MASTER

The improved design of a circular supply chain in the sporting goods industry

Alamdary Badlou, S.

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The Improved Design of a Circular Supply Chain in the Sporting Goods Industry

Author:
Siros Alamdary Badlou
Student ID: 0810949

supervised by
S.S. Dabadghao - TU Eindhoven
S.D.P. Flapper - TU Eindhoven

The data in this Thesis is fictive, because of confidentiality reasons.

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LIST OF ABBREVIATIONS

3PL  Third-party Logistics
4PL  Fourth-party Logistics
CO₂  Carbon Dioxide
CO₂-e Carbon Dioxide-equivalent
APLA  Asia, Pacific and Latin America
CLSC  Closed-loop Supply Chain
DC  Distribution Center
ELC  European Logistics Center
EMEA  Europe, Middle East and Africa
EOL  End of Life
EUHQ  European Headquarters
EVA  Ethylene-vinyl acetate
FTW  Footwear
FY  Fiscal Year
GHG  Greenhouse gases
GWP  Global Warming Potential
kJ  kilojoule
kWh  kilowatt hour
LCA  Life Cycle Assessment
LT  Lead Time
MSW  Municipal Solid Waste
NA  North America
RYS  Sporty Shoe Recycling Program
SC  Supply Chain
LIST OF CONCEPTS

**Box**  A rectangular container used for the shipping of the end of life footwear, no standardized size

**Footwear Unit**  A pair of shoes

**Pre-consumer Footwear Units**  All shoes that have not been in the possession of the consumer yet (Pre-sell, samples etc.) or have been returned within the guarantee period (Product Claims).

**Post-consumer Footwear Units**  All shoes that have been worn by the consumer and are considered end of life

**Processed Footwear Units**  All shoes that have been recycled by the recycling facility

**Returns**  All products that have been purchased and returned by the consumer, for a set of reasons.

**Sporty Shoe Recycling bin**  A bin in a retail store to dispose end of life footwear

**Sporty Shoe Recycling Program**  The program Sporty started to collect end of life footwear units and recycle them

**Shipment**  The action of shipping goods

**Take-back network**  The logistical network of taking back the end of life footwear units from stores to the recycling facility
ABSTRACT

Circular economies become increasingly important within the fashion and sporting goods industry. In this report, we developed an improved design of a circular supply chain. To realize this design, a framework was presented. This framework enabled us to analyze the circular supply chain involved and to give an advice for its future. Applying the framework, we started with a problem statement. Here we tried to understand the project scope and develop the research questions. In the next step, a process analysis was conducted. This analysis gave insights on the relevant transportation flows regarding our product, the recycling process, the associated costs and the associated environmental emissions. The product at stake here is End of Life Footwear. The next step was a quantitative analysis, which started with a multi-objective optimization model. This model gave further insights into the financial and environmental performance of future possible scenarios. These insights were then used in a multi-criteria decision-making method. The Analytical Hierarchy Process-method was applied to determine which future scenario fits best to the management’s beliefs. The main criteria considered here were economical criteria, environmental criteria, market value criteria and business feasibility criteria. The future scenario chosen through this method implied that the quantity of units recycled should be increased. To realize this, improvements regarding the redesign of the program were presented. Innovative take-back solutions were explored to evaluate new logistical solutions for taking back the shoes. This finally enabled us to give a final advice regarding the future strategic decision-making of this recycling program.
MANAGEMENT SUMMARY

This report presents the advice on an improved design of a circular supply chain in the sporting goods industry. Designing for circular economies becomes increasingly important within the fashion and sporting goods industry. Companies have different capabilities regarding their waste management options, such as reusing and recycling. A big challenge in these waste management options is the actual collection of the end of life product. In this project, we focus on the Sporty Shoe Recycling Program (RYS-program). Sporty is the fictive name for the global sporting goods company where we conducted this research. The RYS-program was initiated by Sporty in the 1990s. In this program, post-consumer end of life footwear is taken back and recycled. This leads to three material outputs; rubber, EVA and fluff. The material outputs can be reused in new applications, such as sport floorings. The report will give a strategic advice on the continuation of the RYS-Program activities, and how the design can be improved accordingly. Therefore, the main research question of the report is:

"How can the environmental performance of the take-back and processing activities of end-of-life footwear in the Sporty Shoe Recycling Program be improved, while minimizing the total cost?"

Since there is only few research regarding the (re)designs of circular supply chains in the fashion-and sporting goods industry, a framework was developed to structure the research (Figure 1). The framework consists of a problem statement, analysis of the process, quantitative scenario analysis and an analysis of the improvement potential. To conclude, the final step should present a set of strategic recommendations regarding the solution implementation.

Figure 1. Applied Scientific Framework

The first step of the framework is all about understanding the project which is presented in Sections 1 and 2. In these sections, the project is introduced, the problem is defined and the research questions are developed. The main focus of the project is on post-consumer footwear units which are collected via disposal bins in the stores. The main reason for the focus on post-consumer End-of-Life Footwear (EOL FTW) is Sporty’s desire to provide the extra service to the consumer of being able to contribute something to a better environment.

Analysis of the process
Section 3 presents a literary background which will increase the readers knowledge on what already has been done regarding the topics of interest. Section 4 presents the strengths and weaknesses in the
processes regarding collecting and processing the EOL FTW. This includes an analysis of both the costs and the emissions that are made throughout the different processes. The main findings presented here are:

- A clear overview of which stores are participating is lacking. Problems in the actual pick-up process of participating stores are encountered. There is no standard box size and boxes are not always filled, which led to higher unit costs.
- Current bottlenecks in the recycling process are the supply of EOL FTW units and the productivity of the workforce. This causes a very low expected utilization rate of 17.4%.
- 45% of the expected variable costs of the recycling process are due to fluff waste management practices. The variable cost could decrease significantly if an application would be found for this fluff (e.g. isolation material).
- The take-back costs are much higher than desired. The main reasons causing these increased costs are three countries without negotiated rates on a package basis, using the wrong services, not filling the boxes completely and invoicing mistakes.
- Our calculations show that recycling has a reducing effect on total CO₂-e emissions while landfilpping and energy recuperation have an increased effect on total CO₂-e emissions.

**Quantitative Scenario Analysis**

In Section 5, a multi-objective optimization model was developed according to the 'ε – constraint’ method. The results present how the absolute total costs increase with increased environmental performance, while the relative unit cost decreases. The optimal solutions dedicate all the budget available for recycling purposes instead of energy recuperation purposes. In the sensitivity analysis, we see that a lack of supply turns out to be a risk. With the insights from this model, we continue with Section 6 where we focus on a multi-criteria decision-making model. There are different possible future scenarios which Sporty can choose regarding volumes of EOL FTW units processed. Together with three sustainability managers within Sporty, an ‘Analytical Hierarchy Process’-session (AHP) was held. In this session the hierarchical structure of important criteria regarding strategic decision making was determined (Figure 2). The outcome of the AHP-session was that the scenario with capital investments was the most preferable scenario according to management beliefs.

![Figure 2. Hierarchical Structure developed together with Sporty EUHQ Sustainability team](image-url)
**Analysis improvement potential**

In the first three steps, the points of improvement were identified and a decision was made regarding the desired amount of FTW Units processed. Section 7 represents the fourth step, which includes one of the biggest challenges of circular supply chains, designing the take-back network. We assessed six different designs based on six criteria of which we feel they are important in the design of this take-back network (Table 1). We concluded that a collaboration with a 4PL-Supplier is the best option. This 4PL-supplier is able to provide a design that could decrease current costs. Meanwhile, they are a trusted partner which is able to grow and adapt according to changing needs and increasing quantities. Outsourcing all recycling operations is a solution which would mean a total strategic reset, but is a relevant solution to keep in mind. We zoomed in on how to improve store operations, mainly based on the challenges we identified in Section 4. The action-oriented framework of Gaur et al. (2016) was applied to find ways on how to increase the EOL FTW supply in a structured way.

**Table 1.** Performance different take-back scenarios (Scale 1-7)

<table>
<thead>
<tr>
<th>Final Ranking</th>
<th>Costs</th>
<th>Complexity</th>
<th>Flexibility</th>
<th>Partnership</th>
<th>Quality/Reliability</th>
<th>Stakeholders</th>
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<tbody>
<tr>
<td>Weight</td>
<td>0.336</td>
<td>0.116</td>
<td>0.125</td>
<td>0.223</td>
<td>0.125</td>
<td>0.076</td>
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<tr>
<td>Improve Current</td>
<td>5</td>
<td>7</td>
<td>4</td>
<td>2</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>4PL-Supplier</td>
<td>4</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>Collaborate Returns</td>
<td>6</td>
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<td>1</td>
<td>5</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Merge outbound</td>
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<td>1</td>
<td>4</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Collection Facility</td>
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<td>5</td>
<td>4</td>
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<td>5</td>
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<tr>
<td>Outsource</td>
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<td>7</td>
<td>1</td>
<td>5</td>
<td>4</td>
<td>6</td>
</tr>
</tbody>
</table>

**Scientific Contribution**

- The framework that was applied throughout this report (Figure 1) is a good hands-on to solve problems regarding different waste management processes. We recommend waste management problem owners in established industries to follow the steps as presented in the framework.
- The $\varepsilon$-constraint method is a suitable method when the two objectives at stake are costs and environmental performance. The actual objective functions regarding multi-objective optimization models will often be case-specific. We recommend to study our general formulas presented to develop similar, but case-specific multi-objective optimization models.
- AHP remains a suitable method to make a strategic decision in dilemmas regarding sustainable programs. The hierarchical structure developed should be applicable in a broader set of cases. However, the structure should always be discussed with management to agree on the important decision (sub-) criteria.
- A relatively untouched topic in literature is how to design a take-back logistics network. The deep dive into take-back networks with different setups in this report can be considered of significant scientific relevance. To evaluate the designs, six criteria were presented that can be applied into the AHP-method (Table 1). When evaluating different take-back designs, we recommend to use the same method and criteria.
Long-term Recommendations for Sporty

- The quantity of processed footwear units should be maximized by doing capital investments. This should go hand in hand with an increase of the utilization. Because of the higher quantities, a proper plan will have to be developed to ensure the workforce is able to process the desired quantities. This requires a redesign of the processes within the facility.
- The number of stores participating with a RYS-bin should increase to increase supply. Also, the awareness about the RYS-program should be increased. This means more information about the RYS-program should be available on the website and around the products themselves.
- The redesign for the take-back network we propose is a solution with the 4PL-supplier. With them, we expect a more reliable and flexible partnership with a mutually trusted partner. Costs could be decreased and a partnership can be set up that enables Sporty to adapt to future needs and increasing quantities.
- We recommend to consider and further research a collaboration with Partner 5 in which all recycling and take-back activities are outsourced. This would mean a complete strategic reset, but could be a business model that both performs very well regarding CO₂-e emissions and costs.

Short-Term Recommendations for Sporty

- The most relevant short-term recommendation should be to negotiate package rates for Spain, Portugal and Italy in the current design.
- The stores should be educated again on how to participate in the RYS-program. They should get clearer directions on the box they should use. We recommend the 10-packs, the biggest boxes that come in. The stores must realize that these boxes should be completely full, as we will pay based on a package rate.
- The current IT-portal which is used by the stores should be improved. The main aspect here is to decrease the possibilities of adjustments on the shipment from the store manager. Preferably, someone within Sporty should have more control over the settings of the portal.
PREFAE

After 6 months of hard work, the final deliverable of my Thesis is finally done. What a good feeling it is to write down these last words as a student. I am very happy and proud to present what I have been doing in this project as a closure of five amazing years at the Eindhoven University of Technology.

Doing this thesis was an opportunity which I never could have imagined. Combining professional knowledge with my biggest passion, sports, was a privilege which I enjoyed to the fullest. The inspiring and ever-changing environment boosted my motivation and learning curve during the project. I would like to thank Kim for giving me that opportunity. I remember when I was in the middle of the Colombian desert when I got an e-mail to schedule an interview. Because of the slow Internet, it took me hours to write an answer. A week later, there I sat in a conference room in a fancy hotel in Bogotá to conduct the interview. Kim, your ongoing enthusiasm, passion for sustainability, strong feedback and continuous interest for my project kept me going through this internship! I would also like to express my gratitude to Mike. The responsibilities that I got during the project gave me the opportunity to not only learn a lot about the topic, but also develop my leadership- and communication skills. Above that, I very much appreciate the fact we could combine work with a dose of humor and that you never forgot me despite your busy schedule. It was a valuable and enjoyable period.

Furthermore, I would like to dedicate a special thank you to my university supervisors. Shaunak Dabadghao, I very well remember when you were assigned as my Bachelor Thesis mentor. You were just new at the TU/e and nobody knew you. It turned out to be the beginning of a fruitful collaboration. Therefore it was no hard choice to choose you as my Master Thesis mentor. I like your no-nonsense, to-the-point style of giving advice. For me this worked perfectly. Also I would like to thank Simme Douwe Flapper. When I asked you to review my work in progress, I knew I was going to get a paper full of notes and comments. These comments were always on point and added significant value to the report as it is now.

It is hard to imagine that the school- and student life is over now. Starting at primary school and playing football every single day. Taking it to the next step at high school, having tons of fun and experiencing great moments with friends. Then, moving to Eindhoven to experience the flexible life of being a student at the university, with its many perks and possibilities to also develop your soft skills. My student life gave me the opportunity to do an amazing board year (NEGENTIEN!) at Interactie where I learned incredibly much. Furthermore, I had the unique chance to travel around all over Europe and make an amazing network of friends thanks to ESTIEM. While progressing with my Bachelor, I boosted my experience with internships at Syneratio.com and KFC NL. And I will never forget my amazing exchange semester in Colombia where I lived in the enormous city of Bogotá, learned Spanish and got to know a whole other way of life. Now, studying is done. I am ready for the next step!

I would like to dedicate the final words to my dear mother. Life was not always easy, but she was always there and worked her tail off to provide. Look where we are now :)
1 INTRODUCTION

This Master Thesis presents the results of a research that concerns the design of a circular supply chain for footwear (FTW) in the sporting goods industry. This research was conducted at a Sporting Goods company which we call Sporty for the remainder of this Thesis. A general framework is followed to give advice to Sporty about the continuation of their Sporty Shoe Recycling Program (RYS) deployed in Europe. In this RYS-program, End of Life (EOL) FTW is collected and transported to the Sporty Grind facility, where the FTW is recycled and the resulting output is processed into other products. This project will focus on analyzing and improving the current processes of the RYS program.

The chapter continues with a short company introduction. We will then proceed to the problem statement. Based on this statement, the research design will be presented. The design includes the research questions and the structure followed during the thesis. After following this structure, a set of recommendations can be defined. The work concludes with its scientific contribution.

1.1 About Sporty

Sporty is a company delivering high-quality products in three product engines (FTW, apparel and equipment). Sporty helps athletes achieve the best possible results. Sporty products are produced in 42 different countries, and sold in almost every country worldwide. Sporty has several distinguishable product categories, including Football, Running, Basketball etc. Sporty uses a matrix structure based on the company portfolio, product engines, categories and geography. These are supported by enabling functions such as IT, Legal, Finance and Supply Chain. For example, the matrix of an employee working at the Sales department of Football in North America would include:

- Product engine (Footwear)
- Category (Football)
- Geography (North America)
- Function (Sales).

Sporty considers four strategic geographic areas: North America (NA); Europe, Middle East and Africa (EMEA); Greater China; and Asia, Pacific and Latin America (APLA). The Master Thesis project has been conducted at the European Headquarters (EUHQ) in the Netherlands. This office is responsible for the whole EMEA-region. An important part of the thesis takes place in the European Logistics Center (ELC) in Belgium.

Sporty’s value chain consists of seven critical stages: Plan, Design, Make, Move, Sell, Use and Reuse. With Reuse, the value chain presents the willingness of implementing closed-loop supply chains (CLSC). Sporty knows they have an environmental impact throughout their whole value chain. Realizing that, Sporty is trying to reduce its environmental footprint. Sustainability is high on the agenda within the Sporty business model. The Sporty Shoe Recycling Program is one of those programs to contribute to a lower environmental impact.

1.2 Sporty Shoe Recycling Program

The RYS-program was initiated in the early 1990s. A high-level overview visualizing the process starting from two types of EOL FTW and ending at their final destination after recycling, is presented in Figure 3. Within this program, both pre-consumer EOL FTW and post-consumer EOL FTW are collected and recycled. Pre-consumer EOL FTW is all the FTW that was not bought yet by the consumer
(or returned via a product claim), while post-consumer FTW are those FTW units that have been used by consumers. When the consumer considers these FTW units as EOL and throws them away, these shoes are seen as post-consumer FTW units. All EOL FTW is transported to the recycling facility in Belgium. This facility grinds the whole shoe and then splits the relevant rubber, ethylene-vinyl acetate (EVA, which is a type of foam) and fluff via separators. A more detailed explanation on the grinding process will follow later in the thesis. Sporty Grind is the brand name that is used for the set of products that are made with the material output after processing EOL FTW. The processed materials from FTW are then used for example in sport courts. With Sporty Grind, Sporty tries to comply with the desire of implementing a CLSC whilst reducing their environmental impact.

![High-level overview of the FTW Recycling Process at Sporty](image)

**Figure 3.** High-level overview of the FTW Recycling Process at Sporty

Sporty distinguishes three types of graded FTW within their inventory management systems. To understand the manner of grading Sporty FTW, Sporty’s selling channels of their products have to be understood. The selling channels in the highest price segment and the newest collections, are the Inline Stores. The Wholesale selling channels are the retailers that sell Sporty products, such as Foot Locker, JD and Intersport. The biggest assortment can be found on the website, Sporty.com. Finally, there are the Sporty Factory Stores (SFS), which sell products at a somewhat lower price level which includes e.g. last-season collections in their assortment. Sporty qualifies the marketability of their shoes as follows:

- A-grades, which is FTW of the newest collections and highest quality.
- B-grades, shoes that cannot be sold as A-grades but still have the quality and potential to be sold in other selling channels such as the Sporty Factory Stores.
- C-grades, shoes that will not be sold anymore because of a different set of reasons. Examples could be quality issues or when they are from a previous season.

Sporty has an extensive Returns network for FTW units. Wholesalers, Sporty.com and Sporty Inline stores participate in this Returns network. When these parties for example receive product claims or returns, have excess inventory or encounter pre-selling problems, they can send these units to the Returns facility, also in Belgium. There, a thorough check on the FTW is done and the decision is made whether these shoes are A-graded, B-graded or C-graded. A shoe can be C-graded for different reasons, e.g. customer returns that are unsaleable in the future, mistakes and/or damages created in the production facility and mistakes and/or damages caused in the Inline and wholesale stores. If C-graded,
the FTW will be sent to the RYS-facility if they fulfill the requirements for recycling. There are several reasons why a shoe cannot be recycled. An example is the type of FTW that includes metal, like football shoes with metal cleats. When FTW does not comply to the recycling requirements, the FTW will be incinerated to recuperate energy, in the energy recuperation facility. This facility is located in Germany and is managed by an external party. Sporty pays a fee of €0.165/kg for all of their products to send their waste and get it processed.

Figure 3 presents an important incoming stream of the RYS-program, post-consumer FTW. This post-consumer FTW has to be collected to be able to recycle the FTW units. In certain Sporty Inline and SFS stores (exact data on locations unavailable), Sporty has special RYS-bins where customers can dispose their shoes. These shoes do not have to be of the Sporty-brand. The disposed shoes are then sent to the recycling facility located in Belgium via a third-party logistics (3PL) transport service. Sporty wants to scale up the number of processed FTW units without harming the business financially. The ultimate goal of increasing the number of processed units is a reduced environmental impact. Sporty wants to reach an increased input of EOL FTW through the stream of post-consumer FTW. The main reason for the focus on post-consumer EOL FTW is Sporty’s desire to provide the extra service to the consumer of being able to contribute something to a better environment. Improving the processes regarding pre-consumer FTW will be out of scope within this report, as these units do not involve the consumer.
2 RESEARCH DESIGN

Until recently, there was little focus on the RYS-program within Sporty Europe. Sporty has limited insights in the current set of processes involved in Figure 3. Knowledge is spread over the organization regarding the process of taking back the EOL FTW. This includes, amongst others, the location of the bins, how the retail stores perceive the process of sending the bins back and how the different processes work regarding both pre- and post-consumer FTW. Sporty has the perception that costs are higher than necessary at the moment. Costs were made and approved while they were not checked for optimality.

Sporty perceives the incurred costs of the take-back logistics network as one of the most relevant problems. The take-back of the RYS-bins is a completely independent transport stream, separated from other transports stream involved in Sporty. Quick calculations of the management team dividing the total costs made in 2016 and 2017 versus the total volumes in these years revealed that costs made in Europe were higher than in the USA. Sporty does not have detailed insights in the costs of the transport network. The project will need to identify the cost drivers of the current take-back solution. There are also no insights on potential future alternatives for this network, that could potentially reduce Sporty’s costs. Different solutions for a new design of the take-back network will have to be explored.

Sporty desires to increase volumes in the RYS-program to lower the environmental impact and therefore increase environmental performance. This will also increase the opportunity for Sporty to provide the consumer an extra service to contribute to a better environment by enabling them to dispose their EOL FTW in a responsible manner. Increasing volumes cannot be achieved if the program would harm the business financially with higher volumes. Before scaling up to bigger volumes, an advice on the design of the take-back network in the upcoming years is needed. As explained in Section 1.2, the focus will mainly lie upon analyzing the different processes regarding post-consumer FTW. Upon this analysis, an advice can be developed on how Sporty could continue in the future. This is a multi-criteria decision making problem that involves several aspects such as costs, environmental impact, market value and business feasibility risks.

