Designing an efficient reverse logistics system for dismantlers:

Increasing recycling rate of plastics from end-of-life vehicles

Master's Thesis in the Master's Programme Supply Chain Management

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Abstract

In the constantly growing automotive industry it is assumed that the amount of plastics in vehicles will increase. New EU-directives of increased recycling rates of material in old and crashed cars, also known as end-of-life vehicles (ELVs), makes it a requirement to recycle plastics from automotives to a higher degree. Today, the plastic follows the car body to a fragmentation plant where it becomes part of the so-called fluff fraction that typically goes to incineration. This is where most of studies have focused on to increase the recycling rate of plastics from ELVs. However, another way to increase the recycling rate is to dismantle the plastics at dismantlers and recycle them instead of sending plastics to a fragmentation centre to become fluff. The reason why ELV plastics are sent to the fragmentation is that it is assumed that the handling costs associated with plastic recycling exceed the material value, which is considered to be the biggest barrier. This thesis shows that it is possible to earn money from recycling plastic from ELVs by removing and sorting out the plastic already at the dismantler. The purpose of this thesis is to design and analyse a reverse logistics (RL) system for the dismantlers that creates profit and is feasible for them to implement. To fulfil the purpose, data has been collected from semi-structured interviews with potential customers, and direct observations and interviews at dismantlers, a research institution, and a recycling firm. Furthermore, request for quotations (RFQs) has been sent out to possible suppliers of machinery for recycling plastics in order to gain information regarding current prices of the machinery needed for the activities connected to recycling plastics. The thesis has focused on six different plastic parts in ELVs of which four was of interest for potential customers. This information was used to establish several cases and for each case, a simulation was performed in order to identify the most efficient RL system. The most appropriate solution is that the dismantler sells size-reduced plastic and granulated copper. This is achieved by investing in a shredder machine used for plastics and cables and a granulation machine used for the size-reduced cables. This will allow the dismantler to increase the recycling rate of plastics while simultaneously making profit out of it. If it is thought that all Sweden's dismantlers would dismantle the identified plastic parts for recycling purposes, 5328 tons of plastic per year could be recycled instead of being sent to incineration.

Keywords: *Reverse logistics, Circular economy, Plastic recycling, End-of-life vehicle.*

Abbreviations and definitions

ASR	Automotive Shredder Residues
ATA	As they are
CE	Circular Economy
CIT	Chalmers Industriteknik
DES	Discrete Event Simulations
ELV	End of Life Vehicle, any type of motor vehicle that is classified as waste e.g. crashed or old cars, the thesis concludes only cars.
Fluff	See ASR
FTL	Full Truck Load
FSC	Forward Supply Chain
RL	Reverse Logistics
SC	Supply Chain
SCM	Supply Chain Management

Table of contents

List of figures

List of tables

1 Introduction

In this chapter the background and introduction of the thesis are presented, followed by the purpose and the research questions. Finally, the scope of the thesis is described.

1.1 Project background

Supply Chain Management (SCM) includes all activities from sourcing and procurement to a point of consumption and includes several logistical activities e.g. transportation, material handling, and planning and control (Ballou, 2004). With increased social and environmental concerns, it is becoming more important for companies to endorse SCM in order to lower their costs, meet customer requirements, and reduce use of the planet's resources. The typical forward supply chain (FSC) involves the forward flow of a product or service, often with a focus on lowering costs. This has gotten much attention recent years and firms continuously work with improving their efficiency (Frei et.al, 2016). But for companies to further endorse the concerns of environment and cost savings, it is of importance that they also develop their reverse logistics (RL). The RL starts with the end customer in the FSC, includes activities of moving the product, possibly refine it, and finding new use of it. When the product is consumed and no longer wanted, there can still be a value in it, of both economic and environmental character. RL is the process of moving the product from the typical end user to any other possible process that might find value in the product, e.g. reuse or recycling (Hawks. K, 2006, Schultmann et al. 2006). It is not only profit that drives recycling or reuse of products, legislatives and directives are also motivators for taking advantage of material in used products (Schultmann et al. 2006).

Reusing and recycling materials are getting more important than ever since the earth's population is growing steadily and uses more materials in all types of consumption while earth's resources are limited. To recycle is to create or take advantage of value in waste by reprocessing materials that are no longer used in their original form (Subramanian & Knovel, 2016). By using and keeping the value in a product as long as possible and avoiding throwing it away and consider it as waste, is to have a Circular Economy (CE). This thesis is conducted as part of a research project that Chalmers Industriteknik (CIT) is involved in. The aim of the research project is to strengthen the Swedish automotive recycling industry´s role in a more circular economy. CIT is responsible for analysing and proposing solutions for efficient reverse logistics of challenging materials (such as bulky plastics parts) for dismantling of scrapped cars, in order to achieve higher recycling rates. The car dismantler plays a key role in the research project and as such also in the master thesis. A car dismantler is typically dismantling parts from old or crashed cars: end-of-life vehicles (ELVs) and reuses all functioning parts and sends the other parts to a recycling firm. The case companies in the master thesis are Eklunds Bildelslager AB (Eklunds) and Walters Bildelar AB (Walters).

To increase the recycling rate of plastics from ELVs the dismantlers need to find new ways of working. By increasing the recycling rate of plastics from ELVs it is possible to lower the use of natural resources and avoiding sending plastics to incineration or landfill. One possible scenario that is investigated in this thesis is if the dismantlers could find profit in dismantling plastics from ELVs for recycling. If the dismantlers do this, they will increase the recycling rate of plastics from ELVs since it would then be possible to use the plastics for new products and moving towards CE instead of sending them for fragmentation and by that energy recovery. For this to be possible it is necessary to find what activities in the RL system the dismantlers should perform. Depending on what activities the dismantlers perform, different customers with different demands on the plastics will come about.

As is shown in Figure 1, there is a hierarchy of waste handling, in which prevention is the highest priority, followed by reuse, recycling, energy recovery and landfill (Kurdve et al. 2011). Concerning plastic recycling, which is the focus in this thesis, recycling plastics does not only give environmental benefits, preserves energy, and reduces waste, it also has a value to produce plastics second handed, e.g. as granulate to plastic processors (Sakai et.al. 2014). To make it economically justified to recycling materials such as plastics, and striving for CE, the cost for sorting, size reducing, transporting, washing, and recycling must be lower or equal to cost of producing raw materials (Dalmijn & Jong, 2007). This puts high demands of designing the RL system, since e.g. several of the steps are costly, the plastics as they are, are bulky and expensive to transport which is a difficult conundrum to solve. By finding new ways of designing activities in RL it is possible to use less of scarce resources and create a more sustainable environment.

Figure 1: The figure shows the hierarchy of waste handling with prevention as most wanted step and landfill as the least wanted step (Kurdve et al. 2011).

1.2 Project introduction

In recent years, it is getting more common to own automotives also in developing countries, something that will result in an increased number of ELVs, which in turn need to be taken care of (Sakai et.al. 2014). Automotives are developed to use less fuel and one important part to make them more efficient is to use plastics because of the materials light weights (Gerrard and Kandlikar, 2007, Buekens and Zhou, 2014). This development has increased rapidly in recent years, and parallel with this the goals of recycling are set high. According to the EU-directives 2000/53/EC of 18 September 2000, 95% of a vehicle's weight needs to be recovered, and 85% needs to be recycled or reused in order to save resources and make as little impact on environment as possible. By recycling and finding a value in a product that is no longer used is a step towards circular economy (CE) and a more sustainable environment (Ellen MacArthur Foundation, 2015). To meet the EU directives as well as the demand for CE it will be important to increase the recycling rates of plastic.

An increased recycling rate of plastics from ELVs can be achieved in two ways. It can be done either by leaving the plastics on the ELV for fragmentation and handling the plastics afterwards, or to dismantle and recycle the plastics before the fragmentation of the ELV. Fragmentation is when the entire chassis is fragmented into small pieces and sorted into different fractions such as aluminium, ferrous metal, etc. and is commonly done at recycling firms. Currently, there are not many studies focusing on dismantling plastics before shredding in order to increase the recycling rate of plastics, which is the scope of this thesis. It is often argued that it is more efficient, both in terms of cost and recycling perspective, to sort out materials before it is processed to get as clean product as possible, this could save both man hours and unnecessary investments in equipment (Worrell and Reuter, 2014).

Figure 2, illustrates current RL flow of plastic wastes of ELVs in Sweden. As it can be seen some of the plastic parts will be dismantled and sold to be reused as spare parts, and some plastics are left on the ELV`s chassis and sent to recycling centres for fragmentation, where it becomes Automotive Shredder Residues (ASR) or “fluff”, a fraction with mixed materials such as plastics, textile, and rubber. Today, most research is focusing on ASR and how to sort out the plastics from other materials in the fraction, and new expensive technologies are making the ASR easier to sort, hence purer recycled plastics (Subramanian, 2016). To a large extent, ASRs goes to energy recovery or landfill (ibid). There is a gap in research when it comes to dismantling plastics for recycling. The intent of investigating this area is to find economic feasible ways of working for dismantlers and also to fill in a research gap of ways to increase plastic recycling from ELVs.

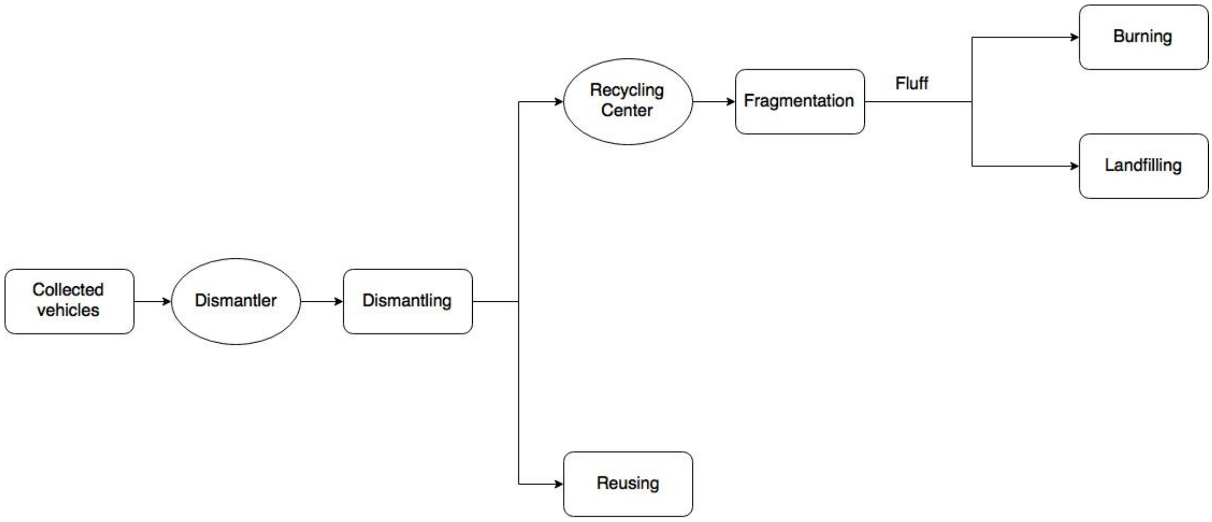

Figure 2: Current reverse logistic flow of plastic wastes of ELVs in Sweden.

Previous research indicates that it is difficult for dismantlers to find value propositions that are profitable enough to invest in technologies and creating business for recycling plastics (Duval & MacLean, 2007). Some of the factors dismantlers need to take into consideration when looking into new business plans are type of machines needed, their cost, and competence required to use them. One problem when dismantling plastics from ELVs are the high labour costs due to time consuming processes (Dodbiba and Fujita, 2004). Vermeulen et al. (2012) states that when dismantling ELVs for recycling, the increased labour costs and uncertain prices for plastics makes the economic perspective of recycling unreliable, while the environmental perspective is positive. Today's automotives are not designed to be easily dismantled, but this is getting more attention due to the higher demands on recycling ELVs (Gerarrd and Kandlikar, 2007) and at the same time dismantlers are working with new ideas of how to disassemble in more efficient ways. If the plastics can be dismantled and sorted before it is further processed, it is considered that it could have possible other market value, compared to ASR, to some possible customers depending on what the customer requirements are.

