Additional thesis

DECEMBER 2024

COLLECTORS

A review on take back waste collection systems in Europe: Best practices evaluated.

Delft University of Technology
Faculty of Civil Engineering and Geosciences
Supervisors:

Prof. Dr. P.C. Rem, TU Delft
Ing. JH. Welink, TU Delft
Dr. Tjerk Wardenaar, PNO consultants

Author: S.H.M.I. Alnajar

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 776745.

PREFACE

First of all, I would like to thank PNO consultancy for the oppurtunity to be a part of a Horizon2020 project. The experience i have gained these last months are priceless and will always be much appreciated. I have learned a lot about solid waste and solid waste management in Europe, allowing me to participate in different casestudies has given me valuable insight in a sector I was completely unfamilair with.

My special appreciation goes to my supervisors consultant Ir. Twan van Leeuwen and Senior consultant Dr. Tjerk wardenaar for their continuous support and sharing knowledge that kept me on the right track during these few months. Our weekly meetings, brainstorm sessions, constructive feedback and advice has helped me a lot in developing the conceptual understanding and organization of the study. Also my gratitude goes to Max Siebelist, my fellow intern in the project and the rest of the colleagues in team Energy & Environment for the wonderful days.

Finally, I would like to extend my heartfelt thanks to Dr. Jan-Henk Wellink for taking the time to review my report, especially during such a significant period as Professor Rem's retirement. Your insights and feedback have been invaluable, and I deeply value your dedication and support.

Thank you once again for your guidance and for making a positive impact on my academic journey.

Abstract

This study investigates the economic performance of waste electrical and electronic equipment (WEEE) collection schemes in Europe, focusing on two case studies: Cyclad, France, and Helsinki, Finland. Guided by the European Union's WEEE Directive, the research employs cost-benefit analysis (CBA), sensitivity analysis, and stakeholder interviews to evaluate collection systems under varying socio-economic and geographic conditions. Key metrics such as collection rates, investment costs, operational expenses, and producer responsibility organization (PRO) fees were analyzed across standard, best-case, and worst-case scenarios.

The results highlight the influence of regional variables, including population density and geographic area, on the financial and operational performance of WEEE collection systems. Cyclad, operating in a rural setting with a dispersed population, faced higher logistical costs and required additional investments in theft prevention and public awareness. In contrast, Helsinki benefited from its urban density and centralized infrastructure, which facilitated cost reductions and increased collection efficiency. While Cyclad's financial performance showed greater sensitivity to fluctuations in PRO fees, Helsinki demonstrated resilience across scenarios due to its mature system.

This study emphasizes the importance of tailored financing models, public engagement strategies, and technological innovations to optimize WEEE collection systems. These findings offer valuable insights for policymakers and stakeholders aiming to enhance the sustainability and cost-effectiveness of WEEE collection practices across diverse European regions.

Contents

1. Introduction

1.1. COLLECTORS

For the purpose of gaining better insight into the overall performance of systems and to support decision-makers in shifting to better performing systems. The main goal of the COLLECTORS project is to harmonize and disclose available information on different take-back waste collection systems in Europe. The project focuses on the following three waste streams:

- Paper and Packaging waste (P&PW)
- Waste electrical and electronic equipment (WEEE)
- Construction and demolition waste (CDW)

To reach this goal, the project is split up into three phases along the duration of 30 months (Figure 1).

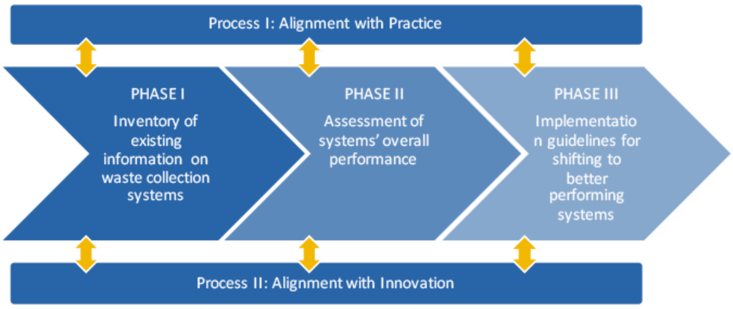


Figure 1: an overview of the three main phases of the COLLECTORS project

An overview of the project phases is given in figure 1. Last year, the first phase of the project launched with the focus on implementing an inventory that maps waste collection practices on a web-based platform capturing 250 examples of take-back collection systems throughout Europe. Currently, the assessment of the overall performance of 12 case studies in different geographical areas are measured using life cycle assessments and cost-benefit analyses. In 2020, the results of the assessments in the final phase will focus on providing implementing guidelines for the three waste streams based on type of location. In parallel, the phases are verified to ensure practical implementation with the reliance of focus groups and capacity-building along the alignment with other projects. Local and regional authorities play a key role to ensure the consistency of the projects' activities with the practical consent and to disseminate its outcomes. Regional working groups provide regular feedback, validate key steps of the technical work and test the proposed methods. Together with nine partners a consortium has been designed in such a way that it covers all EU states via local offices and member organizations along the full innovation chain. See figure 2.

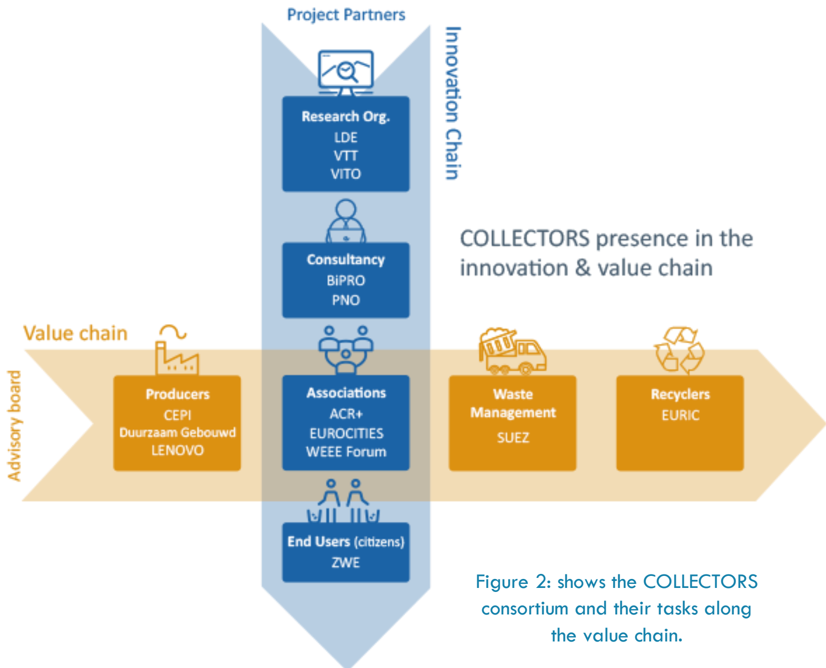


Figure 2: shows the COLLECTORS consortium and their tasks along the value chain.

The project is coordinated by PNO consultants and together with three universities and research institutions; Leiden, VITO and VTT as well as the presence of four networks; ACR+, Eurocities, WEEE forum and Zero Waste Europe in the partnership allows the direct connection to more than 2000 local and regional governments spread across the EU (COLLECTORS, 2019).

1.2. Goal and scope of the study

The main objective of the study is to analyze existing examples of well-functioning collection systems that will serve as benchmarks for other, similar regions in achieving or improving collection rates set by the EU. The EUs collection rate is purely based on the mass of EEE put on the market and collected WEEE:

$$\text{Collection rate} = \frac{WEEE\ collected\ (Mt)}{EEE\ Put\ On\ Market\ (POM)}$$

However, a higher collection rate does not necessarily result in a better sustainable materials management (i.e. higher degree of material cycle closure, improved recovery of relevant materials and/or avoidance of environmental burdens) (Nelen, 2014). This will be further outlined and explained in the coming chapters of this report.

Due to its heterogeneity, not only differing in functionality, but also because of different product sizes, weights and material compositions. WEEE covers a wide spectrum of products containing up to 60 different elements (Schluep et al., 2009). Because of their Increasing potential for recovery of valuable materials and their rapid increase in numbers, this report focusses on the following three categories of household WEEE: Small equipment, small IT and lamps. As all WEEE-categories face their specific challenges, these categories were chosen because of their small size and various material composition with many recoverable materials. Including, other materials embedded in some of the products have high potential for toxicity and other environmental impacts if improperly disposed (Sepúlveda et al., 2010).

As a crucial player in financing proper WEEE collection and treatment, the PRO has been chosen as the focus of the performance assessment of collection take-back schemes of two case studies; Cyclad, France and Helsinki, Finland. To be able to assess the performance of such collection system in both regions, a cost-benefit analysis (CBA) will be performed from the PRO point of view. The point of view is chosen to

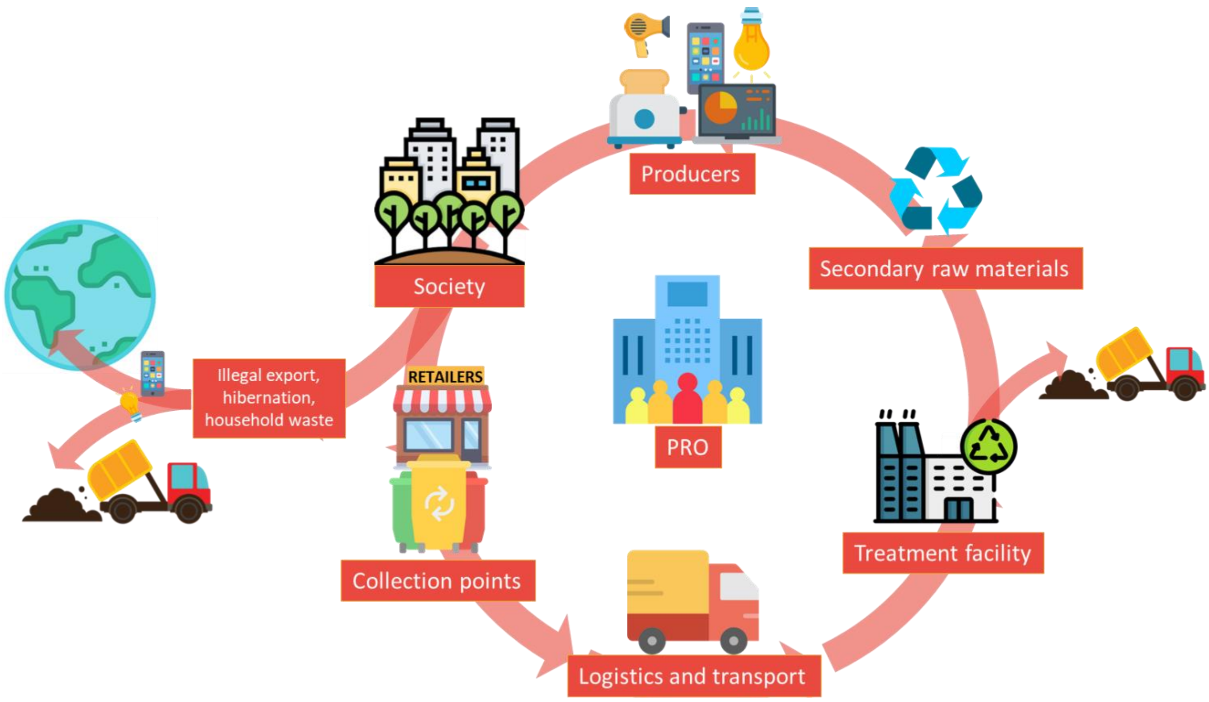


Figure 3: gives an overview of the process flow of a product put on market until its end-of life processing emphasizing on closed loop and open loop recycling.

include the cost and benefits of the executing party responsible for fulfilling the collection target rate.

Since there are obligations and fines towards the European Union, countries have an active interest in the fulfillment of the target and therefore producers have the obligation to register at such organizations to at least manage their collection when reaching end-of-life. An general overview is presented in figure 3, starting at the top where electrical appliances are put on the market by producers or retailers, after that the appliances 'go through' society, and when at end-of-life they are collected in collection points, transported to treatment facilities and can come back as a secondary raw material in the production of new appliances (closed loop). Central in this process is the Producer Responsibility Organization (PRO), the coordinating entity. However, two additional flows are added where materials 'leave the circle' (open loop), either via illegal export or through residual waste routes, or as unrecyclable material to landfills or incineration.

1.3. Research questions

To be able to investigate and analyze the present flow of WEEE on collection performance in a specific region, the following main research question has been derived as follows:

"How can the economic performance of a collection scheme in a region be assessed given specific socio-economic conditions?"

To answer this question, the problem will be divided into smaller pieces as it covers a rather long procedure of retrieving, collecting and analyzing data leading to the following sub questions:

1) Who are the main stakeholders involved?
2) What will be the investment and operating costs of WEEE collection in such a region?
3) What impact does the PRO fee have on the collection of WEEE?
4) What are the factors that will raise or bring down costs for the collection of WEEE?