2.1 Research Question

To justify the continuation of the RYS-program within Europe, a well-grounded advice will have to be presented. This advice should include which future scenario Sporty should execute and according to what design Sporty should realize that scenario. This advice can only be given if the different processes are well-understood such that the main points of improvement can be identified and the advice can be formed. The main research question should lead to this advice. This brings us to the following main research question of this thesis:

"How can the environmental performance of the take-back and processing activities of end-of-life footwear in the Sporty Shoe Recycling Program be improved, while minimizing the total cost?"

The main research question is an open question, of which the answer should be an advice explaining the point of improvements in the process and how these can be realized.

2.2 Leading framework

According to Aken et al. (2012), business problems are not given but chosen by stakeholders. They present the problem solving cycle. This cycle can be used as a framework when solving a business problems or a problem mess. There is few research to apply or develop such a framework in the context
of waste management problems and with multiple decision criteria. Inspired by the problem solving cycle, we developed a framework that could be applied to established industries which would like to redesign their waste management processes. This framework is presented in Figure 4. The framework will be applied in this report.

The first step of the framework is all about understanding the project. This step is presented in Sections 1 and 2. In these sections, the project is introduced, the problem is defined and the research questions are developed.

The second step focuses on analyzing the relevant processes. A literature overview will increase the readers knowledge on what already has been done regarding the discussed topics. This is presented in Section 3. In Section 4, the current state of the RYS-program is analyzed. That means the strengths and weaknesses in the processes regarding collecting and processing the EOL FTW will be assessed. This includes an analysis of both the costs and the emissions that are made throughout the different processes. This enables us to understand how the RYS-program works and how it is currently performing. Based on this analysis, points of improvement can be identified.

The third step is a quantitative scenario analysis. In Section 5 a multi-objective quantitative model is developed that indicates the quantitative performance for different theoretically optimal scenarios. These scenarios incorporate assumptions for e.g. the maximum capacity and the minimum of environmental performance that Sporty wants to achieve in terms of CO$_2$-e reduction. The analysis includes a sensitivity analysis to understand risks involved when quantities are changing. By executing this scenario analysis, insights are gained on the expected performance of both costs and emissions in different scenarios. This enables the management to improve informed decision-making. To facilitate decision-making, Section 6 presents the Analytical Hierarchy Process (AHP). There are different possible scenarios which Sporty can choose regarding volumes of EOL FTW units processed. Sporty will have to make a decision on their preferences regarding the trade-off between environmental performance and costs. Influencing factors such as risk and market value cannot be ignored in choosing

**Figure 4.** Applied Scientific Framework
this solution, but these factors are hard to measure and estimate. AHP is a method that quantifies management beliefs to facilitate decision-making. Based on the outcomes of the multi-objective analysis and the AHP-session, a strategic decision can be made between the scenarios that are possible to realize.

In the first three steps, the points of improvement will be identified and a decision should be made regarding the desired amount of FTW Units processed. In the fourth step, an analysis is done upon the different measures that should be taken to improve the identified aspects. These measures should reduce the discrepancy between the as-is situation and the desired future scenario. This is presented in Section 7. The take-back logistics network is perceived by Sporty as one of the biggest challenges. An extensive research on the potential future alternatives for this network will be conducted. Choosing a scenario which includes the desire of processing more EOL FTW units means abundant supply will need to be ensured. A strategy for increasing the supply of post-consumer FTW will be presented.

The final step is a set of strategic recommendations for implementation of the solutions. These are presented in Section 8.

2.3 Subquestions
To support the structure of Figure 4 to solve the problem, the research will be designed according to the following subquestions:

1. What is the current state of the whole RYS-program? - Section 4
2. What are the optimal solutions in a multi-objective approach of environmental performance and costs made in the RYS-program? - Section 5
3. What should be the preferred scenario in terms of yearly unit volumes for the RYS-program? - Section 6
4. How should the future take-back network be setup? - Section 7

The thesis will continue with a theoretical background in Section 3. This background provides the reader with relevant prior work regarding similar problems. Methods identified and explained in this section will be used in the following sections that focus on the subquestions. Finally, conclusions and recommendations will be presented in Section 8.
3 THEORETICAL BACKGROUND

In this section, a closer look will be taken upon the theoretical background regarding sustainable supply chains (SC), closed loop supply chains (CLSCs) and multi-objective optimization problems. A literature review (Alamdary Badlou (2017)) was conducted and this section will emphasize the most important outcomes of this report. This theoretical background aims to better understand the topics in the thesis. It will present existing research and models that could be used to solve the research questions and identify in which way this research could contribute to science.

3.1 Sustainable Supply Chains

In this section, a closer look will be undertaken on the incentives of incorporating sustainability and sustainable SCs into your strategy. The long term success of an organization is not only built on profitability anymore, but also on its contribution to the future of people and the planet (Barbosa-Póvoa (2009)). The awareness about the concept of sustainable supply chains is rising in both the industries and academic communities. Barbosa-Póvoa recognizes the definition of sustainability as defined by the World Commission on Environment and Development in 1987: "the use of resources to meet needs of the present without comprising the ability of future generations to meet their own needs".

Pearson (2015), managing director at Accenture, believes that establishing responsible and profitable supply chains can lead to an increase of revenues by as much as 20%, a decrease of costs up to 16% and a reduction of the carbon footprint up to 22%. Besides, they estimate a strengthening of the brand value of at least 30%. With sustainable-designed SCs improving revenue and brand reputation while decreasing cost and risk, acting ethically can provide companies with a real competitive advantage. Pearson presents a holistic view on how to create value through sustainable supply chains. Other frameworks identifying key elements in sustainable supply chain management were presented by e.g. Rogers (2011) and Ageron et al. (2012). These frameworks present how important it is to embed sustainability within strategy and culture. A key take away from these frameworks is that risk management and incorporating uncertainties should also be taken into account. Rogers (2011) refers to a study of IBM which shows that lack of risk management is the second greatest threat of global supply chains after lack of supply chain visibility. Translating this to the Sporty Grind project, uncertainties have to be taken into account when considering the strategic directions.

According to Linton et al. (2007), sustainable SC management extends beyond the core of SC management, such as minimizing fuel usage in transport. It also must integrate issues and flows such as product design, manufacturing by-products, by-products produced during product use, product life extension, product EOL, and recovery processes at EOL. This research project will especially focus on the last two topics, EOL products and their recovery process, in the sporting goods industry. Sporting goods and fashion product companies have to deal with a competitive environment and respond to consumer demand quickly. Fast fashion industries have extra negative impacts on environment due to the short life cycles of the products (Hu et al. (2014)).

Guide (2000) discuss complicating characteristics for remanufacturing firms. An important aspect is the cost to obtain the failed product and how it compares to the remaining value-added. Collection and transportation is one of the biggest hurdles within waste management programs. If Sporty decides to merge their take-back logistics flow with a different, already existing flow, allocating the handling cost is also an extra complexity. Corbett and Klassen (2006) state that at a minimum reverse logistics
must take into account the collection and reintegration of used products. Meanwhile, it should minimize the system-wide resource consumption. The timing aspect is also important and closely relates to reverse logistics. This is because Lead Times (LT’s) could be increased to lower the cost. For Sporty, there is no need to return the FTW as fast as possible to the recycling facility. When costs can decrease with higher LT’s, Sporty could accept that.

A subject hard to grasp is how the environmental performance translates to business performance. A lot of research was done on this important, but unclear subject. Articles by for example Corbett and Klassen (2006), Ortas et al. (2014) and Choi and Hwang (2015) present conflicting results. However, it seems that Sustainable SC management can not only benefit a company in terms of increased revenues or decreased costs. Some of these benefits are hard to quantify, such as employee motivation and increased organizational reputation.

**Thesis Contribution**
This Thesis could contribute to research by demonstrating the importance of sustainable SCs for a big sporting goods company and how it is applied in its business operations. Furthermore, it could develop a general model that can be applied to larger numbers of SCs, and it could incorporate a multi-objective approach that takes uncertainty into account.

### 3.2 Waste Management
This Thesis considers different waste management scenarios. Lansink (2017) developed a simple waste hierarchy framework that shows a preference sequence of what should be done with waste: Prevent, Reuse, Recycle, Energy Recuperation, Burning and Landfill. While the design of FTW at Sporty for example could prevent a big stream of waste, the project scope of the RYS-program is limited to Recycling, Energy Recuperation and Landfill. Landfill is the author’s assumption as end destination for all FTW that is not collected. As the machine has certain capacities and not all FTW in the world can be collected, a certain maximum of units within the system will be be considered within the scope. We will elaborate on this later in the report.

As a measurement for the environmental impact, a commonly used unit is the CO₂-equivalent or Global Warming Potential (GWP). As stated by Assamoi and Lawryshyn (2012), GWP accounts for the emission of greenhouse gases (GHGs), whose characterization factors are based on the model developed by the Intergovernmental Panel on Climate Change. They usually refer to a time horizon of 100 years (GWP100). GHGs refer to the gases present in the earth’s atmosphere which contribute to increasing temperatures through the greenhouse effect (CO₂, CH₄, N₂O). In the paper of Assamoi and Lawryshyn (2012) they write about municipal solid waste facilities that do energy recuperation, incineration and landfilling. An interesting outcome is their statement that the majority of the emissions come from their operations. The emissions from transporting the waste to the facility can be considered insignificant. In the following subsections, a closer look will be taken upon the different waste management options.

**Recycling**
Recycling of waste is defined as any recovery operation for which waste materials are reprocessed into products, materials or substances either to their original purposes, or for different ones. It includes the reprocessing of organic material but does not include energy recovery and the reprocessing into materials that are to be used as fuels or for backfilling operations (Eurostat (2017)). For Sporty, recycling means reprocessing the EOL FTW into Sporty Grind granular.
Within Sporty FTW, there are three significant materials which are the outputs of recycled FTW, namely rubber, a type of shoe foam (abbreviated as EVA) and the rest output, fluff. The Higg Materials Sustainability Index (HiggMSI (2017)) is a professional tool that provides access to a large amount of information about impacts of material production used in apparel, FTW and home textile industries. For example, the tool gives the information on the GWP of the produced material. This includes all the production stages starting from raw material sourcing until the finishing production step of the material. As the recycling facility recycles rubber and EVA and does not do anything with fluff yet, we look solely at the positive impact of the materials which can be reused after the recycling stage. According to the Higg MSI tool, the emissions of the different rubber compositions that are assumed to be used in Sporty FTW range between 4.63-6.29 CO\(_2\)-e. The weighted average of emissions needed for rubber production in Sporty FTW is estimated to have an environmental impact of 5.94 CO\(_2\)-e. For EVA, there is a more exact estimation as there is only 1 type of EVA. This impact is 4.92 CO\(_2\)-e. The following subsections will explain a little bit more about the materials involved.

**Rubber**

On average, Sporty assumes that 25% of a shoe consists of rubber. Jawjit et al. (2010) have presented a research concerning emissions of greenhouse gases associated with the production of rubber in the world’s largest natural rubber producer as of 2010 in Thailand. They created a visualization of the rubber processing sequence as can be seen in Figure 5. It starts with extracting the fresh latex from the rubber trees in liquid form. Consequently, it can be processed into primary rubber products, which are then processed into final rubber products. The most important primary (intermediate) rubber products include concentrated latex (raw material for dipped products such as medical gloves and condoms), block rubber (raw material for high viscosity products such as soles and belts), and ribbed smoked sheet rubber (raw material for vehicle tires and industrial rubber parts).

![Figure 5. Visualization rubber production, Jawjit et al. (2010)](image)

**EVA (Shoe Foam)**

The second material outputted is EVA (Ethylene-Vinyl Acetate) which is mainly used in the mid-sole of FTW (Lopes et al. (2015)). In the Global Ethylene Vinyl Acetate Market 2017-2021 report of Gabi (2017), there is further explanation of EVA. It is a tough and elastic material, has resistance to environmental stress cracking and water and is also known as foam rubber. In sport shoes, they are used as shock absorbers.
Fluff
The remaining 50% of the output is fluff. The definition of fluff according to the Oxford-Living-Dictionary (2017) is: "Soft fibres from fabrics such as wool or cotton which accumulate in small light clumps." Seeing and feeling fluff would make a person compare it to what we know as dust. Currently, there is no application for fluff at Sporty, but they do realize there is some potential. Sporty would like to find a market application for this type of waste too (and possibly gain some revenue from it). There is limited research on these market applications, but Chang et al. (1999) have examined the profile of recycled post-consumer fibers, comparable to fluff. They found the following potential applications of fibers: carpet cushion, home insulation, fiber stuffing, clean-up products, mattress pads/futons, geotextiles, landscaping, and concrete reinforcement. As fluff usually has different compositions, Sporty has to find out the possibilities with their fluff by conducting a fiber content analysis. Fluff could improve the positive impact of recycling even more, but is out of scope for the Master Thesis conducted.

Incineration and Landfilling
There are two, less preferable, waste management possibilities for Sporty FTW in the case the FTW is not recycled. The first one is energy recuperation, which is defined as the combustion of solid and liquid waste in controlled incineration facilities (Paustian et al. (2006)). According to IPCC, incineration and open burning of waste are sources of greenhouse gas emissions, like other types of combustion. Relevant gases emitted include CO₂, methane (CH₄) and nitrous oxide (N₂O). Normally, emissions of CO₂ from waste incineration are more significant than CH₄ and N₂O emissions. However, recuperating energy by incinerating waste is a better option for all non-recyclable waste compared to landfilling. All the post-consumer Sporty FTW that is not collected by Sporty, is assumed to be landfilled. There exists some research on the impact of energy recovery and landfilling, which is mainly focused on municipal waste, thus a big blend of components.

Jeswani and Azapagic (2016) researched the impacts of incineration and landfilling of municipal solid waste (MSW) in the UK. They state that earlier studies present different results, which is partly due to differences in energy recovery rates. In their literature review, they refer to reports finding a GWP of incineration ranging from -58 to 408 kg CO₂-e/ton MSW, while other papers find big differences between countries (-326 kg CO₂-e/ton MSW in Greece versus 172 kg CO₂-e/ton MSW in France). This is due to the fact that energy production from other sources is way more efficient in France, and thus the energy production resulting from energy recuperation will not save as much emissions compared to normal-produced energy. Jeswani and Azapagic find an environmental impact of energy recuperation that falls within the range of these aforementioned numbers (174 CO₂-e/ton MSW).

Morris (1996) did an energy conservation analysis on recycling versus incineration. The paper shows that for 24 out of 25 solid waste materials, recycling saves more energy than is generated by incinerating mixed solid waste in an energy-from-waste facility. A specifically interesting element of their paper is their estimations for rubber other than tires, regarding energy recuperation from incineration (11,505 kJ/kg) versus energy conserved by recycling (Between 67,000 and 229,000 kJ/kg). Morris admits these estimations are rough, but the fact that recycling conserves 6 times more energy on the low-end and almost 20 times more on the high-end, indicates the huge impact of recycling rubber versus incinerating it.

Cherubini et al. (2009) did a LCA on different waste management strategies. This was focused on the waste of the Municipality of Rome, Italy. They report a net GWP of 224 CO₂-e kg/ton MSW
for incineration to produce energy, versus 1914 CO\textsubscript{2}-e kg/ton MSW for landflling. They state that the critical point of a landfill is that it is not an isolated system. It should be considered as a chemical reactor which remains active for thousands of years. All the out coming chemicals will inevitably pass the landfill system and affect the environment. In order to minimize the environmental impact, a landfill needs to be monitored during all this time.

**Thesis Contribution**
Understanding and quantifying environmental emissions of materials is a subject hard to grasp, and estimations will have to be made. It became clear that different papers have slightly different estimations. Cherubini et al. report values that make sense when comparing to the other papers. We assume these values are the respective values for energy recuperation and landfilling. This Thesis could contribute to research by applying the used estimations into environmental performance models based on the different waste management options.

### 3.3 Closed-Loop Supply Chains
CLSC can be seen as the traditional forward SC supplemented by reverse operations for recovered products that are reprocessed and possibly re-entered in the forward SC. CLSC can be defined as ”the design, control, and operation of a system to maximize value creation over the entire life cycle of a product with the dynamic recovery of value from different types and volumes of returns over time” (Stindt and Sahamie (2014)). A major part in CLSC is the collection and its corresponding logistics of the EOL products, often described in literature as cores. Different definitions for the take-back process exist in literature, such as reverse distribution. Kannan et al. (2009) identify different forms of reverse distribution, collection and transportation of used products and packages. It can take place through the original forward channel, through a separate reverse channel, or through combinations of the forward and the reverse channel. A lot of research is done concerning quantitative CLSC models. These are often focused on the trade-off between costs and emissions. Unfortunately, a lot of the theoretical models presented in literature are quite case-specific and nearly impossible to implement within Sporty. The current transport network design of the Sporty CLSC is based on an express-pickup service of a 3PL-supplier. Whenever stores want to, they can send out a pickup order. Based on a standard courier service, they dedicate themselves to a delivery within five days throughout Europe.

Another issue in CLSC is the actual supply of cores. Currently, Sporty has dedicated RYS-bins in some of their stores. Sporty is exploring different ways on how to increase the collection of cores. This could involve an improvement of the current collection system or possibly a setup with e.g. domestic collection. Gaur et al. (2016) have dedicated an article for developing an action oriented framework on core acquisition. They state that core acquisition is one of the most critical steps of CLSC, but also one of the major barriers to success. This is due to the uncertainties with timing, quantity and quality of the EOL products. Their framework is based on eleven verified propositions and is one of the first papers in CLSC-literature that takes consumer disposition behavior into account. These are ranked according to AHP. For the framework, please see Figure 33 in Appendix A.

**Applied case of FTW Waste Management**
There exists some research regarding waste management and product recovery in the FTW industry. Staikos and Rahimifard (2007a) worked on a decision-making model for waste management in the FTW industry. This article was followed up with an EOL decision support tool for product recovery considerations in the FTW industry (Staikos and Rahimifard (2007b)). The first paper states that most EOL FTW are disposed in landfills and EOL FTW amounts are rising. The throughput time of a certain
collection in Sporty is based on fast-fashion and this leads to shorter life cycles of their FTW. Also, the footwear per capita has increased significantly from one pair per person in 1950 to 2.6 pairs per person in 2005. A framework is presented for the different EOL treatment options and their environmental impacts, economic values and technical requirements. This decision-making model can be found in Figure 6. The first step that can be seen is to design the shoe waste management model and identify the different waste management options such as reuse, reprocessing into the same product or other products, incineration and disposal. There are three scenarios of what can happen with EOL FTW within Sporty as mentioned before: Recycling the FTW in the Grind Facility, sending them to Energy Recuperation or not collecting them at all.

![Figure 6](image)

**Figure 6.** Staikos and Rahimifard (2007a): Decision-making model FTW industry

Donating is out of scope. There are good reasons why donating only happens on a low scale. These reasons may not be obvious. There is a strong debate about these activities, because of their overall environmental impact and the economic consequences for the local communities (Staikos and Rahimifard (2007b)). Collecting and distributing EOL FTW in developing countries brings post-consumer waste from the developed world to poorer countries without an infrastructure to deal with it, which has a negative effect on the environment. Also, it may lead to net economic damage. An example is Uganda where donations have significantly reduced the size of the local FTW industry. Thus, donation is not per se as good for third-world countries as it seems.

Figure 6 presents the set of criteria that are evaluated. These are quantitative economic and environmental factors as well as qualitative technical factors. To rank the different alternatives, Staikos and Rahimifard use Analytical Hierarchy Process (AHP) which they consider as one of the most comprehensive multi-criteria decision making methods. The AHP method decomposes a complex decision problem into a hierarchy and allows the consideration of both quantitative and qualitative factors. Application of the AHP method requires a structuring of the problem into a hierarchy,
making pairwise comparisons, calculating criteria weights and synthesizing the priorities. The decision hierarchy is structured such that the top level represents the overall objective, and the lower levels are the factors, criteria and sub-criteria upon which this goal is dependent on. Once the structured hierarchy is developed, the next step is to make pairwise comparisons of any two decision variables along the same hierarchical level. This is done using the fundamental Saaty scale (Table 2).

<table>
<thead>
<tr>
<th>Numerical rating</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Both criteria equally important</td>
</tr>
<tr>
<td>3</td>
<td>Very slight importance of one criterion over the other</td>
</tr>
<tr>
<td>5</td>
<td>Moderate importance of one criterion over the other</td>
</tr>
<tr>
<td>7</td>
<td>Strong importance of one criterion over the other</td>
</tr>
<tr>
<td>9</td>
<td>Extreme or absolute importance of one criterion over the other</td>
</tr>
<tr>
<td>2, 4, 8</td>
<td>Intermediate values between two adjacent judgements</td>
</tr>
</tbody>
</table>

Table 2. Saaty Scale

The relative weights of the decision criteria and alternatives need to be identified. From the set of pairwise comparisons a judgment matrix $A$ is generated with $n$ rows and $n$ columns. $n$ is the number of variables being considered.

$$A = \begin{bmatrix} A_{11} & \ldots & A_{n1} \\ \vdots & \ddots & \vdots \\ A_{1n} & \ldots & A_{nn} \end{bmatrix}$$

The next step is to calculate the waste management criteria scores in order to identify the relative weight of each waste management criterion. In Staikos and Rahimifard (2007b) for example, the benefit-to-cost approach (BCR) is used for the different waste management scenarios. For every quantitative criterion, a score can be made and compared. The technical criteria should also be calculated by using the AHP method. For these criteria, the weight value relies less on numbers and statistics but more on e.g. expert opinions and case studies. The final step in the AHP method is to calculate the final score of each scenario and rank them. In Appendix B, an extensive step-by-step example on AHP is given (Mu and Pereyra-Rojas (2016)).