1.3 Purpose

The purpose of the thesis is to design an efficient RL system for dismantlers to achieve a higher recycling rate of plastics in ELVs. This purpose will be achieved by (1) exploring the value creating steps in ELV RL processes for dismantlers, (2) discovering the market demand components from ELV dismantlers, and (3) identifying equipment and machineries required for each value creating step.

1.4 Research questions

To know how to improve the RL system it is important to understand the current process flow of the recycling chain and how it can be connected to dismantlers. Drawing a process flow diagram including dismantlers and the different value adding processes will help reaching this realization. Hence, the following research question has been framed:

(RQ.1) - What possible value adding activities are included in the RL chain of plastic parts in ELVs? The following sub questions have been formulated in order to clarify RQ1:

- How does the plastic recycling and processing industry look today?
- What are the necessary preconditions for each activity?

In order to identify which processes in the recycling chain that are necessary and adds value for the customer, it is crucial to understand the market requirements regarding recycled plastic. Therefore, the following research question has been formulated in order to achieve a higher understanding of customer base and their requirements:

(RQ.2) - What requirements do the customers have on their incoming plastic materials? The following sub questions have been formulated in order to clarify RQ2:

- Which are the primary customer categories for recycled plastics?
- What are the requirements in terms of form, quality, amount, competencies, type of plastics, delivery volume and frequency etc. for the different customer categories?
- How much are the customers willing to pay based on different requirements?

As mentioned earlier, based on the customer requirements, there are different value-adding processes with numerous possible scenarios that can be adopted by dismantlers. In order to reach the most beneficial solution and scenario, different technical and logistical methods with their respective costs and preconditions needs to be identified. The following research question has been framed in order to reach this purpose:

(RQ.3) - What are the technical solutions and existing machinery for enabling value creation for car dismantlers? The following sub questions have been formulated in order to clarify the third research question:

- What technical solutions are used today to collect, transport and recycle plastics? What are the costs for investing in equipment for collecting, transporting and recycling plastics? What competencies are needed?
- What are the costs for dismantlers to develop the business into the different stages of the chain?

1.5 Scope

The scope of the master thesis is shown in Figure 3. The primary focus will be on the dismantlers, Walters and Eklunds, and potential customers for recycled ELV-plastics located mainly in Sweden. Regarding activities looked into, the main attention will be only on the recycling processing activity within RL in automotive industry. The dismantlers are not interested in transporting containers themselves, therefore third party logistic providers (3PL) are assumed to be hired. By conducting a market research and finding what demands customers have on recycled plastics and what price they are willing to pay for recycled plastics, different cases of potential value adding activities will be simulated.

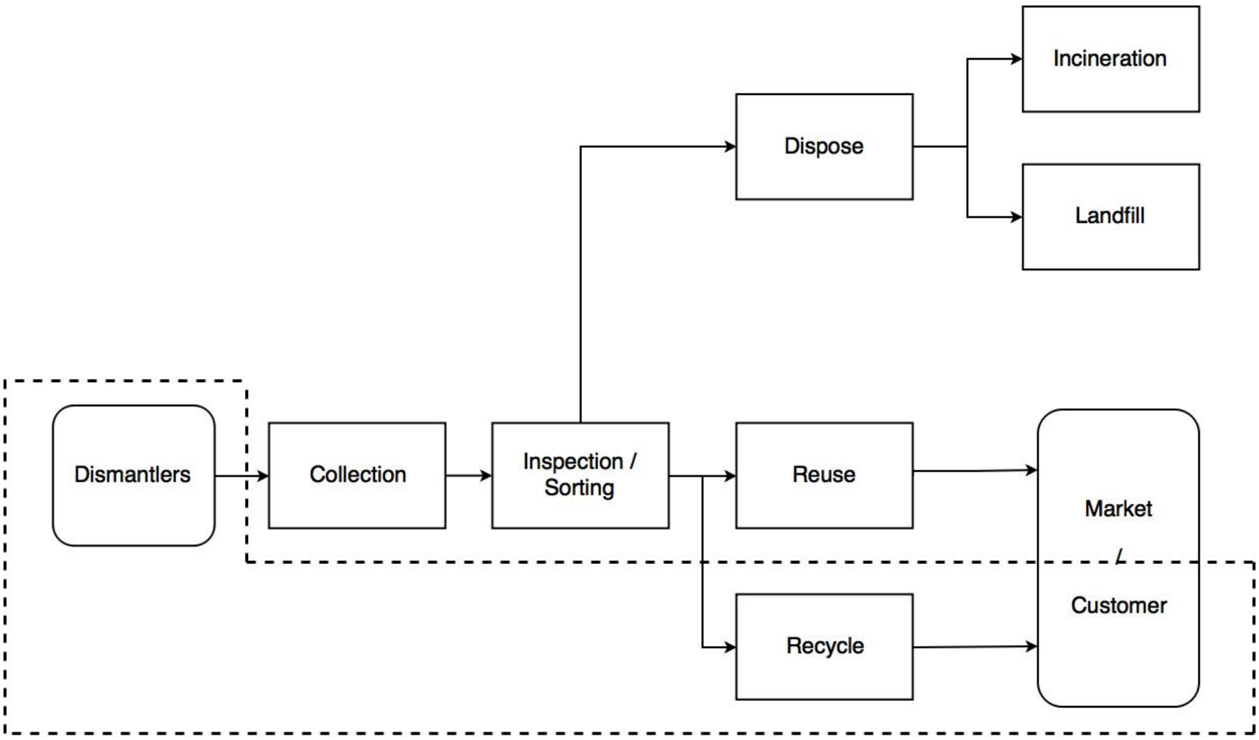

Figure 3: The figure illustrates the scope of study for the master thesis.

According to previous research, several plastic parts which were of value and feasible to dismantle have been identified (Cullbrand, 2015). By combining the result from this research with several practical inputs from CIT's research team, six different plastic parts have been chosen to be included in the scope of this thesis and can be found in table 1. The types of plastics that are investigated are Polypropen (PP) and Polyeten (PE), which are both thermoplastics with different qualities (Naturskyddsföreningen 2017). PP is one of the more common plastics used due to its low density and high abrasion resistance. PE is common to use for products containing different liquids since it is highly resistant against acids, bases, and alcohols. Images of each plastic part can be found in Appendix A.

Table 1: The table shows the plastic parts in ELVs that are investigated in the thesis.

Plastic part	**Avg. weight (kg)**	**Total in a car**	**Total weight (kg)**	**Type of plastic**
Bumper	5	2	10	PP
Wheelhouse	1.2	4	4.8	PP
Skid plate	1	1	1	PP
Fuel tank	11.4	1	11.4	PE
Washing fluid tank	0.8	1	0.8	PE
Expansion tank	0.5	1	0.5	PE

2 Methodology

This chapter will present how the project was conducted and arguments for the chosen approach. First, the approach and design will be explained to give the reader an understanding of why the authors have chosen the way of work. This is followed by a more detailed presentation of how the work has progressed.

2.1 Research approach and research design

In this thesis both qualitative and quantitative approaches are used. The qualitative approach is about collecting data through interviews and observations (Bryman and Bell, 2003). The qualitative approach was used in the beginning of this thesis project to collect information and to gain knowledge of how the collection of plastics and recycling process looks like, and how car dismantlers are working today. This qualitative data was then used to design the different cases that are seen as potential scenarios for dismantlers to adapt. This knowledge is then supporting the gathering of information for the quantitative approach. The quantitative information consists of e.g. prices, volumes, and weights that are needed for simulating the potential flows of plastics and to evaluate the qualitative data (Bryman and Bell, 2003). By combining the two approaches it is assumed that the data is valid for giving suggestions of how the dismantlers can develop their businesses.

At first it was assumed that the project was supposed to be approached in a deductive way, as described by Bryman and Bell (2003) to first finding theory and then build a hypothesis based on the theory. But it was later clear that the empirical findings needed to be compared to theory several times and therefore as argued by Dubois and Gadde (2002) an abductive approach was used. By using an abductive approach, it was easier for the authors to understand the fairly new concept of reverse logistics and thus come up with valid scenarios to simulate.

According to Bryman and Bell (2015) there a several different research designs for instance: case study design, comparative design, and experimental design. When starting a research, it is important to choose research design to have a framework for how to collect data and how to analyse it (ibid.). A case study is to investigate a certain case, which can be an organization, a sample, or such. Furthermore, the approach of comparing several cases with quantitative and qualitative data is defined as a multiple case study (Bryman and Bell, 2015). The research design of this study is therefore decided to be multiple case study with the aim of comparing different cases of reverse logistics flows with different scenarios based on gathered data. Each case is a scenario of a potential customer’s demand which makes the focus being on customers. This also makes it possible to add further potential customers to the scenarios during the project.

In figure 4, it can be seen how the research has been conducted in this study.

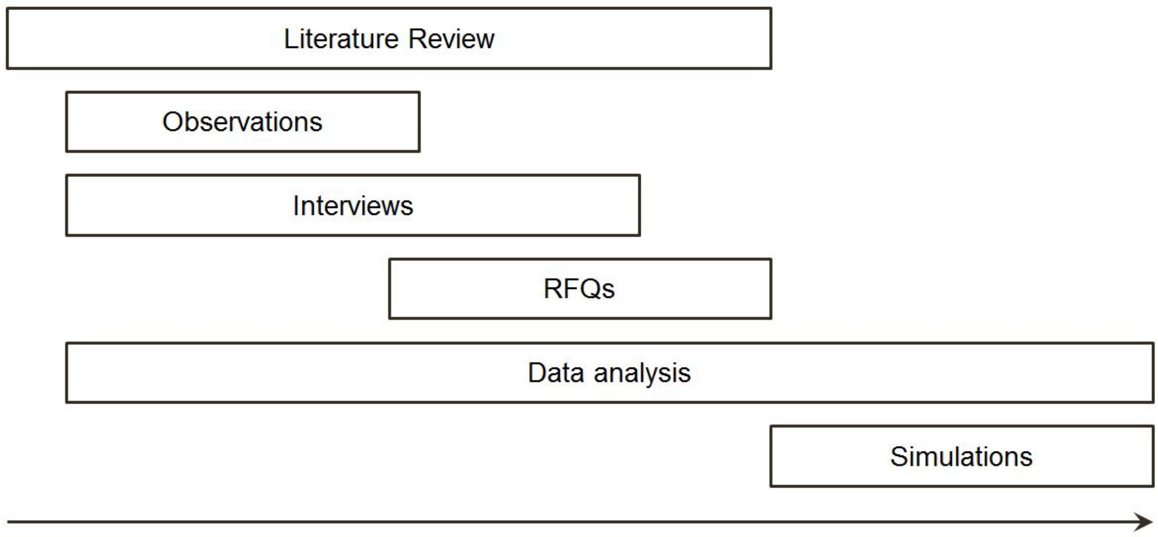

Figure 4: Overview of methodology over time used in the study.

2.2 Data Collection

This chapter will describe how the qualitative and quantitative data was collected.

2.2.1 Literature review

To gain knowledge about RL and to be able to reach the purpose of the thesis, a literature review was conducted. To increase the understanding of the chosen framework, key terms for the literature search was: “reverse logistics” and “circular economy”. This gave the authors an initial familiarization of how the reverse side of a supply chain (SC) looks like in general. To connect the framework with the context of recycling plastics and to gain a deeper understanding of how to strive for CE within the area, the key terms were combined with “recycling”, “plastics” and “ELV”. To be able to know how the practicalities of recycling plastics work a search for “recycling plastics” was also made. The literature search was made in Summon at lib.chalmers.se, which is the online library at Chalmers University of Technology, and in Google Scholar.

