 €	6,708 €	6,708 €
EBITDA		**- 17,565.48 €**	**- 19,821.62 €**	**- 22,077.75 €**	**- 22,077.75 €**	**- 24,333.89 €**	**- 26,590.02 €**	**- 31,102.29 €**	**- 33,358.43 €**	**- 37,870.70 €**	**- 42,382.97 €**	**- 46,895.24 €**	**- 53,663.64 €**	**- 60,432.05 €**	**- 69,456.59 €**	**- 78,481.13 €**
Depreciations		1,629.66 €	1,629.66 €	1,629.66 €	1,629.66 €	1,629.66 €	1,694.66 €	1,694.66 €	1,694.66 €	1,694.66 €	1,759.66 €	1,759.66 €	1,759.66 €	1,824.66 €	1,824.66 €	1,889.66 €
EBIT		**- 19,195.14 €**	**- 21,451.27 €**	**- 23,707.41 €**	**- 23,707.41 €**	**- 25,963.54 €**	**- 28,284.68 €**	**- 32,796.95 €**	**- 35,053.08 €**	**- 39,565.35 €**	**- 44,142.62 €**	**- 48,654.89 €**	**- 55,423.30 €**	**- 62,256.70 €**	**- 71,281.24 €**	**- 80,370.78 €**
Interest		- €	- €	- €	- €	- €	- €	- €	- €	- €	- €	- €	- €	- €	- €	- €
EBT		**- 19,195.14 €**	**- 21,451.27 €**	**- 23,707.41 €**	**- 23,707.41 €**	**- 25,963.54 €**	**- 28,284.68 €**	**- 32,796.95 €**	**- 35,053.08 €**	**- 39,565.35 €**	**- 44,142.62 €**	**- 48,654.89 €**	**- 55,423.30 €**	**- 62,256.70 €**	**- 71,281.24 €**	**- 80,370.78 €**
Tax		2,879.27 €	3,217.69 €	3,556.11 €	3,556.11 €	3,894.53 €	4,242.70 €	4,919.54 €	5,257.96 €	5,934.80 €	6,621.39 €	7,298.23 €	8,313.49 €	9,338.51 €	10,692.19 €	12,055.62 €
Net Profit		**- 22,074.41 €**	**- 24,668.96 €**	**- 27,263.52 €**	**- 27,263.52 €**	**- 29,858.08 €**	**- 32,527.38 €**	**- 37,716.49 €**	**- 40,311.05 €**	**- 45,500.16 €**	**- 50,764.02 €**	**- 55,953.13 €**	**- 63,736.79 €**	**- 71,595.21 €**	**- 81,973.43 €**	**- 92,426.40 €**
Depreciations		1,629.66 €	1,629.66 €	1,629.66 €	1,629.66 €	1,629.66 €	1,694.66 €	1,694.66 €	1,694.66 €	1,694.66 €	1,759.66 €	1,759.66 €	1,759.66 €	1,824.66 €	1,824.66 €	1,889.66 €
Cash-Flow		**- 20,444.75 €**	**- 23,039.31 €**	**- 25,633.86 €**	**- 25,633.86 €**	**- 28,228.42 €**	**- 30,832.72 €**	**- 36,021.83 €**	**- 38,616.39 €**	**- 43,805.50 €**	**- 49,004.36 €**	**- 54,193.47 €**	**- 61,977.13 €**	**- 69,770.55 €**	**- 80,148.77 €**	**- 90,536.74 €**
Discounted Cash-flow		- 17,846.79 €	- 17,556.02 €	- 17,050.97 €	- 14,884.27 €	- 14,307.98 €	- 13,642.13 €	- 13,912.79 €	- 13,019.63 €	- 12,892.40 €	- 12,589.79 €	- 12,153.71 €	- 12,133.10 €	- 11,923.15 €	- 11,956.22 €	- 11,789.64 €
NPV	**- 233,078.95 €**															