**Thesis Contribution**

This section has improved our understanding on the definition on CLSCs. The Thesis will contribute by applying the framework of Staikos and Rahimifard (2007b) to an established multinational within the fashion industry. This framework focuses on a similar problem regarding FTW and gives a structured approach in a multi-criteria decision-making environment. Real-life applications of academic waste management models at established companies within this industry are sparse.

### 3.4 Multi-objective optimization

Managing and optimizing sustainable supply chains reveals multiple challenges involving social, economic and environmental issues (Saen et al. (2016)). In many real world cases these objectives could conflict. Building upon the previous section about CLSC, a majority of CLSC models in research include multiple objectives. Garg et al. (2015) remark that when comparing two different objectives, one should think about how the units of the objectives compare/scale to each other. In a multi-criteria optimization with environmental performance this certainly is a challenge, as measuring the units is hard and e.g. monetizing the $\text{CO}_2$-e value is a method hard to grasp and apply.
There is an abundance of multi-objective techniques, but it is key to choose the right one for your problem. Besides, within established industries the applied model should fit the business situation. Many quantitative multi-objective models in CLSC were developed, of which several are presented and/or reviewed in Garg et al. (2015), Stindt and Sahamie (2014), Nagurney et al. (2007), Mohajeri et al. (2014), Wang and Hsu (2010) and Paksoy et al. (2011). Many of these theoretical models focus on for example combining the forward and reverse network or assume easy adaptations to for example fleet sizes or facility locations. In Sporty’s case, there is not an owned fleet as 3PL-suppliers are used. The locations of the DCs and recycling facilities are fixed. The current forms of outbound transport to stores as well as Sporty.com are assumed to be fixed, as there will be no influence on these locations or changing the forward transportation network. These models can thereby not be applied to this project.

This means that a case-specific model should be developed. For this project, the ‘ε − constraint’ method is a good multi-objective approach. In this method, one objective is selected for optimization and the other objectives are reformulated as constraints (Chaabane et al. (2011)). The advantage of this method is that a single-objective optimization model is developed. The model does not need an adaptation of the units of environmental performance and costs, as the restrictions can be expressed in their related units. If a model is used that uses for example a weighted sum, this would incorporate an extra uncertainty factor in the correctness of the solution, because of the challenge to monetize environmental performance.

There are different methods to present the results in multi-objective optimization. Oh and Jeong (2014) used a well-known technique: The efficient frontier, also known as the Pareto Front. An efficient frontier graphs two conflicting objectives and visualizes those situations where there is no situation to improve the performance on one objective without deteriorating the other objective. The advantage of this method is that it is possible to graph the solution while only optimizing to one variable and constraining the other. A different method is the Lagrange multiplier method. In this method, mathematical optimization problems involving equality constraints can be solved and presented. However, our problem does not involve equality constraints, but constraints on maximums and minimums.

A good example combining the ‘ε − constraint’ method expressed in an efficient frontier is presented in the paper of Ramezani et al. (2013). They focus on a multi-objective stochastic model for a forward/reverse logistic network design incorporating responsiveness and quality level. They have three objective functions concerning maximizing profit, maximizing service level and minimizing the number of total defects in raw material obtained (Sigma quality level). While focusing on maximizing profit, they put constraints on the other objectives:

Customer Service Level $\geq \varepsilon_1$

Total Number of Defects $\leq \varepsilon_2$

The behavior of this model has been studied with some uncertain parameters (e.g. price, production costs, operating costs, collection costs, disposal costs, demands and return rates) which are described by a finite number of the possible scenarios. These different possible scenarios are connected to a probability, and based on those probabilities the final expected values are computed for the Pareto Front. Such an approach should be applied while developing the model within this report.
Thesis Contribution

In this section, a closer look was taken upon multi-criteria optimization models. A key takeaway is that the current models existing in CLSC are not directly applicable to Sporty. They assume the flexibility in some parameters which cannot be influenced, such as a location of the DC, the number of DCs etcetera. The $\varepsilon$-constraint method was explained. This method is suitable with the conflicting objectives of environmental performance, which is hard to monetize, versus costs. The results can be presented in a Pareto front, like Ramezani et al. (2013) did too. The report could contribute to scientific research by demonstrating how to develop this model. This would incorporate an analysis of environmental performance, the financial performance and company-related restrictions.

3.5 Scientific Relevance

This section zoomed in on the theoretical background of earlier scientific work which could be relevant in this project. The increasing importance of sustainability and sustainable SCs was reflected upon. A closer look was taken upon the different waste management models and their environmental performance in other researches. As the RYS-program is one of the most important manners of implementing a CLSC at Sporty, a section was dedicated to improve the understanding on what are CLSCs. Furthermore, a framework on evaluating FTW Waste Management alternatives was discussed. Many quantitative CLSC models involve multi-criteria optimization models. The $\varepsilon$-constraint and the efficient frontier methods were explained. While many valuable insights were gained, several gaps in literature were also identified. Barbosa-Póvoa (2009) elaborated on four gaps:

- Further work should be done on how to measure properly the environmental impacts
- General models of CLSC that are applied to large numbers of SCs are still scarce/non-existent,
- Sustainable supply chain structures should also incorporate uncertainty analyses
- Multi-objective approaches need to be explored encompassing all earlier mentioned gaps.

By developing a multi-objective optimization of the CLSC, these gaps can partly be covered. It would incorporate a method of estimating environmental impacts for the different waste management options, applied to the FTW industry. Developing the actual model in steps would give the reader guidance in how to develop such a multi-objective model. By doing sensitivity analyses, uncertainties could be incorporated within the simulation of the model.

There is little research on different take-back possibilities in real-life cases. Also missing is a method on how to evaluate the different alternatives in a complex environment of a multinational with different stakeholders and already implemented logistical processes. By diving deep into the take-back logistics network, new insights can be given into possible options of collecting EOL FTW and even EOL products in general.

Another part of this thesis will focus upon applying the framework of Staikos and Rahimifard (2007b) and developing AHP. This framework does not encompass the analysis of the current possibilities in the problem situation, neither does it involve take-back logistics. A framework is followed in this thesis that could be generalized and used in similar problem situations (Figure 4). This framework would be another big contribution to scientific research. It presents the method followed in this thesis and provides the reader with a structure in like-wise problems.
4 CURRENT STATE

The goal of this chapter is to understand the strengths and weaknesses of the different processes regarding collecting and processing EOL FTW. A closer look will be taken upon the different types of FTW that are recycled. To understand which future scenarios are possible, insights are needed on the capacity of the recycling machine. The costs of the recycling process are analyzed by checking the budget of FY17 and FY18 of the recycling facility, which is the only available data. Also, the take-back network costs are analyzed. Finally, we take a closer look on the environmental impact of recycling.

The data used in the formulas and figures are fictive due to confidentiality reasons.

4.1 Mapping the processes involved in the RYS-program

There are different processes distinguished in the RYS-program, such as the process regarding the retail stores with their RYS-bins and the returns-process. These are managed by different stakeholders within Sporty. Meetings with stakeholders within Sporty and at the RYS-facility were set up to clarify how these processes work. Tours at the RYS-facility and the Returns-facility in Belgium were given to get to know every single step in the process. This gave the opportunity to get insights on all the streams of FTW coming in at RYS (or potential streams that are not coming in), and understand different decision variables. The ownership of the many processes is divided over many different employees, thus specific knowledge usually is limited to a small part of the network. Because of that, the mapping of Figure 7 is valuable as it gives full understanding of what happens for the streams of FTW which could potentially end up in the recycling facility.

In the following subsections, a closer look will be taken upon the different processes. Figure 7 presents firstly how from the DCs in Belgium, the (still to be sold) FTW is delivered to the selling channels. These selling channels were presented in Section 1. They include Sporty-owned stores (Inline and SFS), Sporty.com and wholesalers. A small stream of FTW goes to other types of facilities for business purposes. An example is the EUHQ, where samples are needed for tests and demonstrations. In the following sections, a closer look will be taken upon the potential flow of a FTW unit from the different locations to its EOL. Each of the sections represents a location that is marked with bold borders.

**Sporty-owned Stores (Inline and Factory Stores)**

The Sporty-owned stores only participate in the RYS-program if a RYS-bin is present. In addition, the pick-up process must not face hurdles that could influence the end destination of the EOL FTW in the bins. It is unknown in which stores bins are present, as there are no correct data files for this. From an internal Sporty research, we do know that 38% of the 276 stores declared to own a bin in a survey in March 2017. The Sporty Store Locator on the website should indicate the stores with a bin, but does so incorrectly. Another problem could arise regarding the pick-up of a store-owned bin. Two of those stores are the SFS Stores in Utrecht and Eindhoven. It was not possible to discover examples of other stores, as this is not allowed by the Store Operations department. However, these examples show that there is still room for improvement for stores in the process to send back EOL FTW. When visiting the store in Overvecht there was a problem with signing in upon the pick-up order system. This caused that the General Manager had to throw away the FTW (even though he was willing to participate). In Eindhoven, there is a bin, but there are no records of incoming shipments from Eindhoven to the RYS-facility. It is thus clear that improvements within these pick-up processes and better collaborations with the Retail Stores are needed.
For the Inline Stores and SFS, there are both pre- and post-consumer types of EOL FTW streams. The post-consumer FTW are the worn shoes that are EOL. Consumers do not want to wear these shoes anymore and need a proper waste management option for disposal. They can discard these shoes in the RYS-bins located in the Sporty store. With this service, Sporty helps the consumer to contribute to a better environment.

A pre-consumer stream could include several types of problems which make the shoe unsellable, such as obsoletes and in-store damage. If the store decides that these FTW units are not sellable anymore, the units go into the bins. If there is a pre-consumer problem that is caused before arrival at the stores, the store will send it back to the Returns facility where there will be a check on the FTW

Figure 7. Process mapping RYS
and a possible refund to the store. The same holds for consumer claims and returns. If there is a return of a product that is still in excellent state and which is still in the store collection, the product will be resold at the store. If a product cannot be resold, and the claim is justified, it will be sent to the returns facility in Belgium. If the FTW cannot be resold and the condition is too bad to be sent back to the returns facility, the store can locally destroy it (which means they should put it in the RYS-bin).

**Wholesalers**

The next significant stream of FTW is from the DC to wholesalers. Examples of wholesalers are Footlocker, JD and Zalando. Once they receive Sporty FTW, they sell it through their own selling channels. In this process flow, Sporty receives requests for returns from the wholesalers who sent FTW back for a range of reasons such as consumer claims or excess inventory. The Returns facility will approve whether the returns can be sent back at all or not. If the wholesalers do not comply to the agreed-on restrictions, the FTW will not be allowed to be sent back to the Returns facility. This means the wholesaler will need to manage the EOL FTW waste themselves. A second option is that it is sent back, but the wholesalers will not get a refund, because they handled the FTW in a way that is not according to guidelines. If they do comply to the restrictions and the guidelines, the Returns facility will refund the full price to the wholesaler. The facility will further process the FTW.

The wholesalers will have EOL FTW in their facilities as well. While Footlocker sends these FTW units already to the RYS-facility, it is still unknown what happens with unsellable shoes at the other partners. For this project, it will be out of scope. Sporty’s first priority is to increase the inbound flow of EOL FTW via their end-consumers. It is important to mention though in the case they would need an even bigger inflow of FTW in the future.

**Sporty.com**

A special selling channel is the website of Sporty, Sporty.com; Via this website, consumers order their products and get it delivered at home or at special pick-up points. With their orders, they get the chance to return these products for up to 30 days if they decide not to use the product for any reason (misfit, satisfaction etc.). A 4PL-supplier specialized in reverse logistics is involved in this process. Via their warehouses, the products come back at the Returns Facility.

Consumers that buy from Sporty.com and are not coming to the stores at all, have no option to return their EOL FTW. They can mail it at their own cost to the recycling facility, but this happens rarely. Thus, a (yet) non-existing stream of post-consumer EOL FTW is a flow from the consumer directly to the RYS-facility. This could be domestic collection or collection via designated drop-off points. Realizing this existing stream is a potential improvement of the program in the future. This is a stream not necessarily exclusively for Sporty.com consumers.

**Returns Facility**

All the returns coming from the selling channels of the previous three sections, arrive at the Returns Facility. The earlier explained grading of the FTW (A-grade, B-grade, C-Grade) is done here. While all the A and B-grades are reallocated for distribution, the C-grades are immediately sorted. Almost all these EOL FTW units go directly into a big container, which will be transported to the RYS-facility. The costs are low and the trucks are full, so this is a process for which Sporty does not expect any further improvements. Only FTW that cannot be recycled, like the units that contain metal, are sent to energy recuperation.
**Other Facilities**

Besides the before mentioned FTW streams, there is an exceptional stream of FTW that could be entering the RYS-facility. One stream could be excess inventory from the DC. Unfortunately, Sporty will pay custom costs to bring EOL FTW from the DC to the recycling facility and this is a challenge to overcome. This is a problem that is being worked upon and thus will stay outside of the research scope. Another exceptional stream could be samples, such as from the EUHQ. These samples are merged with the RYS-bins coming from the EUHQ-store. Just like the EOL FTW coming directly from the wholesalers, these exceptional incoming streams from other facilities will be put outside the scope of the project.

**4.2 Recycling Process**

At the recycling facility in Belgium, an organization is supporting Sporty with the recycling activities. We will call this organization De Hurk. De Hurk participates in special projects to help decrease the gap for people to the labor market, that at the moment is too big for a diverse set of reasons. Their mission is to coach and supervise vulnerable people, to help them grow and find their place in society. This means these workers should be supervised by a supervisor during the whole day. With this collaboration, Sporty improves their corporate social responsibility activities.

Because of this setup, the process should take into account some special aspects. Currently, the workers are active 7 hours a day, of which 1 hour is dedicated to preparation and shut-down of the recycling machine. This means, the machine is running around 6 hours per day. In Figure 8, the amount of processed shoes over the last five years is visualized. It is fluctuating because of various reasons from both the supply and problems with the machine itself. There was a move to a new facility in November 2016. This new facility gave the capability for increasing numbers of processed shoes.

![Figure 8. Overview FTW Units Processed, fictive data](image)

Figure 8 shows a respective increase of respectively 11.1%, 6.6% and 4.5% for the final three half years. As we see a trend along time, we assume a constant increasing trend of 5% for FY17 Q3/Q4, FY18 Q1/Q2 and FY18 Q3/Q4. This means, we expect a total throughput of 162,000 shoes for FY18, rounded up. This estimation is based on the assumption that there are no major changes in the current RYS-program (e.g. increased marketing efforts). Around 170.1 million FTW units were sold by Sporty in FY17. This means around 0.1% of the FTW units sold is taken back currently. The bottlenecks in this process, assuming an abundant supply, are the sorting and the preparation of the FTW units before even going into the machine and the production rate of the shredder.

In theory, the machine itself could handle 5 shoes every 16 seconds, which means the production rate in theory is 0.3125 seconds/shoe on average. There are 260 working days in a year of 52 weeks with 5 working days per week. We assume that out of these 260 days, there is 30 days without production because of holidays, maintenance or breakdown. Thus, we assume a total of 230 working days. In an...
improved environment, we are assuming the workforce is available 8 production hours per day. This means a total of 6,624,000 seconds are available for processing in a year. We assume a 90% utilization (as expecting a 100% utilization does not include any extra inefficiencies or problems in the process). Based on these numbers, we can calculate the theoretical capacity of the machine, assuming no other bottlenecks from the workers and the supply:

\[
\text{Theoretical Capacity} = \left( 90\% \times \frac{6,624,000 \text{ seconds}}{3125 \text{ shoes/second}} \right) \times \frac{1}{2 \text{ shoes per pair}} = 931,500 \text{ units/year} \tag{1}
\]

This means the current expected utilization of the machine is around 17.4%, which is quite low.

Currently, there are 3.5 Full-Time Employees (FTE’s) working at the recycling facility that are subsidized by the government. From the 1st of January 2019, the facility may increase this to 5 FTE’s. Hiring 1 FTE costs around €21,000, which means a total of €31,500 would be necessary for this increase. It must be noted that these employees need a supervisor at all times. This should also be incorporated with the rostering and extra salary.

Several capital investments are available to increase this capacity by installing a pre-shredder, together with a metal detection unit and the running belt (€80,000), improving the shaking sieve with installing a rotary valve above (€8,300) and a zigzag replacement (€63,000). By installing a properly dimensioned pre-shredder, the throughput of the grinder will in addition be doubled. However, other bottlenecks would be revealed, of which no data is available. We will assume a rate of 0.5 shoe/second, which is an increase of 60% in the production rate. This would lead to an overall yearly capacity of 1,490,400 FTW Units. This would also require the extra FTE’s.

### 4.3 Financial Analysis

In this section, we will focus upon a thorough cost analysis of the RYS-program. The relevant cost that are incurred are the transport costs of the take-back logistics flow, and the operating cost of the recycling plant. For the recycling plant, there is limited data on previous incurred costs. We have the expected budget for FY18, and an overview on the made costs at the recycling plant of FY17. Together with the sustainability manager, assumptions will have to be made regarding the fixed and variable costs. Also, we need to know the revenue that we are able to obtain from the Grind, which is the granular output of the recycling process. This will give insights on costs, utilization and revenue. In Sporty, units of FTW are pairs, and not individual shoes. The final measurement unit to express the costs is €/pair. To express the formula of this recycling process costs, we reasoned according to the above stated logic and the formulas of Chaabane et al. (2011). This leads to the following costs formula with Fixed Costs ($FC$) for the recycling facility and Variable Costs ($VC$) for both the transport and the recycling facility, and subtracting the income of the grind after selling the output ($I_{Grind}$):

\[
\text{Total Costs per year} = FC_{recycling} + VC_{recycling} + VC_{transport} - I_{Grind} \tag{2}
\]

As, in the current situation, the average cost per shipment differs per country, we make a difference for all $n$ countries within our scope.

\[
\text{Total Costs per year} = FC_{recycling} + VC_{recycling} + \sum_{j=1}^{n} VC_{transport,j} - I_{Grind} \tag{3}
\]
After analyzing the costs made of FY17 and the budgeted costs of FY18, an estimation was made on the total costs of the facilities, separated into FC and VC. This separation had to be made based on assumptions, as there is no other data available which could indicate the cost behavior with changing volumes. In collaboration with the sustainability manager, the actual budget was analyzed and assumptions were made on which costs are variable and will change according to changing volumes. This budget can be found in Figure 9. The budget presents the costs on the waste management of fluff. There is a big opportunity here to reduce costs. If an application for this fluff can be found, these costs of €13,500 (VC of around €0.083/unit) could not only be avoided, but some revenue to cover the extra costs could be generated. Although the focus of the project is not upon this part, it is an important point to underline.

<table>
<thead>
<tr>
<th>Fixed Costs</th>
<th>Amount</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extraordinary Wages</td>
<td>€ 13,725</td>
<td>Account Management and working hours for knife sharpening</td>
</tr>
<tr>
<td>Water</td>
<td>€ 540.00</td>
<td>Sanitary/kitchen</td>
</tr>
<tr>
<td>Alarm Costs</td>
<td>€ 675.00</td>
<td></td>
</tr>
<tr>
<td>Knife maintenance</td>
<td>€ 16,200.00</td>
<td>Grinding blades will be done with same frequency, if volumes increase.</td>
</tr>
<tr>
<td>Insurance</td>
<td>€ 729.00</td>
<td></td>
</tr>
<tr>
<td>Rent Standard</td>
<td>€ 49,410</td>
<td></td>
</tr>
<tr>
<td>Service Cost Standard</td>
<td>€ 18,408</td>
<td></td>
</tr>
<tr>
<td>Labour cost RAS</td>
<td>€ 140,843</td>
<td>Note: Extra worker will cost around 23,000€ a year</td>
</tr>
<tr>
<td>Other</td>
<td>€ 22,950</td>
<td>Unexpected Expenses</td>
</tr>
<tr>
<td>Total FC Currently</td>
<td>€ 261,541</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Variable Costs</th>
<th>Amount</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Other Professional</td>
<td>€ 3,375</td>
<td>Services: Special cleanings, office maintenance</td>
</tr>
<tr>
<td>Electricity</td>
<td>€ 8,775</td>
<td>Heating, light and machine</td>
</tr>
<tr>
<td>Operating Supplies</td>
<td>€ 4,270</td>
<td>Bags for the grind etc.</td>
</tr>
<tr>
<td>420 Mail &amp; Shipping Expense</td>
<td>€ 675</td>
<td></td>
</tr>
<tr>
<td>480 Waste, destruction</td>
<td>€ 13,500</td>
<td>Fluff Waste Management</td>
</tr>
<tr>
<td>Total VC currently</td>
<td>€ 30,595</td>
<td></td>
</tr>
<tr>
<td>Total Units currently</td>
<td>€ 162,000</td>
<td></td>
</tr>
<tr>
<td>Total Variable Cost/unit</td>
<td>€ 0.1889</td>
<td></td>
</tr>
<tr>
<td>Total costs</td>
<td>€ 261,541</td>
<td></td>
</tr>
</tbody>
</table>

**Figure 9.** Overview of the estimated costs per year of the recycling process. Based on fictive data

The lower half of the budget in Figure 9 presents the cost aspects which are assumed to be variable. Based on the expected number of units (162,000) as presented in Section 4.2, \( VC_{Recycling} \) is computed. This is equal to €0.1889/unit. The function now becomes dependent solely on the amount of shoes processed, \( Q_{Recycling} \):

\[
FC_{recycling} + VC_{recycling} = 261,541€ + 0.1889€ \times Q_{Recycling} \tag{4}
\]

For the transport costs, an estimation has to be made based on a country-specific analysis. The transport is outsourced to a 3PL-supplier. For confidentiality reasons, we will name this 3PL-supplier Partner 1 in the rest of this Thesis. A dataset was obtained from Partner 1 which gives insights on the number of shipments made, the number of boxes per shipment and the cost per shipment, over the period of January-August 2017. This period is the best possible representation that we can analyze as it is the most current and specific data that we have. With the changing trend as presented in Figure 8, this current data is assumed to be the most similar to what is going to happen in the future. The countries active currently within the program, and their relative share of the 280 shipments in 2017 are visualized in Figure 10. This information is coming from a data file about all shipments, as provided to
Furthermore, a data file of the weight of every box arriving over the months of January 2017 until August 2017 is recorded by the recycling facility as presented in Figure 11. The average weight of a box is 11.94 kg. While in theory this data file should match completely with the data file of Partner 1, this is only the case for about 80% of the data. This means we cannot link weights of shipments to the cost of that particular shipment within the project time frame. It is important to make assumptions on the transport costs per FTW unit, as the rates themselves are per based on a per box basis.