1.4. Research approach and methodologies applied

This chapter describes the approach and methodology used in the study. First, an extensive literature review on different take-back collection schemes in Europe was used as a tool to give a general overview of the state-of-the-art collection systems currently applied in different geographical

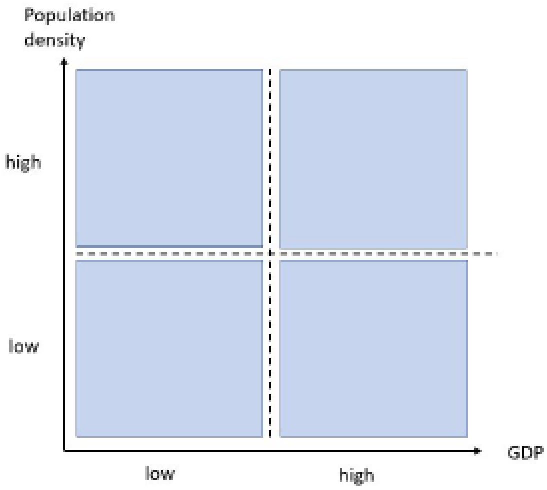


Figure 4: shows the criteria chosen in the assessment cluster during the selection of the case studies.

environments. This has helped in understanding the arrangement of collection channels and logistics including the identification of different stakeholders involved. Also, it is important to gain a full understanding of the whole life cycle of EEE, by understanding the overall process, the possible cost producers would have to pay can be taken into account.

Second, two case studies of the five were selected for the analysis of this study. Prior to analyzing a certain waste collection system, partners of PNO Consultants were in charge of predetermining multiple options from around Europe. Multiple criteria were taken into account in order to provide examples on a variety of circumstances. The cases were chosen to cover all parts of the cluster shown in figure 4.

The collection of accurate and detailed data is key to this research paper, however, has also its complications. Data on investments or changes in waste collection systems are generally not clustered in open sources. Consequently, PNO consultants is required to work together with a big cluster of regional and international partners.

A standardized approach was established for data collection, overall assumptions and evaluations. In this way, results of the CBAs are to a large extent comparable. It should be noted, however, that because of the specific characteristics of the waste collection systems (different context, different locations, data uncertainty, etc.) it is important to be prudent with drawing conclusions on comparisons between these CBA-results. The procedure of retrieving data is explained below.

Data collection

The data for the CBAs is preliminary collected using questionnaires and interviews. As the CBA results are highly sensitive to underlying assumptions and data, any missing data or assumptions made in the analysis is approached as follows:

(1) Data from local databases or reports;
(2) Data from interviews with local stakeholders;
(3) Data from national databases or averaged national benchmark reports;
(4) Data from European databases or averaged European benchmark reports (e.g. Eurostat);
(5) Data from peer-reviewed article or institutional reports/databases;
(6) Data from market prices – based on at least 3 quotations;

In all cases, the relevant municipalities and/or their waste management companies, and waste experts are consulted to validate (and adjust) the selected data and assumptions.

All estimations are based on a relevant reference period (varying per case due to data availability) and calculated with a 4% financial discount rate.

Sensitivity analysis

The financial feasibility of the project depends on a number of variables and assumptions. Sensitivity testing focuses on the impact of the assumptions made in the CBA that effects the FNPV of a project. By variation of these assumptions, the robustness of the project results can be evaluated. The following parameters are tested:

- EPR fee
- Collection and transport costs
- Treatment and recycling costs

For each parameter various scenarios have been drafted, and the effect of changing the parameter or assumption on the overall result has been analyzed.

Evaluations

Evaluation of the CBA-results was performed on the following indicators:

- *FNPV:* refers to the financial net present value that is established by the difference between the present value of cash inflows and the present value of cash outflows over the reference period. In this way, the FNPV provides insight into the economic justification of a project and on the possible return on investment (in case that cash inflows exceed cash outflows).
- *Cost effectiveness:* refers to overall investment costs (i.e. all investments) divided by the project effect (i.e. the additional WEEE collected). This enables the comparisons of alternative waste collection systems with a common effect, but which differ in approach and size.

2. Background

2.1. WEEE directive

This study, as part of the European collectors project (COLLECTiOn systems assessed and good pRacticeS identified) seeks to close knowledge gaps by gathering data on well-functioning waste collection systems which can serve as benchmarks for other similar regions in achieving or improving collection rates set by the European Union (EU) (COLLECTORS, 2019). Since the introduction of the first waste directive for electronic and electric waste (WEEE)-directive 2002/96/EC in 2003. The European Union, legislation demanded a separate waste management system regarding the waste stream of EEE (Directive E. U., 2002). Electrical appliances contain valuable materials ranging from plastics to metals and rare earth elements. Due to the dependency of Europe on imports of materials, a high collection and recycling rate of electrical appliances has been given an increased focus.

The directive imposed the producer responsibility principle, which states that producers (importer, retailers, manufacturers, exporters) of electric appliances are financially responsible for at least the collection of disposed equipment to the recycling points.

Producers were obligated to introduce a system where consumers were able to return their appliances free of charge to the shop or join a specialized collection organization also known as "Producer Responsibility Organizations" (PROs). Manufacturers were encouraged to design their products sustainably, meaning introducing appliances that could easier be dismantled and/or repaired/recycled.

Following the introduced principles, the revised directive 2012/19/EU brought forth in 2019 changed the definitions of WEEE from the original 10 into 6 categories in which collected quantities are to be reported according to their treatment method and size. Whereas before, appliances were grouped together based on their function (Directive E. C., 2012).

1. Temperature exchange equipment
2. Screens and Monitors
3. Lamps
4. Large equipment
5. Small equipment
6. Small IT and telecommunications equipment

Organizations were given a transition period from 13 August 2013 to 14 August 2018 to apply the changes to their administration. Article 7 introduced collection rates of 45% by 2016. In 2019, member states are obliged to collect 65% of average EEE put on the market, over the preceding three years, or 85% of actual EEE put on market.

2.2. WEEE and its characteristics

Electrical and electronic equipment (EEE) has become absolutely essential to all parts in daily life of people with the ever-advancing growth of technology in today's culture. It is estimated that the global marketplace presently sells more than 660 kinds of electronic devices (Huisman et al., 2012). These products have a range of characteristics, including cost, feature, size, interior design, components and material composition. As a waste stream, WEEE poses a very complicated challenge, due to the variety of materials and the number of different appliances the category contains (i.e. the difference between a mobile phone and a fridge) (OECD, 2001; Puckett et al., 2002). Not only the amount of hazardous substances embedded in its products requires special treatment to avoid the potential for toxicity for health and safety measures, but also environmental and resource impacts should be managed as priorities through policymaking. According to several studies by Wang et al. on take-back and treatment of electronic waste, most categories have a financial deficit between collection and suitable treatment because of the streams' complexity and heterogeneity, the cost of collection and treatment differs considerably by product type. Today's recycling plants and processes are designed to collect the most valuable materials, such as steel, aluminium, copper and gold, into concentrates that are sellable to smelters or metallurgical refineries (Crowe et al, 2003). This approach becomes more challenging with time, because the amounts of valuable materials in WEEE are continuously decreasing and many materials can no longer be concentrated to a level that recycling is even nearly commercial (Deubzer O. et al, 2018).

3. E-waste takeback systems

3.1. Producer responsibility organizations

Establishing WEEE take-back systems is motivated mainly by appropriate legislation. Since the introduction of the producer responsibility principle also called extended producer responsibility (EPR) in Europe, producers are financially responsible for the end-of life of electrical and electronic equipment at source. This is considered to give producers a financial incentive to reduce waste, followed by product reuse and material recovery in order to avoid disposal to landfill (Communities, 2009) (Wilson, 2001). As a result, policymakers and producers have created specialized systems for collecting and processing WEEE also known as compliance schemes. Such schemes organize and coordinate the collection and treatment of WEEE on behalf of them. Famous examples of countries in Europe that apply EPR schemes are the United Kingdom, Austria, Netherlands, Belgium, France and Finland (European commision, 2014) (Stiglitz, 2016) (NVMP, 2013). However, it must be noted that some compliance schemes do not finance the entire chain of activities. An overview of the activities financed by producers in the before mentioned countries are presented in table 1.

Table 1: shows an overview of the financial responsibility of PRO's per country.

	Collection	Logistics	Sorting	Treatment
United Kingdom	No	Yes	No	Yes
Austria	Yes	Yes	Yes	Yes
Netherlands	Yes	Yes	Yes	Yes
Belgium	Yes	Yes	Yes	Yes
France	Yes	Yes	Yes	Yes
Finland	Yes	Yes	Yes	Yes

Producers pay the PRO's according to their payment plan. How the collection and treatment is financed varies per organization. In the case of Austria, the Netherlands, Belgium, France and Finland the total chain is financed by producers whereas in the UK the system operates differently, financing of collection is done through evidence notes issued by approved authorized treatment facilities or approved exporters at receipt of the WEEE. These evidence notes are obliged to be presented by the PRO's to prove that it reached its collection target every year.

3.2. Financial flows in the WEEE value chain: from and to the PRO

PRO Fee

The most common fee payed by producers is according to the amounts of appliances sold on the market, either paid by ton, per category or per appliance. This price is already incorporated in the purchasing price for consumers, called eco-participation. The PRO fee varies per country and has been decreasing over the last couple of years due to more and more competition between PRO's.

Contribution to collection points

As can be seen in **Error! Reference source not found.**, in some countries PROs are financed for the c ollection activities. This can be done through supplying collection containers, boxes or bags, either directly to the households or via local collection points. In addition, the PRO's pay collection points (e.g. civic amenity sites run by the municipal waste collector, or retailers) a certain amount per collected ton of WEEE. Depending on the manner of collection, this compensation can vary. Some PRO's work with flat fees, and some stimulate the collection of separate fractions by giving out higher compensations per ton when the WEEE is collected in more categories. Often communication and education campaigns are launched or financed by the PRO and are accounted for under contribution to collection points (as a local component) in this overview.

Logistic costs

Depending on the location and collected fraction, the WEEE will be transported either to a pre-treatment facility, transshipment location, or directly to a recycling plant. In most cases, the PRO finances the logistics, which can be a significant part of the overall operation costs.

Treatment costs

During treatment, the dismantling, pre-treatment, shredding and recovery takes place. Not all materials can be recovered or recycled, therefore landfilling or incineration is also included. These pre-treatment facilities often collect a fee for their services. A part of the treatment cost is covered by the output recycled and sold materials (i.e. metals, secondary raw materials, etc.). The treatment costs, and revenues vary largely per WEEE category. Recovery and recycling of small appliances produces a revenue of about 98 €/t, which is not enough to cover the entire costs. Lamps generally don't have complex structure which results in lower dismantling and sorting costs, but can contain toxic elements, making treatment very expensive while producing no revenue. See figure 5 below.

Costs or revenues from material recycling

Today's recycling plants and processes are designed to collect the most valuable materials, such as steel, aluminium, copper and gold, into concentrates that are sellable to smelters or metallurgical refineries (Crowe et al, 2003).

Compliance

In order to combat illegal export, scavenging and improper treatment, aspects such as monitoring, legal requirements in logistics, and depollution are becoming more and more important. These costs are included as compliance, and assumed to be covered by the PRO.

Costs on society for uncollected or wrongly collected WEEE

When electrical appliances are not collected via the proper routes and treated correctly, materials can get lost when they end up in residual waste. Usually they end up in landfills or incineration plants.

Also, the existence of informal or non-contract recyclers may cause resource losses and environmental damage due to uncontrolled e-waste treatment in global dumping sites such as major international destinations like China and India (Bridgen, 2005).

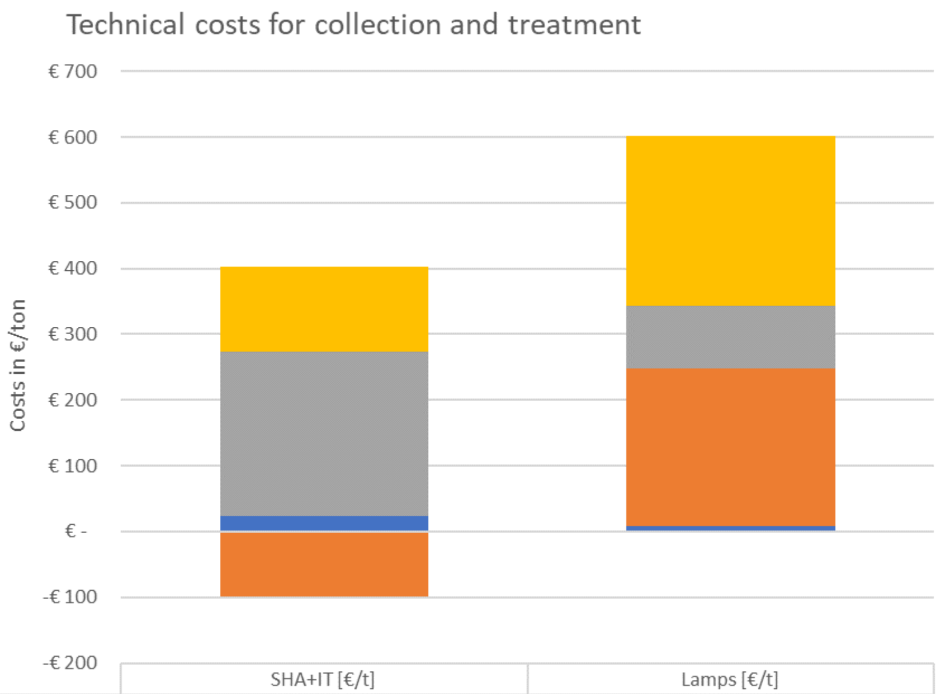
Often, most of the costs that arise in these processes are not directly paid for (by the polluter), and therefore hard to address.