Table 8 - Economic results for Scenario C1+S2+T1

SCENARIO C1+S2+T1

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
Investment	**45,406 €**	**0 €**	**0 €**	**0 €**	**0 €**	**0 €**	**0 €**	**0 €**	**0 €**	**0 €**	**0 €**	**0 €**	**0 €**	**0 €**	**0 €**	**0 €**
Revenues		3,600 €	4,500 €	5,400 €	5,400 €	6,300 €	7,200 €	9,000 €	9,900 €	11,700 €	13,500 €	15,300 €	18,000 €	20,700 €	24,300 €	27,900 €
Direct Costs		20,714.28 €	23,870.42 €	27,026.55 €	28,277.91 €	31,434.05 €	35,841.54 €	42,153.81 €	46,561.31 €	54,124.94 €	61,688.57 €	70,503.56 €	81,223.32 €	93,194.45 €	108,321.71 €	124,700.33 €
Gross Profit		**- 17,114.28 €**	**- 19,370.42 €**	**- 21,626.55 €**	**- 22,877.91 €**	**- 25,134.05 €**	**- 28,641.54 €**	**- 33,153.81 €**	**- 36,661.31 €**	**- 42,424.94 €**	**- 48,188.57 €**	**- 55,203.56 €**	**- 63,223.32 €**	**- 72,494.45 €**	**- 84,021.71 €**	**- 96,800.33 €**
Operating Expenses		12,851.04 €	12,851.04 €	12,851.04 €	13,874.88 €	13,874.88 €	14,898.72 €	14,898.72 €	15,922.56 €	16,946.40 €	17,970.24 €	20,017.92 €	21,041.76 €	23,089.44 €	25,137.12 €	28,208.64 €
EBITDA		**- 29,965.32 €**	**- 32,221.46 €**	**- 34,477.59 €**	**- 36,752.79 €**	**- 39,008.93 €**	**- 43,540.26 €**	**- 48,052.53 €**	**- 52,583.87 €**	**- 59,371.34 €**	**- 66,158.81 €**	**- 75,221.48 €**	**- 84,265.08 €**	**- 95,583.89 €**	**- 109,158.83 €**	**- 125,008.97 €**
Depreciations		2,113.05 €	2,113.05 €	2,113.05 €	2,113.05 €	2,113.05 €	2,113.05 €	2,113.05 €	2,113.05 €	2,113.05 €	2,113.05 €	2,113.05 €	2,113.05 €	2,113.05 €	2,113.05 €	2,113.05 €
EBIT		**- 32,078.37 €**	**- 34,334.51 €**	**- 36,590.64 €**	**- 38,865.84 €**	**- 41,121.98 €**	**- 45,653.31 €**	**- 50,165.58 €**	**- 54,696.92 €**	**- 61,484.39 €**	**- 68,271.86 €**	**- 77,334.53 €**	**- 86,378.13 €**	**- 97,696.94 €**	**- 111,271.88 €**	**- 127,122.02 €**
Interest		- €	- €	- €	- €	- €	- €	- €	- €	- €	- €	- €	- €	- €	- €	- €
EBT		**- 32,078.37 €**	**- 34,334.51 €**	**- 36,590.64 €**	**- 38,865.84 €**	**- 41,121.98 €**	**- 45,653.31 €**	**- 50,165.58 €**	**- 54,696.92 €**	**- 61,484.39 €**	**- 68,271.86 €**	**- 77,334.53 €**	**- 86,378.13 €**	**- 97,696.94 €**	**- 111,271.88 €**	**- 127,122.02 €**
Tax		4,811.76 €	5,150.18 €	5,488.60 €	5,829.88 €	6,168.30 €	6,848.00 €	7,524.84 €	8,204.54 €	9,222.66 €	10,240.78 €	11,600.18 €	12,956.72 €	14,654.54 €	16,690.78 €	19,068.30 €
Net Profit		**- 36,890.13 €**	**- 39,484.68 €**	**- 42,079.24 €**	**- 44,695.72 €**	**- 47,290.27 €**	**- 52,501.31 €**	**- 57,690.42 €**	**- 62,901.46 €**	**- 70,707.05 €**	**- 78,512.64 €**	**- 88,934.71 €**	**- 99,334.85 €**	**- 112,351.48 €**	**- 127,962.66 €**	**- 146,190.32 €**
Depreciations		2,113.05 €	2,113.05 €	2,113.05 €	2,113.05 €	2,113.05 €	2,113.05 €	2,113.05 €	2,113.05 €	2,113.05 €	2,113.05 €	2,113.05 €	2,113.05 €	2,113.05 €	2,113.05 €	2,113.05 €
Cash-Flow		**- 34,777.08 €**	**- 37,371.63 €**	**- 39,966.19 €**	**- 42,582.67 €**	**- 45,177.22 €**	**- 50,388.26 €**	**- 55,577.37 €**	**- 60,788.40 €**	**- 68,593.99 €**	**- 76,399.58 €**	**- 86,821.65 €**	**- 97,221.80 €**	**- 110,238.43 €**	**- 125,849.61 €**	**- 144,077.27 €**
Discounted Cash-flow		- 30,357.88 €	- 28,477.30 €	- 26,584.46 €	- 24,725.57 €	- 22,898.73 €	- 22,294.59 €	- 21,465.77 €	- 20,494.99 €	- 20,187.91 €	- 19,627.94 €	- 19,471.08 €	- 19,032.86 €	- 18,838.74 €	- 18,773.66 €	- 18,761.65 €
NPV	**- 377,398.76 €**															