To compute the average cost per box, one could simply take the total cost and divide those by the total number of boxes based on the period of Jan-Aug 2017:

\[
\text{Average Cost per Box over Period} = \frac{\text{Total Cost over Period}}{\text{Total Number of Boxes over Period}}
\]  

(5)

Figure 10. Relative shares of incoming shipments different countries (Jan - Aug 2017)

Figure 11. Frequency of different box weights in kg (Jan-Aug 2017)
Dividing this number by 11.94 kg, this leads to an average cost of €3.24/kg. We see that within a country, the cost per box per shipment is quite stable with minimal deviations. There are some exceptions though, for example in Spain, Portugal and Italy where there are high deviations between the cost per box for different shipments. Better insights in the costs could be presented if the weighted average per shipment is taken instead of the weighted average per box. This is due to the fact that the average cost per box could compensate expensive shipments from country A with cheaper shipments with more boxes from country B. Computing this number for shipment \( i \) in a certain period and dividing by the number of shipments within country \( j \) in that period gives the expected cost per box per country over the period:

\[
\text{Cost per Box}_i = \frac{\text{Cost Shipment}_i}{\text{Total Number of Boxes of Shipment}_i} \quad (6)
\]

\[
E[\text{Cost per box over Period}]_j = \frac{\sum_{i=1}^{\infty} \text{Cost per box}_i, j}{\text{Total Number of Shipments over Period}_j} \quad (7)
\]

In this way, the expected cost per box for a shipment can be expressed taking into account all the different prices for the different countries. Sporty wants to have insights into the total cost per kg, as this gives them better insights into how far the current costs deviate from the desired transport costs (€0.50/kg). The data set of the 3PL-supplier does not include the weights involved in the shipments though. This means costs cannot be directly linked to weights. As mentioned earlier in this section, the average weight of a box is 11.94 kg. Dividing the costs per box by the average of 11.94 kg/box, gives the expected transport cost/kg/country. The results can be found in Figure 12. The €0.50 threshold in the figure presents the desired transport cost in the future for Sporty. This value was determined in consultation with the global Sporty Grind team.

![Expected and Average Cost/KG per country (Fictive data)](image)

**Figure 12.** Expected Transport Cost/Kg/Country based on Fictive Data

With the previous calculations, we are able to find an expected transport cost per box, regardless of the country the extra box comes from. This is an important difference with the average costs, because it takes into account the fact that the given rates per box are not complying to the actual rates per box for some shipments. This takes better into account the shipments that were executed incorrectly, leading to higher bills. The average costs do this to a lesser extent, as a correctly executed shipment with a lot of boxes could mask the effect of the incorrectly executed shipments. Thus, formula 8 gives a
better indication of the costs that can be expected for future shipments than formula 5. To compute the expected cost per extra box for the upcoming year, we should take these costs, \( E[\text{Cost per box}]_j \), and multiply them with the probability that a shipment comes for a certain country \( j \) as we know from Figure 10.

\[
E[\text{Cost per box}] = \sum_{j=1}^{n} P_{\text{shipment}, j} \times E[\text{Cost per box}]_j \tag{8}
\]

Diving this number by 11.94 kg, this leads to an expected cost per kg of €3.71, taking into account the probability of the origin of the shipment. In the continuation of the program, Sporty could influence the volumes that are coming in per country both in an increasing or decreasing direction. This will be kept in mind for future strategic advices.

The data of the transport costs also enabled us to find causes of why costs were higher than expected and/or necessary. Five main causes were found.

1. The rates per country are supposed to be based on a per box basis. However, a high variability between cost/box has been seen in the countries of Portugal, Spain and Italy. It turned out that the variability and prices were so high because these countries do not have a fixed price per box. Because of that, the rates are based on weights which led to uncompetitive prices. For the rates, see Table 3 (*Without Spain, Portugal and Italy). The rates are fictive due to confidentiality reasons.

2. There were shipments which used alternate services than the service with the negotiated prices. While the Portal is supposed to be set up not to be able to choose another service, for some locations this was untrue. Because of that, for example France has an average price which is way above the given rate.

3. 3PL-suppliers measure weight in two different manners, the actual weight and the dimensional weight (based on the package size). The rate will increase if the difference between the dimensional weight and the actual weight is big. This means that either boxes were not full or boxes were bigger than they were supposed to be. What should be the proper size of the box will be elaborated upon in Section 7.3.1.

4. Additionally to the previous point, manual mistakes made by either Sporty or the 3PL-supplier were invoiced without checking. For example, when a manual error was made regarding the dimension (800 cm instead of 80 cm), this automatically impacted the invoice dramatically.

5. Every shipment that was rated correctly, was still around €0.30/box-€0.50/box higher than the given rates. This was due to changing fuel prices and some extra taxes. No improvement will be possible here.

Regarding possible revenues that partly cover costs, the negotiations for the pricing of the recycled EVA and rubber are currently ongoing. This is outside of our influence, as the Global Sporty Team will lead these price negotiations. The price for both rubber and EVA will for now be assumed to be €0.40/kg. As mentioned before, there is no solution for fluff yet. No revenue stream is expected yet for fluff.
**Table 3.** Rates per package Partner 1* (Based on fictive data)

<table>
<thead>
<tr>
<th>Belgium</th>
<th>Netherlands</th>
<th>France</th>
<th>UK</th>
<th>Germany</th>
<th>Spain</th>
<th>Italy</th>
<th>Portugal</th>
</tr>
</thead>
<tbody>
<tr>
<td>€8.41</td>
<td>€10.03</td>
<td>€13.38</td>
<td>€13.08</td>
<td>€11.42</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

### 4.4 Environmental Analysis

Sporty considers three different waste management options for their EOL FTW: Recycling, energy recuperation and landfilling. All of these options have a different environmental impact. To demonstrate how recycling reduces Sporty’s environmental impact, an environmental analysis concerning the three different waste management is conducted. This is relevant, as reducing environmental impact is the main goal for the RYS-program. The analysis will be expressed in CO$_2$-e units, which stands for Carbon Dioxide-equivalent, as explained in section 3.2. This focus is chosen, because it accounts for the GWP for other damaging substances than CO$_2$ such as NOx and particular matter. For this reason, CO$_2$-e is the standard metric in the Sporty sustainability reports.

Regarding recycling, there are two materials that are an output of the process and will be reused. These are rubber and EVA, each accounting for 25% per FTW unit. A FTW unit is estimated by Sporty to be 600 grams. This means that one recycled FTW unit will produce 125 grams of rubber and 125 grams of EVA. Based on the estimated emissions in section 3.2 for production of 1 kg of the used rubber in Sporty FTW (5.94 kg CO$_2$-e) and 1 kg of EVA (4.92 kg CO$_2$-e), one FTW unit saves 1.3575 kg CO$_2$-e that would have been emitted when producing these materials. The emissions involved in take-back transport and the electricity involved in the recycling process need to be deducted from that.

The overall average GWP per kWh in Belgium is 0.184 kg CO$_2$-e/kWh (Messagie et al. (2014)). From Figure 9, we know that we expect an electricity cost of €8775 for 162,000 pairs, which is equal to €0.0542 per pair. Based on recent researches, the average price in Belgium is around €0.215/kWh (Selectra (2017), StromReport (2017)). Dividing the price per pair by the price per kWh gives us a total energy usage of 0.271 kWh per unit. Based on the average GWP per kWh in Belgium, this means the extra emissions due to electricity in the recycling facility is 0.0499 kg CO$_2$-e/unit.

All newly registered trucks and buses in Europe must comply with the Euro-VI standard per January 1 2014. 3PL-suppliers are increasingly focusing on sustainability and environmental performance will thus only improve in the future. Therefore, we assume that all trucks in the network comply to the Euro VI trucks of the regulated Euro standards. According to a report presented by ICTT (2016), the average real world NO$_X$ and CO$_2$ emissions of Euro VI trucks in Europe are respectively 0.210 g NO$_X$/km (1 kg of NO$_X$ equals 298 CO$_2$-e/kg, EPA (2017)) and 0.895 kg CO$_2$/km. Using the CO$_2$-e/kg metric, this means the GWP/km is 0.9576. Sporty is not involved in the actual transport, and thus no data is present regarding the cubic capacities of the vans/trucks. We assume that in the current setup vans of 7 m$^3$, which was an internal estimation of the logistics team. The average size of the box is assumed to be 0.6 meter*0.4 meter*0.4 meter, with a cubic capacity of 0.096 m$^3$. This means in theory 72.92 boxes would fit in a truck. Dividing the earlier mentioned amount of 0.9576 GWP/km with the total amount of boxes gives us a total output of 0.0131 GWP/km/box. Based on the road distances of the key cities of the countries mentioned in the financial analysis and the weighted average of the number of shipments per country, the expected mileage per shipment is around 220 km. This finally leads to an estimated
emission of 2.8891 kg/box, and with the average weight of a box (11.94 kg) and an unit (0.6 kg) the final estimated emission is 0.145 kg CO\(_2\)-e/unit for transport. This will only decrease in the future as 3PL-suppliers are focusing more and more on carbon-zero transportation, using electric vans etcetera.

Putting all these results together, the emissions saved by recycling are estimated to be 1.3575 – 0.0499 – 0.145 = 1.1626 kg CO\(_2\)-e/unit.

As presented in Section 3.2, Cherubini et al. (2009) reported a result of the extra emissions for energy recuperation (224 CO\(_2\)-e kg/ton MSW) and landfilling 1914 kg CO\(_2\)-e /ton MSW. As these outcomes are well in line with other researches, and there is no other option within the project frame to have proper measurements or estimations, they are assumed to be correct. This means we assume that the extra emissions of energy recuperation are 0.1344 CO\(_2\)-e kg/unit and for landfilling 1.1484 CO\(_2\)-e kg/unit, based on a 600 gram FTW unit.

To translate this into the current environmental analysis, an assumption has to be made on the total amount of FTW units within the considered system. The theoretical capacity of the machine with capital investments 1,490,400 FTW Units. Based on this capacity, we assume the system to include 1,500,000 FTW units. This means that every FTW unit that is not send to either recycling or energy recuperation, ends up with an emission estimation equal to landfilling. There could be several reasons why FTW would be send to energy recuperation. A good example is the excess inventory at the DC, as Sporty has to pay customs if they want to recycle the FTW. Meanwhile, only the usual costs for energy recuperation are paid. These FTW units are thus not sent to recycling yet. Our final conclusion on the emissions per waste management option is as follows:

\[
\begin{align*}
\text{Emissions Saved Recycling} &= \left( 1.3575 - 0.0499 - 0.145 \right) \times Q_{\text{Recycled}} = 1.1626 \times Q_{\text{Recycled}} \quad (9) \\
\text{Emissions Energy Recuperation} &= -0.1344 \times Q_{\text{EnergyRecuperation}} \quad (10) \\
\text{Emissions Landfilling} &= -1.1484 \times Q_{\text{Landfill}} \quad (11)
\end{align*}
\]

### 4.5 Section Conclusion

This section has focused upon the current state regarding the RYS-program at Sporty. We saw in Section 4.1 there is limited data on which Sporty-owned stores own a RYS-bin on the moment. Some of the stores that do have a bin have a problem with the pick-up process. Improvements in store operations are therefore necessary. Other quick-wins for an increase of EOL FTW supply could lie within collaborations with wholesale partners. The EOL FTW units that were C-graded in the Returns facility and the exceptional stream (e.g. samples) are already sent in full truck loads. The problems with customs to send excess inventory of the DC to the recycling facility is a problem which is worked on.

The expected total throughput for FY18 is 162,000. Based on the theoretical capacity, this is still a utilization of only 17.4%. This is a significant finding and a major point of improvement. We saw that the expected transport costs were higher than the desired transport costs of €0.50/kg. Main cost drivers were rates that were not negotiated, using the wrong type of service, not using the right type of boxes (or not filling them) and invoicing mistakes.

Finally, an environmental analysis was presented. We saw the value of emission reduction of EOL FTW recycling versus the extra environmental impact of the other waste management options.
5 PARETO OPTIMIZATION

In the previous section, the current state of the recycling process was assessed and insights on how the program worked were gained. The goal of this project is to give an advice for the future direction of the RYS-program in the upcoming years. In the strategic decision-making, it is important to have insights on how the system will behave, given the financial and environmental performance that is expected. This section will provide the reader with the theoretical optima of the multi-objective problem we are facing. By plotting these points as a Pareto Frontier (Oh and Jeong (2014)), it can be visualized where the theoretical optima are for the RYS-project, how the current performance of the program is related to the theoretical optimum and how, further in the project, the possible scenarios decrease this distance to the theoretical optimum. Section 5.4 focuses on a sensitivity analysis.

5.1 The Multi-Objective Problem Formulation

The main objectives of the RYS-program are maximizing the environmental performance, while minimizing the total costs of the program. An increased environmental performance means more FTW Units would have to be processed. When more FTW Units are processed, higher costs are incurred. A trade-off will have to be made regarding these two objectives. As reflected upon in Section 3.4, the $\epsilon - \text{constraint}$ method is a suitable method to develop a model for the problem we are facing (Chaabane et al. (2011), Ramezani et al. (2013)). In this method, one objective is selected for optimization while other objectives are formulated as constraints. A mathematical model in R was implemented to find the theoretical optima in different scenarios, incorporating these constraints. The model developed focuses on minimizing the total cost. The other objective, maximizing environmental performance, is modeled as a constraint. The model also puts constraints on the maximum capacity, an important aspect in the strategic decision-making for Sporty which influences model performance.

Objective Function

The objective is to minimize the total costs ($TC$). The decision variables are based on the waste management options for Sporty. Thus, the amount of shoes that are respectively recycled ($Q_{\text{recycling}}$) and sent to energy recuperation ($Q_{\text{recuperation}}$) on a yearly basis. The rest of the EOL FTW units that are in the considered system and not collected by Sporty for these waste management options, are assumed to be landfilled ($Q_{\text{recycling}}$).

\[
\text{Minimize } TC(Q_{\text{Recycled}}, Q_{\text{EnergyRecuperation}}) = C_{\text{Recycling}} + C_{\text{EnergyRecuperation}} + C_{\text{Landfill}}
\]

\[
= C_{\text{Recycling,Fixed}} + C_{\text{Recycling,Variable}} - I_{\text{Recycling}} + C_{\text{Transport,Recycling}}
\]

\[
+ C_{\text{EnergyRecuperation}} + C_{\text{Transport,EnergyRecuperation}} + C_{\text{Landfill}}
\]

\[
= C_{\text{Recycling,Fixed}} + C_{\text{Recycling,Variable}} \cdot Q_{\text{Recycling}} - p_{\text{Recycling}} \cdot Q_{\text{Recycling}}
\]

\[
+ C_{\text{EnergyRecuperation}} \cdot Q_{\text{EnergyRecuperation}} + C_{\text{Transport}} \cdot (Q_{\text{Recycling}} + Q_{\text{EnergyRecuperation}})
\]

\[
+ C_{\text{Landfill}} \cdot Q_{\text{Landfill}}
\]

The costs for recycling have been presented in Section 4.3. The costs of energy recuperation are €0.165/kg, which is a given price that Sporty has to pay. This is equal to €0.099/unit. There are no costs for landfilling, as this is the assumption when FTW is not collected. In section 4.3, we also presented an ideal desired transport cost for Sporty in a future setup. This was equal to €0.50/kg or €0.30/unit. These costs have to be accounted for those FTW Units that are both taken back for recycling and energy recuperation. A sensitivity analysis will be conducted for the case that the costs of a new take-back network turn out to be higher. The price of the output influencing the income of the
recycling activities is estimated to be €0.40/kg, based on current negotiations by the Global Team. It is expected that this is the minimum price, which can only increase. As 50% of the granular output of a 600 grams unit can be sold, the income is equal to €0.12/unit. We translated these values into the parameters of Formula 14:

\[
= 261,541 + 0.1889 \times Q_{\text{Recycling}} - 0.12 \times Q_{\text{Recycling}} \\
+ 0.3 \times (Q_{\text{Recycling}} + Q_{\text{EnergyRecuperation}}) + 0.099 \times Q_{\text{EnergyRecuperation}} \\
= 261,541 + 0.3689 \times Q_{\text{Recycling}} + 0.399 \times Q_{\text{EnergyRecuperation}}
\]  

**Constraints**

Within the constraints, we develop different scenarios. These impose constraints on the minimum environmental performance \( \varepsilon_1 \) and the maximum capacity \( \varepsilon_2 \). \( e_{\text{RubberProduction}} \) and \( e_{\text{EVAProduction}} \) are negative, because the prevention of production emissions. This occurs because of the reuse of these materials instead of using newly produced rubber and EVA. We explained this in Section 4.4.

\[
\text{FTW Units in System} = Q_{\text{Total}} = Q_{\text{Recycling}} + Q_{\text{EnergyRecuperation}} + Q_{\text{Landfill}}
\]

\[
Q_{\text{Recycling}} \leq \text{Capacity Machine}
\]

\[
\text{Extra Emissions Outputted} = e_{\text{Recycling}} \times Q_{\text{Recycling}} + e_{\text{EnergyRecuperation}} \times Q_{\text{EnergyRecuperation}} \\
+ e_{\text{Landfill}} \times Q_{\text{Landfill}} - e_{\text{RubberProduction}} \times Q_{\text{Recycling}} - e_{\text{EVAProduction}} \times Q_{\text{Recycling}} \\
= (e_{\text{Recycling}} - e_{\text{RubberProduction}} - e_{\text{EVAProduction}}) \times Q_{\text{Recycling}} \\
+ e_{\text{EnergyRecuperation}} \times Q_{\text{EnergyRecuperation}} + e_{\text{Landfill}} \times Q_{\text{Landfill}}
\]

\[
\text{Extra Emissions Outputted} \leq \varepsilon_1
\]

\[
\text{Capacity Machine} \leq \varepsilon_2
\]

In Formula 23 the actual values are applied. The values were presented earlier in Section 4.4.

\[
\text{Extra Emissions Outputted} = -1.1626 \times Q_{\text{Recycling}} + 0.1344 \times Q_{\text{EnergyRecuperation}} \\
+ 1.1484 \times Q_{\text{Landfill}}
\]

With our main focus on the positive effect of \( Q_{\text{Recycling}} \), we focus on the positive part of the emissions that are reduced by recycling the shoes. This means Formulas 21 and 23 are multiplied by -1 in the implemented model.

\[
\text{Emissions Reduced} \geq \varepsilon_1
\]

\[
\text{Emissions Reduced} = 1.1626 \times Q_{\text{Recycling}} - 0.1344 \times Q_{\text{EnergyRecuperation}} - 1.1484 \times Q_{\text{Landfill}}
\]

**Scenarios Considered in the model**

The model can be ran for different scenarios of the constraints. We will put constraints on the capacity of the machine, and the minimum environmental performance (expressed in emissions reduced). As we need to develop a limited set of scenarios, we chose an arbitrary interval value of 300,000. This leads to a total of 24 scenarios including all possible sets of:

\[
\text{Emissions Reduced} = \varepsilon_1 = (0; 300,000; 600,000; 900,000; 1,200,000; 1,500,000)
\]
Capacity_{Machine} = \varepsilon_2 = (600,000;900,000;1,200,000;1,500,000) \tag{27}

The constraint on the emissions reduced starts at 0 (reflecting the situation where environmental performance has little relevance) and ends at 1,500,000 kg CO_2-e, which is the maximum number of emissions reduced with the maximum theoretical capacity after capital investments, taking into account the arbitrary interval value of 300,000. The minimum capacity of the machine is based on the current capacity of the machine. The maximum capacity of the machine is based on the theoretical maximum of the machine, as presented in Section 4.2. \( Q_{Recycling} \) will never exceed this capacity. It is possible that some of the scenarios do not have a valid solution as the capacity does not allow the minimum environmental performance. This is another important insight that will be gained from the model.

**Sets and Parameters**

The following parameters were considered:

- \( TC \) = Total Cost per Year
- \( C \) = Cost per Waste Management Option per Year
- \( c \) = Unit Cost per Waste Management Option
- \( I \) = Income per Year
- \( p \) = Unit Price
- \( e \) = Unit Emission Output
- \( Q \) = Units Processed per Waste Management Option per Year
- \( \varepsilon \) = a constraint to be applied.

In the following section, the results will be presented.

### 5.2 Developing the Pareto Curve

In literature, several methods for multi-objective optimization are presented. A Pareto curve is a commonly used tool to present the results in multi-objective optimization. In this curve, the data points are identified where there is no possibility to improve one objective function without maintaining or improving the other objective functions. The axes we will use plot the costs versus emissions. With a Pareto curve, different scenarios can be plotted ranging from a cheap, but low-performing environmental solution to the most expensive (and risky), but best-performing environmental solution. Consequently, based on the decision-maker’s preferences, several methods can be followed to make a decision on which direction to go, which will be presented in the next section.