2.2.2 Interviews

To be able to find relevant information of what value adding activities are related to RL within recycling, customer demands, and existing drivers and barriers for recycling plastics, interviews were held with potential customers. The potential customers were found by googling “plastic producers”, “plastic processors”, “plastic recycling”, and “plastic companies”. Not all companies from the search were interviewed, but only the ones that stated that they use the certain plastics in the scope of the thesis. From previous research projects at CIT the personnel had contacts within plastic industries which also were used. In order to increase validity and reliability from the interviews, interview templates were constructed and used as guides, these can be found in Appendix B. The interview templates were constructed based on where in the SC they are located and the templates are structured with three sections: purchasing, production, and sales/market. To increase the validity of the answers, data was gathered from the same processes in the different steps of the chain. There were 26 interviews in total and the interviews took between 25-40 min each. In order to save the information from the interviews the answers were written down in the interview templates, and after each interview the authors discussed the answers to see if there were any gaps in information that needed to be further investigated.

By using interview templates all respondents got the same questions which will minimize differences that can occur (Bryman and Bell, 2003). However, it is assumed that the interview templates do not cover all possible attendant questions, therefore the method used for interviews is to be seen as semi-structured, which give the interviews room for gathering more information if needed. According to Gillham (2007) the semi structured interview is flexible and can diverge from the interview template and thus intercept valuable information from the respondent which strengthens the author's choice of interview method.

The interviews helped the authors to construct the different possible cases and to find other relevant data for mapping the flows of plastics. The potential customers were divided into collectors, recyclers, and processors. Further information of the interviews, when the companies were interviewed, what position the respondent has, and where in the chain the company is identified to be placed are found in Appendix C.

Furthermore, to gain understanding of how the plastic recycling is done, semi-structured interviews were also held with experts at Swerea, which is a research institute with test facilities for plastic recycling. Prior to the interviews the authors made theoretical research of basic steps in recycling plastics and what sort of equipment that could be possible to use. This helped the authors with questions to Landberg[1] at Swerea, and gave information-rich interviews which gave insight in plastics recycling and some of the common procedures and possible problems to consider when designing a setup for recycling.

2.2.3 Simulation

To improve a process, it is vital to understand it. A good help is to design and run a simulation, which is considered to be highly relevant when making decisions regarding changes in business (Brailsford et.al. 2014). One common way of designing simulations is with Discrete Event Simulations (DES), which have the flexibility of showing resources, activities, entities, and queues during certain set time schedules (ibid.). In order to evaluate prices, costs, and handling time for the seven identified cases a simulation is an adequate method. CIT were responsible for coding and running the simulations, which was based on the retrieved information from RFQs and interviews. The simulation program “Simul8” was used to easily determine whether or not the cases would be economically profitable. The cases that were identified as possible for dismantlers to undertake were set up in Simul8, the flows used in the simulations can be found in Appendix F. All cases have scenarios with low and high capacity equipment in different price ranges as well as different potential selling prices

[1] Johan Landberg, Mechanical engineer with expertise within polymers at Swerea.

for plastics. At first average prices of both high and low capacity and average selling prices were run in all scenarios in order to see which of them that might be most suitable for the dismantlers. When the most suitable scenarios were identified, they were simulated with the exact cost of potential investments and selling prices. The simulations were set to show the results of three and five-year plans, which is considered enough iterative to give accurate information.

The quantitative data needed for simulations consist of prices of machinery and services that is needed for recycling plastics, labour cost, volume of transports, distances for transports, and price of reprocessed plastics. This quantitative data was gathered by sending Requests for Quotations (RFQs) to potential suppliers of equipment. The information in the RFQ was essentially based on literature review and further developed by information gained from interviews and observations. The list of suppliers is to be found in Appendix D and the RFQs are found in Appendix E. When the RFQs were received they were summarized in a table to later be presented as information for the dismantlers to give them insight of how the market of machinery looks like.

2.2.4 Direct observations

One common way of collecting qualitative data is to observe processes, situations, and behaviour (Bryman and Bell, 2015). Participative observations were made by the authors at Walters Bildelar (2017-09-13, 2017-12-14) Eklunds Bildelslager (2017-12-21), potential customer (recycler) (2017-12-15) and Swerea (2017-10-18, 2017-11-03, and 2017-11-23).

The participative observations and interviews at Walters Bildelar and Eklunds Bildelslager was made to see how the handling of ELVs are performed today, how much time it takes to dismantle parts from ELVs, and what challenges there might be for changing the way of working. The authors were given guided tours which showed how the dismantling is performed. The observations also gave insight in how the premises look like and what potential the company has for storing bulky parts and if they have enough space for placing large machinery.

The visit at the recycler gave the authors knowledge about how an entire high capacity cleaning line works. The visit took four hours so that the cleaning process could be thoroughly investigated and information about positive and negative aspects really comprehended. During the visit, plastics from ELVs were shredded, cleaned, and grinded. These plastics were later on analysed by the recycler in order to understand what quality other potential customers could expect from the recycled plastics.

A deeper understanding of the technical aspects and how to gain high quality of recycled plastics were the results of three separate observations combined with interviews at Swerea. These observations and interviews took between five to six hours each. Swerea do research of recycling several materials, including plastics, which gave the authors much knowledge about what technical solutions that might be needed for recycling plastics from ELVs, and thus helping with information to answering research question one and three. According to Bryman and Bell (2015) in comparison of interviews, questionnaires and other ways of researching, direct observations helps to understand situations on a fundamental level.

2.2.5 Environmental analysis

To reach a circular economy it is important to recycle as much plastics as possible from the ELVs, but other environmental aspects are also of importance in order to evaluate the entire RL. Transports use fuel and machinery uses electrical power that needs to be produced somewhere. To consider these aspects an simple environmental analysis was conducted, based on energy usage of machinery, and transport distances to customers. Since the purpose of the thesis is to increase recycling rates of plastics, which is considered as being within an environmental area, the scope of the thesis is foremost of finding economic profit for dismantlers. Therefore it is considered that the environmental effects from the recycling activities are relevant to look into, but not to have the same focus as the economic perspective.

2.3 Data analysis

This section will describe how the qualitative and quantitative data is analysed.

2.3.1 Qualitative data analysis

The predominant part of qualitative data was gathered from interviews which was transcribed and analysed directly after the interview was finished and is according to Bryman and Bell (2003) common when analysing qualitative data. The interviews were analysed by discussions between the authors and CIT. By analysing the interviews directly afterwards they were held, new questions arose and could be asked to the next potential customer that were to be interviewed. By using a systematic combining approach presented by Dubois and Gadde (2002) the qualitative data was compared to the theoretical findings from the literature search, by doing this the authors could identify in which areas more information was needed. This approach also made it possible to better understand what quantitative data was needed to set up the simulations. The information gathered from observations was handled in the same way, summaries were written and the authors directly analysed the information that was gathered.

2.3.2 Quantitative data analysis

From the interviews and RFQs the authors retrieved quantitative data of prices customers are willing to pay for recycled plastics, distances between dismantlers and customers, and investment and service cost for machinery. This information was used in the simulation program “Simul8” to see what scenarios are economically feasible for dismantlers. By triangulating the results from the simulation with the qualitative data, is according to Bryman and Bell (2003) increasing confidence in the findings.

2.4 Trustworthiness of the methodology

To evaluate a study there are several aspects to consider (Bryman and Bell, 2015), here the reliability and validity of the thesis are presented.

2.4.1 Validity

Bryman and Bell (2015) argues that for a thesis to have validity it needs to present what it was designated to do. Further validity is divided into internal and external validity. The internal validity is about whether or not there is a relationship between variables (ibid), as in this thesis would be if the study has correlation with theory. By using and abductive approach and discussing ideas with CIT it is considered that the thesis internal validity is solid.

The external validity is related to the generalization of the study (Bryman and Bell 2015), in other words if the scenarios are applicable for other dismantlers than Walters and Eklunds. The external validity is considered high since the process of recycling plastics would be the same for all dismantlers. Furthermore, the simulations are based on both low and high capacity machinery to ensure that dismantlers of different company sizes could relate to the results.

2.4.2 Reliability

If a report has high reliability it is considered that the outcome would be the same if the researchers were to repeat the study (Bryman and Bell, 2003). According to Bell and Nilsson (2006) a risk with abductive research is that the researcher or interviewees might involve their own thoughts and impressions. Many of the interviews were held with potential customers and were regarding prices. It was noticed that many of these companies were not inclined to discuss exact prices neither tell too much about their business network. To cope with this risk several interviews with companies within the same area of production was made and the stated prices were gathered to average prices.

By dividing interview questions to three different departments within companies it is considered that the reliability of the interviews is high. Furthermore, all interviews and summaries of observations are documented and all steps in the research are explained both in method, and more detailed, in the empirical findings.

3 Theoretical framework

The first part of this chapter will give the reader an understanding of the concept of CE. The second part addresses RL and actors and activities within RL. The third part describes plastic recycling in general as well as within automotive industry. Finally, the drivers and barriers that have been found in the theoretical framework will be summarized.

3.1 Circular economy

In nature there are several materials that will decompose and function as energy to new plants which will be eaten by an animal which will decompose and so on, commonly known as circle of life. Humans have invented another way of using earth's resources, a linear approach where natural resources are used without any recycling and does not come to use again (Ellen Macarthur foundation, 2016). CE is about reuse or recycling all products and trying to use the resources again instead of discard them as waste (Weetman, 2017). According to Ellen Macarthur foundation (2016), the way that humanity is used to consume “take-make-dispose” is not sustainable in the future due to scarcity of resources and restrictions of use of resources are getting more common. By closing both economic and ecological loops of resources, it is possible to reduce use of virgin raw materials and thus make less negative impact on environment (ibid.).

Even though CE is considered a fairly new subject within academia there are several definitions. Ellen Macarthur foundation (2016) defines CE as “an industrial economy that is restorative or regenerative by intention and design” while Yuan et.al. (2006, pp. 5) defines it as “the core of CE is the circular (closed) flow of materials and the use of raw materials and energy through multiple phases”. Best suited for this thesis is the definition by Ellen Macarthur foundation, since it focuses on open loops and not only closed loops. The strict definition of a closed loop is that the recycled material goes back to the same producer that made the original product, while open loops regards if the material is recycled and used again by any producer (Yuan et.al. 2006).

CE is a comprising area that includes both technical materials and biological materials (Ellen Macarthur foundation, 2015). Products and materials can be put back in to the system in different stages of a supply chain, and thus closing the loop. The way that is considered to be best for environment and economy is to prevent disposal by designing products to last longer and to be easily maintained so that they have longer life cycles (ibid). This is described as the inner circle in Figure 5, while the other circles are reuse and redistribute, refurbish and remanufacture, and recycle. This thesis is focusing on the outermost arrow; recycling, which is the most favourable option after reusing and remanufacturing. According to Lieder and Rashid (2016) most research regarding CE is focusing on the environmental and resource scarcity aspects while there is a lack of research regarding the economic aspects of CE. They also stress the importance of looking at the economic aspect for individual companies since it is these companies that need to e.g. design their SC, create business models, and design products to implement a functioning CE.