Table 9 - Economic results for Scenario C1+S1+T2

SCENARIO C1+S1+T2

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
Investment	**593,578 €**	**0 €**	**0 €**	**0 €**	**0 €**	**0 €**	**975 €**	**0 €**	**0 €**	**0 €**	**975 €**	**0 €**	**0 €**	**975 €**	**0 €**	**975 €**
Revenues		3,002.45 €	3,389.51 €	3,864.05 €	4,450.09 €	5,176.45 €	6,021.37 €	7,004.20 €	8,147.46 €	9,477.32 €	11,024.25 €	12,823.67 €	14,916.80 €	17,351.58 €	20,183.77 €	23,478.25 €
Direct Costs		15,211.06 €	16,935.68 €	19,050.11 €	21,661.32 €	24,897.79 €	28,662.53 €	33,041.76 €	38,135.79 €	44,061.28 €	50,953.96 €	58,971.69 €	68,298.11 €	79,146.82 €	91,766.31 €	106,445.59 €
Gross Profit		**- 12,208.60 €**	**- 13,546.17 €**	**- 15,186.06 €**	**- 17,211.23 €**	**- 19,721.34 €**	**- 22,641.15 €**	**- 26,037.55 €**	**- 29,988.33 €**	**- 34,583.96 €**	**- 39,929.72 €**	**- 46,148.03 €**	**- 53,381.31 €**	**- 61,795.25 €**	**- 71,582.53 €**	**- 82,967.34 €**
Operating Expenses		17,653.73 €	19,064.79 €	20,794.78 €	22,931.22 €	25,579.24 €	28,659.48 €	32,242.49 €	36,410.33 €	41,258.46 €	46,897.93 €	53,457.89 €	61,088.59 €	69,964.81 €	80,289.84 €	92,300.17 €
EBITDA		**- 29,862.34 €**	**- 32,610.96 €**	**- 35,980.83 €**	**- 40,142.45 €**	**- 45,300.58 €**	**- 51,300.63 €**	**- 58,280.04 €**	**- 66,398.66 €**	**- 75,842.43 €**	**- 86,827.65 €**	**- 99,605.92 €**	**- 114,469.91 €**	**- 131,760.06 €**	**- 151,872.38 €**	**- 175,267.51 €**
Depreciations		25,215.46 €	25,215.46 €	25,215.46 €	25,215.46 €	25,215.46 €	25,280.46 €	25,280.46 €	25,280.46 €	25,280.46 €	25,345.46 €	25,345.46 €	25,345.46 €	25,410.46 €	25,410.46 €	25,475.46 €
EBIT		**- 55,077.80 €**	**- 57,826.42 €**	**- 61,196.30 €**	**- 65,357.91 €**	**- 70,516.04 €**	**- 76,581.10 €**	**- 83,560.50 €**	**- 91,679.12 €**	**- 101,122.89 €**	**- 112,173.11 €**	**- 124,951.38 €**	**- 139,815.37 €**	**- 157,170.52 €**	**- 177,282.84 €**	**- 200,742.98 €**
Interest		- €	- €	- €	- €	- €	- €	- €	- €	- €	- €	- €	- €	- €	- €	- €
EBT		**- 55,077.80 €**	**- 57,826.42 €**	**- 61,196.30 €**	**- 65,357.91 €**	**- 70,516.04 €**	**- 76,581.10 €**	**- 83,560.50 €**	**- 91,679.12 €**	**- 101,122.89 €**	**- 112,173.11 €**	**- 124,951.38 €**	**- 139,815.37 €**	**- 157,170.52 €**	**- 177,282.84 €**	**- 200,742.98 €**
Tax		8,261.67 €	8,673.96 €	9,179.44 €	9,803.69 €	10,577.41 €	11,487.16 €	12,534.08 €	13,751.87 €	15,168.43 €	16,825.97 €	18,742.71 €	20,972.31 €	23,575.58 €	26,592.43 €	30,111.45 €
Net Profit		**- 63,339.47 €**	**- 66,500.38 €**	**- 70,375.74 €**	**- 75,161.60 €**	**- 81,093.45 €**	**- 88,068.26 €**	**- 96,094.58 €**	**- 105,430.99 €**	**- 116,291.32 €**	**- 128,999.07 €**	**- 143,694.09 €**	**- 160,787.68 €**	**- 180,746.10 €**	**- 203,875.27 €**	**- 230,854.42 €**
Depreciations		25,215.46 €	25,215.46 €	25,215.46 €	25,215.46 €	25,215.46 €	25,280.46 €	25,280.46 €	25,280.46 €	25,280.46 €	25,345.46 €	25,345.46 €	25,345.46 €	25,410.46 €	25,410.46 €	25,475.46 €
Cash-Flow		**- 38,124.01 €**	**- 41,284.92 €**	**- 45,160.28 €**	**- 49,946.14 €**	**- 55,877.98 €**	**- 62,787.80 €**	**- 70,814.12 €**	**- 80,150.53 €**	**- 91,010.86 €**	**- 103,653.61 €**	**- 118,348.62 €**	**- 135,442.21 €**	**- 155,335.64 €**	**- 178,464.80 €**	**- 205,378.96 €**
Discounted Cash-flow		- 33,279.51 €	- 31,459.24 €	- 30,039.43 €	- 29,001.16 €	- 28,322.56 €	- 27,780.84 €	- 27,350.70 €	- 27,022.98 €	- 26,785.42 €	- 26,629.81 €	- 26,541.49 €	- 26,515.17 €	- 26,545.44 €	- 26,622.56 €	- 26,744.31 €
NPV	**- 1,015,194.16 €**															