After running the model as presented in Section 5.1, we can plot the results of the costs versus the amount of emissions reduced as presented in Figure 13. In Appendix E, we find the numerical values of the parameters. As we expected, the better the environmental performance is, the more it will cost in absolute terms. 7 out of 24 scenarios were not possible, as the capacity of the machine was not enough to comply to the constraint of minimum number of emissions reduced. The data points on the actual efficient frontier are those scenarios with an abundant capacity. The amount of FTW units sent to energy recuperation for these solutions is 0 and the amount of FTW units that are recycled is minimized while complying to the constraints. This means that cost-wise the amount of FTW not collected (and thus land-filled) is maximized in these cases, while complying to the requirements. The fact that these data points are on the efficient frontier, tells us that shifting a shoe from landfill to energy recuperation (to improve environmental performance) or from recycling to energy recuperation (to reduce costs) will distance the total multi-objective solution further away from the efficient frontier. Thus, the model shows it is recommendable to allocate all the money available for waste management for recycling.
purposes. The non-optimal solutions are those solutions where the capacity of the machine is fully used for recycling, but it is still needed to collect units for energy recuperation to fulfill the emission requirement.

Even though the total costs increase with increasing environmental performance, Figure 14 presents how the total costs/unit decrease while increasing the amount of FTW recycled. This is also as expected since the fixed cost of the recycling process will be spread out over more units, meaning that the recycling costs/unit decrease when the total amount of FTW units to be recycled increases. In the bottom left corner of Figure 13 and the upper left corner of Figure 14 an outlying data point that is plotted in red can be found. This is the result with $Q_{\text{Recycling}}$ equal to the expected quantity of the current situation; 162,000 (Section 4.2). This data point has a very low utilization. This shows how bad the performance of the current state is, as the environmental performance is very low and the unit cost is very high. A first step to come to the Pareto Optimal solutions would thus be to increase the utilization.

In Section 6, we will evaluate a set of scenarios that can actually be realized in terms of amount of FTW Units processed. The figures demonstrate valuable results to better inform Sporty what will happen with the environmental performance and expected costs for the different scenarios. This will lead to a better supported decision-making process.

5.3 Model Validation and Verification

The purpose of verification and validation is to increase confidence in a model (Robinson and Brooks (2010)). According to them, validation is the process of ensuring that a model serves the purpose at hand. Verification is the process of ensuring that the mathematical model designed produces accurate results. From a philosophical point of view, they state a model can only be proven invalid. It is impossible to prove a model is valid, but the purpose of validation and verification is to increase confidence in a model. Here the term confidence is not defined as the statistical confidence in a model, but the overall belief in the model and its results. Sargent (2013) confirms that a set of tests and evaluations should be conducted to obtain sufficient confidence for the model to be considered valid for its intended application. Sargent states that validation and verification of every modeling project is a new and unique challenge. There is no set of specific tests that can easily be applied to determine the correctness of the model. They present several techniques which confirm the validity of the model and/or verify it. In the remainder of this subsection, we will define and discuss several of these techniques.
**Face validity**

The face validity can increase model confidence by asking individuals that are knowledgeable to the situation to assess the model on its goals, behavior and results. The results were presented to three managers active in Sporty’s sustainability department. They confirmed that the model output is valuable as it gives insights on the total costs for different values of $Q_{\text{Recycling}}$. Also, the insights of increasing total costs and decreasing unit costs is of relevance for strategic decision-making. The prove of the multi-objective model that all the budget available should be dedicated to recycling (instead of energy recuperation) further contributes to increased insights that the model produces. This increases our confidence in the validation of the model. Moreover, the input-output relationship were found reasonable. The behavior of the costs are logical, just as the actual value of them. Thus, the face validity technique also increases our model confidence regarding verification.

**Animation and Operational Graphics**

Visualizing results is a technique that enables a person to have a broad understanding about the model behavior and results, without diving into the numbers. For this reason, Figures 13 and 14 were already presented. These figures also support the validation and verification of the models. We increase the confidence of the validation of the model by examining the figures and realizing the purpose at hand: Seeing the relation of the total costs and unit costs versus the environmental performance. Besides this, the results show a behavior which seems logical and feasible, which also support the verification of the model.

**Degenerate tests**

The degeneracy of the model’s behavior is tested by evaluating an appropriate selection of values of the input parameters. An extensive analysis of the parameter values was undertaken in Section 4, which argues that the parameter values are appropriate. A part of the parameter values is based on assumptions. To challenge these assumptions, Section 5.4 presents a sensitivity analysis. The sensitivity analysis is a further extension of testing the degeneracy.

**Extreme condition test**

A test on extreme values of the system or unlikely combinations of a level of factors should be done to further increase the confidence regarding verification. Regarding extreme values, we did a simulation with the boundaries for $\varepsilon_1$ and $\varepsilon_2$ increased by a factor 10, which is a highly unlikely, but a theoretically possible situation. If the amount of FTW Units in the system is not increased, the model experiences problems as the amount of FTW units in the system are way below the capacity, which makes it hard to comply to the emission constraints. This error increases the model confidence since it demonstrates that the model incorporates the maximum amount of FTW Units considered. For the initial extreme value test we wanted to execute, we thus also need to increase the FTW Units of the system. Having done that, the model still demonstrates similar behavior and produces similar results compared with the assumed parameter values. Another run was done where the capacity of the machine was set as 0. As expected, the model gave no feasible solutions. There is no feasible solution as the emissions reduced for the other waste management options are negative, while $\varepsilon_1$ remains a positive constraint.

For other unlikely combinations of factors, we looked at the constraints. We saw in Section 5.2 that there is no feasible solution when the capacity of the machine is too low to comply to the emission constraint. Also, there exists no solution where $Q_{\text{Recycling}} > \text{CapacityMachine}$. This increases our confidence regarding the constraints that were developed according to the '$\varepsilon - constraint'$ model. We
also ran tests in which $Q_{\text{Recycling}}$ or $Q_{\text{EnergyRecuperation}}$ are set equal to zero. In all cases, we saw that $Q_{\text{Total}}$ would still equal the number of FTW Units in the system.

**Tracing**
In the tracing technique, the behavior of the entities within a model is traced (followed) along the code to determine whether the model’s logic is correct and if the necessary accuracy is obtained. The logic of the multi-objective problem formulation in Section 5.1 was checked thoroughly before implementing the model. Then, the code was traced alongside these formulas in order to check whether the code was implemented as intended. No discrepancies were found. The previous validation and verification techniques confirm that.

The different validation and verification techniques all increased the confidence of the model. None of the techniques used demonstrate that the model was not valid or could not be verified.

### 5.4 Sensitivity Analysis
The presented model is based on the assumptions of having abundant supply, reaching the optimal transport cost of €0.30, not including investment costs in the yearly costs and neglecting the risk regarding deviations of the estimation on environmental performance. These uncertainties are risks that should be taken into account. Thus, several sensitivity analyses will be conducted to assess what happens if these risks turn out to become reality. All the numerical values of the sensitivity analyses are presented in Appendix E.

**Sensitivity Analysis 1: Increased Transport Costs**
The biggest gap between the current state and the desired state is due to the transport costs. In an ideal situation, Sporty aims for a transportation costs of €0.30/unit. Sporty should keep in mind the risks of not achieving the aimed for transport cost/unit. Thereby, the first sensitivity analysis increases the transport cost per unit from €0.30/unit to €0.60/unit ($= €1/kg$). This will logically lead to increased costs for the same environmental performance, as shown in Figures 15 and 16. The costs per unit also increase due to the increased transport costs, but still decrease for increasing volumes. Therefore, the interpretations of the model will not be different when transport costs turn out to be higher.

![Efficient Frontier: Cost versus CO2-e reduction](image1)

![Unit Cost versus Quantity](image2)

**Figure 15.** Sensitivity Analysis 1: Efficient Frontier  
**Figure 16.** Sensitivity Analysis 1: Unit Costs versus Quantity
Sensitivity Analysis 2: Including Investment Costs

In the given analysis, we assume we are able to have the higher capacities without investments. The scope here is strategic and focused upon the long-term future. The model could possibly change when the investment costs are incorporated. In Section 4.2 the one-off investments were presented. There is no exact data on the influence of a capital investment on the total theoretical capacity, so an assumption has to be made based on the explanation of the investments by the engineering consultant of the RYS-facility. We assume that a capacity investment of 900,000 processed FTW Units is based on the €8,300 investment. The investment to reach a capacity of 1,200,000 processed FTW Units costs €63,000 and the final investment to reach a capacity of 1,500,000 processed FTW Units costs €80,000. Furthermore, all investments would need an extra 1.5 FTE. Hiring 1 FTE costs around €21,000 per year, which means a total of €31,500 per year would be necessary for this increase. We spread these investment costs over a pay-back time of five years.

The costs per year of the different scenarios increase only slightly. This means that Figures 17 and 18 only have slight differences compared to Figures 13 and 14. These results are as expected. In the extreme case of maximum capital investments, we have a total cumulative investment cost of €182,000. Over a five-year payback period, this means an increased cost of €182,000/5 = €36,560 per year. This is an increase of <5% of the total costs. On a cost/unit level with 1,500,000 processed FTW units, this is an increase of €0.024/unit. The behavior of the cost is hardly affected. The sensitivity analyses showed that incorporating the investment cost should not influence decision-making.

Sensitivity Analysis 3: Lack of Supply versus Capacity

In all the previous analyses, there was no focus on the possible bottleneck of lacking supply. However, if there are less FTW units taken back than the capacity of the machine can handle, the situation of total costs and environmental performance changes. Figures 19 and 20 present the results if the supply is only 80% of the realized capacity.

With a lack of supply, only 6 out of 24 scenarios are able to comply to the constraints. This is a logical outcome as a lack of supply will make it harder to comply to the requirement of CO₂-e emissions reduced. This means only a few data points are projected in Figures 19 and 20. Two of these
data points are not visible, as they have an equal result regarding costs and FTW Units processed. With a supply of lower than 50% of the theoretical capacity, none of the scenarios is feasible. This is an important insight as the current utilization is only 17.4% (Section 4). With the current utilization, the value of emissions reduced will be negative for all these scenarios. The implications of these results is that the lack of supply is a significant risk, as it will negatively influence the environmental performance. For any chosen strategic direction, the number of FTW Units processed will be lower than possible, which means a decreased environmental performance.

**Sensitivity Analysis 4: Decreased differences in Environmental Performance**

In the final analysis, we will focus upon what happens if the difference between environmental performance per waste management option is not as big as assumed. This could be when improved facilities appear for Energy Recuperation and even Landfilling. Also, it could be that recycling incurs higher emissions due to transport or that the recycled materials do not reduce as much emissions as expected. A model was run with a 0.75 CO₂-e/kg for landfilling, 0 CO₂-e/kg for energy recuperation and a positive impact of 0.5 CO₂-e/kg for recycling. The results are presented in Figures 21 and 22.
As expected, the environmental performance decreases for every scenario. This means that less scenarios will be able to comply to the emission restriction with the given capacities. The results still implicate that all the budget available should be allocated to the recycling of FTW Units instead of sending them to Energy Recuperation. This risk should not influence strategic decision making.

5.5 Section Conclusion
In this section, a simulation model was made that gave us a closer look upon possible future scenarios and the optimization of them. We found that costs will indeed increase when environmental performance increases. On the other hand, we saw that the cost per unit will decrease with increasing volumes and thus increasing environmental performance. The outcomes of the model showed us that all the money that Sporty has for collection and waste management of FTW Units should be spent on recycling activities. Thus, Sporty will have to make a strategic decision on how much they want to invest in the upcoming years. The sensitivity analyses presented how important this decision is, as risks are present. One of the biggest risks is a lack of supply, which will decrease environmental performance significantly. An important take-away is that with the current utilization the emission reduction requirements cannot be met. The following section will apply AHP to make a strategic decision on where the program should go in the future.
6 SELECTING A PREFERRED SCENARIO

Through Section 5 insights were gained on the behavior of the multi-objective optimization model. It became clear that a trade-off has to be made between the costs and the environmental performance. This is dependent on the number of units that are processed in the recycling facility. This section continues with defining four realizable scenarios within the upcoming years. The first two scenarios, terminating the RYS-program and continuing with the current quantities, are obvious options when we look at the future. In the findings of Section 4, we saw that the utilization was low, so the third scenario focuses on improving the utilization rate. We saw in Section 5 that the cost per unit will decrease for increasing quantities. The fourth scenario is therefore based on the maximum capacity that can be achieved after capital investments.

The goal of this question is to find out which of the realizable scenarios is most aligned with Sporty’s management beliefs. This depends on multiple criteria. Inspired by the waste management framework of Staikos and Rahimifard (2007a), the preferred scenario can be found. This will be done by defining a hierarchical structure of the different involved criteria. The (sub-)criteria will be assigned weights, and scores will be given for each scenario. This is done according to the AHP-method as explained in section 3.3. Based on AHP, conclusions can be drawn regarding the strategy that best fits Sporty’s management beliefs.

6.1 Possible Scenarios

1. **Terminate the RYS-program.** If the RYS-program is ceased immediately, the existing problems with costs that were perceived to be too high will all be gone. The budget of these costs could be reallocated to other innovative, but yet undefined, sustainability projects. The scenario would be harmful for the environmental performance as the EOL FTW units will not be collected and recycled anymore, but landfilled (Section 5). Stopping the program could also harm Sporty’s brand value. A grounded explanation would be needed if e.g. the media would make a lot of commotion around it. Sporty has an existing process and is owner of the machine, so should decide what to do with all these capabilities and capital if they choose to terminate the RYS-Program. Finally, Sporty envisions circular economy as the future and this decision would contradict that vision.

2. **Continue with current quantities.** The advantage of this solution is that there is a low risk of extra excessive or unexpected costs, as Sporty is gaining experience with processing these quantities. Sporty could continue with its Sporty Grind brand, putting neither more efforts nor less efforts into it. The environmental performance would be equal. However, the utilization of the recycling machine would remain low which automatically means the cost/unit would still be higher than optimal. A higher utilization would mean an increased environmental performance. Continuing with these quantities would still mean an improved design is needed. For example, this solution would still need a take-back logistics redesign, such that the transport costs go down. Also, the operational processes in the stores will have to be improved either way.

3. **Invest for increased utilization of the recycling machine.** Currently, the estimated machine utilization is below 20%, as presented in Section 4.2. There is a lot of potential to increase the volumes processed without doing big capital investments. This means a huge win could be made regarding the environmental performance and cost/unit. Increasing processing quantities would mean there is more connection with the consumer, as more quantities will be brought back. This
solution would need a redesign of the working processes and employee schedules at the recycling facility. A boost in marketing of the RYS-program will also be needed to increase the supply of post-consumer EOL FTW. It would increase the total logistical costs and a redesign of the take-back network would become even more relevant to overcome the take-back logistics risks. Increasing quantities could also mean that new, but unknown, challenges may be faced.

4. **Capital Investments for increased capacity.** As demonstrated in Section 5, this would lead to the highest environmental performance and lowest cost/unit. On the other hand, this would lead to the highest absolute costs and incorporates the highest risks of all scenarios, because of the bigger quantities. Sporty will be confronted with new and unknown challenges and problems regarding the machine and handling those quantities. The logistical take-back network will be used the most, so if decreasing transport costs cannot be realized, the costs will become even more excessive. This means a significant increase of resources would be needed to ensure a proper redesign of the whole network, that is subsistent and able to handle the volumes.

6.2 Multi-Criteria Decision-Making Method: AHP

Sporty will make a strategic decision based on these scenarios. Such a strategic decision relies on different criteria such as costs, emissions, risks and complexity for a certain scenario. These criteria can differ per use case. Figure 23 shows an example of a hierarchical structure of criteria in a decision-making dilemma for End-of-Life Management options (Staikos and Rahimifard (2007a)). In this section, we will further elaborate upon the use case of this Thesis.

![Figure 23](image-url)

**Figure 23.** Decision criteria for Waste Management options, Staikos and Rahimifard (2007a)

To identify the important criteria, insights are needed that represent manager beliefs. A strategic session was initiated with the Director of Sustainable Performance, a sustainability manager who was involved in the RYS-program and a sustainability manager from ELC, not directly involved in the
RYS-program. With their different roles and backgrounds, they were able to give an advice based on different viewpoints. In the first part of the session, the hierarchical structure was developed. This structure is presented in Figure 24. We identify four main criteria:

1. **Economical Criteria.** These include three sub-criteria focused on the expected direct costs made in the RYS-program. The total operational cost per year is the expected absolute cost incurred per year, as given in the results from Section 5. The operational unit cost is based on the total operational cost per year and the amount of EOL FTW units processed per year. The investment cost is a one-off cost in case of investments. Whether these costs can be realized depends on budget availability. The management also needs to take into account the projected period over which they can 'spread' the investment costs, which makes a difference dependent on the time period e.g. 3, 5 or 10 years.

2. **Environmental Criteria.** For the case of the RYS-program there is one major sub-criteria, which is the total GWP-impact, as presented according to Formula 25 in Section 5.

3. **Market Value.** This is a topic somewhat harder to grasp because it is hard to measure. The first sub-criterion is the added value of the connect with the consumer. The RYS-program gives the opportunity for Sporty to connect with the consumer by providing them a service to bring back their EOL FTW and contribute to a better environment. The second sub-criterion is the level of alignment with the strategic fundamentals of Sporty. The third aspect is the public opinion. On the one hand, the public opinion can be positive by boosting your brand. On the other hand, it could be necessary to be involved in sustainable practices, because you want to avoid a risk of damaged brand value. Finally, we have the matter of distinctiveness versus competitors. This criterion answers the question on how far the program contributes to the matter of distinction of Sporty from other brands.

4. **Business Feasibility.** This criterion is mainly related to risks within the RYS-program along the value chain. If processed EOL FTW quantities should increase, it means that supply should also be ensured. This ties together with market efforts to gain volumes. Sporty must also take into account the risk when too much FTW is being brought back by the consumer. These risks are defined as the supply risks. Regarding the take-back there were already some problems, both regarding costs and the partnerships. The impact of these take-back risks will increase with increasing volumes. Once the EOL FTW units are in the recycling facility, they should be ready to be processed. With higher production volumes of the machine, the corresponding production risks will also increase. A facility restructuring would be needed which can be complex. New and unknown challenges could be faced when bigger quantities are incurred. To have a purpose for the costs made and for the recycling activities, the recycled rubber and EVA should be reused. There is a risk at stake when demand does not match supply. Thus, the final risk is the demand risk.

The next step in the AHP-method is to assign weights between the different main criteria, and between the sub-criteria that belong to a main criterion. This is done according to the Saaty Scale from 1-9 (Staikos and Rahimifard (2007a), Table 2). After introducing the hierarchical structure, presenting the definitions and explaining unclarities, each participant filled in their pairwise comparisons. Just as in Table 7 of the example in Appendix B, pairwise comparisons were made between the main criteria. Also, pairwise comparisons were made between the sub-criteria per main criterion. This was not done for the environmental criterion, as there is only 1 sub-criterion. When everyone was done, all
For every pairwise comparison, a consensus was made. While there were some differences in the initial scores, there were little problems coming to a consensus when everyone presented their point of view. The final step was to assign scores per scenario to each of the sub-criteria. These were scored based on a Likert scale from 1-7 (Steffers (2015)). As presented in Table 4, the scores are based on whether the new scenario deteriorates or improves for that sub-criterion regarding to the current business situation.

**Table 4.** Likert Scale for assigning scores to the scenarios, Steffers (2015)

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Major Deterioration</td>
<td>Deterioration</td>
<td>Slight Deterioration</td>
<td>Neutral</td>
<td>Slight Improvement</td>
<td>Improvement</td>
<td>Major Improvement</td>
</tr>
</tbody>
</table>

To determine the final scores, the same discussion method was used as with assigning the weights. The participants started with filling in the scores individually and came to a consensus after the discussion. Figure 25 presents the final weights that resulted from the pairwise comparisons after a group consensus. In the green cells, the scores per scenario are given. In Appendix C, similar figures are given based on the individual scorecards.
Figure 25. The final scores and weights assigned given by the Sporty EUHQ Sustainability team after consensus

Regarding the main criteria, we see that 'Market Value' turned out to be the most important criterion with a weight of 0.549. Especially the connect with the consumer and the impact of the public opinion are the most relevant sub-criteria of 'Market Value'. With a weight of 0.244, the environmental criteria is the second most important criterion. It is important to underline that the sub-criterion regarding the GWP-performance is the most important sub-criterion of all, due to its multiplication with its main criterion. For example: the total weight for 'Connect with Consumer' is $0.398 \times 0.549 = 0.219$ versus a total weight for 'GWP' of $1 \times 0.244 = 0.244$; 'Business Feasibility' is the criteria with the least weight, as the discussion panel expects the corresponding risks can be tackled. An interesting result can be seen regarding the demand risk. This was determined to be the most important risk, because the purpose of the recycling process will vanish if there is no destination for the rubber and EVA. The scores indicate that the situation will improve regarding the current situation. The reasoning behind this can be found from the point of view from the sports flooring partners. The higher amounts of rubber and EVA mean a more reliable supplier that can live up to its demanded quantities. Based on the weights and scores, the ranking of the scores can be calculated. The total ranking is presented in Figure 26.