For the five cases studied in the COLLECTORS project the WEEE composition in residual household waste is limited but can still add up to significant amounts for the three waste streams in scope. In Wales for example, the percentage of WEEE found in the residual waste can be up to 2.2% (BBC, 2016). This means significant amounts of appliances go straight to waste incinerators or landfill, after which materials are lost. In addition, this results in a direct financial cost for incineration or landfilling. The government of Wales estimates, that by compliant recycling, every year they save approximately € 110 per ton of WEEE by not having to send materials to landfills. (My Recycling Wales, 2018).

As mentioned above, the 'lost' value of scavenged and other unreported flows is significant.

Lastly, a final cost for society is in the environmental analysis. Proper collection and recycling can yield an environmental benefit of not having to mine, process and transport the materials again. However, this will not be the main focus of this study yet, the potential CO_2 savings would be relevant to include in the financial analysis, as CO_2 emissions are becoming more and more a pollutant that organizations, companies and governments need to pay for. However, as this is not yet fully incorporated in the waste collection and management processes, it is excluded from the analysis.

As WEEE collection has become very competition sensitive, little case specific financial data has been obtained. For most analysis, averages for the collection and treatment costs have been used. In the figure below, average operational costs per phase are presented (data from long running systems) (United Nations University, Review of directive 2002/96 on Waste Electrical and Electronic Equipment (WEEE), 2008). Collection costs for small appliances are quite low (129 €/t) but treatment costs are fairly high.



	SHA+IT [€/t]	Lamps [€/t]
Transport and collection	€ 129	€ 259
Shredding, sorting, dismantling and pretreatment	€ 249	€ 95
Recycling and recovery	-€ 98	€ 240
Incineration and landfill	€ 24	€ 8

Figure 5: Average EU technical costs for collection and treatment of WEEE (source: UNU, 2008).

From a more recent report in 2015, the minimum technical cost for WEEE recycling (treatment, depolution, disposal and compliance) were analysed. Based on an assessment of 13 EERA Members, encompassing 27 treatment locations in 13 countries in Europe for a total volume reported of 465.000 tons, recycling costs were estimated for four categories (SHA, LHA, screens and cooling appliances) (United Nations University, 2018). For small household appliances, these are estimated to be € 266/ton. In addition, this report endorses the importance of compliance, which is on average found to be around € 37 per ton, depending on the category.

As can be seen, the 2015 treatment costs are quite similar to the 2008 values. Based on these two reports, the following table with the average opeartional costs has been drafted. Where case-specific information is unavailable, these values are used. However, this has been rarely the case. The WEEE sector lins the overall lack of transparency to the high level of competition on the WEEE market, which makes it difficult to share economic information, even aggregated. As a result, for most cases, the average costs from the table below have been used.

Average operational costs	SHA+IT [€/ton]	Lamps [€/ton]
Transport and collection	129	259
Shredding, sorting, dismantling	203	95
Recycling, recovery	-98	240
Incineration and landfilling	50	50
Compliance	37	37

Table 2 – Average technical costs for collection and treatment for SHA, IT and Lamps.

For every case, a relevant period of 2– 8 years has been identified, preferably a period in which an investment has been made to boost WEEE collection. Within this period the investment costs, operational costs for collection, processing and recycling as well as the benefits of the system are identified and graphed. The assessment will focus on the investments done by the PRO, municipality or collection entity in order to improve the amounts of officially registered WEEE in the local collection sites. The operational costs and the revenues from the PRO are mapped. All these financial flows are processed in a Cost Benefit Analysis, which ultimately aims to highlight the cost effectiveness of increasing the WEEE collection, the options of different stakeholders to invest in a better-performing collection system and the financial flows of the WEEE collection system.

3.3. Best practices of waste collection systems: Case studies

Cyclad, France

Figure 4: Territory of Cyclad in Charante-Maritime (CYCLAD, 2014).

Cyclad is a syndicate that offers public service in the collection, treatment and recovery of household waste produced on its territory; the north-eastern part of Charante-Maritime with an area of 3,264.3 Km^2 (INSEE, 2015) located on the southwestern coast of France. Its territory is a reflection of the political will of the rural sector to come together to ensure consistent management of household waste. Consequently, in December 2014, the candidacy of Cyclad and its 34 partners was chosen in the context of the Zero Waste territory with a main goal of achieving a collection rate set by the European directive 2012/19/EU of 65% for WEEE by 2020.

In 2017, five participating municipalities of 147430 inhabitants were responsible for the disposal and pre-sorting of WEEE since its launch in 2014. The EPR compliance organizations responsible for the collection, depollution and sorting of household WEEE and lamps are Eco-systemes and Recylum respectively. Since January 2018, both companies merged by the name, ESR, with the interest of developing a more circular economy and promoting eco-design initiatives of member producers (ESR, 2019).

Collection system

The collection consists of recovering WEEE from consumer-dwellers, sorting them into 3 separate streams and making them available to its service providers at collection points, these consist of waste disposal centers, shops and Emmaus centers. This work is carried out by the partners/stakeholders of the territory (communities, distributors, social and solidarity economy shops). Twenty-five civic amnesty sites spread over the territory are provided per zip codal area. In addition to that, Cyclad cooperates with a number of retailers. There are different requirements and regulations regarding the disposal of different types of items of WEEE. Since producers are required to organize and finance the take-back, treatment, and recycling of WEEE, any purchasing electronic equipment from small items such as hairdryers to larger household appliances such as washing machines, are now obliged by retailers to take back if no longer wanted. This is to prevent items from being taken to landfill sites. The shop is then responsible for the disposal of the item, but locals can arrange for disposal themselves if they prefer, there you will need to take proof that you live in the area; a utility bill, ID and the registration documents for your car. Also, supermarkets provide drop off points for lamps and mobile phones. In total, there are 11 social economy shops and 1 Emmaüs centre on Cyclad's territory, where people can drop off WEEE and buy second hand upcycled/recycled WEEE objects (CYCLAD, 2017).

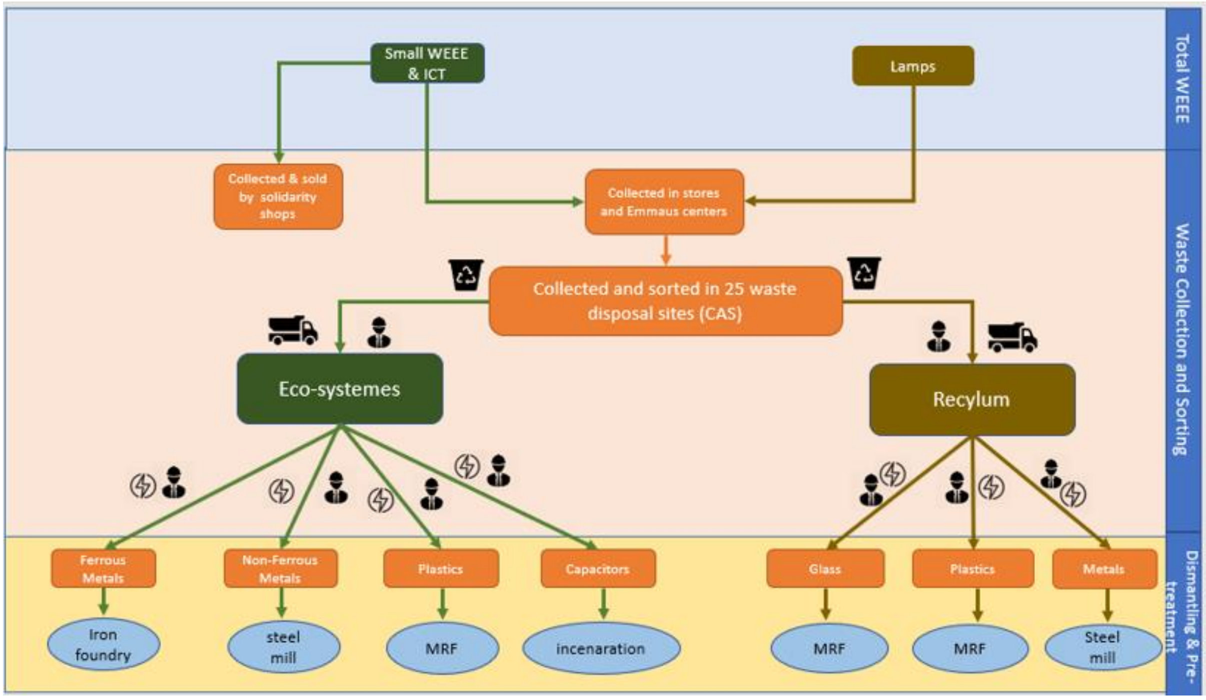


Figure 6: overview of Cyclad's collection system.

The biggest problem related to WEEE collection Cyclad has been facing was theft of valuable WEEE components. In order to protect metals, WEEE and batteries Cyclad bought containers (20ft) with special locks. In addition, Cyclad invested in video surveillance at all sites. Marking appliances with bright orange paint to make WEE collected easier to recognize has been another effective measure. Furthermore, they have a special contract with the police, who regularly checks the collection sites. The national ban in 2011 on cash transaction for metals, to avoid WEEE leakage at borders and to include scrap dealers in the system and avoid WEEE non-compliant treatment.

Additional measures include awareness raising campaigns to mobilize small WEEE that people keep at home in their drawers. For a long time, there was a hoax in France that all collected WEEE was going straight to India, which discouraged people to bring their WEEE to the correct collection points.

Several campaigns have been launched to inform the general public on the correct WEEE treatment routes in France. All the measures together have resulted in a constant increase of collected small WEEE quantities as shown in the figure below.

Thanks to these measures the stealing decreased significantly and the WEEE flow is better under control. In 2017, Eco-systèmes collected 533.640 t of WEEE amounting to 50 % of the global amount, i.e. 10.2 kg/capita. Out of this number 6.6 kg/ capita (65 %) are collected at CAS, 1.7 kg/capita (17 %) at supermarkets and retail stores and 0.3 kg/capita (3%) at social reuse centers, and 1.5 kg/capita (15 %) via other channels. In the Cyclad region, a total of 1.568 t of WEEE has been collected in 2017 (equivalent to 260.104 domestic appliances) in 4 categories, small WEEE & IT (546.8 t), screens (218.4 t), cooling devices (258.3 t) and large WEEE (544.9 t). Also, since 2014, a lot of effort has been made by ESR to raise awareness in the collection of lamps to avoid it ending up in residual waste which can be very dangerous for both the environment and human health. An increase of 38.5% has been reported from 2015 until 2017 reaching a collection amount of 5.4 t in 2018 (DEEE, 2017) (Partida, 2019) (Vitre, 2019).

Figure 7: storage containers against theft (R) and Marking of WEEE (L).

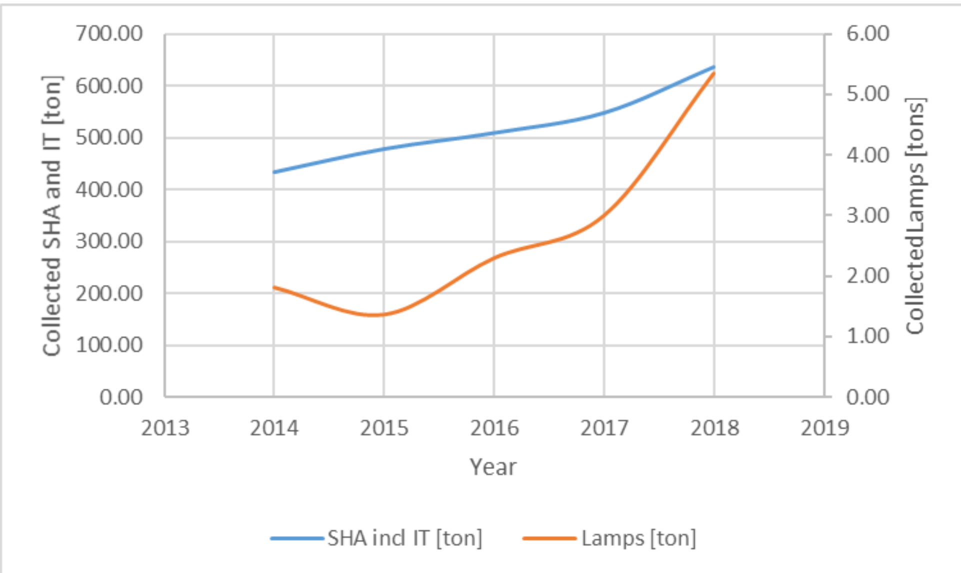


Figure 8 – WEEE collection in Cyclad, France over the years.