Table 10 - Economic results for Scenario C1+S2+T2

SCENARIO C1+S2+T2

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
Investment	**614,539 €**	**0 €**	**0 €**	**0 €**	**0 €**	**0 €**	**0 €**	**0 €**	**0 €**	**0 €**	**0 €**	**0 €**	**0 €**	**0 €**	**0 €**	**0 €**
Revenues		3,002.45 €	3,389.51 €	3,864.05 €	4,450.09 €	5,176.45 €	6,021.37 €	7,004.20 €	8,147.46 €	9,477.32 €	11,024.25 €	12,823.67 €	14,916.80 €	17,351.58 €	20,183.77 €	23,478.25 €
Direct Costs		21,467.86 €	23,192.48 €	25,306.91 €	29,169.48 €	32,405.95 €	37,422.05 €	41,801.28 €	48,146.67 €	55,323.52 €	63,467.56 €	73,988.01 €	84,565.79 €	97,917.22 €	113,039.43 €	131,472.79 €
Gross Profit		**- 18,465.40 €**	**- 19,802.97 €**	**- 21,442.86 €**	**- 24,719.39 €**	**- 27,229.50 €**	**- 31,400.67 €**	**- 34,797.07 €**	**- 39,999.21 €**	**- 45,846.20 €**	**- 52,443.32 €**	**- 61,164.35 €**	**- 69,648.99 €**	**- 80,565.65 €**	**- 92,855.65 €**	**- 107,994.54 €**
Operating Expenses		23,796.77 €	25,207.83 €	26,937.82 €	30,098.10 €	32,746.12 €	36,850.20 €	40,433.21 €	45,624.89 €	51,496.86 €	58,160.17 €	66,767.81 €	75,422.35 €	86,346.25 €	98,718.96 €	113,800.81 €
EBITDA		**- 42,262.18 €**	**- 45,010.80 €**	**- 48,380.67 €**	**- 54,817.49 €**	**- 59,975.62 €**	**- 68,250.87 €**	**- 75,230.28 €**	**- 85,624.10 €**	**- 97,343.07 €**	**- 110,603.49 €**	**- 127,932.16 €**	**- 145,071.35 €**	**- 166,911.90 €**	**- 191,574.62 €**	**- 221,795.35 €**
Depreciations		25,698.86 €	25,698.86 €	25,698.86 €	25,698.86 €	25,698.86 €	25,698.86 €	25,698.86 €	25,698.86 €	25,698.86 €	25,698.86 €	25,698.86 €	25,698.86 €	25,698.86 €	25,698.86 €	25,698.86 €
EBIT		**- 67,961.03 €**	**- 70,709.65 €**	**- 74,079.53 €**	**- 80,516.35 €**	**- 85,674.47 €**	**- 93,949.73 €**	**- 100,929.14 €**	**- 111,322.95 €**	**- 123,041.92 €**	**- 136,302.34 €**	**- 153,631.01 €**	**- 170,770.20 €**	**- 192,610.76 €**	**- 217,273.48 €**	**- 247,494.21 €**
Interest		- €	- €	- €	- €	- €	- €	- €	- €	- €	- €	- €	- €	- €	- €	- €
EBT		**- 67,961.03 €**	**- 70,709.65 €**	**- 74,079.53 €**	**- 80,516.35 €**	**- 85,674.47 €**	**- 93,949.73 €**	**- 100,929.14 €**	**- 111,322.95 €**	**- 123,041.92 €**	**- 136,302.34 €**	**- 153,631.01 €**	**- 170,770.20 €**	**- 192,610.76 €**	**- 217,273.48 €**	**- 247,494.21 €**