![Overall Results AHP-Session](image)

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Weight</th>
<th>Economic</th>
<th>Business Feasibility</th>
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<td>Total Costs</td>
<td>Cost/Unit</td>
<td>Investment Cost</td>
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<th>Market Value</th>
<th>GWP</th>
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<tbody>
<tr>
<td>Connect with Consumer</td>
<td>0.549</td>
<td>0.244</td>
</tr>
<tr>
<td>Strategy Alignment</td>
<td>0.398</td>
<td>0.147</td>
</tr>
<tr>
<td>Public Opinion</td>
<td>0.301</td>
<td>0.089</td>
</tr>
<tr>
<td>Distinctiveness</td>
<td>0.098</td>
<td>0.098</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Scenarios</th>
<th>Total Score</th>
<th>Ranking</th>
</tr>
</thead>
<tbody>
<tr>
<td>Terminate RAS-Program</td>
<td>2.952</td>
<td>4</td>
</tr>
<tr>
<td>Continue Current State</td>
<td>4.000</td>
<td>3</td>
</tr>
<tr>
<td>Increase to Full Capacity</td>
<td>4.816</td>
<td>2</td>
</tr>
<tr>
<td>Capital Investment</td>
<td>5.250</td>
<td>1</td>
</tr>
</tbody>
</table>

Figure 26. Final Ranking of AHP-application based on the scores and weights of Figure 25

As Figure 26 shows, the best option turned out to be scenario 4. This was also the outcome for each individual participant, as can be found in the results of Appendix C. Increasing to full capacity also has a favorable score (4.82). Terminating the RYS-program has a unfavorable score that is lower than 4 (2.95) The results suggest that the number of EOL FTW units have to be increased. The advantages of doing capital investments are that large, that it is worth it to realize the investments.
6.3 Sensitivity Analysis

A sensitivity analysis was conducted to assess what would happen with the results if the hierarchical structure would change. In Appendix D, we present Figures 37, 38, 39 and 40. In each of the analyses, we excluded one of the main criteria. In every case, the ranking stayed equal. This means that scenario 4 with Capital Investments would still be the most preferred.

In Figure 27, we address the situation where we only look at the economical criteria and the business feasibility risks. We see opposite results, where terminating the RYS-program would be the most preferred scenario and doing capital investments the least preferred scenario. Another interesting result is that increasing to full capacity is still preferred over continuation in the current state. These results do not deviate from expectations. The most important reasons to execute the RYS-program are clearly the environmental and market value criteria.

![Figure 27. Sensitivity Analysis AHP with only economical and business feasibility criteria](image)

6.4 Section Conclusion

In this section, a multi-criteria decision-making method was applied to make a decision for a future strategic scenario regarding the RYS-program. We saw that the scenario where capital investments are being done was the most preferred scenario. The main reasons for this are the high assigned relevance for the environmental- and market value criteria of this program. In Section 4.2, we saw that the total capacity will be 1,490,400 processed FTW Units after capital investments. If we translate this result to the scenarios presented in Section 5 and Appendix E, we see that these quantities will enable the model to comply to the optimal solution with the highest emission reduction constraint. This solution has an utilization of 93.6% with 1,394,500 processed units. This means that the percentage of FTW units taken back compared to the total FTW units sold (170.1 million in FY17) should increase from 0.1% (162,000 units) to 0.82%. When only the economical and business feasibility criteria are taken into account, doing capital investments is the least preferred scenario and the whole RYS-program should in turn be terminated.
7 DESIGN OF THE FUTURE TAKE-BACK NETWORK

In the final subquestion, we take a look at an essential aspect for a successful continuation of the RYS-program, the take-back network. We have seen in Section 4 that there is a lot to improve in the take-back process that could decrease costs, improve operational processes and ensure supply. We include four main aspects along the supply chain:

1. Increased supply of EOL FTW Units
2. Improved store operations
3. Take-back logistics redesign
4. Redesign Recycling facility

In the following subsections, each of these aspects will be studied.

7.1 Market efforts to ensure increased volumes

One of the risks identified in Section 5, is a lack of supply. It will be important to think of ways to increase the amount of EOL FTW that consumers bring to the store. A structured manner to achieve this, is the action-oriented framework of Gaur et al. (2016) which is presented in Figure 33 in Appendix A. The framework starts in the upper right corner, and goes down step by step with decreasing relevance. It also takes consumer disposition behavior into account. We will discuss a set of the questions that are relevant in this project. We do not include the financial incentive requirements. This is because we do not expect it will be possible to tie a financial incentive to the program. The RYS-program should be a service to the consumer to contribute to a better world. Also, the legal requirements are not a current problem regarding the program.

**Do you have a proper ease of the return process?**

The process itself is simple, as a consumer can simply bring their EOL FTW to the store and throw the FTW into the bin, without a hassle. The RYS-bins are usually a bit hidden between the FTW racks. It would be a nice improvement to put the RYS-bin in a more visible place (or at least have some directions). The process could be even more simple if the consumer could hand in their EOL FTW via domestic collection, or via drop-off collection. This would require a change of the current take-back design.

**Do you have enough numbers of collection centers?**

According to a survey sent to the Sporty-owned stores conducted by Sporty around March 2017, only 106 out of 276 respondents (38%) have a RYS-bin in their store. This number can certainly be increased. Ideally, every store owns a RYS-bin.

**Is information on firm’s take-back offers available?**

Sporty has a website regarding Sporty Grind where the consumer is informed about the possibility of bringing their EOL FTW to the stores. However, it is hard to find information on the main Sporty.com website. The non-informed consumer will not be triggered to get to know more about the RYS-program when just visiting the website. Another essential input for customers is the earlier mentioned Store Locator, in which they can apply a filter for all stores with a RYS-bin. Unfortunately, as for January 2018, the store locator of Sporty.com does not have a well-functioning map. The map cannot be moved and if the filter 'owns a RYS-bin' is applied, the result is a location in the US. A first step would be to increase consumer awareness on where the current collection centers are and that Sporty is active in these recycling activities. Big wins could be made by improving website communications and
In the stores themselves, there is also limited information available. The RYS-bins themselves are quite big, but the bins are usually in a relatively hidden place and directories are lacking. As a result, the bins are easy to miss for a customer that is unaware of the RYS-program. Information could also be given through products and receipts. We will elaborate on that in the product documentation question that is following.

**Can you identify environmental consciousness of consumers?**
Sporty is a brand that is meant for consumers all over the world, of all ages and from all cultures. Previous sustainable innovations have been highly appreciated, so Sporty certainly has customers with environmental consciousness. If the awareness of the RYS-program would increase, Sporty expects that customer participation would increase with it.

**Can you identify consumers who are Purgers?**
Purgers are those consumers who, from the behavioral aspect, continuously explore the other options available to them related to substitute products and psychologically are quite willing to discard their belongings (Gaur et al. (2016)). We could identify those customers that are participating in the current RYS-program as Purgers who have explored and found the option available to discard their used shoes. Sporty can currently not identify which type of customers exactly are those Purgers.

**Does your national culture promote the returning used products?**
As the RYS-program is global, Sporty is not dealing with one national culture.

**Is your product documentation proper?**
Informing the consumer about the RYS-program could be a huge and easy quick win to increase awareness. This could be done through an extra flyer within the shoe boxes, a remark on the shoe box itself (which would be more environmental-friendly), or a remark on the receipts that customers receive. This would be an easy way to inform the consumer.

**7.2 Store Operations**
Educating the stores about how to work with the bins and arrange the pick-ups is proven to be a relevant factor to ensure supply and minimal costs. A standardized process will make the process easy for the stores, while errors are minimized. The IT-portal that the stores utilize to request the pick-up should be easy to use and standardized as well. A user manual should be available for the stores to fall back on if anything is unclear, and there should always be a contact person whom they can communicate with.

One of the problems in the current RYS-setup is filling the boxes when requesting the pick-ups. The box sizes differ per store. As there are no standard box sizes and the 3PL-rates are based on a package basis, it could be that bigger boxes could have been used. The 3PL-rates always use the actual weight and the dimensional weight, which is based on a special formula for the dimensions. If the dimensional weight exceeds the actual weight, costs could increase. Thus, it is important to fill the boxes as much as possible. Stores have to be educated on that as not all store managers seemingly realize this. All of this could be included in a manual which also explains the pick-up process, which is already done by Sporty. What Sporty could improve is making the user manual easier to find for the store manager. This manual is not in an apparent place on the internal Sporty website. Once Sporty chooses a strategic future solution, it should be first priority to have a standardized process, a good IT-portal, a manual that is up to date and a contact person with whom the store manager can always reach out to.
7.3 Take-back Network Redesign Scenarios

In Section 4 we presented the current setup for the take-back network, which is based on a parcel service of a 3PL-supplier (Figure 28). Within established supply chains of a multinational like Sporty, there are different possibilities to set up the take-back network. In Sections 7.3.1 and 7.3.2, we will focus upon the exploration of solutions that would still involve a transport stream independent from the other existing transport streams within Sporty. In Section 7.3.3, we will explore whether it would be possible to collaborate with the Returns-department and the 3PL-supplier involved for the returns flows. Section 7.3.4 will focus upon the possibilities of making use of the returning outbound trucks. Section 7.3.5 explores the opportunity to work with a collecting- and sorting partner. Finally, Section 7.3.6 will be an innovative exploration on an out-of-the-box scenario, where the whole RYS-program will be outsourced to a partner.

While researching the different take-back options, there are a few relevant aspects to consider. It is important to understand that the restrictions of the different solutions will be case-specific. For other companies in the sporting goods industry with different supply chains and partners, other flows could be more suitable as a recommended solution compared to the outcome in this paper. This also means the outcomes of the research will be influenced by the limitations of the partners and their willingness to collaborate. Zooming in on the RYS-program specifically, Sporty has no specific Lead Time (LT) restrictions for the FTW units as they are EOL. The only requirement is that the EOL FTW units will arrive in the recycling facility and not at any other final destination. A reasonable time frame for arrival of the units at the recycling facility would have to be agreed upon with the solution provider. Sorting does not need to be done by the partner, as this can be done in the recycling facility. It will be important that the partner is able to collect proper and relevant data, including at least the origin of the shipment, the number of boxes per shipment, the costs per shipment and the weight per shipment. Having this data in a proper overview would enable Sporty for quick detection of what type of shipments are costing too much in the future. This could influence which countries should be included in a future setup of the RYS-program. We will evaluate each design along six criteria that we think that can be important in the design of this take-back network.

1. **Costs.** The RYS-program is based on sustainable incentives, but it is still an objective to minimize the costs. A take-back network is desired that is as cheap as possible, which makes this one of the most important aspects to consider per design.

2. **Complexity.** An important factor is also the complexity of a certain redesign. The more complex a design is, the harder it is to manage the take-back network and the higher the risk of things getting wrong in the system. The ease of implementation is thereby an important indicator.

3. **Flexibility.** The RYS-program currently finds itself in a period where a lot can change. It is still not determined whether the Global team will choose for a change of strategic direction. Also, research on new technologies increases opportunities to improve recycling practices. Another aspect is that this project could result in a set of stores that will start (or stop) participating in the RYS-program. All of these potential changes are easier to cope with if the design and the partner are flexible.

4. **Partnership.** A good partnership where both partners can trust and rely on each other is perceived as important for Sporty. This could mean for example that communication is good. For the long-term, it can be essential to have a partner that is willing to think along to solve issues and improve the take-back network continuously.
5. **Quality and reliability risks.** There is no required LT of the take-back network. This does not mean it is not relevant to carry out the made agreements. It is for example important that 100% the EOL FTW Units for the bin will arrive at the recycling facility. Also the quality of the EOL FTW Units is important. An input of high quality would e.g. contain a lot of athletic FTW without metal and leather, but also without harmful chemical substances. The design of the take-back network could potentially influence this.

6. **Stakeholders.** Each setup will include a stakeholder analysis, discussing the most relevant advantages and challenges for the involved stakeholders. The involved stakeholders in this case next to Sporty are the involved partner, the stores and the customer.

### 7.3.1 Improvement of the current flow - Partner 1

Currently, a 3PL-supplier delivers individual shipments via a courier service from a store in Europe to the RYS-facility (Figure 28). We mentioned before that we will name this supplier Partner 1 for confidentiality reasons. In this section, we will research the future opportunity to continue and improve the design of the current transport flow which is independent from all other flows. We identify two possibilities: [1] an improvement of the current take-back logistics setup (Figure 28) or [2] an adapted design of the independent stream (Figure 29). In Figure 29 we see a design where the EOL FTW units are bulked in regional hubs. When the volumes of a FTL are reached, a FTL drives to the recycling facility. This design is an important one to consider, but Partner 1 was not able to collaborate in these business development practices during this project.

![Figure 28. Current take-back logistics setup](image)

![Figure 29. Adapted design of a setup with a parcel service](image)
**Costs**

In section 4.3, the main cost driver of Partner 1 turned out to be the shipments for Spain, Portugal and Italy. These rates were increasing for heavier packages. Meanwhile, the rates were more or less constant on a package basis for The Netherlands, Belgium, France, UK and Germany. A short-term negotiation improving the rates for these countries will get the costs down significantly. This would decrease the differences between countries as presented in Figure 12.

Sporty perceives that the cost/kg for EOL FTW is the most suitable unit to evaluate the costs of the transport. To calculate the average cost/kg for the future, we need to know the weight of a box. This means the size of the box has to be standardized, which was not been done before. Sporty could use the boxes which are used for the delivery of pre-consumer FTW to the stores. There are different sizes, such as 6-packs, 8-packs and 10-packs, given the number of shoe boxes that fit in there. The size of a 10-pack was measured with measuring tape in the EUHQ Store. The size is approximately 61.5cm*48.5cm*39.5cm (117,820 cm$^3$). We were able to test the how many FTW units would fit into a 10-pack. 37 FTW units fit into a 10-pack, with a weight of 12.7 kg. We would have to encourage stores to fill up the boxes as much as possible. In Table 5, the expected rates/kilo based on the rates/carton are presented, if everything goes according to plan and no mistakes are made anymore. This includes a small correction for extra taxes and fluctuating fuel prices, which would add around €0.04/kg.

<table>
<thead>
<tr>
<th>Belgium</th>
<th>Netherlands</th>
<th>France</th>
<th>UK</th>
<th>Germany</th>
<th>Spain</th>
<th>Italy</th>
<th>Portugal</th>
</tr>
</thead>
<tbody>
<tr>
<td>€0.70</td>
<td>€0.83</td>
<td>€1.09</td>
<td>€1.07</td>
<td>€0.94</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

We have to realize that these rates are already there, but did not turn out to be the actual rates on the invoices. This means cost savings still can be achieved. A redesign with these quick-wins should be implemented quickly, having fixed rates for Spain, Italy and Portugal. Reviewing the rates of Table 5 show that it will be difficult to reach the desired cost of €0.50/kg. Two other cost drivers were based on mistakes in the process. It should be prevented that any senders use a service other than the negotiated service and the boxes should be as full as possible to prevent significant differences between the actual weight and the dimensional weight.

A possibility would be to renegotiate the rates for all countries. Partner 1 could hereby increase the lead times and bulk up to bigger quantities for the longer distances, as displayed in Figure 29. Unfortunately, Partner 1 was not able to participate in business development meetings yet to discuss the new design of Figure 29 and fixed rates for Spain, Portugal and Italy.

**Complexity**

For the short term, the easiest solution is to continue working with Partner 1. The processes of this system are already set up, operations will be similar and there are several quick-wins for an improvement of costs. Also, this design only involves one partner and no other departments as it is an independent flow.

**Flexibility**

Because of the low complexity of the design, it is easy to for example add or delete stores to the take-back network. For small changes, we could say this design is quite flexible. However, during the
project it has proven to be quite hard to change processes and the design itself with this partner. This is important for consideration in the future. Especially when home pick-up or drop-off points will be under consideration. It seems like this design with Partner 1 is not fit for growth.

**Partnership**
An important aspect of a partnership is mutual appraisal and trust. It is doubtful whether the relationship between Sporty and Partner 1 is good enough. During the project, Partner 1 showed little support and willingness to collaborate, both for finding root causes of the excessive costs nor exploring innovative solutions. For the long-term, this might be a big downfall. A trustful and mutually appreciated relationship can be crucial for continuous improvement.

**Quality and reliability**
While several things went wrong in the last years within the RYS-program, the shipments themselves encountered few problems and were delivered within the expected time span. We do not expect quality and reliability problems for this design.

**Stakeholder analysis: Continuation partnership Partner 1**
- **The Consumer:** For the customer, there would be no noticeable change for this setup, as they can bring back their EOL FTW in the same manner as before.

- **Partner 1:** The advantage for this solution for Partner 1 would clearly be that they have continued business. Good relations with Sporty will not only be important for this transport flow, but possibly also other transport flows which Sporty has/could set up with this Partner. A renegotiation of the rates will not be an advantage for Partner 1, but they cannot avoid that it is fair to have competitive prices for every country. Renegotiating the service by redesigning the whole process could be a bigger challenge. If lead times are increased and bigger quantities are bulked, Partner 1 would have increased storage space and handling. Although, they would have more time to execute the shipments which gives them more space to optimize their transport flows. Above that, it gives Partner 1 the opportunity to actively participate in a transport flow with the purpose of sustainable practices. To conclude, changing processes could be a challenge for Partner 1 which can be both advantageous and disadvantageous. This highly depends on their own business capabilities. If the current situation does not improve, Partner 1 will lose a big partner in Sporty.

- **Sporty Stores:** The biggest advantage for this solution is that it does not require a system change. Thus, no training is needed for the store employees to work with a different system. There are some operational problems with the pick-up right now, like problems with the Portal, and standardization of the boxes. These problems will need to be fixed. It must also become easier to troubleshoot problems with a contact person. For the Sporty stores, it does not matter whether this is someone from the Sporty Transportation team or the Partner 1 team.

**7.3.2 Use of a 4PL-Supplier - Partner 2**
Another solution that would maintain the independent transport flow of the RYS-program is making use of a fourth-party logistics supplier (4PL) instead of a 3PL-supplier. A 4PL-supplier is an outsourcing supplier that neutrally manages the entire logistics process (Hingley et al. (2011)). A 4PL-supplier combines process, technology, management and different logistical providers. This means that the partner would manage the take-back network, but the design would not be much different as presented
in either Figure 28 and/or 29. Still, the use of a 4PL-supplier can have some extra advantages.

Partner 2 is a 4PL-supplier from the Netherlands. They have a special focus upon Reverse Logistics solutions. A brainstorm session was set up with them to discuss how a collaborative solution could look like for the RYS-program. There are many capabilities Partner 2 can offer, which have positive possibilities for the potential setup for the RYS-program. They have 18 DC’s all over Europe, including all the countries that are currently active in the RYS-program. As they are an independent party, they can use different 3PL-providers per country. They know the different markets and know the ‘local heroes’ with the best capabilities regarding to the service you need. In this case, a country-specific focus is possible through using providers that are as cheap as possible. From all the regional DC’s, they already have full linehauls being sent to their big central hub in Duisburg, Germany. This hub is around 160 km from the recycling facility. The current volumes in the RYS-program would not be able to fill linehauls from a regional DC to Duisburg, but Partner 2 indicated that Sporty can make use of the full linehauls while only paying the competitive unit price of the space/weight that is actually used.

Partner 2 is also able to set up an extended take-back design regarding drop-off points. This would mean that a customer is able to bring EOL FTW to a local drop-off point instead of coming to a Sporty store that contains a bin. This would enhance Sporty’s goal to provide their customers with a service to contribute to a better environment by choosing a sustainable waste management option for their EOL FTW. There are some challenges regarding the setup of such a network design. The first and most apparent thing are the costs. Partner 2 indicated that they expect a 400%-600% higher price than desired, because of the storage and handling costs of the drop-off point itself. It could also be that drop-off points start complaining as soon as EOL FTW Units are dirty, wet or smelly. Both Sporty and Partner 2 only have limited control on what customers will bring back. For now, there was no time for further and more specific research on this design. We would suggest this is subject to future research, if Sporty would like to take their take-back network to the next level.

**Costs**
Partner 2 indicated that the main cost driver for them will be in the first mile. After that, they have the capabilities of storing the EOL FTW Units and transport them in trucks that are possibly filled with other products also. Another important aspect is that they are independent of the 3PL-supplier, such that they can choose the cheapest ones per country. The other side is that they are still an intermediate 4PL-provider, instead of a 3PL-provider. This means an extra party is involved in the process which could drive the costs. The design would thus be similar to Figure 29. A primary test calculation was developed by them to give us the rates for the Netherlands (Cheapest country) and Portugal (Most expensive country). The respective rates were €1.35/kg and €4.54/kg. Reflecting on Figure 12, we see a lower expected price for Portugal, but a slightly higher expected price for the Netherlands. We expect slightly higher expected prices for the UK and Germany too. For Belgium, France, Spain, Portugal and Italy we expect an improvement of the current expected price. Looking at the overall costs of this design compared to the current design, we expect a cost decrease. Only if the ideal situation of Partner 1 could be realized, that design would be cheaper.

**Complexity**
From Sporty’s perspective, this design is a huge improvement regarding complexity as they do not have to manage the take-back network. Partner 2 is responsible for the setup in each country and will thus also manage the challenges. This is their expertise and they should be able to do so.
A strong asset of Partner 2 is their IT infrastructure. On the front-end, they have a user-friendly portal that can be designed both country and store-specific. On the back-end, the system is the same all over Europe, in every single DC. They underline the importance of data collection and are thereby able to collect all the data Sporty would like to be collected. This will enable Sporty to have better insights in costs and troubleshooting the root causes whenever and wherever costs are deemed excessive. Sophisticated data is an extra advantage regarding the complexity of the take-back design and understanding the performance of it.

**Flexibility**

As Partner 2 is independent, they can easily adapt to each country and market without being fixed to a 3PL-supplier. That enables them to set up a country-specific network with partners that best fit our needs. Furthermore, Partner 2 has proven that they are willing to think along our needs, build the solution together and are very clear in their communication. Partner 2 is a partner which would be able to grow along Sporty’s needs.