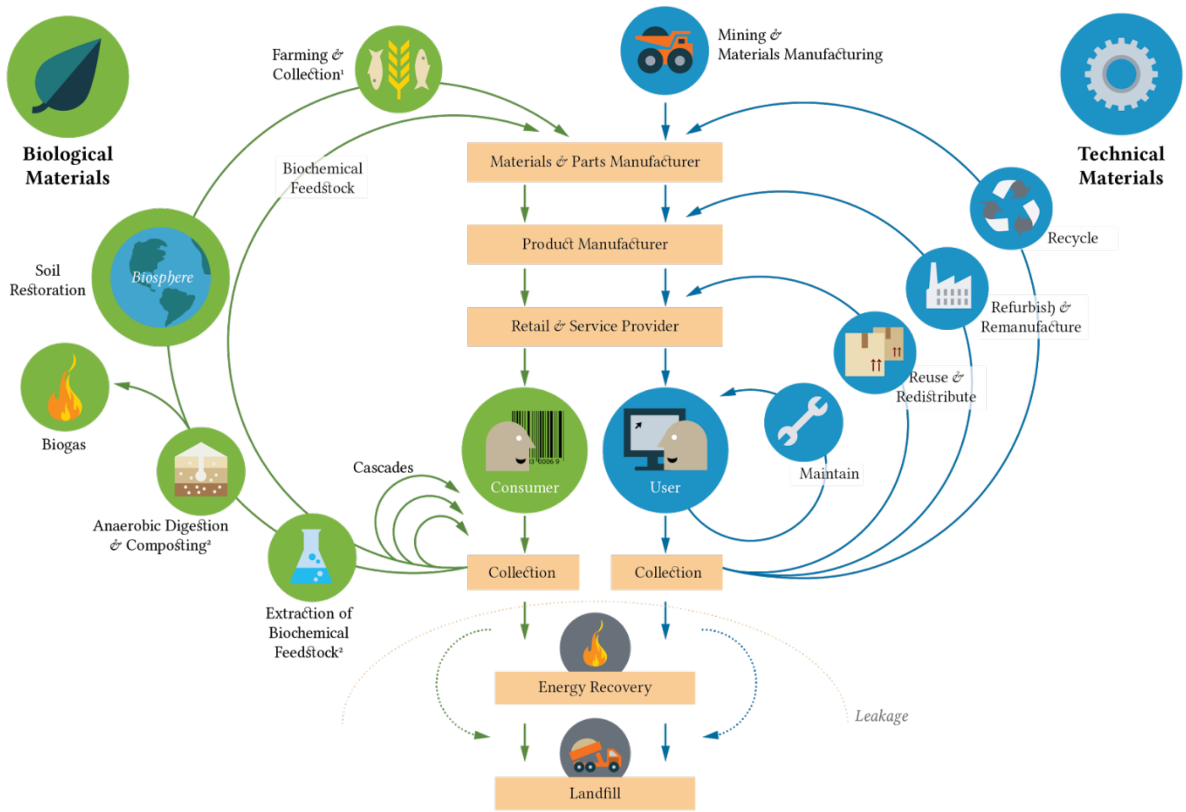

Figure 5: The figure shows the idea of Circular Economy with both ecological (to the left) and technical (to the right) aspects. The inner circles show the most favorable option while the outermost circles shows the least wanted options in CE. At the bottom is energy recovery and landfill which are leakages (Ellen Macarthur foundation, 2015).

3.2 Reverse Logistics

RL includes all logistics activities connected to recycling, disposal, and source reduction (Stock, 1992). Customers are becoming more aware of whether or not a company is involved in environmental work which puts pressure of using innovative ideas to create sustainable RL systems (Dyckhoff et al. 2004). Further, Rogers and Tibben-Lembke (1999, pp. 2) have defined RL as “the process of planning, implementing, and controlling the efficient, cost-effective flow of raw materials, in-process inventory, finished goods, and related information from the point of consumption to the point of origin, for the purpose of recapturing value or proper disposal”. Moreover, RL is the process of moving the product from the typical end user to any other possible process that might find value in the product, e.g. reuse or recycling (Frei et al. 2016, Hawks. K, 2006, Schultmann et al. 2006). The value does not need to be only of economic character, it can also include indirect values of marketing and strategic issues (Schultmann et al. 2006).

By developing RL, companies can manage the ever-increasing environmental demands from governments and by creating new business models that includes RL, companies can stay competitive and thus find economic benefits from returned products (Lieder and Rashid, 2016). According to Schenkel et al. (2015) an efficient RL can lower costs for entire SCs, at the same time as customer satisfaction increases and gives the company a better corporate image by being more sustainable. Bonev (2012) have identified economics, legislations, and corporate citizenship as key drivers for affecting decisions regarding the activities in RL. Other examples of strategic issues other than preparing for future legislatures, are gaining market shares in early stages to gain competitive advantages (Schenkel el al. 2015).

According to Schenkel et al. (2015) it is possible to create value through RL by considering revenue generation and cost reduction. The reuse or recycling of materials can lead to increased revenues if value is added in form of refining the material and thus increasing the selling price (Tibben-Lembke and Rogers, 2002). Tibben-Lembke and Rogers (2002) further argues that by putting the material to use in a new product, costs can be saved since recycling can in some cases be cheaper than buying virgin material. In order to evaluate possible profits in RL, costs need to be considered. The cost reduction can be connected to creating more efficient processes and improving reuse or recycling of materials and thus lowering e.g. waste disposal cost. The cost should include processes such as collect, disassemble, sort, transport, investments etc. (Schultmann et al. 2006).

One example of where RL is an important factor is for instance the legislation of extended producer responsibility, in which producers need to ensure that waste materials have a minimum of environmental impact (Lindhqvist and Lidgren, 1990). In order to ensure this, the producers need to have a functioning RL to be able to retrieve the products and properly dispose the them. Schenkel et al (2015) states that by developing their activities within RL a company can support environmental sustainability and reduce use of scarce resources.

Due to uncertainties in number of products returned and the condition of the product, RL are considered to be more complex and challenging to work with compared to traditional logistic issues within forward supply chains (Tibben-Lembke and Rogers, 2002). The incoming products could be defect, damaged, or fully functional and at the same time have high uncertainties in quantities and timing, therefore they all require different handling and are difficult to plan for further processing (Tibben-Lembke, 2002). A higher value is often obtained if the returned product is retrieved in an early stage of its life cycle. Some materials are being worn down by external variables, while others are considered old and no longer wanted, which can limit the potential of reusing or remanufacturing the material (Weetman, 2017).

3.2.1 Activities in reverse logistics

Within a RL system, several activities are involved; activities such as collecting, cleaning, disassembly, inspection, storage, transport and recovery operations. In following figure 6, a typical integrated logistic system with both forward and reverse flows is illustrated:

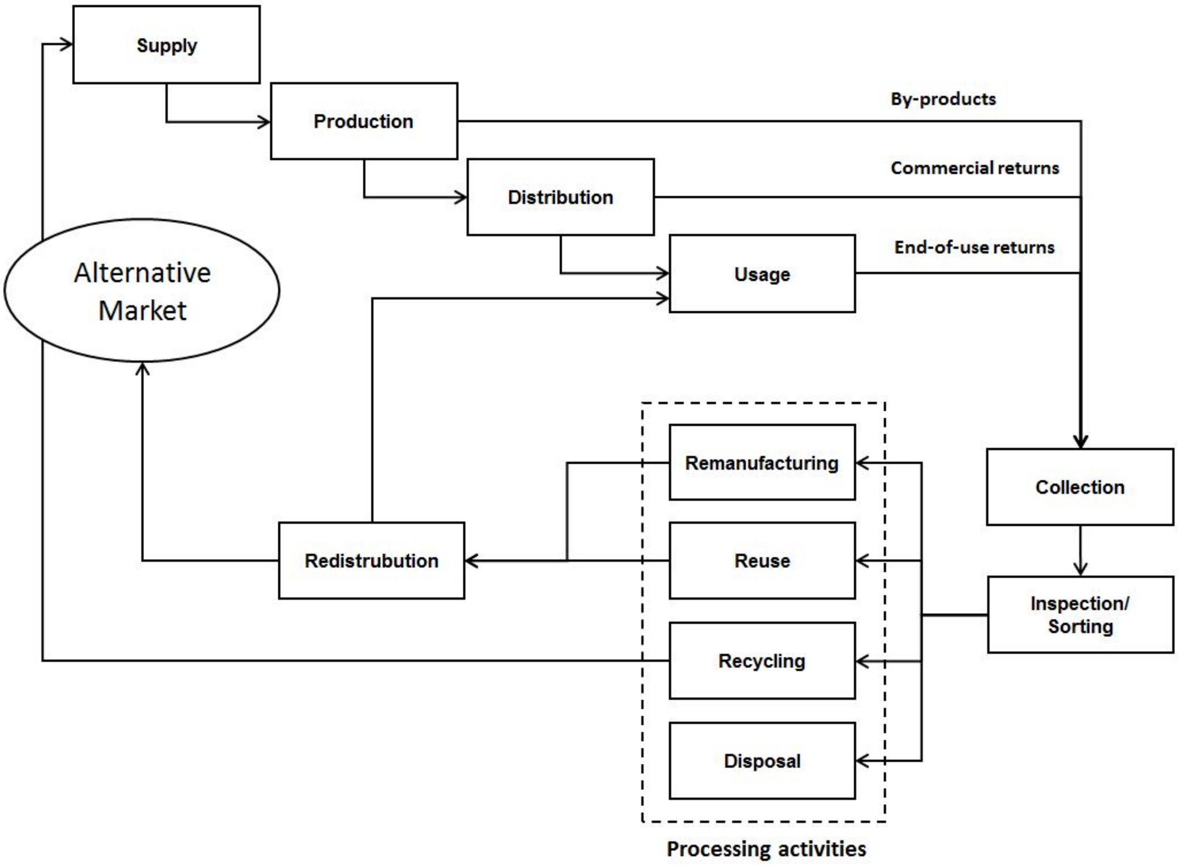

Figure 6: The figure illustrates the flow of materials, both forward and reverse (adapted from Bonev, 2012).

The RL flow in figure 6 can be divided to the following three main phases:

- Collection phase
- Inspection and sorting phase
- Processing phase

Collection of returns is the starting point of RL and comprises all activities centred on gathering the goods that are in need of return (end of use products, leftovers or by-products) and transporting them to a suitable location where further examination and processing can be done. This activity is of high importance, as the collection process is both a costly and time-consuming process. However if it is handled efficiently, companies will be able to reduce costs and use it as a competitive advantage (Bonev, 2012). Noteworthy is that collection activities may, to a certain degree, be forced and necessitated through environmental legislations on organizations. As an example, Bonev (2012) mentions that in some Western European countries there are obligations for manufacturers on 100% collection of white goods. Furthermore, at this point of RL system, organizations will deal with a high degree of uncertainties related to location of the collection, quantity of the products and time of arrival. When it comes to planning and designing of the collection process, it is of high importance to carefully consider these uncertainties (ibid).

In the inspection and sorting phase, all the collected products will be further examined and depending on their quality, determined if a product (or parts of it) should be reused, remanufactured, recycled or simply disposed. As it can be seen in figure 6, the inspection phase will sort and split the products into different return flows according to what appropriate processing that is needed. In general, this phase requires a lot of manual work which implies that the inspection and separating phase can be quite costly and time-consuming. Therefore it is important to develop an efficient solution in order to avoid excessive costs for companies (Bonev, 2012). Some activities that are involved in an inspection and separation phase are disassembling, shredding, testing, sorting and storing (ibid.).

As mentioned earlier, depending on the condition and quality of the product, different processes can be implemented in the processing phase (e.g. reuse, remanufacture, recycle or disposal). Remanufacturing involves a series of activities (i.e. disassemble, clean, reassemble, overhaul and replacement) which is necessary in order to recover the used product to an “as new” state and condition (Dalmijn and Jong, 2007). Reusing can be applied when a product is in such a good shape and condition that it could be used right away with almost no necessary repairing process. If the products are in a too severe condition and can neither be reused nor remanufactured due to excessive repair costs then recycling is a good option (Miller et al. 2014). In the recycling process, the products are disassembled, processed and their materials divided into homogenous components. The recyclable material will then be treated to acquire the quality required for further use. An example of recycling can be seen in the automotive industry where dismantling and shredding are two stages of the recycling process (ibid.). In the first stage, cars arrive at dismantlers either through car dealers or customers and being dismantled. Reusable and valuable components will be separated, tires and fuels will be removed, and the remaining body will be transported to the shredding processor where the components of the body will be separated to ferrous, non-ferrous and non-metallic materials. If the products are not suited for the above-mentioned processes due to quality or economic reasons, then the returned products need to be disposed (Dalmijn and Jong, 2007). A disposal process usually involves transportation, landfilling and incineration activities (Bonev, 2012). After the products have been processed, the need for redistribution occurs. Products that are directly usable or reusable through remanufacturing will be redistributed to either the original market or to new customers in alternative markets (ibid.).