Helsinki, Finland

The capital and most populous city in Finland include the cities of Helsinki, Espoo, Vantaa and Kauniainen. Located on the shore of the Gulf of Finland and has a population of 1.2 million inhabitants within an area of 1157 km^2. To reduce waste, Finland has been applying the producer responsibility principle since the mid-90s. Because of its long tradition in metals recycling; Metal-rich WEEEs have been recycled long before the implementation of the waste act in Finland, a great example is the kuusakoski recycling company which looks back on 100 years of history. Yet, to fulfil the requirements of the WEEE directive 2012/19/EU, a recovery network needed to be built in Finland after 2003 and as a consequence the launch of separate collection of WEEE began in 2004. From this point on, the overall WEEE collection rate in Finland has exceeded 9 kg/capita/year. The main feature of the Finnish collection system is the separation of WEEE based on brand and not on type or source. These are financed by producer associations, provided by the municipality and in some cases by private companies or social enterprises. (HSY, Jätehuollon vuositilasto 2017) (HSY, Vuosikertomus 2016) (HSY, Pääkaupunkiseudun seka- ja biojätteen koostumus, 2016).

Figure 9: Map of the greater Helsinki area in Finland showing the cities of Helsinki, Espoo, Vantaa and Kaunianen in the capital region. (dark orange) (Wikipedia, 2019)

Collection system

In Finland, the collection of WEEE is arranged mainly as a permanent collection; in 2011, approximately 450 collection points existed around the country. Private users and households can bring their end-of-life products to the collection points free of charge. However, permanent collection systems are not always efficient, due to e.g. long distances and low quantities of returned devices. Therefore, WEEE collection in Finland is also organized as a mobile collection in the 50 smallest or least populous

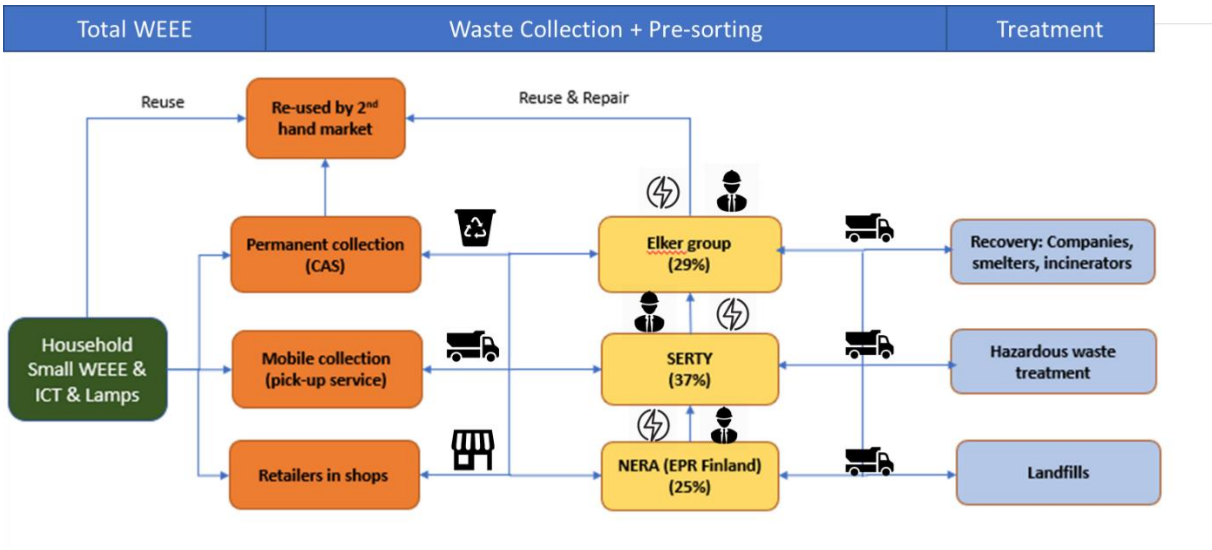


Figure 10: gives an overview of the collection system structure in Helsinki, Finland.

municipalities. In Helsinki region, mobile collection of small WEEE is organized twice a year, in addition to the permanent bring points and civic amenity sites (CAS). While one round is organized by the regional waste management company HSY, the other one is organized by the regional recycling centre (Kierrätyskeskus). The recycling centre collects only functional devices (169 tons/year) (Ylä-Mella et al., 2014). In addition, the amounts of WEEE received in retail stores have also increased. The transportation of WEEE from reception points and registered stores to the regional treatment plants is managed by the producer associations. The logistics services are typically sourced from private regional operators. At the collection points, the WEEE is divided into four different fractions with lamps and batteries being collected separately: Cooling appliances, large domestic appliances, small domestic appliances and IT appliances. All kind of lamps are collected separately of other SDA by FLIP association, a producer organization responsible for the producer responsibility of lamps falling within the scope of the WEEE directive. Together with FLIP and four other producer associations; ERP Finland, SERTY, ICT and SELT have provided centralized services to manage practical affairs related to the obligations set out in the WEEE Directive and to fulfil the corresponding obligations of Finnish legislation. An overview on how WEEE is collected and further treated is given in figure 9.

After collection, WEEE is transported to regional sorting plants, where WEEE is separated based on brands, not on product categories or source, for different product cooperatives, weighed, and sorted into reusable and not reusable fractions. Functional devices are manually separated and directed for preparation for re-use. The rest of the WEEE is sorted out according to WEEE categories and is pre-treated before sending to the various treatment plants for final treatment. The companies offering sorting and dismantling services to producers' associations are typically social economy enterprises, but a few private companies also exist in the field. Some of the dismantling and pre-treatment plants provide also final treatment services for particular WEEE fractions; however, most of the sorted and pre-treated WEEE is forwarded to detached recovery and/or final treatment plants located mainly in Finland. While all WEEE of a certain producer is treated at the same pre-treatment stations, they are all sent to the same final recycling plant. Another reason for the increased collection quantities is the improved reporting and reporting accuracy thanks to new treatment operators.

In the Helsinki urban area where HSY operates, the collection of SHA, IT and lamps has been steadily increasing, as can be seen in the figure below.

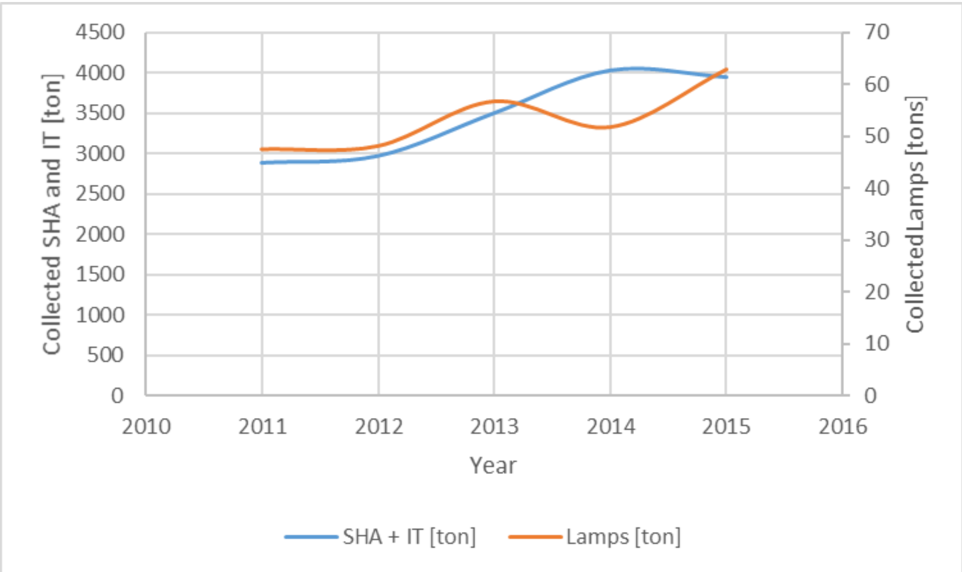


Figure 11– WEEE collection in the Helsinki region, Finland.

4. Cost- benefit analysis

A cost-benefit analysis (CBA) strives to estimate positive and negative effects of a project or policy on the welfare of the region or country in which it is located. The assessment in COLLECTORS takes the perspective of the project owner, which for WEEE collection in most cases is the local or national Producer Responsibility Organization. The CBAs for the COLLECTORS project have been conducted in accordance with the EC CBA guidelines (Guide to Cost-Benefit Analysis of Investment Projects, European Commission, December 2014).

A CBA generally consists of the following steps:

1. The reference case
2. Problem analysis
3. Estimation of costs and benefits
4. Monetization
5. Discounting future effects
6. Sensitivity analysis

In the problem analysis, the rationale behind the project is explained. The context and underlying problem of the situation are described and the project that will solve the problem is introduced. Alternative solutions to the problem are also mentioned.

The project definition describes what the project entails and which assumptions are made. The reference case represents the future situation without implementation of the project, which is used as a base case for the comparison.

The main costs that need to be taken into account for the COLLECTORS project are investment costs (including e.g. machinery, trucks, containers, etc.) and operational expenses (collection, transport, processing and compliance costs). The benefits may include direct revenues (from recycled recovered materials, fees from the waste industry or producers and citizen taxes) and avoided costs (tax on incineration or landfilling costs). In addition, the European Commission's decision to introduce penalties and laws on country level has led to a variety of funding initiatives from the side of governments. Where available, those support measurements for the WEEE management system have been taken into account. Indirect benefits may also occur (effects on other markets such as the labor market and utilization of valuable secondary materials). External effects are the unintended impacts of the project on third parties, such as avoided CO_2 emissions due to reuse or recycling of materials. These environmental impacts are excluded from the CBA and are further analyzed in the COLLECTORS Life Cycle Assessment (LCA), see Deliverable 3.1 and 3.3.

In order to make current and future costs and benefits comparable, future effects are discounted to obtain their present value (PV). The present value is generally lower than the future value because the money has interest earning potential, often referred to as the time value of money. For this CBA, a discount rate of 4% and a time horizon of 10 years are used, as suggested by the EC CBA guidelines. The following equation is used for discounting to obtain present values of costs and benefits:

$$PV(B) = \sum_{t=0}^{n} \frac{B_t}{(1+s)^t} \qquad PV(C) = \sum_{t=0}^{n} \frac{C_t}{(1+s)^t}$$

The net result of the CBA is the Net Present Value (NPV), computed by the following equation:

$$NPV = PV(B) - PV(C)$$

In this equation, n indicates the project lifetime in years, B the benefits in year t, C the costs in year t and s indicates the discount rate.

Lastly a sensitivity analysis is used to assess the robustness of the assumptions. By varying the assumptions on which the calculations are based against the FNPV value, the effects of uncertainties on the CBA results are evaluated. The following parameters are tested:

i) ***the PRO fee***; ii) ***the collection costs*** and iii) ***the recycling costs.***

The PRO fee

The exact PRO fee charged is not publicly available. It is also not known whether PRO charges its members per category, however, it does charge per product/device. It is therefore assumed that the PRO receives the national average PRO fee for SHA and the European average PRO fee for lamps. For 2013 – 2016 average EEE fees are known. Due to the uncertainties, the following scenarios were assumed;

1. The PRO fees stabilize for future years;
2. The PRO fees are 10% lower than the average fees and decreases with a yearly 10% for future years;
3. The PRO fees are 10% higher than the average fees and increases with a yearly 10% for future years;

Collection costs

The collection costs are largely based upon values of 2008, which might be outdated and have decreased due to efficiency gains. Therefore, a scenario is foreseen where the collection costs decrease by 50%.

Recycling costs

The recycling costs consist are largely based upon 2008 and 2016 values, which again might be outdated and have decreased due to efficiency gains. The recycling costs consist of the cost for shredding, sorting, dismantling; recycling and recovery. It is quite possible that either one of these processes has become more efficient or cost effective in the last years, which would mean a decrease in cost. Similar to the collection costs, a scenario is foreseen where the recycling costs decreases by 50%.

This results in three possible scenarios, displayed in the table below. The first scenario is marked as the standard scenario, as this is based upon the currently available information. The second scenario is marked as the worst-case scenario, where the PRO fee further decreases due to competition between PRO's. The collection costs and recycling costs stay at standard values. Lastly, scenario three is marked as the best-case scenario, as in this scenario the PRO fees increase, and both the collection and recycling costs decrease.

Scenario	PRO fee	Collection costs	Recycling costs
1	Stabilized	Standard	Standard
2	Decreasing	Standard	Standard
3	Increasing	Decreased 50%	Decreased 50%

Table 3: shows the three scenarios tested on the PRO fee, Collection costs and Recycling costs.

4.1. Reference case

In order to judge the financial impact and cost-effectiveness of investments since the beginning of the reference period it is necessary to compare the current and prospected future status of a system to a reference case.

This reference case is defined as the collection system in the first year of the reference period. Along with its indicators such as collection rates, consumer awareness, infrastructure, landfilling and recycling rate it serves as the point of reference. From that point on we observe the changes that investments have caused in the following years.