Tax		10,194.15 €	10,606.45 €	11,111.93 €	12,077.45 €	12,851.17 €	14,092.46 €	15,139.37 €	16,698.44 €	18,456.29 €	20,445.35 €	23,044.65 €	25,615.53 €	28,891.61 €	32,591.02 €	37,124.13 €
Net Profit		**- 78,155.19 €**	**- 81,316.10 €**	**- 85,191.46 €**	**- 92,593.80 €**	**- 98,525.64 €**	**- 108,042.19 €**	**- 116,068.51 €**	**- 128,021.40 €**	**- 141,498.21 €**	**- 156,747.69 €**	**- 176,675.66 €**	**- 196,385.73 €**	**- 221,502.37 €**	**- 249,864.50 €**	**- 284,618.34 €**
Depreciations		25,698.86 €	25,698.86 €	25,698.86 €	25,698.86 €	25,698.86 €	25,698.86 €	25,698.86 €	25,698.86 €	25,698.86 €	25,698.86 €	25,698.86 €	25,698.86 €	25,698.86 €	25,698.86 €	25,698.86 €
Cash-Flow		**- 52,456.33 €**	**- 55,617.25 €**	**- 59,492.60 €**	**- 66,894.94 €**	**- 72,826.79 €**	**- 82,343.33 €**	**- 90,369.65 €**	**- 102,322.54 €**	**- 115,799.35 €**	**- 131,048.84 €**	**- 150,976.81 €**	**- 170,686.88 €**	**- 195,803.51 €**	**- 224,165.64 €**	**- 258,919.48 €**
Discounted Cash-flow		- 45,790.59 €	- 42,380.51 €	- 39,572.92 €	- 38,842.46 €	- 36,913.31 €	- 36,433.31 €	- 34,903.68 €	- 34,498.34 €	- 34,080.93 €	- 33,667.96 €	- 33,858.86 €	- 33,414.93 €	- 33,461.03 €	- 33,439.99 €	- 33,716.33 €
NPV	**- 1,159,513.97 €**															

As presented in Table 11, despite the negative values of the NPV, it is possible to infer that option S1 for the storage phase – store WEEE in 20ft containers – is preferable to option S2 – building a storage facility. In the same sense, in the treatment phase, option T1 – export WEEE to Portugal – is economically better than option T2 – building a treatment facility, as the volume of WEEE generated is too small to justify the great investment in building a treatment facility.

Table 11 - NPV for each scenario

Scenarios	C1+S1+T1	C1+S2+T1	C1+S1+T2	C1+S2+T2
NPV	**- 233,078.95 €**	**- 377,398.76 €**	**- 1,015,194.16 €**	**- 1,159,513.97 €**

Therefore, given the need for a WEEE management system in the country due to its current state, besides the collection practices common to all scenarios, it is advisable to store the WEEE in 20-foot containers and export it to Portugal for proper treatment (Scenario C1+S1+T1).