**Partnership**

Partner 2 is already a respected partner in other transportation flows of Sporty outside of the RYS-program. They have shown to be reliable, collaborative and flexible. Their headquarters are only a 20 minute drive from the EUHQ and they have a company culture that is similar to Sporty, with young and international employees. Their eagerness to collaborate in a mutually valued way means Partner 2 could become a valued long-term partner.

**Quality and reliability**

We do not expect big influences of this design on the quality of the EOL FTW Units. We do expect Partner 2 meets its agreements. What happens with the FTW Units in the respective countries is a bit harder to control, as different partners are involved. When data collection is as good as Partner 2 claims, these kind of problems should also be detected quickly.

**Stakeholder analysis strategic partnership with Partner 2: A 4PL-provider**

- **The Consumer:** If Partner 2 would just be used in a setup for taking back the bins, there are no noticeable changes for the customer. Partner 2 is potentially able to set up a network with drop-off points. This would give the customer an extra option to help for a better environment and dispose their EOL FTW. If the customer has the desire to recycle their shoes at their own cost without going to the store, Sporty gives the possibility to do so. This could be an extra advantage in the future for the customer.

- **Partner 2:** Partner 2 is a growing reverse logistics provider. Increasing business relations with Sporty and improving the mutually valued relationship is something that they will certainly desire. Furthermore, the RYS-program is a way of expanding their business with one of the most famous programs of circular economies in the footwear industry, which is good for their storytelling.

- **Sporty Stores:** Partner 2 has user-friendly portals, are strong in communication and try to make the processes exactly as we want it. Partner 2 is a flexible partner that is able to adapt to Sporty’s desires and and a constantly changing industry, which Sporty operates in. Working with Partner 2 could thus provide significant advantages.

**7.3.3 Set up a collaboration with the Returns-flow - Partner 3**

Many established brands in the fashion and sporting goods industry have a returns flow for products that were returned by the customer within a certain guarantee period. Reasons could include product
claims, misfits or wrong expectations of the product. Companies could make use of this existing returns flow to also take back their EOL-products.

For Sporty, a feasible option could involve a collaboration with the Returns Network and Partner 3, the 3PL-provider that is involved for the Returns of the Sporty stores. Stores have the possibility to send returns back to the Returns Facility in Herentals, which is near the RYS-facility. Returns are units that are not necessarily EOL, but have been returned from the customer and should be assessed again in Herentals. This transportation network is currently completely independent from the RYS transport. A potential possibility could be to merge these flows. In the Returns Facility, there is already a container for all the FTW Units that are C-graded. These will be brought to the recycling facility. A separate stream from the trucks containing RYS-bins to the containers should be easy to implement, according to the area managers of the Returns facility.

**Costs**

If this process would be set up perfectly, it could be a strong and cost-effective solution for Sporty, as the RYS-bins could partly make use of already paid for trucks. For those shipments that cannot profit from these trucks, a different setup would have to be arranged in a similar way like with Partner 1. As Partner 1 and Partner 3 are respected 3PL-suppliers from similar size, we also expect similar prices for these shipments. Overall, this is potentially one of the cheap solutions.

**Complexity**

Several brainstorm calls were setup with business development managers of Partner 3 to discuss the challenges of such a setup. The main complexity is that a solution would need to be found that integrates different flows. In Figure 30, we see the different possibilities of the setup design. Partner 3 has two types of transportation flows from Sporty Inline stores to the Returns Facility Herentals. The first one has weight-based rates, which is the case when a shipment contains < 10 boxes or < 3 pallets. We call this the Parcel Service. If the shipment exceeds this requirements, Sporty has to pay a fixed price for a full truck. We call this the Freight Service. A big benefit could be reaped if the RYS-bins will be loaded upon the Freight trucks as these trucks were already paid for whether the truck is completely filled or not. However, many stores will not have paid for the Freight service as they do not exceed the requirements. A decision has to be made whether the RYS-bins of those stores will be merged with the Parcel service (paying a weight-based rate, but still merging with Returns) or not. If not, the bins could be transported directly to the Grind Facility, or they can go to a local hub. If they go to a local hub, they can be bulked until they would fit into a truck that is coming nearby for a Freight service pick up.

Another important aspect is that SFS-stores are not participating in the Returns-network, as customers cannot return those products. Many bins are placed in SFS-stores, so this type of store is relevant to consider. An integrated solution will have to be found that either merges these EOL FTW with the trucks that were paid for, or with a solution that is similar to Section 7.3.1. As Figure 30 presents, many different decisions are involved in the process which increases complexity.

It is also possible that all the EOL FTW is aggregated in the Belgian hub of Partner 3. That would only need a process change regarding pick-up with Partner 3, and no process change at the Returns facility. It would mean that Partner 3 needs to use extra storage space and dedicate more time into handling of the EOL FTW.
From an operational view, there are also challenging aspects involved. The EOL FTW boxes should be registered differently, as they should not be mixed up with the Returns. An extra process will have to be created for this by Partner 3.

**Flexibility**
From Figure 30 we see that the take-back system has to be flexible and be able make a short-term decision that is interdependent of the Returns Flow. There are many decisions involved based on other variables, which might be hard to implement. Moreover, this may affect the flexibility regarding adaptations to the take-back network in the future. Partner 3 is a respected and collaborative partner for Sporty, but has also proven to be a bit inflexible due to their size. This could possibly be an extra challenge with both implementation and managing the network.

**Partnership**
The current relations between Sporty and Partner 3 are relatively good. While there are some challenges in the other streams, Partner 3 is willing to build a solution together while looking at all the different challenges.

**Quality and reliability**
Partner 3 is a trusted partner on which Sporty can build upon and expect that agreements are met. However, due to the high complexity of the network, there is also a higher risk of things going wrong within the system. It is hard to assess whether the quality and reliability could be maintained to a reasonable level in such a complex design.
Stakeholder analysis merge of Returns flow: Partner 3

• **The Consumer:** Again, this setup would only mean a logistical change behind the scenes. The customer will not experience any changes with respect to the current solution.

• **Partner 3:** There are several benefits for Partner 3 to set up this transportation flow. It will expand their business, but it also gives them an opportunity to be involved with sustainable projects. Partner 3 has shown willingness to participate in these kind of projects, and being involved within the RYS-program would take them a step further. Partner 3 is a big 3PL-provider though. They need to show flexibility to set up this process. This might be a downfall. It might be a challenge to design a new process for a transportation flow that is relatively small within their overall business.

• **Sporty Stores:** As the Sporty Inline stores are already working with Partner 3, it would be easier if they could request the pick-ups for the RYS-bins from the same partner. This would mean that the store only needs to use one information system in which it can request all its pick-ups. A successful implementation of the request and pick-up process is the key to success here. The stores may not be disadvantaged if pick-up of the RYS-bins takes too long, because freight trucks are not requested.

7.3.4 Merge with returning trucks of outbound transportation

Many scientific articles focus upon an integrated solution between the forward and reverse logistics network. Thus, we will also research the process of filling the returning trucks from outbound transportation. A potential redesign could involve filling empty trucks that have just delivered to the respective store, like visualized in Figure 31.

![Figure 31. Merge take-back network with outbound network](image)

To understand how the process would have to be set up, we first need to understand the outbound flow within Sporty. For the European countries, all the Sporty FTW, apparel and equipment is sent
from the ELC in Laakdal, Belgium. From there, the designs of the outbound transportation flows are different per country. This also means that Sporty works with different partners to get the goods to the stores. For example for France, where a Belgian 3PL-company ships the goods to two different local partners in Paris. The first local partner is responsible for the Sporty Inline stores in Paris, the second local partner is responsible for the rest of the stores in the country and all the wholesalers. This means agreements would have to be made with all the partners involved from every country, to enable the pick-up of the RYS-bins. Looking only at France, processes would have to be set up with already three different partners.

**Costs**
In theory, using the empty space of returning trucks would be an ideal and cheap solution. It does not seem that theory can be applied in practice in this case though. As all of these partners are independent and also have other clients, they will optimize their own routes too. This means they will prevent driving around empty trucks as much as they can to optimize their own revenues. Using empty space in the trucks for EOL FTW is therefore not 100% applicable. Thus, there will not exist an opportunity for a big win. The Sporty transportation managers agreed with that.

**Complexity**
The implementation of this design would involve many different partners and country-specific designs. Sporty would be dependent from the many different 3PL-providers and actual performance could differ greatly between countries. Another challenge is the IT structure behind it. It must be considered whether all the stores could use a similar system or not. If they can, all the partners should also be able to access it. If not, all the different stores should be trained differently with the different system and it would be challenging to output data of different system in the same format. Because of the several imposed challenges, managing this take-back network seems to be quite complex.

**Flexibility**
Related to the complexity of the system, this system also seems to be quite inflexible. When changes to the network will be applied in the future, this should be communicated with every partner. It will ask way more resources from Sporty to manage all the different stakeholders within this network.

**Partnership**
There is not much to say about partnerships, as the design mainly is a small addition to existing partnerships. It would not have big positive or negative consequences on the current existing partnerships.

**Quality and reliability**
Looking on the design purely per partner, the design should not be challenging for them and we can expect they are able to meet agreements. Because of the structure regarding many partners, it will be quite a challenge to track data of all the shipments. This also means it will be hard to track errors in the system and make sure everything goes well.

**Stakeholder analysis integrative solution forward- and take back logistics network**
- **The Consumer:** The Sporty customer would not notice any changes with this setup.
- **Different Outbound Partners:** They would need not to work solely with Sporty, but also with other involved partners within the Sporty SC. Another disadvantage is that it will give them less opportunities to combine their routes with other clients. The actual advantages of extra business will be limited, as every single partner would only be involved in a small part of the quantities.
• **Sporty Stores:** For Sporty stores, this setup could actually be more advantageous, as they would have one moment for receiving their new goods while picking up the EOL FTW units. This would reduce time spent working on these processes, and would increase space available as the bins are picked up faster.

### 7.3.5 Collaborating with a collection- and sorting facility - Partner 4

In this subsection, we will take a look at a solution that goes a step further than collecting only with store-based bins and using regular transportation providers. Throughout Europe, there are several companies that do collecting and sorting activities of old clothing and FTW. These companies have containers located on crowded locations, e.g. next to supermarkets. Their business model is based on a take-back network that brings all content via local hubs to a central facility. In the central facility, the clothing and FTW are sorted. The primary goal of these companies is to sort those pieces of clothing or FTW that can be resold second-hand. If this is not possible, they will try to send it to recycling partners. The final destination would be incineration, which is still a better destination for the clothing than landfilling. Such a partnership could give the consumer an extra opportunity for recycling by putting EOL FTW into collection containers of the partner instead of the RYS-bins.

Partner 4 is a Dutch family-owned company with several partners throughout Europe. They have several sorting facilities, of which the biggest one is in a rural area around Rotterdam. They are collecting any kind of clothing and FTW through containers located on the streets. They sort the received clothing into many different categories. For FTW, they start with sorting the higher-quality FTW pairs. This may include athletic FTW, but also FTW containing metal, leather or high heels. The higher-quality FTW pairs goes to partners that will try to resell them second-hand, while the lower-quality FTW pairs will go to the incineration facility. All the high-quality individual shoes (so not in pairs) are sent to a second stage, where one worker tries to match them into pairs so that they can still be resold. We have researched two designs together with Partner 4. The first design would be a setup where Partner 4 would collect EOL FTW from both the RYS-bins in stores and via their own collection network. The second option would be a take-back design where consumers can solely dispose their EOL FTW within the collection network of Partner 4.

Partner 4’s main business model behind collecting the EOL FTW is to stimulate reuse of the FTW by selling them second-hand. This would mean that lower-quality second-hand Sporty FTW would be sold on certain markets in a partnership stimulated by Sporty. This is not desirable as it could harm Sporty’s brand image of high-quality FTW, the second-hand FTW would compete with Sporty’s first-hand FTW and it does not benefit the Sporty business. It would be possible to keep ownership on all the Sporty FTW, but this would mean a competitive price has to be paid against the second-hand market value plus the extra sorting activities. As a result of this business model, it is expected that either costs will be relatively high or a high percentage of EOL FTW will end up in the second-hand market.

Another disadvantage for both designs is the high variety of shoe quality. Even if only athletic FTW is sorted by Partner 4, there will be an increased percentage of non-Sporty FTW. The recycling machine is able to grind non-Sporty FTW. However, a high percentage of the current input is still Sporty FTW of which is known that certain hazardous substances are not used. The same holds for FTW of the biggest competitors in the high-end FTW industry. It is unknown what would happen with the quality of the rubber and the EVA if there is a significant increase of EOL FTW of lower quality.

In a design where RYS-bins would participate in the collection network of Partner 4, the EOL FTW
units will first end up at the sorting facility. All these EOL FTW units would be sorted there. This is an extra action that would be rather unnecessary (as it can be done in the recycling facility) and only imposes an extra cost. On the other hand, when the design where RYS-bins are not a point of collection anymore, Sporty would lose an opportunity to attract customers to their stores.

**Costs**
The nature of the business model of Partner 4 is to gain revenue through selling their collected FTW second-hand. A design with Partner 4 would require them to sort their FTW Units and send them to the recycling facility. Partner 4 will ask for a price that is competitive to the market value of second-hand FTW units. Since this market value is expected to be higher than the minimum costs Sporty desires to pay, both designs seem to score low for costs.

**Complexity**
Partner 4 would manage the supply chain and even sort the FTW. The extra processes in sorting would therefore also needed to be managed by Partner 4. We do not expect that the implementation of this design would be complex from Sporty’s perspective.

**Flexibility**
Partner 4 has partners in several, but not all European countries. Expanding the network could thus be difficult. A pro is that Partner 4 is willing to change their processes such that it complies to Sporty requirements. This will come at a cost which should be advantageous to their business model though.

**Partnership**
Partner 4 is a company that already is in touch with Sporty for several years. While this did not lead to tangible partnerships yet, they have proven to be a party that can be trusted. They are strong in communication and follow up on their agreements.

**Quality and reliability**
This could potentially one of the biggest downfalls of this design. As mentioned before, the quality of the input of EOL FTW units would significantly change. This could mean the relative share of Sporty or other high-quality EOL FTW could decrease, at the expense of lower quality shoes. We do not know how this would impact the quality of the grind. This should be subject to further research. A pilot was initiated in which Partner 4 can give further indications on the EOL FTW mix that would be sent to the recycling facility. The results of this pilot were not known during the project time frame, but could be a valuable input for this further research.

**Stakeholder analysis: Working with a collection- and sorting facility**

- **Partner 4**: Partner 4’s business model is focused upon reselling their collected shoes, which will gain the most market value while it is a better waste management option from an environmental point of view according to Lansink’s ladder (Lansink (2017)). Implementation of the solution will take some time, but is not expected to be a big challenge. On the other hand, a partnership with Sporty would increase Partner 4’s visibility which could also increase their inflows of other pieces of clothing. Speaking about their overall business, it might thus be also beneficial from a financial point of view.

- **Sporty Stores**: A partnership would not necessarily mean the RYS-bins would disappear from the stores. In that case, there would not be big changes for the stores and there will be two channels available simultaneously for EOL FTW disposal. If a long-term partnership would
mean that the collection containers would be the only way of collecting EOL FTW, this would
mean the stores could focus more on sales in the time they would have spent on the handling of
the RYS-Bins. On the other hand, it would also mean that customers will lose the incentive of
visiting the store when they want to let their shoes be recycled, and Sporty in general would lose
the service aspect for customers to bring back their EOL FTW in the stores.

- **The Customer:** With a collaboration with Partner 4, the customer gets an extra possibility to
  bring back their EOL FTW. If this is easier for the customer, it could lead to advantages for
  them. Their EOL FTW would potentially have a different end destination than in the current
  RYS-program, depending on the underlying business model that Sporty and Partner 4 agree on.
  It is for the customer to decide whether they would prefer their FTW to be recycled or resold in a
  second-hand market.

The analysis of this section showed there are a lot of challenges to make this design the core
of the RYS-program. It is also possible to implement design within the take-back network where a
collaboration with Partner 4 is an addition to the existing activities. This may lead to synergies and
benefits both parties. In this design, Sporty would get involved with the current design of Partner 4
without necessarily promoting it with their own customer. In Partner 4’s current business activities, they
send a quantity of their received FTW to incineration that could be possible input for the Sporty Grind
activities. Incinerating costs money for Partner 4, so selling these EOL FTW units to Sporty could
be interesting. Also, it could significantly decrease the handling time of pairing up individual shoes
by sending them to Sporty. Meanwhile, recycling would also be more aligned to Partner 4’s vision of
contributing to a better environment. From a Sporty perspective, it could potentially be a cheap extra
inflow of FTW units without a lot of effort. Such a setup would need an extra process in the sorting
facility of Partner 4. An extra bin should be added that separates FTW that will not be resold into the
FTW that does meet the requirements for the recycling facility versus those that do not (Leather, Metal,
High Heels). Partner 4 could also make an easier and faster decision on the individual shoes, that could
be sent immediately to the recycling facility instead of putting them into a costly second stage of trying
to pair them. This design could be a win-win situation.

### 7.3.6 Outsource all recycling and take-back operations - Partner 5

In this subsection, we will take a look at a solution that could result into a complete strategic reset
for Sporty. The design considered would be a collaboration in which recycling would be completely
outsourced. There are several recycling companies who are experts in collecting and recycling EOL
FTW and clothing. While the recycling company gains market value out of it, the fashion company
that partners up with this recycling company can participate in sustainable practices without too much
effort and costs. The recycling companies offer programs in which the fashion brand can customize and
personalize the way they want to design their take-back network. A good example is H&M, who have
bins in every store. People can dispose their old clothes in the designated bins. A recycling partner
collects and processes all the EOL clothes.

There are several companies specialized in recycling networks. In this project, we came into contact
with one of the biggest textile recycling companies in the world, whom we will call Partner 5. Partner 5
is an established recycling company from Germany, already working together with several bigger
brands. They have had varying contacts with Sporty in the past, which never resulted in a collaboration.
Inspired by the Sporty Grind activities, they have started their own pilot with a FTW recycling machine.
The concept is similar to the Sporty Grind recycling facility. Their machine is also able to recycle
FTW containing metal and leather. They claim that their machine will be able to process similar amounts of FTW per year compared to the theoretical capacity of the Sporty Grind machine within half a year. Their ultimate goal is to have a volume that will reach around 6 million pairs per year. This would also mean they would need to work in a multiple-shift schedule. This design could give Sporty the opportunity scale up volumes and contribute to the environment on a bigger scale. Partner 5 claims they cannot find enough market value in the sport flooring industry. They already found applications for the different materials, like reusing rubber in new soles. An extra advantage is their continuous research and development activities on innovations of the machines and applications for fluff. Partner 5 is still looking for a strategic partner to elevate their business. They want to make big steps in circularity and are willing to build a new circular solution for FTW together with their partners. Also, Sporty would outsource all the recycling and collecting activities to a partner who is an expert in these activities. Sporty would have to dedicate less resources in terms of effort for this solution.

This decision would be a complete strategic reset and an end of the current RYS-pilot as we know it. A majority of the work done in the RYS-program will be terminated. The machine will not be used anymore, and Sporty has invested quite significantly in that machine. Also, Sporty has to decide what they want to do with their Sporty Grind activities. It is a strong brand and a great story, contributing to Sporty’s brand value. It could be the case that Sporty would like to keep the ownership of those materials such that the Sporty Grind brand on sports floors can keep on existing. If so, arrangements will have to be made on the rubber and EVA to claim this ownership. Sporty has to make serious considerations where it wants to go in the next 10, 20 or even 50 years. This solution could have a great impact on that strategic decision. Whether Sporty wants to implement this will be dependent on the Global team and their strategic vision.

**Costs**

Working with Partner 5 will enable Sporty to convert the costs currently made into a business model that would possibly run break-even or even gain revenue. The business model with Sporty would be based on an income where Partner 5 pays Sporty per kg of EOL FTW, minus the transport costs. Making money is not Sporty’s main goal for the RYS-program, but if it can be combined with an environmentally friendly and scalable solution, it is a nice extra advantage.

**Complexity**

All the resources that Sporty had to dedicate to managing the recycling facility and challenges in the process would be decreased to a minimum. Sporty could have a setup with the same RYS-bins and designs as before. This setup would thus score very well regarding complexity.

**Flexibility**

It was emphasized in this section that this solution would mean a total strategic reset. It would require dedication for at least several years. Choosing for this strategic reset would make it very difficult to go back to the old RYS-program as it was, making this design quite inflexible.

**Partnership**

A partnership would mean that the recycling activities would be outsourced to a company which are experts in recycling. They have experience, focus fully on these activities, are trying to improve themselves continuously and are always researching new innovations. They are willing to work together with Sporty. They are willing to build a solution according to Sporty’s requirements as soon as they get
serious. Therefore, Sporty is not too familiar yet with Partner 5. With this, the cons of collaborating with Partner 5 are rather unknown.

**Quality and reliability**
For the same reasons as explained in the previous subsection, Sporty does not know Partner 5 so well yet. As a result, it is hard to evaluate whether we can expect Partner 5 to live up to the agreements. Since they are an established recycling company with other big fashion partners, we expect there is not much too worry about.

**Stakeholder analysis: Outsourcing all recycling activities**
- **Partner 5:** For Partner 5, a collaboration with Sporty would be beneficial. They will have the opportunity to increase the inbound flow of EOL FTW enormously, which will have a serious beneficial impact on their business. They will have found a strategic partner that is an established sports brand and one of the biggest FTW brands in the world. This is a great story for them. If Sporty seriously follows through on this, Partner 5 will most probably follow.