For comparability purposes, it is assumed that the process of material recovery is equal to the one in 2019, when this report was written.

4.2. Problem analysis

Currently, collection rates in the EU range from below 20% in Malta to over 90% in Croatia in 2016 (Eurostat, 2019), however, the good practice elements are often very local successes. The figure below shows the collection data from 2016, and the 2019 target of 65%.

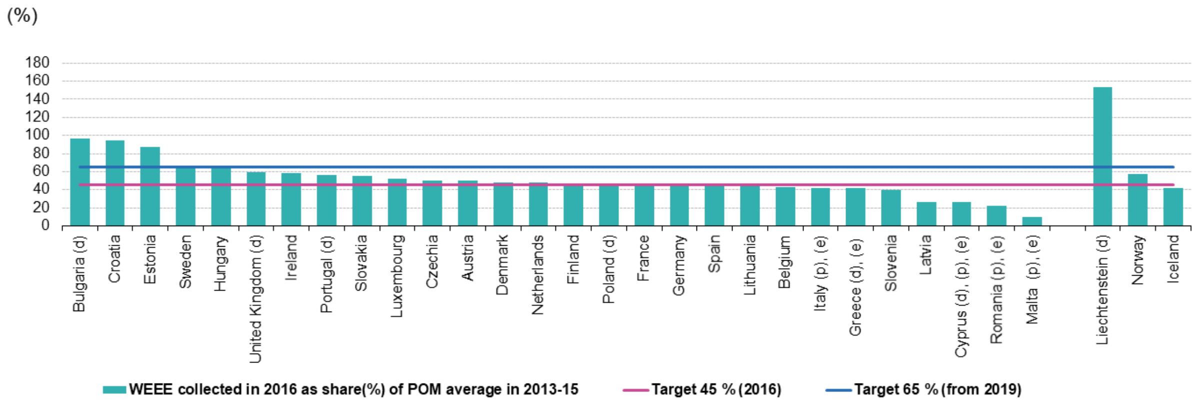


Figure 12: Collection rate for WEEE in 2016 with respect to the average amount of EEE POM from 2013 to 2015 in (%). Source: (Eurostat, 2019).

Different countries have had very disparate successes in implementing a functioning collection system. The Collectors project seeks to gather information from different regions with above average rates and analyse them in order to serve as a reference case. The five case studies all face various (local) challenges and have come up with solutions to increase their WEEE collection. The most vital and shared challenges are;

Hoarding: Hoarding refers to the long-term storage of equipment. This challenge is especially the case for old small appliances that can have emotional value to the owner. Rising awareness for sensitive data on mobile phones, hard drives or cameras can decrease the threshold to bring appliances to the collection points.

Improper disposal: A certain amount of WEEE, still ends up in residual waste due to lack of knowledge or other factors like not having a nearby collection point for the disposal of household WEEE. This is of concern as improper disposal of electronic devices leads to landfills or incineration.

Illegal waste streams: Especially equipment which is financially interesting for scrap- and parts-dealers have a high risk of ending up illegally recycled. Such include large household appliances containing a lot of metal, motors and cables. Small IT is becoming increasingly interesting due to PCB boards that can be sold separately for their precious metals. It is estimated that in 2016 a total of € 120 million euros of small household and IT appliances is lost due to scavenging (circa € 1.480 per ton) (United Nations University, 2018). Illegal export to avoid high disposal and de-pollution costs of, for example displays, can also be a driver.

As can be seen in the breakdown overview below from the ProSUM project, for almost all EU countries there is a significant gap in the documented WEEE streams, ranging over 50% for some countries.

For small equipment

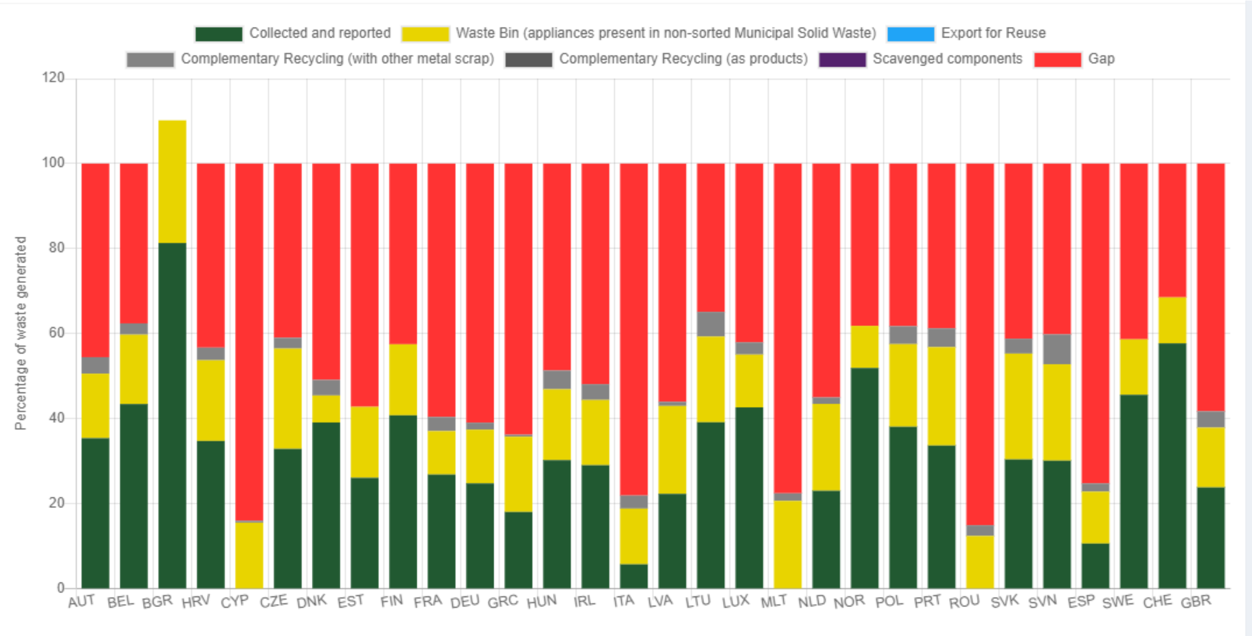


Figure 13: shows the percentage of collected EEE from waste generated in 2015 for small household equipment. Source: (Huisman J., 2017).

For small IT

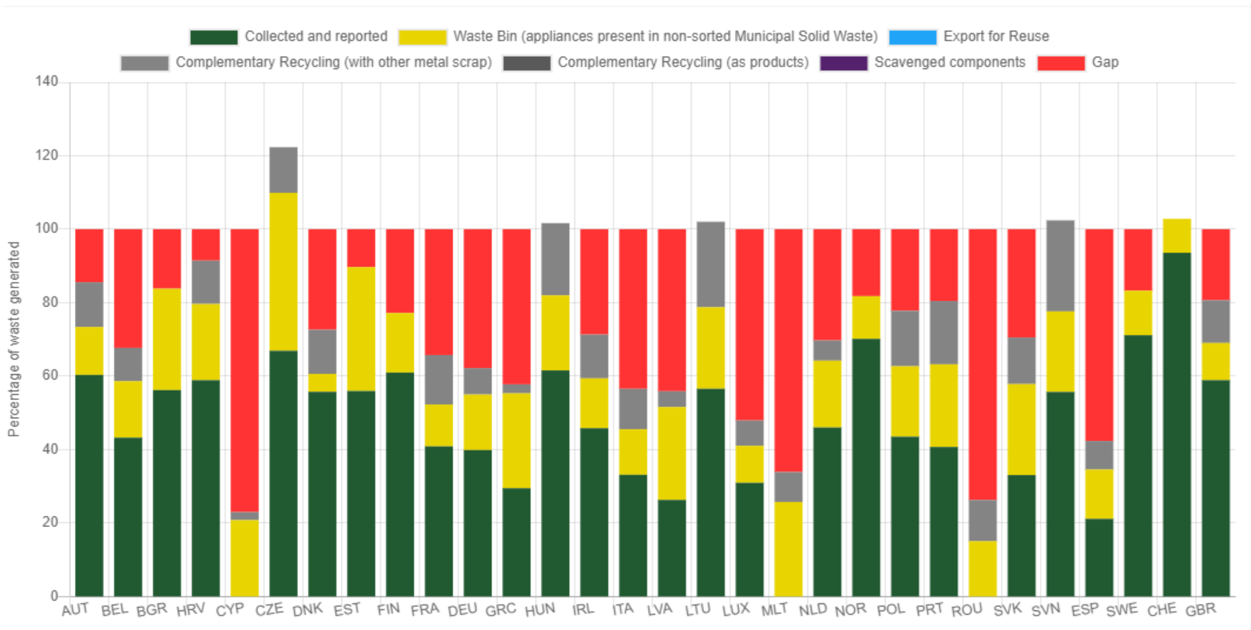


Figure 14: shows the percentage of collected EEE from waste generated in 2015 for small IT equipment. Source: (Huisman J., 2017).

For lamps

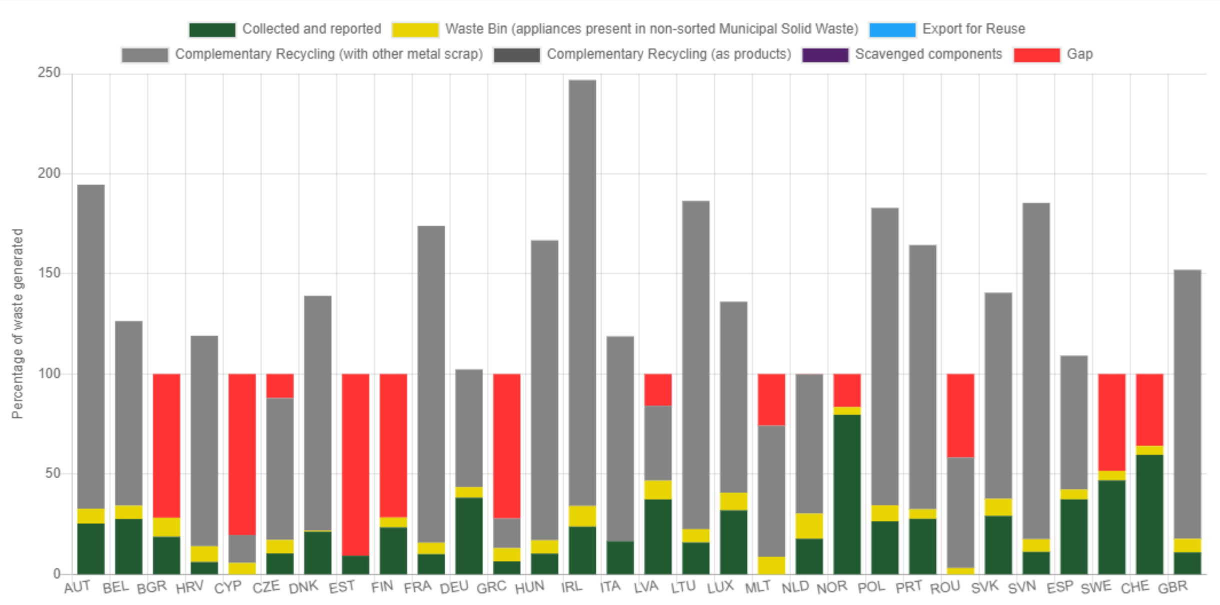


Figure 15: shows the percentage of collected EEE from waste generated in 2015 for lamps. Source: (Huisman J., 2017).

4.3. Identification of Costs and Benefits for Cyclad, France

4.3.1. Investment costs

Item	Assumption/data source	Unit cost
Containers for WEEE storage	In 2014, Cyclad invested in 20ft containers to prevent theft of valuable WEEE appliances. One container cost approximately € 2.500. Cyclad has 25 disposal sites for WEEE[1], and 2-4 containers per site[2].	€ 64.748
	Assumed allocated costs for awareness for these waste streams are calculated based on a mass percentage (SHA, IT, and lamps compared to the total WEEE stream = ~ 35%).	
Video surveillance and protection[3]	In 2014, Cyclad invested in video surveillance for protection of the WEEE. The costs for video protection are € 5.000 per disposal site[1]. Cyclad has 25 disposal sites for WEEE[4].	€ 43.166
	Assumed allocated costs for awareness for these waste streams are calculated based on a mass percentage (SHA, IT, and lamps compared to the total WEEE stream = ~ 35%).	

Table 4: shows the gathered information on investment costs through skype interviews and local reports from Cyclad.

4.3.2. Operational costs

Eco-Systemès supports logistics costs and treatment of WEEE from collection points. Logistics operations include the collection (massified or not), but also the consolidation and provision of pallets crates and

[1] Information on WEEE disposal in Cyclad in 2018, retrieved on March, 2019 from http://www.cyclad.org/page.php?P=55
[2] Telephonic interview Cyclad in March 2019.
[3] Eco-systemes, www.eco-systemes.fr/soutiens-protection
[4] The evolution of the Italian EPR system for the management of household Waste Electrical and Electronic Equipment (WEEE). Technical and economic performance in the spotlight: http://www.weeenmodels.eu/upload/030716100520.pdf

bins. Side recycling, pollution control and sorting of materials are the most important treatment processes.