3.2.2 Actors in Reverse Logistics

RL involves all processes that takes place when a product or component are being somehow returned to productivity with the intent of taking advantage of the products remaining value by refurbish, repair, resell, recycle, or scrap (Frei et al. 2016). All these activities need to be performed by some of the actors in the SC. The actors identified in the SC regarding plastic recycling are collectors, recyclers, and processors. There are no clear boundaries for the identified actors, on the contrary, they have all different business plans where they go differently far in the SC. It is important for the dismantlers to rethink what they are doing now and look in to new possibilities for making business of parts from the ELVs. According to Lieder and Rashid (2016) it is vital for manufacturing companies to develop new collaborative business models and to find new partners to be successful. By mapping the process flows in a SC with its actors and activities it is possible to analyse potential improvements and which the value adding activities are. Whether or not it is done on a detailed level its purpose is to find potential improvements and value adding activities (ibid.).

3.3 Plastic Recycling

According to Miller (2014) one of the obstacles to develop new technologies and ways of working with recycling plastics from automotives is that there is an uncertain future for making revenues on the market. This is because some of the plastics are cheap to produce from raw material, and because the market will likely be dependent on legislatives.

To justify investments in machinery for recycling materials the price of the new product needs to be high enough to cover the costs, as well as low enough for possible customers to consider the recycled material as an alternative to virgin material (Dodbiba and Fujita, 2004). The quality of recycled plastics from open loops is known to be lower than virgin plastics (Dodbiba and Fujita, 2004). Pollutants such as dust, different types of plastics and paint are known examples in recycled plastics that are difficult to handle. It is costly to clean the plastics from the pollutions through e.g. melt filtration, but necessary if the plastics are going to be used in products that demand certain levels of quality. If the plastics comes from a closed-loop SC it is easier to guarantee high quality due the low risk of pollutions and can therefore be priced higher than open-loop plastics (Schultmann et al. 2006). The further in the process of value adding activities the plastics have come, intuitively, the price gets higher.

One of the greater problems with recycling plastics from ELVs is the bulky parts that make transportation costly due to low fill rates (Fråne et al. 2012). By using high fill rates in each transport, it is possible to reduce number of transports and thus reducing costs as well as emissions and environmental effects (Lumsden, 2009). The distances of transports are also important to consider, longer transports require more fuel and create more emissions. In Sweden, the transport distances can be relatively long and Dyckhoff et al (2004) identifies transport costs as one of the major costs for recycling plastics. Therefore, to make the recycling beneficial, size reduction of the plastic parts from ELVs to increase fill rates of transports are of high importance.

One challenge is mixed plastics which is hard to recycle since it is difficult, expensive, and time consuming to separate plastics. Multi material products are designed to do certain things, like bumpers are designed to absorb forces of an impact to reduce forces on passengers. Bumpers often consist of PP, EPDM, and talc, which gives them their specific qualities. This mix of materials aggravates the recycling since materials are hard to separate. Closed loop recycling is beneficial if the products consist of mixed materials, since in a closed loop, products of one specific character are recycled in order to produce the same product once again (Ellen Macarthur foundation, 2016). If closed loop recycling is not possible, open loop recycling with third party actors is an option.

According to Briassoulis et al. (2013), a typical recycling process for pellet production begins with pre-treatment-separation process where the mixed and unsorted plastic will be sorted. Afterwards the plastics will be wet-shredded, washed and dried several times, passing through a final drying unit and in the end, they will be extruded, melt filtrated and chopped into pellets. Similar activities and processes can also be seen in a research regarding mechanical recycling of Polylactic acid (PLA) which is a type of plastic, published by Cosate et al. (2016), which are as follow: separation, grinding, washing, drying, extrusion, cooling, granulation and sieving. As it can be seen in the two above mentioned researches, the main activities and steps are similar, however the activity order and technical methods can be different based on customer requirement, material properties, preconditions, etc. (Briassoulis et al. 2013). In this research, activities included in the process of recycling plastics from ELVs (e.g.; sorting, washing, size reduction, extruding, pelletizing) are going to be analysed and required activities identified afterwards.

3.4 Recycling plastics in automotive industry

It is getting more common to own automotives in developing countries, which will lead to increased number of ELV´s that need to be recycled (Sakai et al. 2014). Not all countries have legislations regarding recycling of ELV´s, intuitively different countries has come differently far with developing markets for secondary plastics (ibid). Belgium for instance have come relatively far and encourages recycling to a greater extent, while Australia doesn't have any significant market and therefore does not put any effort in investing in technologies for recycling plastics (Vi Kie Sooa et al. 2016). Research shows that that the main drivers for other countries to recycle parts from ELV´s are of economic character (ibid.). The handling of the plastics (dismantling and sorting) creates high costs for dismantlers and is one of the more difficult processes in the industry (Dodbiba and Fujita, 2004). Countries with low labour costs, such as China, have better opportunities to recycle more of the plastics on the ELV´s before it is shredded and can minimize the recycling costs (Zhang & Chen, 2014). Previous research from Canada showed that lack of legislatives and policies together with low tipping fees are to big barriers for dismantlers to be able to make profit from recycling plastics by dismantling prior to shredding (Duval & MacLean, 2007).

3.5 Summary of drivers and barriers

In theory, several drivers and barriers of recycling plastics can be found. These drivers and barriers are of both global importance such as reducing scarce resources as well as lack of profit on company level. Below in Table 2 the main drivers and barriers are summarized with their respective reference.

Table 2: The table summarizes the drivers and barriers found in theory with their respective reference.

Driver	Barrier	Reference
EU directive		EU directive 2000/53/EC
Legislative		EU directive 2000/53/EC
Sustainable environment		Ellen Macarthur foundation, 2015
Circular economy		Ellen Macarthur foundation, 2015
Value in the product		Hawks. K, 2006, Schultmann et.al. 2006
	Missing regulations	Duval & MacLean, 2007
	Lack of profit	Duval & MacLean, 2007
	High labour costs	Dodbiba and Fujita, 2004
	Not designed to be easily dismantle	Gerarrd and Kandlikar, 2007
	Uncertain prices for plastics	Vermeulen et al. 2012, Miller 2014
Environmental perspective		Vermeulen et al. 2012
Better corporate image		Schenkel et al. 2015
Reduce use of scarce resources.		Schenkel et al. 2015
	RL complex and challenging to work with	Tibben-Lembke and Rogers, 2002
	High uncertainties	Tibben-Lembke , 2002
	Lack of legislatives and policies	Duval & MacLean, 2007
	Low tipping fee	Duval & MacLean, 2007

It is evident from the summary that the main drivers are of a more global character with legislations and an aim of better environment. The legislations make the recycling a must while aspects of better corporate image and reduce of scarce resources lies more within the company's interest in improving their business. The barriers that are found are mostly focusing on companies' problems with finding ways of making profit from recycling plastics. If companies cannot find economic gain from recycling, it might be hard to fulfil the legislatives.

3.6 Theoretical framework

The theory chapter started with explaining CE and continuing further to RL and its associated activities and ending with a summarization of identified drivers and barriers. This chapter is illustrated as a conceptual framework in figure 7.

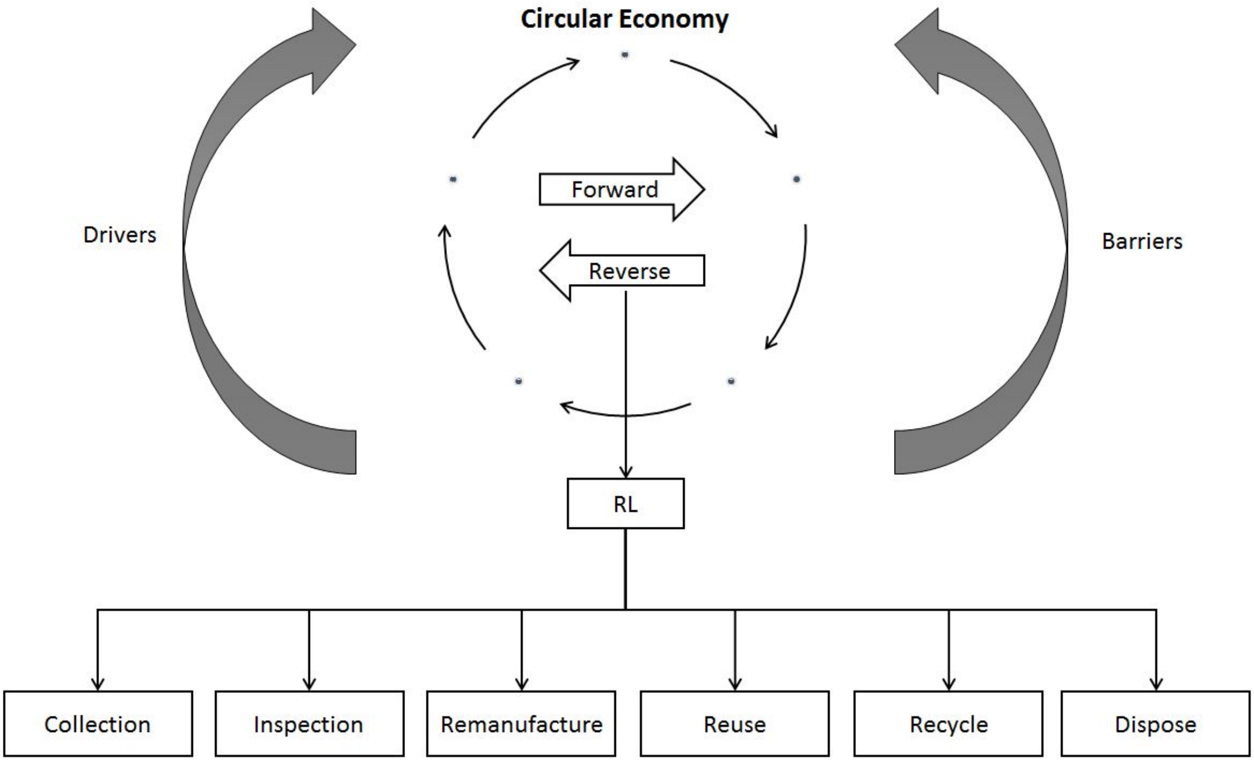

Figure 7: Shows the theoretical framework. CE is the main area and includes RL which in turn includes recycling. The theory contains both drivers and barriers in all its parts.

4 Empirical data

This chapter will describe all information gathered from potential customers of recycled plastics, suppliers of equipment needed for recycling plastics, dismantlers etc. First the dismantlers will be presented, then activities in recycling will be described, then all costs for machinery will be declared, and finally the potential cases that have been identified will be explained.

4.1 The dismantlers; Walters and Eklunds

Walters Bildelar AB founded in 1966 is located in Falkenberg and has 30 employees. Their business is about dismantling approximately 2700 ELVs yearly and selling the functional parts as spare parts, and selling the non-functional parts as scrap to recyclers with the intent of recycling them to raw material. They are ISO9001 and ISO14001 certified and well aware of the targets in the EU directives 2000/53/EC and are working continuously with improvements to be one step ahead (Walters 2017). As of today, Walters does not recycle any plastics from the ELVs but they have a great interest in handling the EU directives by developing a system for recycling.

Eklunds Bildelslager AB, located in Skövde, have the same business model as Walters but are slightly bigger with 3500 ELVs yearly and 33 employees and over 60 years of experience in the business. They are ISO9001 and ISO14001 certified and are continuously developing ways for more effective handling of spare parts and recyclables (Eklunds 2017). Eklunds, just as Walters, have a great interest in recycling plastics and are working closely with Walters to find new ways of developing their business to increase the recycling rates.