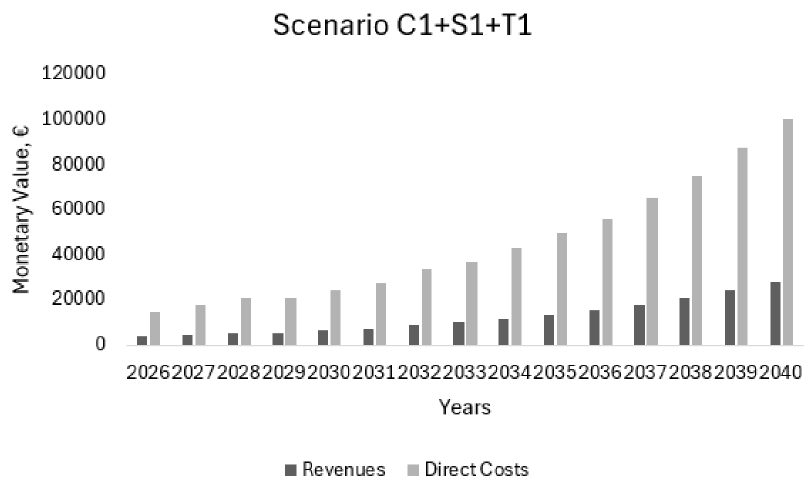


Figure 10 - Revenues and Direct Costs over the years of the project for scenario C1+S1+T1

Regarding the scenario advised, it is possible to observe in Figure 10 that there is no prospect of having a positive result in the future, or at least achieving the breakeven point, as the revenue obtained in the treatment phase each year is substantially lower when compared to the costs.

Additionally, it is possible to understand that the growing quantity of WEEE generated and collected over the years is the factor behind the constant increase in both costs and revenues, in Figure 10. This means that increasing the volume treated will not solve the negative signal of the Net Present Value of the scenarios. Instead, to improve the NPV value of all four scenarios, the country should try to achieve a better value for the unitary gain per ton of WEEE treated and/or container shipped.

5. Conclusion

To address the urgent situation of the WEEE management in São Tomé and Príncipe, the present thesis aims to propose a system to guarantee that this practice is properly performed in the country.

From the scenarios developed and analyzed, it was possible to observe that none of them are profitable for the country, or at least allow it to achieve a breakeven point, in the short and medium terms, as the total costs incurred are substantially higher than the revenues potentially obtained. However, given that the flow of WEEE generated in the country is exponentially increasing, a WEEE management system must indeed be implemented in the country.

Therefore, from the scenarios considered, it is possible to conclude that besides having collection bins in the City Council of each district and hosting a WEEE Collection Period throughout the year, the recommended one encompasses using 20ft containers to store the WEEE collected and later exporting it to Portugal for proper treatment and disposal.

It must be acknowledged that this system will require significant effort on behalf of the country. Therefore, to ensure the successful execution of the project, not only will São Tomé and Príncipe have to cover the considerable expenses that the system will incur, but it should also seek the collaboration of the population and the cooperation of the informal sector. In this sense, the country should reach out to third parties and ask for help to address these challenges.

The proactivity of the entities contacted during this study and their openness in sharing their knowledge on WEEE matters were incredibly noticeable. Thus, a key practice, confirmed by the literature review, is indeed joining the forces of several entities – including private companies, experts, Non-Governmental Organizations (NGOs), and even other governments – and partnering together to bridge the existing gaps along the way.

In conclusion, the development and implementation of the WEEE management system proposed in São Tomé and Príncipe will go beyond its contribution to stopping the increasing trend of WEEE in the country, as it will also generate remarkable social and environmental benefits, assisting the accomplishment of the SDGs and enabling the movement towards the circular economy.

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Annex A – Semi-Structured Interview Guide

The meetings with both the organizations operating in the waste field and with experts on WEEE matters were guided by the questions presented below.

Semi-Structured Interview Guide - Close the Gap, Umicore, and Ecosteryl

- How is the collection of waste being done?
- How often is the collection performed?
- Which type of problems are faced in the collection phase?
- Would you be open to receiving collected waste from other countries?

- How is the storage of waste being done?
- Which type of infrastructure is used for storage purposes?
- Does the waste go through a categorization process and segregation?
- Which safety measures are used in the storage areas?

- How is the treatment of waste being done?
- Are there any organizations that you have partnered with in the treatment phase?
- How are the workers trained to perform the treatment?
- How does the treated material enter the value chain again?
- How are the waste's non-valuable parts disposed of?

Semi-Structured Interview Guide - Mrs. Aysha Lotter and Mrs. Joanna Bingham

- What are the best collection practices in Africa?
- What are the best channels to collect WEEE from households and business entities?
- Which type of problems are the ones mainly faced in the collection phase?