Item	Assumption & data source	Unit cost
Communication and awareness campaigns	ESR supports collection points by providing financial support for awareness and communication campaigns. The costs are specified per regional area type (rural, semi-urban, urban) and per number of inhabitants. Collection points can request financial support up to: - Posters € 800 - Sorting guides € 1.000 - Signs € 1.800 - Communication events € 5.000 This totals to € 8.600 per year per collection point. It is assumed Cyclad requests 50% of the financial support every year.	1.485 €/ year
	Assumed allocated costs for awareness for these waste streams are calculated based on a mass percentage (SHA, IT, and lamps compared to the total WEEE stream = ~ 35%).	
Collection and transport costs SHA	Collection points, such as Cyclad, receive a contribution for their WEEE collection. For Cyclad, the financial contribution for the collection activities are known for the period of 2010-2017[1]. The contribution fluctuates between € 44 – 88 per ton of collected WEEE, depending on the quality. On average, the contribution for collection is € 69.13/ton.	€ 189.13 /ton
	No information is available for transport costs from ESR. The logistical costs for the transport of SHA are estimated to be € 120/ton[5].	
	Detailed WEEE collection data for Cyclad is known for SHA between 2014 – 2018[6,7]. The numbers are reported in four categories; LHA (GEM HF), Cooling appliances (GEM F), Screens (Ecrans) and SHA and IT (PAM).	
Collection and transport costs Lamps	Collection points, such as Cyclad, receive a contribution for their WEEE collection. For Cyclad, the financial contribution for the collection activities are known for the period of 2010-2017[1]. The contribution fluctuates between € 44 – 88 per ton of collected WEEE, depending on the quality. On average, the contribution for collection is € 69.13/ton.	€ 189.13 /ton
	No information is available for transport costs from Recylum or ESR. The logistical costs for the transport of WEEE are on average € 120 per ton[3].	
	Since 2018, ESR is collaborating with the French collection scheme for lamps; Recylum. Recylum reports the amounts of collected lamps in France. For 2018, the amount of collected lamps in Cyclad is available[1]. Unfortunately, for the other years, no specific data is known for Cyclad, and only national data is available[8]. For 2014-2017 national data has been extrapolated based on the total Cyclad inhabitants and the total inhabitants in France[9]. As Collectors focuses on household waste, only collected lamps from household sources are included (Recycleurs DEEE, Collecteurs, Utilsateurs finaux).	
Recycling costs SHA	No actual costs from ESR are publicly available or known, therefore average recycling costs have been used. The technical costs for shredding, sorting and dismantling and depollution of SHA are on average € 203 per ton[10]; the costs for recycling SHA are negative due to recovery	€ 145/ton

[5] Skype interview with WEEEForum members, July 2019
[6] Annual report DEEE, Cyclad 2017 http://www.cyclad.org/UserFiles/medias/doc/2017%20-%20Rapport%20DEEE.pdf
[7] Annual report DEEE Cyclad 2018, http://www.cyclad.org/UserFiles/medias/doc/ESR%202018-compresse.pdf
[8] Recylum, annual report 2017, https://www.recylum.com/presse/rapports/rapport-dactivite-deee-2017/
[9] Google Public Data, Inhabitants France 2014-2017
[10] United Nations University, WEEE Recycling Economics – the shortcomings of the current business model, 2018

	of valuable materials at -€ 98/ton[Error! Bookmark not defined.]; and the average c osts for incineration and landfilling of non-recyclable materials in 2008 are € 24 per ton[13][Error! Bookmark not defined.]. Especially the cost for landfilling a nd incineration might be outdated, as this is easily influenced by policy. The landfill tax in France has been increasing over the last couple of years to € 40 per ton for authorized landfills[11]. Therefore, the landfill tax is assumed to be the cost for landfilling and incineration. For 2017, the net total recycling costs for SHA come down to € 145/ton.	
	It is assumed all collected appliances are shredded, sorted and dismantled. Based on the collection data mentioned above and the ESR WEEE recycling rates[12] the amount of WEEE sent to recycling and to landfill is calculated. Only recycling data for 2017 is known, for other years a similar percentage is assumed.	
Recycling costs Lamps	No actual costs from ESR are publicly available or known, therefore average recycling costs have been used. The technical costs for shredding, sorting and dismantling lamps are on average € 95 per ton; the costs for recycling and recovery of lamps are € 240/ton; and the costs for incineration and landfilling of non-recyclable materials if € 8 per ton[13]. Especially the cost for landfilling and incineration might be outdated, as this is easily influenced by policy. The landfill tax in France has been increasing over the last couple of years to € 40 per ton for authorized landfills[10]. Therefore, the landfill tax is assumed to be the cost for landfilling and incineration. For 2013, the total recycling costs for lamps came down to € 375/ton.	€ 375/ton
	It is assumed all collected lamps are shredded, sorted and dismantled. Based on the collection data mentioned above and the national ESR WEEE recycling rates the amount of WEEE sent to recycling and to landfill is calculated[7].	
Compliance	In order to operate lawfully and abide the procedures set out by the national and European law, the PROs make certain costs for compliance; costs related to proof of legal compliance, quality and service level (e.g. waste classification, control by and reporting to authorities/compliance schemes), and implementation of standards. For both SHA these costs are on average € 37/ton[13]. For lamps, no compliance costs information is available, therefore these are assumed to be identical to compliance costs for SHA.	€ 37/ton

Table 5: shows the gathered information on operational costs made by the PRO Eco-systemes and Recyclum (ESR).

4.3.3. Revenues

The end-of-life of electric and electronic equipment is financed by the Eco-participation fee paid with each purchase of new equipment. Under the EU, WEEE directive vendors have an obligation to recover end-of-life devices. More and more communities are offering this line to their waste treatment centers to facilitate sorting and promote recycling. Eco-systemes distributes the eco-participation as follows:

- 4%: Ecosystemes wages / offices / cars
- 3%: External Communication
- 73%: Operational cost (to collect / transport / recycle / research and development).
- 20%: Financial compensation for the structures who are collecting WEEE.

[11] CEWEP, 2017, http://www.cewep.eu/wp-content/uploads/2017/12/Landfill-taxes-and-bans-overview.pdf
[12] ESR recycling rates for SHA, 2017, https://www.eco-systemes.fr/en/all-about-eco-systemes
[13] 2008 Review of Directive 2002/96 on Waste Electrical and Electronic Equipment (WEEE), United Nations University, 2008

Item	Assumption & data source	Unit cost
PRO fee for SHA	The PRO fee that ESR receives for her services is not known. It is also not known whether ESR charges her members per category. It is therefore assumed that ESR receives the French average PRO fee for SHA[15]. For 2013 – 2015 average EEE fees for France are known. The average fee for 2013 is € 145 per ton, and € 234 per ton in 2015.	€ 234/ton
	The total PRO income is calculated using the above-mentioned PRO fee and the EEE Put on Market values from ESR producers. REPIC is the only compliance scheme active in Cyclad[5].	
	The EEE put on market amounts are calculated from national average French from the Urban Mine Platform[14] and the amount of citizens in Cyclad[5].	
PRO fee for Lamps	The PRO fee ESR receives for her services is not known. It is also not known whether ESR charges her members per category. It is therefore assumed that ESR receives the average European PRO fee for lamps[15]. The average fee for 2014 is € 500 per ton, and € 625 per ton in 2016.	€ 625 /ton
	The total PRO income is calculated using the above-mentioned PRO fee and the EEE Put on Market values from ESR producers. Recylum is the only compliance scheme active in Cyclad[5].	
	The EEE put on market amounts are calculated from national average French from the Urban Mine Platform[Error! Bookmark not defined.] and the a mount of citizens in Cyclad[5].	

Table 6: shows the gathered information on revenues by the PRO from collecting WEEE in Cyclad.

4.4. CBA Results of Cyclad, France

The graph below shows an overview of the investment costs, the operational costs, the total revenues and the financial net present value (FNPV) resulting from the analysis. The operational costs and revenues follow a similar trend. The FNPV therefore is fairly constant and positive.

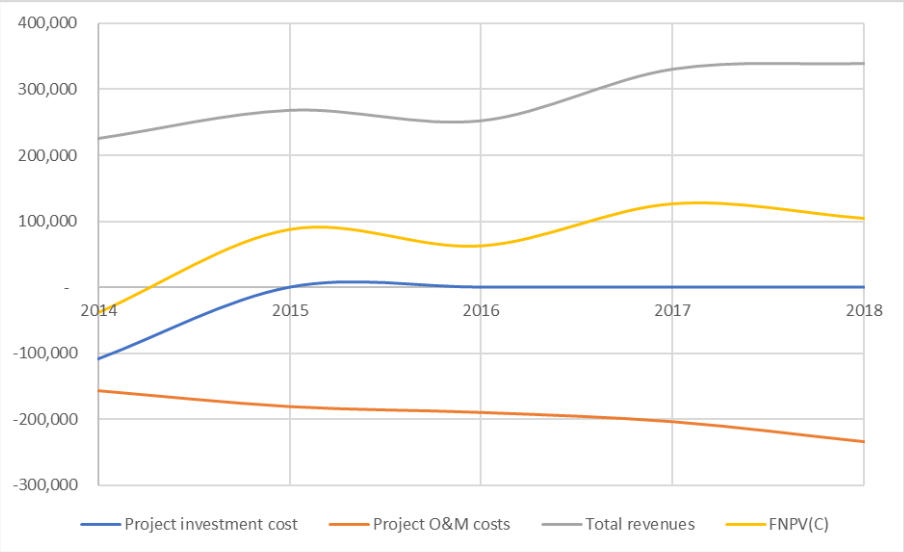


Figure 4 – Overview of the financial flows of WEEE collection in Cyclad, from 2014 – 2018.

---

[14] ProSUM project, Urban Mine Platform, 2015-2018 retrieved on July 2019 from http://www.urbanmineplatform.eu/wasteflows/eee/percentage

[15] EEE fees and WEEE system – A model of efficiency and income in European countries, Sousa, R. Aganta, E. 2018.

Assuming the operational costs haven't increased due to the implementation of the new WEEE collection system, we can assess the cost effectiveness of the investment. Considering the investment of € 107914 made by Cyclad in 2014, and financially supported by ESR, we can assess the cost effectiveness of the collection practice. By this investment, Cyclad was able to increase both the collection of SHA, IT and lamps by keeping the valuable WEEE appliances within their collection grounds. Assuming 2014 as the reference year, with 433 tons of SHA and IT and 1.82 tons of lamps collected, the 2018 collection values show an increase in collection numbers of 201.9 tons of SHA/IT and 3.52 tons of lamps. Taking the full investment, we find a price of € 525.33/ton of additional WEEE collected. Although € 523 per ton of WEEE is substantial, it is significantly smaller than the earlier mentioned € 1.480 per ton of SHA lost due to scavenging.

Total investment	€ 107914	Euro
Extra WEEE collected	205	Ton
Cost effectiveness	€ 525.33	Euro/ton

Table 7 – shows the cost effectiveness of the total investment made by Cyclad on the extra collected WEEE over the years.

4.5. Sensitivity Analysis on Cyclad, France

The results of the sensitivity analysis is shown in the graph below:

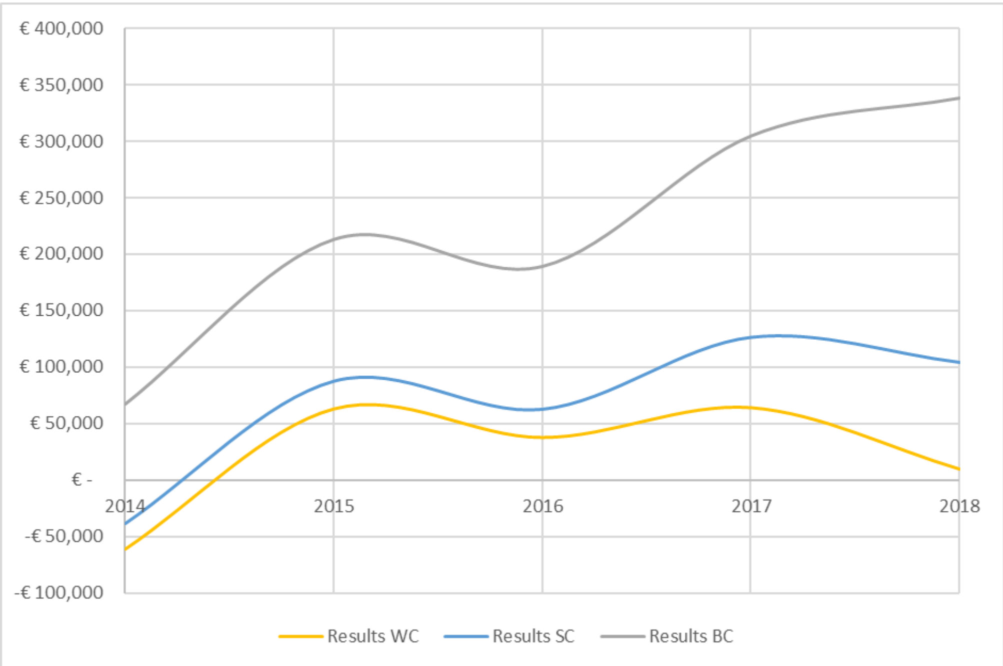


Figure 5: Sensitivity analysis for Cyclad. The yellow line shows the worst-case scenario, blue line shows the standard (current) case and the grey line shows the best-case scenario over the years.