4.2 Dismantling ELVs in Sweden

In Sweden, according to the Swedish Car Recyclers Association (Sbr service 2017), a total amount of 186967 ELVs were dismantled in year 2014. Walters and Eklunds which dismantles 2700 and 3500 ELVs/year, respectively, are considered to be big actors in the business which consists of over 500 dismantlers in total. Out of the 2700 and 3500 cars that Walters and Eklunds are dismantling each year, they assume that 2500 and 3300 respectively are available for recycling purposes. And as can be seen in Table 3, their aggregated volumes of dismantled plastics ready for recycling is 165300 kg/year. The amount of plastics in ELVs will increase in the near future (Gerrard and Kandlikar, 2007, Buekens and Zhou, 2014), therefore the dismantlers will have a safe supply of plastics. Car dismantlers are often located in industrial areas and have plenty of space to store the ELVs, it is therefore assumed that it is possible for them to store the dismantled plastics parts if that would be necessary.

Table 3: Total weight of plastic parts being studied for Walters, Eklunds and whole Sweden.

		Walters	**Eklunds**	**Sweden**	
Plastic part	**Weight/car (kg)**	**Weight/year (kg) - for 2500 ELVs**	**Weight/year (kg) - for 3300 ELVs**	**Weight/year (kg) - for 186967 ELVs**	**% of total in Sweden**
Front bumper	5.6	14,000	18,480	1,047,015	19.65
Rear bumper	4.4	11,000	14,520	822,655	15.44
Skid plate	1	2,500	3,300	186,967	3.51
Wheelhouse	4.8	12,000	15,840	897,442	16.84
Fuel tank	11.4	28,500	37,620	2,131,424	40.00
Washing fluid tank	0.8	2,000	2,640	149,574	2.81
Expansion tank	0.5	1,250	1,650	93,484	1.75
Total	**28.5**	**71,250**	**94,050**	**5,328,560**	**100**

4.3 Value adding activities in ELV plastic recycling chain

By observing the plastic recycling process at Swerea and interviewing Landberg[2], the following value adding activities and process map illustrated in figure 8, have been identified.

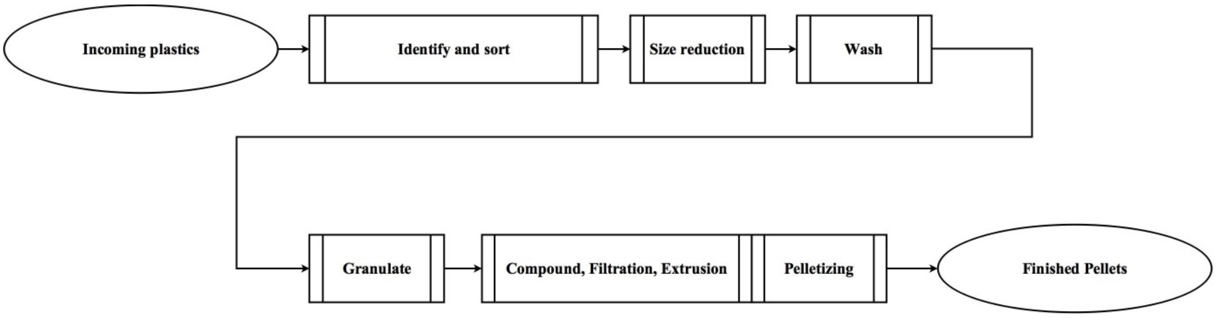

Figure 8: Value adding activities and process map.

Each activity is described as follow:

1) Identify and sort: The plastic parts will be identified and sorted by their plastic type (PP, PE or PP/PE).
2) Size reduction: Plastic parts are being size reduced to sizes of 20-40 mm.
3) Wash: This activity shouldn't be confused with cleaning. In this process, the plastic parts will be washed with warm water in order to get rid of dust and fat from the plastics surface. The plastic parts will be dried afterwards.
4) Granulate: Dried plastics will be further size reduced to 10-15 mm, making them ready for extruder machine.
5) Compound, filtration and extrusion: All the activities are done at the same time in a single extruder machine. The granulated plastics will heat up to their melting point and mixed with additives (if available). The melted plastics will be pushed through a filter in order retrieve a higher plastic quality and further extrude as long plastic strings.
6) Pelletizing: In this process, the long plastic strings from extruder will be chopped to small plastic pellets.

After the recycling process is done, the finished pellets are used in different production processes such as blow moulding, filament extrusion and etc. Plastic filaments are used for 3D-printing application as a raw material which are becoming more and more popular. The actors involved in this project, including the authors, thought that it could be interesting to see what are the requirements for producing filaments, therefore the following activity were identified:

7) Filament extrusion: Here, the plastic pellets are melted and transformed into a string of plastics and rolled up on a spool or reel which is then called plastic filament. The width of the filament is defined by the force and speed that is applied by the winder to the filament as it is pulled out of the extruder.

[2] Johan Landberg, Mechanical engineer with expertise within polymers at Swerea, [2017-10-18, 2017-11-03, and 2017-11-23]

4.4 Customer requirements

Several companies including waste collectors, recyclers, and plastic processors have been interviewed in order to understand the market value, trend and requirements of recycled plastics from ELVs. The collector’s main task is to collect plastics from different areas and to sell the plastic to other actors in the chain. Recycling firm’s main task is to recycle the plastics by performing several of the value adding activities such as size reduction and washing. Most of the processors buy pellets and use plastic moulding to produce plastic parts. However, the identified customers were first thought to be limited to their main tasks, but from the interviews it was learnt that several of the companies perform multiple activities that regards other aspects of RL in plastic recycling. Since the customers could not be divided into collectors, recyclers, and processors due to diversity in their roles, their shape and form requirement of demanded plastics was found to be stable and thus categorized accordingly. The results from these interviews have been summarized and divided based on customer requirements to six customer categories.

Table 4, shows the customer categories as well as their requirements of condition of plastics, what type of plastics they are interested in, demand in volume, quality requirements, and what price they are willing to pay for plastics.

Customer category 1: This customer category will purchase complete plastic parts in separate batches without any required size-reduction. The demand is relatively high and low expectations regarding the plastic quality.

Customer category 2: The customer is interested in buying baled plastic parts in separate batches. The demand is relatively high and low expectations regarding the plastic quality.

Customer category 3: Customers in this category are willing to buy shredded plastic parts in separate batches. The demand is high and the quality expectations are low to medium.

Customer category 4: Here the customer wants washed and granulated plastic in separate batches. The granulated plastic should not contain any metals and the quality expectations are medium to high. The demand in this category is average.

Customer category 5: This customer category is only interested in plastic pellets. The demand varies a lot and depends on quality and market situation. Some of the customers in this category are interested in only uncoloured plastics while others can also think to buy coloured plastics. Therefore, it's important to identify those customers that have no preferences on plastic colour, since the plastic won’t go through a painting process. In this category, the quality depends on the final customer requirements.

Customer category 6: The customer here is the consumption market. Produced filament will be sold on dismantler’s website to all over Sweden. The value of the final product is significantly increased compared to the products for previous category. This customer category has been added to understand how much the value increases if filament production is added, therefore a thorough and detailed customer analysis has not been conducted.

Table 4: The table summarizes the customer categories and their specific requirements.

Category	**Condition/form**	**Demanded material type**	**Demand**	**Quality exp.**	**Price (SEK/kg)**
Customer category 1	Complete plastic parts	PP	High	Low	1.5-3
		PE	High	Low	1.5-2.5
Customer category 2	Baled plastic	PP	High	Low-Medium	1.5-3
		PE	High	Low-Medium	1.5-2.5
Customer category 3	Shredded plastic	PP	High	Low-Medium	2.5-4
		PE	High	Low-Medium	1.5-2.5
Customer category 4	Washed and Granulated plastic	PP	Low	Medium - High	4-5
		PE	Low	Medium - High	4-6.5
		PP/PE	Low	Medium - High	3
Customer category 5	Plastic pellets	PP	Low-Medium	Medium - High	14-16
		PE	Low-Medium	Medium - High	14-16
Customer category 6	Filament	PP	-	-	150-525

4.5 Equipment and technologies

Some investments are needed to develop good possibilities for recycling plastics from ELVs. Investments in machinery are a prerequisite for dismantlers to elaborate new ways for taking advantage of value in plastics from ELVs and meeting the EU-directives. Machinery that are looked into are for instance different size reduction equipment; baler, shredder, and granulator. Depending on where in the recycling process the plastic is sold the price differs. Accordingly, cost for machinery handling the plastics.

To be able to make simulations of cases that are possible for dismantlers to adapt, it is necessary to look into costs for different required machinery. Several companies in both Europe and Asia have been identified as possible suppliers of equipment for the recycling process. The companies were contacted and given the information needed for them to come up with best quotations possible. Following, a brief explanation on different equipment is presented:

Shredders, which are the first step of size reduction, tend to operate at low speeds (around 100 to 130 rpm) with high torque that allows them to cut through almost anything. Shredders can be provided in single-shaft designs that cut down against one or more stationary bed knives, or dual-shaft models that employ two counter-rotating shafts that cut against each other to shred scrap. The dual-shaft models are thought to be more efficient in shredding big and bulky scrap but are more complex, more prone to shaft damage and the knife maintenance is doubled compared to the single shaft models. Single-shaft models typically provide a larger, more robust rotor and utilize stationary bed knives, thus simplifying service and offering heavier duty operation.

Washing line is used to wash and dry the shredded plastic parts. It will also separate plastics and other material with specific density(density< 1 g/cm^3) from PE/PP flakes. In order to be economical justified the capacity of a washing line should be more than 1000 kg/h.

Granulators are used to size reduce the material even further than shredders. They operate at high speeds with relatively low torque. Even so-called "low-speed" granulators have rotors that turn at upwards of 190 rpm whereas standard-speed granulators operate at 400 to 500 rpm or more.

An extruder, as its name implies, is used to extrude plastic strings. What happens is that the granulated plastic will melt in the extruder at the beginning. In this stage, other additives can be added to the plastic mixture in order to affect its characteristics to match the required preferences. The melted mixture will be blend by one or multiple screws and then pushed through a filter in order increase its quality.

In order to make pellets out of plastic strings that have been extruded from an extruder, a pelletizer is used which will automatically chop down the plastic string to pellet size plastics.

4.6 Case descriptions

In this section, based on different process maps, equipment quotations and customer requirements, seven different cases are presented. These cases with their respective scenarios were used as layout for simulations that were conducted by CIT. The input required for each scenario in the simulation can be divided to fixed cost for all scenarios and variable costs that are specific for each scenario. To avoid repeating the fixed costs for each and every scenario, they will be presented here. The first fixed cost is labour cost which has been considered 400 SEK/h. The second fixed cost is electricity cost which according to Vattenfall, a Swedish power company, has been set to 0.685 SEK/kWh. Annual service cost is the third fixed cost for each case. It is assumed that the annual service cost for baler, shredder, and granulator is 15000 SEK each and the annual service cost for washing line and extruder-pelletizing line is 50000 SEK for each line. The fourth fixed cost is transportation cost for each container. In Sweden, the transportation cost when hiring a 3PL is considered to be 25 SEK/km for each 20 ft. container. Since also a customer in Germany has been identified, fix transportation cost of 3500 SEK/transport for each 20 ft. container regardless the destination in Germany is determined. Noteworthy is that the maximum weight capacity for each 20 ft. container varies depending on the final plastic form and condition, something that has been considered in simulations. If the plastics are transported as they are without any kind of size-reduction, the maximum weight capacity will be 3000 kg/container. Baling the plastics will result in 9000 kg/container while shredding them will increase the maximum weight capacity to 8000 kg/container. The best fill rate is achieved when the plastics have been processed to granulated plastic, pellets and filament which increases the maximum weight capacity to 12000 kg/container. Another important input for simulation is how many cars are being dismantled for recycling purposes per day which an average of 11 cars per working day for each dismantler has been considered by CIT based on statistics for Walters and Eklunds.