- What are the best storage practices in Africa?
- What type of infrastructure is best for storing WEEE?
- Which safety measures must be in place in storage facilities?

- What are the best treatment practices in Africa?
- What is your view on how we can formalize the informal sector?
- Which WEEE treatment entities should partner with São Tomé and Príncipe?
- What is your view on how to hire and train people to work in treatment centers in Africa?

Annex B – Material Flow Analysis Complementary Results

Taken from the Trade Map data source, the imports of EEE to São Tomé and Príncipe between 2014 and 2023 are represented graphically in Figure 11. In this period of 10 years, the total amount of EEE received from foreign countries was 7537.00 tons, which encompasses an average of 753.7 tons of EEE imported per year.

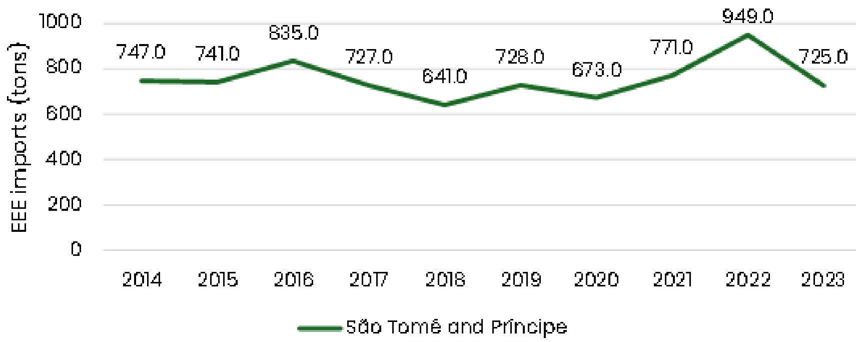

Figure 11 - EEE imports to São Tomé and Príncipe between 2014 and 2023

Regarding the EEE exports from São Tomé and Príncipe, from 2014 to 2023, a total amount of 23.00 tons was registered, which corresponds to 0.31% of the total quantity of EEE imported during the same period. The data concerning the EEE exports is presented in Figure 12.

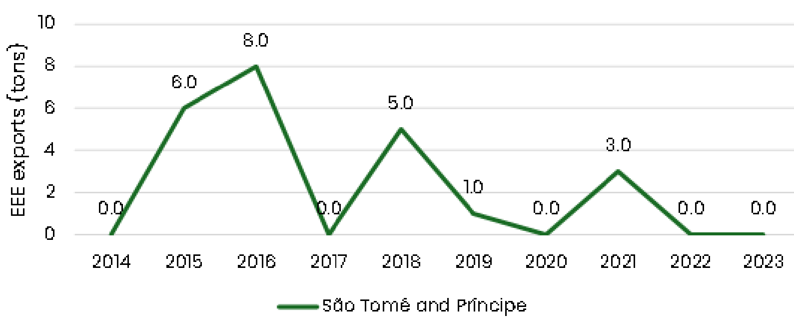

Figure 12 - EEE exports from São Tomé and Príncipe between 2014 and 2023

Furthermore, given that there is no domestic production of EEE in the country (Pereira, et al., 2021), alongside the fact that the EEE exports from São Tomé and Príncipe are negligible when compared to the EEE imports in the same period, it was assumed that the growth rate in EEE consumption for the country is only due to the EEE importations. Between 2023 and 2030, a value of 23% was considered for this rate, as already explained in the methodology. Based on this rate, it was possible to estimate the imports of EEE to São Tomé and Príncipe from 2024 to 2030, as observed in Figure 13.