The graph shows the results of all three scenarios, from worst case (yellow line), standard (blue line) and best case (grey line) scenario, from 2014 to 2018. The graph presents all three scenarios and the effect each scenario has on the FNPV value. The results indicate that for all three scenarios the FNPV fluctuates each year. However, there is a decline observed from 2015-2016, but generally, the FNPV has increased over the years. Although, the worst-case scenario depicts that if the PRO fee will decrease assuming the same collection and recycling costs used, it will eventually take its toll on the FNPV in a negative way. Unlike the best-case where the FNPV is increasing steadily over the years.

4.6. Identification of Costs and Benefits for Helsinki, Finland

Investments costs

Investment costs refer to all fixed investments (e.g. land purchase, buildings, construction, transport facilities) as well as other costs during the preparation and start-up phase of an investment action (e.g. planning & design fees, technical assistance, publicity, project supervision). Depreciation costs are not included in the investment costs; instead future expenditures for replacement are used to take account of these costs. Also VAT is not included in the (investment) costs because VAT does not affect national income, it is only a transfer of money.

In the table below the investment costs are discussed.

Item	Assumption & data source	Unit cost
Expanding collection network	Since May 2013 small WEEE including lighting equipment (all dimensions no more than 25 cm) can be returned with no purchase obligation to electronics shops with area larger than 200 m2 or to grocery shops of 1000 m2 minimum. An investment for around 500 bring containers was made in the Helsinki capital region[16]. It is assumed that only SERTY invested in containers.	€125.000
	Containers are estimated to be of various sizes and cost approximately €250 per piece (including, design, installation, transport and replacement).	

Table 8: shows the investments done on the collection networks performing in the Helsinki capital region.

Operating costs

Operating and maintenance costs are the costs that arise during to the day to day operation in the collection of WEEE, its systems and services. Within the paper packaging waste stream the operational costs regarding the collection . Collection costs are interpreted as the operational costs required for collecting and transporting the waste from the municipality's citizens to the waste management company's storage or sorting facility. The collection costs are defined as all costs that are directly attributable to the collection of the paper and packaging waste. These costs consist of: personnel, transport, means of collection, outsourced services, and other costs such as, for example, PAYT costs.

Item	Assumption & data source	Unit cost
Communication and awareness campaigns	On average, SERTY invested € 50 000 in communication and awareness (e.g. taping of containers).	€ 250.000/ year
	As there are 5 PRO's (i) FLIP ry, (ii) ICT-tuottajaosuuskunta, (iii) SELT ry, (iv) SERTY ry, (v) ERP Finland ry (Elker Ltd. is founded by Flip, ICT and SELT), it is assumed all five spent money on communication efforts.	
Collection and transport costs SHA	No actual costs from Helsinki PRO's are publicly available or known, therefore average collection and transport costs have been used. The technical costs for collection and transport of SHA are on average € 129 per ton[13].	€ 129 /ton

[16] Interview SERTY, June 2019

	Collection data from Finland is known from the Urban mine platform, for 2011 – 2015[17].	
Collection and transport costs Lamps	No actual costs from Helsinki PRO's are publicly available or known, therefore average collection and transport costs have been used. The technical costs for collection and transport of SHA are on average € 259 per ton[13]. Collection data from Finland is known from the Urban mine platform, for 2011 – 2015[17].	€ 259 /ton
Transport	Due to large distances, transportation is the most expensive part of WEEE collection and recycling in Finland. Due to more efficient transport, load weights increased (> 40%) and smarter route planning, the transportation costs were decreased by 30 %. It is assumed this measure is implemented in 2013.	30% decrease
Recycling costs SHA	No actual costs from Finnish PROs is publicly available or known, therefore average recycling costs have been used. The technical costs for shredding, sorting and dismantling and depollution of SHA are on average € 203 per ton[13]; the costs for recycling SHA are negative due to recovery of valuable materials at -€ 98/ton[13].; and the average costs for incineration and landfilling of non-recyclable materials in 2008 are € 24 per ton[13]. Especially the cost for landfilling and incineration might be outdated, as this is easily influenced by policy. The landfill tax in Finland has been increasing over the last couple of years from € 40 per ton in 2011 to € 78 per ton in 2018[18]. Therefore, the landfill tax is assumed to be the cost for landfilling and incineration. For 2015, the net total recycling costs for SHA come down to € 155/ton. It is assumed all collected appliances are shredded, sorted and dismantled. Based on the collection data mentioned above and the WEEE recycling rates[19] the amount of WEEE sent to recycling and to landfill is calculated accordingly.	€ 155/ton
Recycling costs Lamps	No actual costs from Finnish PROs is publicly available or known, therefore average recycling costs have been used. The technical costs for shredding, sorting and dismantling lamps are on average € 95 per ton; the costs for recycling and recovery of lamps are € 240/ton; and the costs for incineration and landfilling of non-recyclable materials is € 8 per ton[13]. Especially the cost for landfilling and incineration might be outdated, as this is easily influenced by policy. The landfill tax in Finland has been increasing over the last couple of years to € 40 per ton for authorized landfills[18]. Therefore, the landfill tax is assumed to be the cost for landfilling and incineration. For 2015, the total recycling costs for lamps came down to € 375/ton.	€ 385/ton

[17] ProSum project, Urban mine platform, accessed on 8th Aug. 2019 from http://www.urbanmineplatform.eu/urbanmine/eee/weightpercountry

[18] Landfill tax in Finland retrieved July, 2019 retrieved from http://www.materiaalitkiertoon.fi/download/noname/%7BF212F529-17B9-45BF-B3DF-5D87FBF3714E%7D/138102, http://ec.europa.eu/taxation_customs/tedb/legacy/taxDetail.html?id=252/1388754737&taxType=Other%20indirect%20tax

[19] Collection rates on WEEE for the Helsinki capital region retrieved June 2019 from https://www.ymparisto.fi/fi-FI/Kartat_ja_tilastot/Jatetilastot/Tuottajavastuun_tilastot/Sahko_ja_elektroniikkalaitetilastot/

	It is assumed all collected lamps are shredded, sorted and dismantled. Based on the collection data mentioned above and the national Finnish WEEE recycling rates the amount of WEEE sent to recycling and to landfill is calculated accordingly[19].	
Compliance	In order to operate lawfully and abide the procedures set out by the national and European law, the PROs make certain costs for compliance; costs related to proof of legal compliance, quality and service level (e.g. waste classification, control by and reporting to authorities/compliance schemes), and implementation of standards. For both SHA these costs are on average € 37/ton[13]. For lamps, no compliance costs information is available, therefore these are assumed to be identical to compliance costs for SHA.	€ 37/ton

Table 9: shows the operational costs provided from interviews with SERTY, local reports provided by HSY.

Revenues

As no case specific information for a PRO was available, the scope has been broadened to all operational PRO's in Helsinki.

<table>
<tr><th>Item</th><th>Assumption & data source</th><th>Unit cost</th></tr>
<tr><td rowspan="3">PRO fee for SHA</td><td>The PRO fee the Finnish PROs receive for their services is not known. As the WEEE flows in Finland are fairly similar to the ones in Norway[20], the Finnish PRO fee is approximated by taking the average of the average EU PRO fee and the PRO fee in Norway[20]. For 2013 – 2015 average EEE fees are known.
The average Norwegian fee for 2013-2015 is € 60 per ton. The average EU fee is presented below. For 2011 and 2012 no data is available, these values are extrapolated based on the 2013-2015 values.
<table>
<tr><td>In €/ton</td><td>2011</td><td>2012</td><td>2013</td><td>2014</td><td>2015</td></tr>
<tr><td>Norway avg</td><td>60</td><td>60</td><td>60</td><td>60</td><td>60</td></tr>
<tr><td>EU avg</td><td>174</td><td>166</td><td>160</td><td>149</td><td>145</td></tr>
<tr><td>Combined avg</td><td>117</td><td>113</td><td>110</td><td>105</td><td>103</td></tr>
</table></td><td rowspan="3">€ 103/ton</td></tr>
<tr><td>The total PRO income is calculated using the above-mentioned PRO fee and the total EEE Put on Market in the Helsinki region.</td></tr>
<tr><td>The EEE put on market amounts are calculated from the Finnish national average taken from the Urban Mine Platform[17] and the number of citizens in the Helsinki region[21,22].</td></tr>
<tr><td>PRO fee for Lamps</td><td>The PRO fee the Finnish PROs receive for their services is not known. As the WEEE flows in Finland are fairly similar to the ones in Norway[20], the Finnish PRO fee is approximated by taking the average of the average EU PRO fee and the PRO fee in Norway[20]. For 2013 – 2015 average EEE fees are known.
The average Norwegian fee for 2013-2015 is € 60 per ton. The average EU fee is presented in below. For 2011 and 2012 no data is available, these values are extrapolated based on the 2013-2015 values.</td><td>€ 275 /ton</td></tr>
</table>

---

[20] Román, E., Ylä-Mella, J., Pongrácz, E., Solvang, W. D., & Keiski, R. (1992). WEEE management system–cases in Norway and Finland. *Environment*, *1991*, 5. https://www.researchgate.net/publication/262603927_WEEE_Management_System_-_Cases_in_Norway_and_Finland

[21] UN population data, 2018

[22] COLLECTORS data base Helsinki retrieved in June 2019 from https://www.collectors2020.eu/wcs-weee/helsinki-capital-region-fi/

In €/ton	2011	2012	2013	2014	2015
Norway avg	60	60	60	60	60
EU avg	695	640	600	500	490
Combined avg	377.5	350	330	280	275

The total PRO income is calculated using the above-mentioned PRO fee and the total EEE Put on Market in the Helsinki region.

The EEE put on market amounts are calculated from the Finnish national average retrieved from the Urban Mine Platform[17] and the number of citizens in the Helsinki region[21,22]

Table 10: shows the data collected from national and local reports concerning the PRO fee in the Helsinki capital region.

4.7. CBA results of Helsinki, Finland

The graph below shows an overview of the investment costs, the operational costs, the total revenues and the financial net present value (FNPV) obtained as a result of the analysis. Again, the operational costs and revenues follow a similar trend. The FNPV is therefore constant and positive. This means that for these assumptions, the operations of the PRO are financially viable.

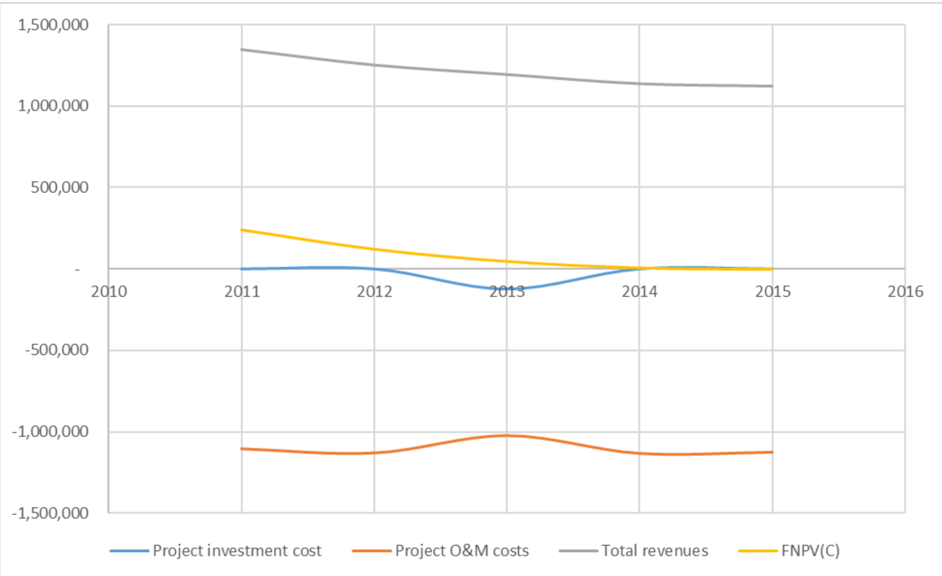


Figure 6: overview of financial flows of WEEE collection in Helsinki region from 2011-2015.

Assuming the operational costs haven't increased due to the implementation of the new WEEE collection system, we can assess the cost effectiveness of the investment. Considering the investment of € 125.000 made by SERTY, we can assess the cost effectiveness of the collection practice. Assuming 2011 as reference year, with 2888 tons of SHA and IT and 47 tons of lamps collected, the 2015 collection values show an increase in collection numbers to an amount of 3944 tons of SHA/IT and 63 tons of lamps. By taking the full investment, we find a price of € 116.67/ton of additional WEEE collected.