4.6.1 Case 1 (Selling plastic parts as "whole")

The first case illustrated in figure 9, is where dismantlers only dismantle the plastics and later on sells them to customers without any value adding activities. As of today, the dismantlers do not dismantle any plastics for recycling, but only for reuse. Therefore, this case is considered to be starting point and will be used to evaluate the other cases against since it doesn't add any value adding activities on the plastics.

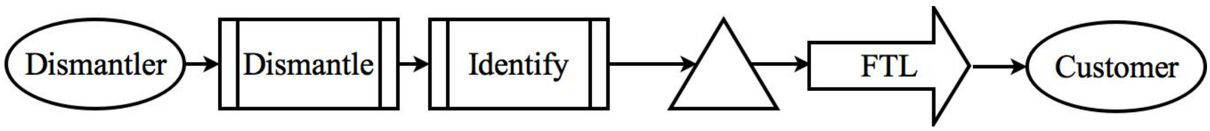

Figure 9: Case 1, selling plastic parts As They Are (ATA).

Two scenarios have been identified for case 1 based on customer's location. In Scenario 1 the plastics are identified/sorted in different batches and then shipped to a domestic customer whereas in scenario 2 it will be shipped to a customer situated in Germany. No equipment is needed for either scenario.

4.6.2 Case 2 (Selling baled plastic parts)

The second case is illustrated in figure 10, and includes a baler that compresses the plastic parts.

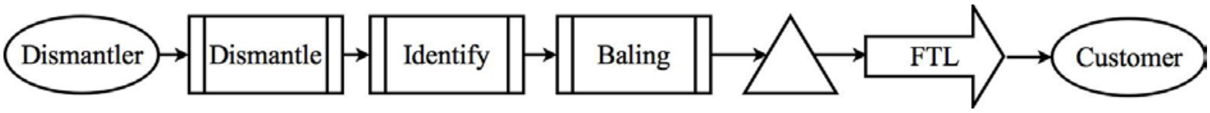

Figure 10: Case 2, baling plastics.

Four scenarios have been identified for case 2 based on customer’s location and the mobility of equipment. In Scenario 1 the plastics are identified/sorted in different batches, baled and then shipped to a domestic customer whereas in scenario 2 it will be shipped to a customer situated in Germany. Scenarios 3 and 4 can be seen as same as 1 and 2 with the only difference being that a mobile baler will be utilized instead of stationary one.

Equipment needed in this case is a baler. A non-mobile heavy-duty baler, suited for both car bumpers and tires, has an average capacity and price on 3000 kg/h and 250,000 SEK. Power consumption for this type of baler is about 22 kW. Noteworthy is that there are also more automated and expensive models in the market that are capable of both plastic and wire strapping automatically but because of their unjustified price (1 MSEK) for dismantlers, they have been removed from simulation. A mobile baler suited for hard plastic is not available on the market. However, based on information provided by CIT the cost of renting a mobile baler is estimated to be 700 SEK/ton.

4.6.3 Case 3 (Selling shredded plastic parts)

The third case utilizes a shredding machine in order to acquire 20-30 mm shredded plastic and is illustrated in figure 11.

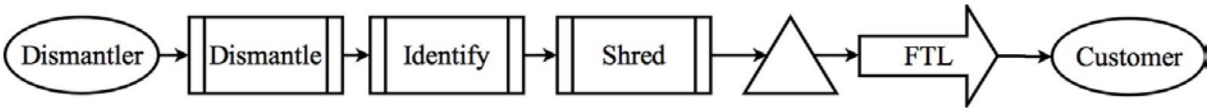

Figure 11: Case 3, Shredding plastics.

Four scenarios have been identified for case 3 based on customer’s location and the mobility of equipment. In Scenario 1 the plastics are identified/sorted in different batches, shredded and then shipped to a domestic customer whereas in scenario 2 it will be shipped to a customer situated in Germany. Scenarios 3 and 4 can be seen as same as 1 and 2 with the only difference being that a mobile shredder will be utilized instead of stationary one.

Equipment needed in this case is a shredder. A non-mobile shredder, suited for dismantlers with low capacity, has an average capacity and price of 100kg/h and 495,000 SEK respectively. Power consumption for this type of shredder is about 30 kW. Regarding a mobile shredder, there is no available supplier who rents it at the moment. However, as in case 2, information from CIT the cost of renting a mobile shredder from is estimated to be 800 SEK/ton.

4.6.4 Case 4 (Selling washed and granulated plastics)

In figure 12 is the fourth case which allows the dismantlers to produce washed and granulated plastics.

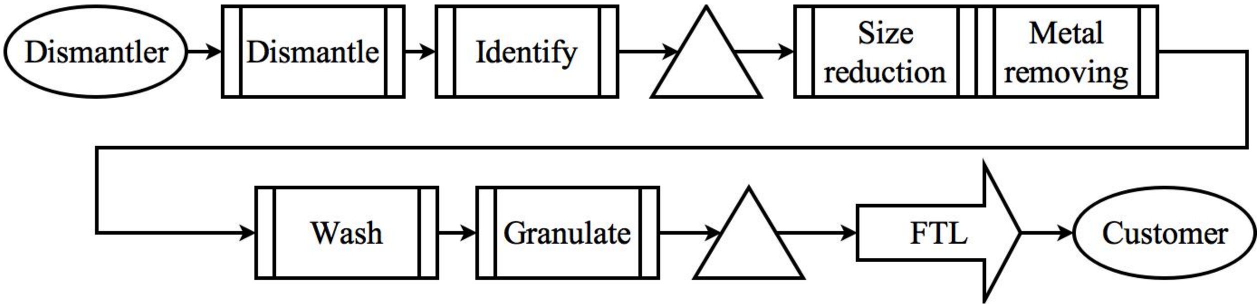

Figure 12: Case 4, selling washed and granulated plastics.

Since there is a wide range of suppliers providing different machineries, it has been decided to look into 3 suppliers representing three price classes. So, in case 4 there will be 3 different scenarios in which the supplier differs based on price and capacity. It is important to understand that equipment from different solutions provided by different suppliers have different specifications and should not be combined in order to prevent incompatibility in installation. In all scenarios, the plastics are identified/sorted in different batches, shredded, washed, granulated and then shipped to a domestic customer. In this case a full washing and granulating line is needed.

In scenario 1, a Chinese supplier has offered a complete washing/granulating line with a capacity of 1000 kg/h for 921,000 SEK. Installation power for this line is 235 kW.

In scenario 2, a European supplier has offered a complete washing/granulating line with a capacity of 1500 kg/h for 8,926,000 SEK. Installation power for this line is 515 kW.

In scenario 3, a Chinese supplier has offered a complete washing/granulating line with a capacity of 1000 kg/h for 1,765,000 SEK. Installation power for this line is 310 kW.

4.6.5 Case 5 (Selling as pellets)

By adding extrusion and pelletizing to the previous case, dismantlers will be able to produce plastic pellets which are of higher quality compared to granulated plastics, this is illustrated in figure 13. The three scenarios presented in case 4 will be used and completed with extrusion and pelletizing in order to create three scenarios in case 5 which uses the same supplier. It is important to mention one more time that equipment from different solutions provided by different suppliers have different specifications and should not be combined in order to prevent incompatibility in installation. The different scenarios for case 5 are based on equipment in different price ranges with different capacity. The most expensive machinery is a large investment for the dismantlers, and it is considered interesting to see how much plastics are needed to make such an investment an option. Because of the high investment costs for an entire washing line with high capacity other options are needed to be looked into. Therefore scenarios 1 & 3 were created. These two scenarios have lower investment costs, with different capacities.

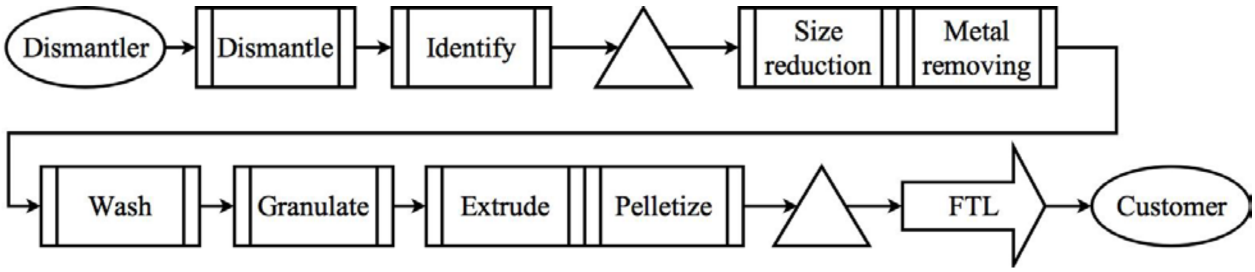

Figure 13: Case 5, Selling as pellets.

In scenario 1, a Chinese supplier has offered a complete washing/granulating line with a capacity of 1000 kg/h for 921,000 SEK. Installation power for this line is 235 kW. Same supplier offers a pelletizing line with a capacity of 200 kg/h for 507,000 SEK. Installation power for the pelletizing line is 280 kW. Both together result in a complete solution for producing pellets with an output capacity of 200 kg/h, a total cost of 1,428,000 SEK and a total power consumption of 515 kW.

In scenario 2, a European supplier has offered a complete washing/granulating line with a capacity of 1500 kg/h for 8,926,000 SEK. Installation power for this line is 515 kW. Same supplier offers a pelletizing line with a capacity of 1500 kg/h for 14,609,000 SEK. Installation power for the pelletizing line is 900 kW. Both together result in a complete solution for producing pellets with an output capacity of 1500 kg/h, a total cost of 23,535,000 SEK and a total power consumption of 1415 kW.

In scenario 3, a Chinese supplier has offered a complete washing/granulating line with a capacity of 1000 kg/h for 1,765,000 SEK. Installation power for this line is 310 kW. Same supplier offers a pelletizing line with a capacity of 800 kg/h for 1,105,000 SEK. Installation power for the pelletizing line is 363 kW. Both together result in a complete solution for producing pellets with an output capacity of 800 kg/h, a total cost of 2,870,000 SEK and a total power consumption of 673 kW.

4.6.6 Case 6 (Selling as pellets and filament)

In this case the dismantlers will use the pellets produced in case 5 and further process them to plastic filaments that can be used for 3D-printing applications. This case is a complementary case for case 5 and has been formulated in order to understand how much value will be added for dismantlers if they produce filament out of pellets, which allows the dismantlers to sell both pellets and filament on the market. This is illustrated in figure 14.

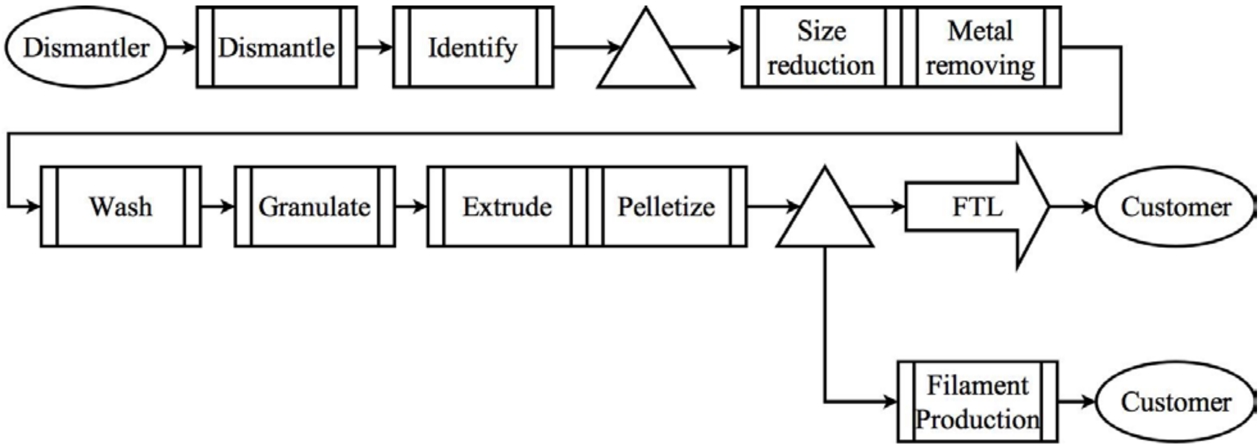

Figure 14: Case 6 Selling as pellets and filament.