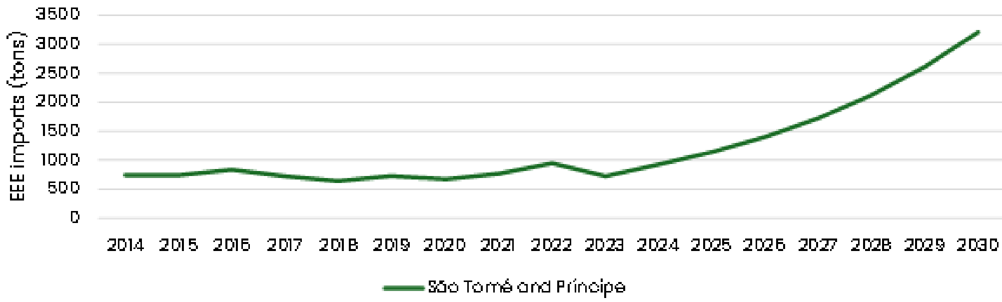

Figure 13 - EEE imports to São Tomé and Príncipe between 2014 and 2030

Annex C – Reasoning behind assumptions used in the Scenario Assessment

<u>Number of trucks required:</u>

In each of the ten days of the WEEE collection period, trucks will be used to perform a door-to-door collection. It was assumed that one truck has an average capture rate of 3 tons of WEEE per hour, which can vary between 1 and 5 tons per hour (Health and Safety Executive, 2025), depending on the location, number of households, and availability of the waste to be collected. Simultaneously, it was established that this collection practice will be performed within a working period of 7 hours. Therefore, each truck can collect up to 35 tons of WEEE.

From the Base Case Scenario, it was seen that the country does not have any spare trucks with this capacity that could be used to perform this task. Given that, in parallel, there is no truck rental service in the country, these vehicles should be bought. To compute the number of trucks needed, the worst-case scenario was considered: collecting WEEE on one of the days of the WEEE Collecting Period, in 2040, which is the year that presents the highest value for the amount of WEEE generated and captured. For this scenario, the need for trucks is approximately one truck, meaning that in the remaining years, having one truck per day will be enough. Therefore, this was the value assumed as the number of trucks available each year, for this collection practice.

<u>Number of workers in the storage facility:</u>

By taking a facility in Cambodia as a reference, it was possible to develop the linear regression between the yearly amount of WEEE collected and stored in the facility and the number of workers needed, which is presented in Figure 14 (Schluep & Spitzbart, 2015).

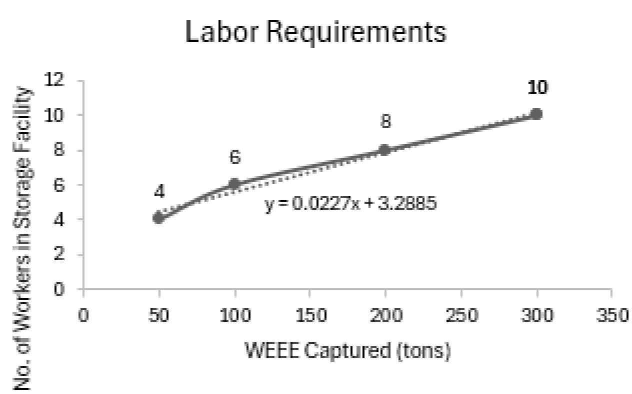

Figure 14 - Number of workers required in the Storage Facility depending on the quantity of WEEE stored

Daily wage per worker:

It was assumed that the daily wage is 4.74€ per worker (Manhart, et al., 2015). Although this value is associated with the daily income of a WEEE sector worker in Ghana, this amount is very much aligned with the minimum income of the country under analysis.

Container shipping costs:

The shipping cost of a single container from São Tomé and Príncipe to Portugal presents a high variability, changing every day. Therefore, to obtain an estimation for this unitary cost, a range of different values for several days (FW Freight, 2025) was considered and used to compute an average value of 2,981€. The values used for the computation are presented in Table 12.

Table 12 - Computation of the unitary shipping cost

	Shipping Cost
30-Apr	2,440 €
1-May	3,157 €
2-May	2,573 €
3-May	3,753 €
Average	2,981 €

Advertising cost:

The cost incurred each time an advertisement goes on air was considered as 32.25€. This value was obtained from the average cost of an advertisement campaign in Togo, which is the country whose GDP is the closest to São Tomé and Príncipe, whose cost was found (Radio France Internationale, 2022).

Containers:

During the WEEE Collection Period, the door-to-door collection will focus on a particular district each day. Within the ten days, the number of days assigned to each of the six districts was determined based on the population's share of each district (City Population, 2025), while ensuring that each district had at least one day assigned to it.

It was assumed that, whenever the container is moved to transport waste to a treatment facility, the empty containers return to their original place. In addition to that, the WEEE Collection Period in each district will happen throughout the year, allowing the full containers to return before the event occurs in the following district. Therefore, the number of containers needed per year was computed considering the need for storage to accommodate the amount of WEEE that will be collected during the WEEE Collection Period in Água Grande, which is the most populous district on the island (City Population, 2025).

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