- **Sporty Stores:** As Partner 5 has expertise in take-back solutions, the Sporty Stores might benefit from a more streamlined pick-up process. The design with the RYS-bins itself would stay intact, so the stores will not be impacted on a large scale.

- **The Customer:** The customer would still be able to bring back their EOL FTW to bins in the stores. Future research could focus upon customer preference of the next destination of their EOL FTW. It will be important to be informed on a customer’s reaction to the change of Sporty-owned recycling activities to an outsourced business model.

**Evaluation different designs**
Now that we have analyzed the six criteria for all the different designs, we can do a quantitative analysis to evaluate the performance. Once again, AHP is a suitable method to do so. In Appendix F, the elaboration of the pairwise comparisons to determine the weights between the criteria can be found. In Table 6, the weights are given. Each redesign is scored on a 1-7 scale, just as in Section 6.2.

### Table 6. Performance different take-back scenarios

<table>
<thead>
<tr>
<th>Final Ranking</th>
<th>Weight</th>
<th>Costs</th>
<th>Complexity</th>
<th>Flexibility</th>
<th>Partnership</th>
<th>Quality/Reliability</th>
<th>Stakeholders</th>
</tr>
</thead>
<tbody>
<tr>
<td>Improve Current</td>
<td>0.336</td>
<td>0.116</td>
<td>0.125</td>
<td>0.223</td>
<td>0.125</td>
<td>0.076</td>
<td></td>
</tr>
<tr>
<td>4PL-Supplier</td>
<td>4</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>5</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Collaborate Returns</td>
<td>6</td>
<td>2</td>
<td>1</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Merge outbound</td>
<td>4</td>
<td>1</td>
<td>1</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Collection Facility</td>
<td>2</td>
<td>5</td>
<td>4</td>
<td>5</td>
<td>2</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Outsource</td>
<td>7</td>
<td>7</td>
<td>1</td>
<td>5</td>
<td>4</td>
<td>6</td>
<td></td>
</tr>
</tbody>
</table>

This leads to the ranking presented in Figure 32.
7.4 Redesign Recycling Facility
An important aspect for Sporty to consider is that scaling up volumes would also require a redesign in the recycling facility. With increasing volumes going through the machine, the facility design should be such that the process flow is better. This could be done according to Lean principles. With a lot of visuals and a convenient process design such that the number of steps is minimized, the same amount of workers would be able to do more work. But more is needed. The actual production hours of the machine should increase to eight hours per day. This would mean that the rostering should change to accommodate this. With a changed rostering, a solution would also need to be found regarding supervision. It is important to comply to the rules of the facility regarding the subsidized workers. The most important thing is that the recycling facility should be flexible and resilient to changes in volumes.

If it turns out that the facility is not able to handle the volumes, Sporty should work on professionalizing the facility. This would possibly mean an integrated solution between subsidized and regular workers. A less preferred, but possibly necessary solution would be to shift totally to regular workers. A proper business case would be needed that proves that productivity would increase.

7.5 Section Conclusion
In this section, we have focused upon the redesign of the take-back network. To ensure increased volumes of EOL FTW Units more stores should participate in the RYS-program. Moreover, more information on the RYS-program should be available to raise awareness about the RYS-program among the consumer. To improve the pick-up process, the IT portal should be improved. Stores should also be educated on the box size they should use and should realize that they should only send completely full boxes. In Section 7.3, we evaluated six different designs regarding the take-back network. Table 6 presents a summary of the outcome of this analysis. We think that working with a 4PL-supplier is the best option, especially for the countries that are further away and therefore more expensive. Partner 1 has had problems and high prices for these countries. While their theoretical rates would be cheap in an ideal situation, the actual costs have been very high for a while now. Besides an overall cost increase, Partner 2 is a strong partner that is able to adapt their design to changing needs and increasing quantities. Outsourcing all take-back and processing activities remains an interesting solution that should be kept under consideration. Finally, Section 7.4 emphasized that an increase of volumes should also result in a redesign of the recycling facility operations.

With the end of this section, we have answered all four subquestions as presented in Section 2.3. Reflecting on Figure 4, we are now going to cover the fifth and final step. This will be presented in Section 8.
8 CONCLUSIONS

In this paper, we have focused upon an improved design of a circular supply chain in an established sporting goods company. To give a proper advice for the future continuation of the Sporty Shoe Recycling Program, we tried to find an answer on the following main research question:

"How can the environmental performance of the take-back and processing activities of end-of-life footwear in the Sporty Shoe Recycling Program be improved, while minimizing the total cost?"

To be able to fulfill the goal of the thesis, a framework was developed. The framework as presented in Figure 4 has been applied. This framework is a structured method of analyzing different waste management processes within an established industry. Circular supply chains could involve different objectives, in this case the environmental performance versus costs. The framework includes the evaluation of multi-objective optimization models and multi-criteria decision-making methods. The framework also encompasses a significant logistic aspect of the circular supply chain by evaluating different take-back options. This section will continue with the main findings of this research in Section 8.1, which are necessary to understand where the RYS-Program can improve. Section 8.2 follows with the recommendations of the author and elaborates on the scientific contribution of this report. Section 8.3 finally closes this report by elaborating on suggestions for future research.

8.1 Main Findings

In Section 4, an analysis of the current established process was done, incorporating the process flows, recycling process, incorporated costs and the environmental performance. The main take-aways we found were:

- There is room for improvement in the store operations part. A clear overview of which stores are participating in the RYS-program is lacking. Problems in the actual pick-up process of participating stores were encountered. There is no standard box size and boxes were not always filled completely, which led to higher unit costs.
- Current bottlenecks in the recycling process are the supply of EOL FTW units and the productivity of the workforce. This led to a very low utilization rate of 17.4%.
- 45% of the expected variable costs of the recycling process were due to fluff waste management practices. The variable cost could decrease significantly if an application would be found for this fluff. This could completely remove this cost or even make it into a small source of income.
- The take-back costs were much higher than desired. The main reasons causing these increased costs were countries without negotiated rates on a package basis, using the wrong services, not filling the boxes completely and invoicing mistakes. These are quick-wins which should be easy to implement and decrease these costs quickly.
- Environmental impact is still a topic that is hard to grasp. Our calculations show that recycling has a reducing effect on total CO$_2$-e emissions while landfilling and energy recuperation have an increased effect on total CO$_2$-e emissions.

In Section 5, a multi-objective optimization model was developed according to the $\varepsilon$-constraint model. The results presented how the absolute total costs increase with increased environmental performance, but the relative unit costs decrease. The optimal solutions dedicated all the budget available for recycling purposes instead of energy recuperation purposes. In the sensitivity analysis, we saw that a lack of supply turned out to be a risk where environmental performance is strongly affected. The other sensitivity analyses demonstrated slight differences in the total outcome of costs and/or emissions, but
should not influence the interpretation of the models.

Section 6 focused on a multi-criteria decision-making model, AHP. With AHP, an actual strategic direction can be chosen. Together with three sustainability managers within Sporty, an AHP-session was held. In this session the hierarchical structure of criteria was determined, weights were assigned and scores were given to each scenario. The outcome of the AHP-session was that the scenario with capital investments was the most preferable scenario according to management beliefs.

Section 7 finally focused on one of the biggest challenges of circular supply chains, designing the take-back network. We found that, if the RYS-programs continues, the use of a 4PL-supplier was the highest ranked alternative. Partner 2 would be a partner that could reduce costs compared to the current situation. Also, Sporty would be able to develop a strong partnership and to collaborate on innovative designs with Partner 2 when the program wants to expand to higher quantities and other types of services, like domestic pick-up of EOL FTW. The second best design was the total outsourcing of the recycling processes. Choosing this design would mean a total strategic reset. It is an interesting design though to keep under consideration.

8.2 Recommendations
In this subsection, we begin with the scientific contribution of this Thesis. Consequently, we want to answer the research question presented earlier in this chapter. The answer is a set of recommendations that we have found based on this report. We start with the long-term strategic recommendations. Additionally, we can distinguish a set of short-term recommendations which are point of improvements that can be implemented quickly, no matter the strategic direction that the Global management eventually chooses.

Scientific contribution

- General models structuring the design process for circular supply chains, which are applicable to a larger number of SC’s are still scarce/non-existent (Barbosa-Póvoa (2009)). The framework that was applied throughout this report (Figure 4) is a good hands-on to solve problems regarding different waste management processes. We recommend waste management problem owners in established industries to follow the steps as presented in the framework.
- The $\varepsilon$-constraint method is a suitable method when the two objectives at stake are costs and environmental performance. The actual objective functions regarding multi-objective optimization models will often be case-specific. We recommend to study our general formulas presented to develop similar, but case-specific multi-objective optimization models.
- AHP remains a suitable method to make a strategic decision in dilemmas regarding sustainable business programs. The hierarchical structure developed should be applicable in a broader set of business cases. However, the structure should always be discussed with management to agree on the important decision (sub-) criteria.
- A relatively untouched topic in literature is how to design a take-back logistics network. The deep dive into take-back networks with different setups in this report can be considered of significant scientific relevance. To evaluate the designs, six criteria were presented that can be applied into the AHP-method. When evaluating different take-back designs, we recommend to use the same method and criteria.
Long-term Recommendations for Sporty

- We have done a AHP-session to evaluate which of the four scenarios that we identified are aligning best with management beliefs. We recommend to allocate all the budget available in capital investments. This should go hand in hand with an increase of the utilization. Doing so will lead to a lower cost/unit and a higher environmental performance. This means that the percentage of FTW units taken back compared to the total FTW units sold (170.1 million in FY17) should increase from 0.1% (162,000 units) with more than eight times to 0.82%. Because of the higher quantities, a proper plan will have to be developed to ensure the workforce is able to handle the desired quantities. This could mean a redesign of the processes within the facility itself is needed.

- We saw that a lack of supply is a big risk when doing capital investments. To ensure the supply is abundant, we recommend to increase the number of stores that are participating in the RYS-network. In addition, awareness about the RYS-program should be increased. An increased amount of information about the RYS-program should be available at for example the website and the product itself.

- Increasing the supply will also mean there will be more usage of the take-back network. The redesign we propose is the design with the 4PL-supplier. With Partner 2, we expect a more reliable and flexible partnership with a mutually trusted partner. Rates should be requested with them for all countries in which Sporty would like to participate. Partner 2 will also be able to think along innovative new designs, like utilizing drop-off points or domestic pick-up for the collection of EOL FTW.

- The RYS-program is a project that is currently being revised by the global management team. We recommend to consider a collaboration with Partner 5 in which all recycling and take-back activities are outsourced. This would mean a complete strategic reset, but could be a business model that both performs very well regarding CO₂-e emissions and costs.

Short-Term Recommendations for Sporty

- Implementing the new design will take some time. The most relevant short-term recommendation should be to negotiate package rates for Spain, Portugal and Italy with the current partner, Partner 1. If the package rate for this country would be for example €20.00 (which is already quite high), the cost savings would already lie around 60% compared to the current situation. This is a significant cost reduction that should be relatively simple to achieve.

- The stores should be educated on how to participate in the RYS-program. They should get directions on the box they should use. We recommend the 10-packs, the biggest boxes that come in. The stores must realize that these boxes should be full, as the rates are per box.

- The current IT-portal used by the stores for pick-up should be improved. The main aspect here is to decrease the opportunity of adjustments on the shipment from the store manager. When they choose a different service or make a manual mistake in e.g. dimensions or number of boxes, this will be billed. Preferably, someone within Sporty should have more control over the settings of the portal. In this way, Sporty is able to help stores with problems without dependency on Partner 1.

8.3 Future Research

- The framework used in this project (Figure 4) could be used by other companies wanting to (re)design their circular SC. Future research would have to show if important aspects are missing in the framework.

- Six different designs for take-back solutions that were discussed. The AHP-method with the six evaluation criteria should be tested in future research. Moreover, the different designs should
be assessed for a different set of business cases. More research on designs of circular supply chains would be needed to identify patterns of chosen take-back designs within certain products or product characteristics. This would enable to give characteristic-specific recommendations instead of case-specific recommendations. Examples of characteristics can be product size, level of cleanliness, perishability, distance from take-back location but also final material destination of re-use.

- Further research could be done on the costs of collection of EOL products at home or via drop-off points. If the RYS-program would expand further than the eight countries currently involved, the rates would first need to be known to estimate expected costs. Partner 2 is able to provide pilots in collaboration with Sporty.

- For Sporty, future research should be done regarding Partner 5 from Section 7.3.6. Collaborating with them would mean a total change of strategic direction regarding the future circular SC. It is important to have a clearer vision on the total costs and what happens with the materials after recycling in a collaboration. Partner 5 could also bring Sporty further in making their whole SC circular. This could include the other two product engines, apparel and equipment, that consist of totally different materials. If a collaboration with Partner 5 would be set up, solutions have to be found for the use of the current machine and how to maintain the Sporty Grind brand.

- Sporty should improve its data collection activities for more operational purposes. Sporty should start making a clear overview on which stores have bins but are not participating in the RYS-program. To gain volumes without increasing unit costs significantly, Sporty can target those stores that are not participating in the RYS-program yet and are located in a country with a favorable negotiated rate. For the recycling process, data collection should improve to have better insights into the actual costs of the recycling process. If more data is available on for example monthly expenses, a better estimation can be made on the variable costs per unit.

- Increasing the quantity of processed EOL FTW units would also have an impact on the recycling facility. From a manufacturing/production point of view, research on required adaptations will be needed to enable the facility to cope with higher quantities.

Extra aspects outside of project scope

Finally, we encountered some aspects during this project on which we could not focus. These should be kept in mind for Sporty though, as their execution could be beneficial for the RYS-program.

- Keep on researching applications for fluff. If fluff can be reused, the total emissions reduced due to recycling will increase. Meanwhile, the variable costs will decrease.

- There are many wholesale partners who probably own a lot of EOL FTW Units. New collaborations could be a quick-win that increases supply against a low cost.

- Keep on working with customs to be able to send excess inventories to the RYS-program at no cost. This is another quick-win to increase supply at a low cost.

- Partner 2 is also the partner for digital returns. They are currently sending the EOL units of SportyID shoes to an energy recuperation facility. These could be send to the recycling facility. This would mean the digital team decreases costs, while the RYS-team would get a free supply of EOL FTW units.
9 APPENDICES

9.1 Appendix A - Framework Gaur et al. (2016)

Figure 33. Action-Oriented Framework for increase core collection
9.2 Appendix B - AHP Example

The aim of this appendix is to give the reader insights on how AHP work by giving an example. Mu and Pereyra-Rojas (2016) give an extensive step-by-step example on how to calculate the priority vectors and how to check on consistency. This is an approximate method with a valid approximation to comparison matrices with low inconsistency. We will implement our AHP-model based on this example. Their example is based on buying a car. This is a decision where three important factors are involved: Cost, Comfort and Safety. In the first step, the pairwise comparisons are made that show the relevance from one factor compared to the other.

Table 7. Pairwise comparison of factors

<table>
<thead>
<tr>
<th>Buying a car</th>
<th>Cost</th>
<th>Comfort</th>
<th>Safety</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
<td>1</td>
<td>7</td>
<td>3</td>
</tr>
<tr>
<td>Comfort</td>
<td>1/7</td>
<td>1</td>
<td>1/3</td>
</tr>
<tr>
<td>Safety</td>
<td>1/3</td>
<td>3</td>
<td>1</td>
</tr>
</tbody>
</table>

This can be translated into a matrix.

\[
A = \begin{bmatrix}
1 & 7 & 3 \\
1/7 & 1 & 1/3 \\
1/3 & 3 & 1 \\
\end{bmatrix}
\]

The next step is to normalize the matrix. This can be done through the following calculation, with the outcomes expressed in Table 8:

\[
A_{x,y,normalized} = \frac{A_{x,y}}{\sum_{n=1}^{3} A_{n,y}} \quad x = 1, ..., 3; \quad y = 1, ..., 3
\]

Table 8. Normalized form of Table 7

<table>
<thead>
<tr>
<th>Buying a car</th>
<th>Cost</th>
<th>Comfort</th>
<th>Safety</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
<td>0.677</td>
<td>0.636</td>
<td>0.692</td>
</tr>
<tr>
<td>Comfort</td>
<td>0.097</td>
<td>0.091</td>
<td>0.077</td>
</tr>
<tr>
<td>Safety</td>
<td>0.226</td>
<td>0.273</td>
<td>0.231</td>
</tr>
</tbody>
</table>

The next step is to find the priorities by taking the row averages as shown in Table 9.

Once the priority vector is known, the consistency has to be tested. For this, first the consistency index of a random generated matrix (RI) is needed. Kumru and Kumru (2014) present a detailed calculation example of AHP in their article about choosing a transportation mode for a logistics company in Turkey, in which they give the indices for \( k = 1 \) to 10, with \( k \) as the amount of factors.
Table 9. Table 8 with an added Priority Vector based on row averages

<table>
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<tr>
<th>Buying a car</th>
<th>Cost</th>
<th>Comfort</th>
<th>Safety</th>
<th>Priority</th>
</tr>
</thead>
<tbody>
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<td>0.692</td>
<td>0.669</td>
</tr>
<tr>
<td>Comfort</td>
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<td>0.091</td>
<td>0.077</td>
<td>0.088</td>
</tr>
<tr>
<td>Safety</td>
<td>0.226</td>
<td>0.273</td>
<td>0.231</td>
<td>0.243</td>
</tr>
</tbody>
</table>

Table 10. Consistency Indices, Kumru and Kumru (2014)

<table>
<thead>
<tr>
<th>n</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RI</td>
<td>0</td>
<td>0.58</td>
<td>0.90</td>
<td>1.12</td>
<td>1.24</td>
<td>1.32</td>
<td>1.41</td>
<td>1.45</td>
<td>1.49</td>
</tr>
</tbody>
</table>

In the example, the value belonging to three factors is 0.58. The next thing we need to know is the consistency index (CI) of the matrix in question. To find CI, $\lambda_{\text{max}}$ has to be computed first. For this we take the priority vector and take the dotproduct with the preference vector of the first pairwise comparisons (Table 7):

$$Sum_1 = [0.669, 0.088, 0.243] \cdot [1.000, 7.000, 3.000] = 2.015$$
$$Sum_2 = [0.669, 0.088, 0.243] \cdot [0.143, 1.000, 0.333] = 0.265$$
$$Sum_3 = [0.669, 0.088, 0.243] \cdot [0.333, 7.000, 1.000] = 0.731$$

These numbers are divided by its priority vector, summed and averaged, which gives us $\lambda_{\text{max}}$:

$$\lambda_{\text{max}} = \left( \frac{2.015 + 0.265 + 0.731}{3} \right) = 0.307$$

Then we find CI (with $k = 3$):

$$Ci = \frac{\lambda_{\text{max}} - k}{k-1} = 0.004$$

Consequently, the consistency ratio (CR) is computed by

$$CR = \frac{CI}{RI} = \frac{0.004}{0.58} = 0.006$$

The CR should be below 0.10 for reasonable consistency.

This should be done for every hierarchy. For this example, we assume that there is no sub-hierarchy and thus we focus upon the possibilities. If there are several scenarios, in this example for example several cars, a priority vector can also be made.

The priority vectors of Table 11 and the consistency can be found in the same manner as explained as before. To rank the alternatives, these priority values (PV) need to be multiplied with its higher hierarchies. So for example, the final score for car 1 would be:

$$0.669 \times PV_{\text{cost.car1}} + 0.088 \times PV_{\text{comfort.car1}} + 0.243 \times PV_{\text{safety.car1}}$$
Table 11. Pairwise comparison of scenarios

<table>
<thead>
<tr>
<th>Cost</th>
<th>Car1</th>
<th>Car2</th>
<th>Car3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Car1</td>
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<td>5</td>
<td>2</td>
</tr>
<tr>
<td>Car2</td>
<td>1/5</td>
<td>1</td>
<td>1/3</td>
</tr>
<tr>
<td>Car3</td>
<td>1/2</td>
<td>3</td>
<td>1</td>
</tr>
</tbody>
</table>

9.3 Appendix C - AHP Weights, Scores and Rankings

Figure 34. Initial AHP Results Participant 1

Figure 35. Initial AHP Results Participant 2
9.4 Appendix D - Sensitivity Analysis AHP-method

Figure 36. Initial AHP Results Participant 3

Figure 37. AHP Sensitivity Analysis without Economical Criteria
Figure 38. AHP Sensitivity Analysis without Business Feasibility Criteria

Figure 39. AHP Sensitivity Analysis without Market Value Criteria
9.5 Appendix E - Outcomes Multi-Objective Optimization

Figure 40. AHP Sensitivity Analysis without Environmental Criteria

Figure 41. Values of waste management options in Optimization Model Section 5
### Figure 42. Sensitivity Analysis 1

<table>
<thead>
<tr>
<th>Scenario</th>
<th>$e_1$</th>
<th>$e_2$</th>
<th>Emissions reduced</th>
<th>Total Costs</th>
<th>$Q_{\text{Recycled}}$</th>
<th>$Q_{\text{Incinerated}}$</th>
<th>$Q_{\text{Landfilled}}$</th>
<th>$Q_{\text{Total}}$</th>
</tr>
</thead>
<tbody>
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### Figure 43. Sensitivity Analysis 2

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<th>$Q_{\text{Incinerated}}$</th>
<th>$Q_{\text{Landfilled}}$</th>
<th>$Q_{\text{Total}}$</th>
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**Figure 44.** Sensitivity Analysis 3

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**Figure 45.** Sensitivity Analysis 4
9.6 Appendix F- AHP Take-back redesign networks

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**Figure 46.** AHP Weights Transport
REFERENCES