Total investment	€	125,000	Euro
Extra WEEE collected		1071	Ton
Cost effectiveness	€	116.67	Euro/ton

Table 11:shows the cost effectiveness of the total investment made by SERTY on the extra collected WEEE over the years.

4.8. Sensitivity Analysis on Helsinki, Finland

As discussed earlier in the table above, the exact PRO fee charged by the Finnish PRO's is not publicly available. It is therefore assumed that the PRO's operating in Helsinki receive either the Norwegian or the European average PRO fee**Error! Bookmark not defined.**. Due to these uncertainties the standard method used i n testing the PRO fee is replaced by, the following scenario's;

1. The PRO fee is equal to the combination of both averages;
2. The PRO fee is equal to the Norwegian (NW) average
3. The PRO fee is equal to the EU average.

Scenario	PRO fee	Collection costs	Recycling costs
1	EU+NW average	Standard	Standard
2	NW average	Standard	Standard
3	EU average	Decreased 50%	Decreased 50%

Table 12: shows the three new scenarios tested on the PRO fee, Collection costs and Recycling costs.

The result of the analysis is shown in the graph below.

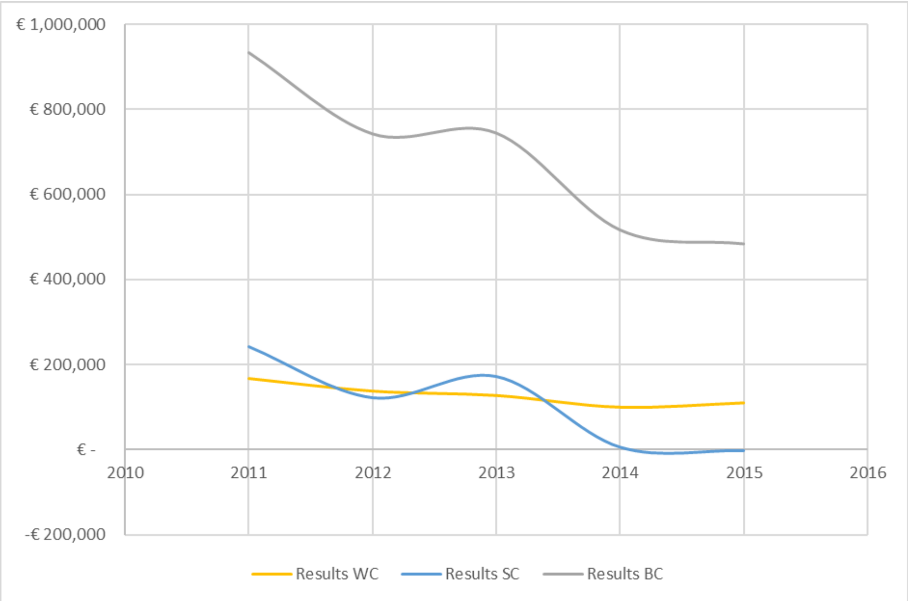


Figure 17: sensitivity analysis for Helsinki. The yellow line represents the worst-case scenario, blue line the standard (current) case and the grey line shows the best-case scenario throughout the years.

The graph shows the results of the assumed three scenarios, from worst case (yellow line), standard (blue line) and best case (grey line) scenario, from 2011 to 2016. The scenarios are plotted against the FNVP value obtained from the cost benefit analysis. In general, the scenarios indicate a decline on the FNVP value over the years. Although, for the best-case scenario the FNPV starts of positively high and stabilizes around 2015 with a value of approximately €500,000. Yet, the worst-case scenario appears to have a positive and a much more stable FNPV, compared to the current scenario, while both scenarios start off around the same FNPV value, a decline is observed from 2013 to 2014 and eventually stabilizes from 2014 to 2015 to a FNPV of zero (neutral).

The results of the analysis are discussed in this chapter of the study. It should be noted that the current results do not take external effects into account, as these are covered by the LCA performed on the

COLLECTORS-project. Including these effects will result in a more realistic and complete display of the facts and will certainly affect the CBA results as the additional societal benefits may increase the total project benefits.

5. Discussion

The findings show that for both case studies in the early stage of establishing a take-back and treatment scheme, owing to original investment and absence of managerial knowledge, expenses may be very large and unstable. However, over the years, the overall cost stabilizes as a result of system optimization, both technically and administrative. Furthermore, the collection rate of WEEE plays a crucial role in the overall cost due to the economy of scale. It is also an important indicator to evaluate the efficiency of established collection channels including the magnitude of the uncontrolled "gap" of WEEE not captured by take-back schemes.

The interesting part observed from the results of the CBA on both case studies is in the sensitivity analysis. Where it clearly highlights the need for a financing scheme to cover the cost of establishing and operating such take-back schemes. The extreme scenarios chosen, best/worst case including the current scenario showed that even though the average operational costs where assumed to be constant, the current way of financing the recycling of WEEE will have a negative effect on the net present value of such take-back systems in future years. Evidently, this was the case for Helsinki where the worst-case scenario turned out to have a much more positive and stable impact on the net present value. According to the analysis, the overall economic profits in most cases are lower or may be even negative and cannot cover the overall system cost needed.

6. Conclusion & Recommendation

This study explored the economic performance of WEEE collection systems in two contrasting European regions: Cyclad, France, and Helsinki, Finland. Through cost-benefit analysis (CBA) and sensitivity testing, the study evaluated the impact of key variables, such as population density, geographic area, and financing mechanisms, on the efficiency and sustainability of these systems.

The findings reveal that the financial performance of WEEE collection systems is highly dependent on regional characteristics. Cyclad, operating in a rural area with a dispersed population, encountered higher per capita costs due to logistical challenges and a need for significant investments in theft-prevention measures and public awareness campaigns. The large geographic area further increased transport costs, making the system more vulnerable to funding fluctuations. The analysis of Cyclad's CBA scenarios shows that while the best-case scenario resulted in steady financial net present value (FNPV) growth, the worst-case scenario highlighted the system's dependence on stable producer responsibility organization (PRO) fees to remain viable.

In contrast, Helsinki, with its higher population density and urban infrastructure, demonstrated greater resilience across all CBA scenarios. Efficient logistics, centralized collection systems, and economies of scale contributed to lower operational costs and more stable financial outcomes. While the best-case scenario showed significant FNPV growth, even the worst-case scenario maintained financial stability due to the system's maturity and efficiency. However, high transport costs associated with Finland's geography tempered some financial gains, particularly in peripheral areas.

The sensitivity analysis for both regions underscores the importance of PRO fees in determining system sustainability. Reduced fees in worst-case scenarios posed significant risks to emerging systems like Cyclad, while mature systems like Helsinki's were better equipped to withstand such challenges. Additionally, the study demonstrates that cost reductions in collection and recycling have a greater positive impact in rural areas, where logistical inefficiencies are more pronounced.

Based on these findings, the following recommendations are proposed:

1. Dynamic Financing Models:

Establish adaptive PRO fee structures that account for regional socio-economic conditions. In rural areas like Cyclad, higher initial fees may be necessary to support investments in infrastructure and awareness campaigns, while urban areas like Helsinki can benefit from more flexible, performance-based funding.

2. Enhancing Public Awareness:

Increase investment in public education campaigns to improve participation rates, especially in rural regions where low engagement remains a barrier to efficient WEEE collection. Tailored messaging can address local misconceptions and encourage proper disposal practices.

3. Improved Infrastructure and Logistics:

In rural areas, focus on optimizing collection routes and investing in secure, strategically located collection points to reduce transport costs and prevent theft. Urban areas should continue leveraging centralized systems while exploring advanced logistics technologies to further cut costs.

4. Technological Innovations:

Promote research and development in recycling and treatment technologies to lower operational costs. These innovations can enhance material recovery rates and improve the financial viability of collection systems in both rural and urban settings.

5. Policy Alignment and Enforcement:

Strengthen regulatory frameworks to combat illegal waste streams and ensure compliance with WEEE directives. Collaboration between local authorities, PROs, and enforcement agencies is essential to minimize losses from improper disposal and illegal exports.

These recommendations provide a roadmap for designing effective, region-specific WEEE collection systems. By addressing unique regional challenges and leveraging local strengths, policymakers and stakeholders can enhance the sustainability, cost-effectiveness, and environmental impact of WEEE management practices across Europe.

References

BBC. (2016). *Wales 'could become Europe's top recycling nation*. Retrieved from BBC: https://www.bbc.com/news/uk-wales-37787961

Bridgen, K. e. (2005). *Recycling of Electronic Waste in China and India: Workplace and Environmental contamination*. Greenpeace, Greanpeace international.

COLLECTORS. (2019). Retrieved from www.collectors2020.eu

Communities, C. o. (2009). Communication From the Commission to the Council, the European Parliament, the European Economic and Social Committee, and the Committee of the Regions: A Mid-Term Assessment of Implementing the EC Biodiversity Action Plan. . *Journal of International Wildlife Law & Policy*, 12(1-2), 108-120.

CYCLAD. (2014). *Chiffres-cles, Rapport annuel sur le prix et la qualite du service public délimination des dechets*.

CYCLAD. (2017). *DEEE*. Eco-systemes. Retrieved from www.cyclad.org

Deubzer O. et al. (2018). *Prevalence, recyclability, cost and financing of CRM recycling from WEEE*. Retrieved from www.scrreen.eu

DEUBZER O., A. A. (2018). Retrieved from Prevalence, recyclability, cost and financing of CRM recycling from WEEE: www.scrreen.eu

Directive, E. C. (2012). Directive 2012/19/EU of the European Parliament and of the Council of 4 July 2012 on waste electrical and electronic equipment, WEEE. . *Official Journal of the European Union L*, 197, 38-71.

Directive, E. U. (2002). Directive 2002/96/EC of the European Parliament and of the Council of Jan. 27, 2003 on Waste Electrical and Electronic Equipment. *Official Journal of the European Union L*, 37.

European commision. (2014). *Development of guidance on extended producer responsibility (EPR)*. European commision.

Eurostat. (2019). *Waste statistics - electric and electronic equipment* . Retrieved from Eurostat statistics explained: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Waste_statistics_-_electrical_and_electronic_equipment#EEE_put_on_the_market_and_WEEE_collected_in_the_EU

HSY. (2016). *Pääkaupunkiseudun seka- ja biojätteen koostumus*.

HSY. (2017). *Vuosikertomus 2016*.

HSY. (2017). *Jätehuollon vuositilasto 2017*. Retrieved from https://www.hsy.fi/sites/Esitteet/EsitteetKatalogi/Jatehuollon_vuositilasto_2017.pdf

Huisman J., L. P. (2017). *Prospecting Secondary Raw Materials in the Urban Mine and mining wastes (ProSUM)*. Brussels, Belgium.

INSEE. (2015). *Recensement de la population*. Retrieved from https://www.insee.fr

My Recycling Wales. (2018). Retrieved from https://myrecyclingwales.org.uk/materials/waste-electrical-and-electronic-equipment?finyear=2017

Nelen, D. M. (2014). A multidimensional indicator set to assess the benefits of WEEE material recycling. *Journal of Cleaner Production*, 83, 305-316.

NVMP. (2013). *Benchmark WEEE systems in Europe*. NVMP.

Partida, S. (2019, March 28). Deputy director of collection. (T. v. leeuwen, & S. Alnajar, Interviewers)

ProSum. (2019). *Weight of Collected and reported EEE in Finland* . Retrieved from UrbanMine Platform: http://www.urbanmineplatform.eu/wasteflows/eee/weightpercolcat

Recylum, E. (2019). *ESR*. Retrieved from http://www.es-r.fr/

Schluep et al., M. (2009). *Sustainable Innovation and Technology Transfer Industrial Sector Studies: Recycling - from E-waste to resouces*. Bonn, Germany: United Nations University.

Sepúlveda et al., A. (2010). A review of the environmental fate and effects of hazardous substances released from electrical and electronic equipments during recyling: Examples from China and India. *Environmental Impact assessment review* , 25(4): 380-383.

Stiglitz, C. (2016). *The Management of Waste from Electrical and Electronic Products in Austria*. Vienna: Institute of Environmental Economics .

United Nations University, U. (2008). *Review of directive 2002/96 on Waste Electrical and Electronic Equipment (WEEE)*.

United Nations University, U. (2018). *WEEE Recycling Economics: the shortcomings of the current business model*.

Vitre, E. (2019, March 29). Director of Cyclad syndicate. (T. van Leeuwen, & S. Alnajar, Interviewers)

Wikipedia. (2019). *Greater Helsinki*. Retrieved from https://images.app.goo.gl/berxAHrP1fBrxbnH7

Wilson, E. J. (2001). Euro-trash: searching Europe for a more sustainable approach to waste management. *Resources, conservation and recycling*, 31(4), 327-346.

Ylä-Mella et al, J. (2014). Implementation of waste electrical and electronic equipment directive in Finland: evaluation of the collection network and challenges of the effective WEEE management. *Resources, Conservation and Recycling*, 86, 38-46.

Ylä-Mella et al., J. (2014). Overview of the WEEE Directive and its implementation in the Nordic countries: national realisations and best practices. *Journal of Waste Management*, 20.