The first scenario from case 5 has been selected to serve this purpose due to its low capacity and low investment cost. The scenario is completed with a filament machine which has 1 kg/h capacity, power consumption of 0.4 kW and an investment cost on 42,000 SEK. So together with scenario 1 from case 5 it will result in a complete solution for producing pellets and filaments with an output capacity of 200 kg/h and 1 kg/h respectively. The total cost of machinery will be 1,428,000 SEK and total power consumption will be 515.4 kW. The reason for having a 1 kg/h filament machine is to evaluate how much does the value gets affected by producing filaments out of the recycled pellets.

4.6.7 Case 7 - Selling granulated copper and shredded plastic parts

Case 7, as seen in figure 15, is a case brought forward due to dismantlers' special interest in granulating cables in order to retrieve copper. A shredder is being utilized in order to size reduce the plastics and cables and since there can be stationary shredder or a mobile shredder, two scenarios have been considered. Then the shredded plastics will be sold in different batches to customers whereas the shredded cables will be processed further in a cable granulator machine which will separate copper from the rest of cable scraps and deliver 99.5% clean copper afterwards, ready to be sold to customers.

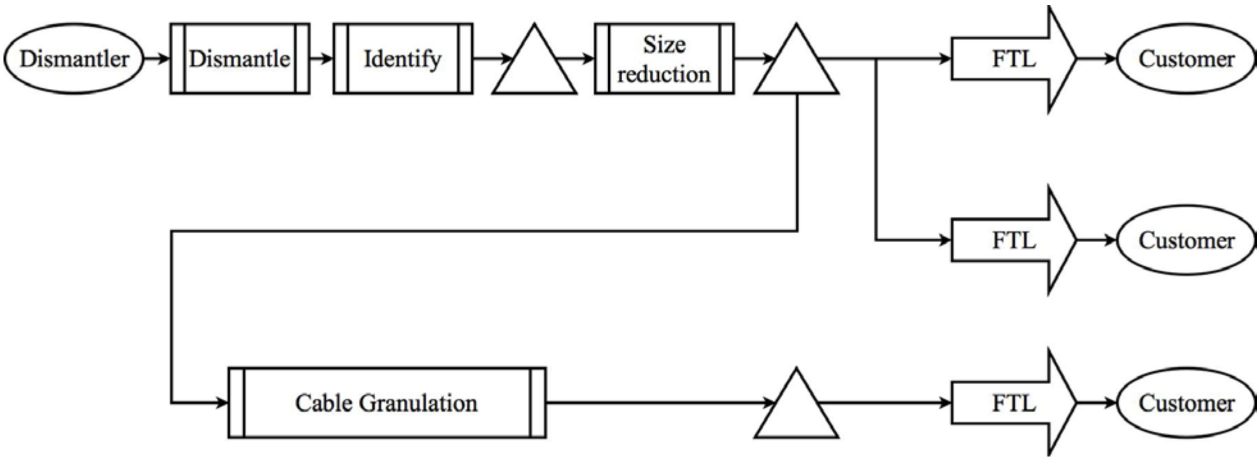

Figure 15: Case 7 - Selling granulated copper and shredded plastic parts.

Equipment needed in this case is shredder and cable granulator. A non-mobile shredder and cable granulator, suited for dismantlers with low capacity, has an average capacity and price of 400kg/h and 1,000,000 SEK respectively. Power consumption for this solution is 67 kWh. For the second scenario, the cost of renting a mobile shredder from a fictitious supplier has been considered to be 800 SEK/ton and a cable granulator prices at 400,000 SEK with a power consumption of 52 kWh.

4.7 Conceptual framework considering empirical data

After presenting the empirical findings, the theoretical framework needs to be tailored accordingly, meaning that a conceptual framework based on recycling plastic parts from ELVs needs to be introduced. By combining empirical findings, that have been presented until this point, with theoretical framework the following updated conceptual framework is presented in figure 16

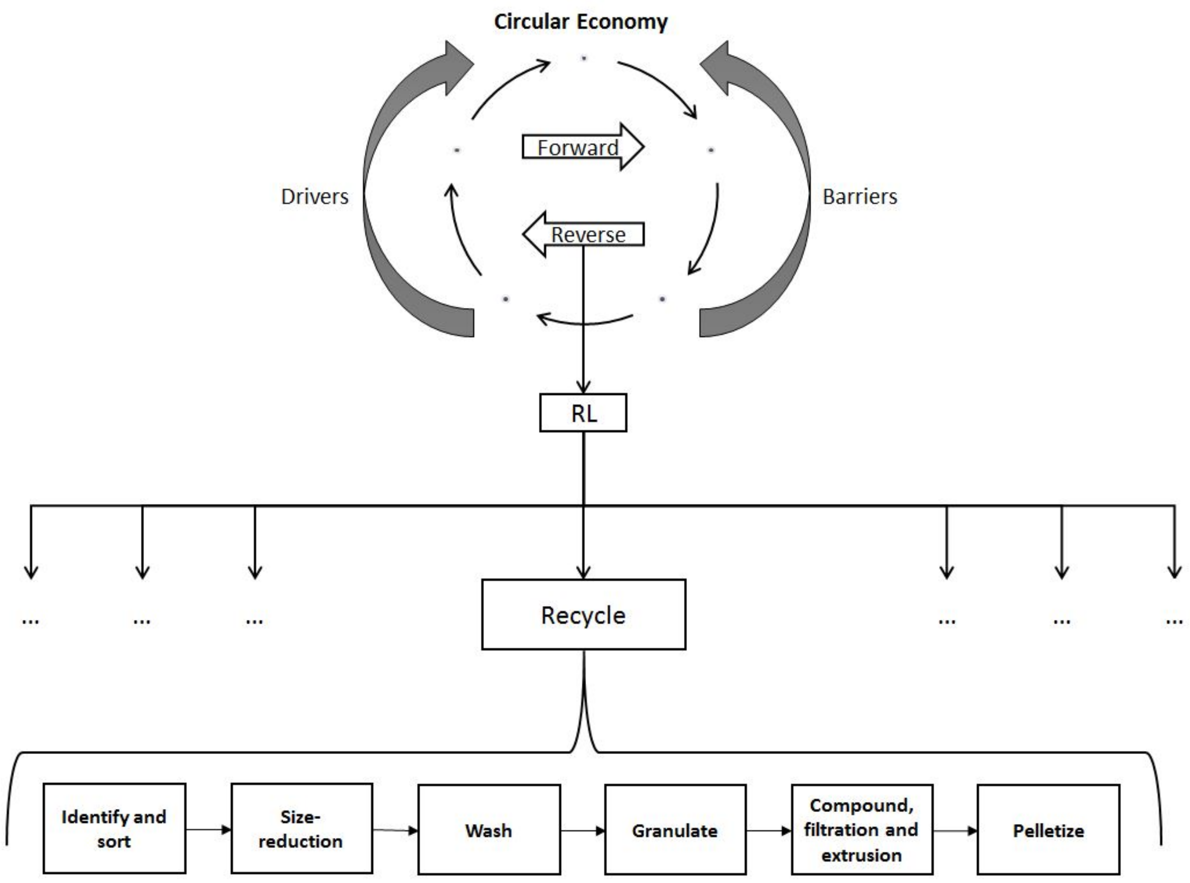

Figure 16: Conceptual framework based on theoretical and empirical findings.

Here it can be seen that the recycling process within RL, consist of the main value adding activities, that have been crucial for structuring different cases, which are identify and sort, size-reduction, wash, granulate, filtration and extrusion, and pelletizing.

5 Results and analysis

The first part of this chapter begins with presenting the test results for different plastic parts and analysing them in order to understand which of them are suitable for further processing. The suitable plastics will be selected in order to be run in the simulation program that is conducted by CIT. The second part presents the simulation results for each case and an economic analysis is performed on these results.

5.1 Results and analysis - Part 1: Selected plastic parts

In the introduction, several plastic parts that were assumed to hold value were introduced. These plastic parts were sent to different customers in order to make different tests and see if the plastics would be suitable for their process or not. Results and feedback were gathered through this process which is presented as follow:

Bumper, Wheelhouse and Skid plate: These parts have been labelled as PP, however they could also be combined with EPDM (ethylene propylene diene monomer) a type of synthetic rubber and TD (talc/talcum). This combination that could be seen very frequently in bumpers will result in high impact resistant plastics. So not being pure PP does not mean that there is no demand for these parts or they have less value; on the contrary due to the high impact resistant characteristic of these parts there is a high demand from a certain market, especially if they are going to be recycled in a closed-loop and being used to produce the same parts again.

Fuel tank: This part is made of high-density polyethylene (HDPE) which is a high demanded material in the market. However, the problem with the fuel tank it has a smell which needs to be taken care of in the recycling phase and before using it in new products. Furthermore, if a recycled plastic with gas smell is going to be used in producing new products, then it is considered best to use it in products that are meant to be used outdoors and not products that are used by consumers directly in their homes.

Washing fluid tank and Expansion tank: These parts have been labelled as PE in the beginning, however by having close observations at dismantlers, the authors realized that washing fluid tanks and expansion tanks can be made of PP, PE or even a mixed PP/PE. Identifying the type of different plastic parts is a time consuming process resulting in extra labour cost. Also, the weight and volume of these parts are very low compared to other parts. As can be seen in table 3 a washing fluid tank weighs 0.8 kg representing 2.81% of total weight of all 6 parts and an expansion tank weighs 0.5 kg representing only 1.75%. Furthermore, test results from the customers show that the material from these parts are contaminated with rubber, explaining that it cannot be used for further processing therefore no demand. Due to these three reasons, it has been decided that washing fluid tank and expansion tank should be excluded from simulations and further discussions.

5.2 Results and analysis - part 2: Cases - Activities

This part begins with analysing case 1, in which no value adding activity is added, based on economic and environmental aspects. Afterwards all other cases will be compared to the first case in order to find the best possible solution for dismantlers. The profit comparison for cases 2 and 3 will be done with their respective scenario in case 1. For case 4, 5 and 6 the comparison will be with only the domestic customers which are case 1 scenario 1. A three year and a five year interval have been considered in simulations, but the profit comparison focuses on 5 years which will provide more time for the scenarios that equipment are purchased to show their actual profit after the investment cost has been returned.

5.2.1 Case 1 (Selling plastic parts as "whole")

The first case is where dismantlers only dismantle the plastics and later on sells them to recyclers without any value adding activities. This case will not solve the problems with transportation and low fill rates but it will meet the demands from the EU-directives of increasing recycling rates of plastics from ELVs. As of now, there are uncertainties whether or not there are customers willing to buy the dismantled plastics as they are but it is assumed that there is an existing market for these plastics.

Table 5: Simulation results for case 1 scenario 1 and 2.

Selling dismantled plastic parts without any size reduction activity	**Scenario 1**		**Scenario 2**	
	3 Year	**5 Year**	**3 Year**	**5 Year**
Category	Value (SEK)	Value (SEK)	Value (SEK)	Value (SEK)
Costs				
Transport PP Total Cost	73,920	122,640	154,440	256,230
Transport PE Total Cost	53,932	89,325	112,679	186,625
Simulation Total Costs	**127,852**	**211,965**	**267,119**	**442,855**
Revenue				
PP to customer Total Revenue	264,000	438,000	330,000	547,500
PE to customer Total Revenue	192,614	319,018	240,768	398,772

Selling dismantled plastic parts without any size reduction activity	Scenario 1	Scenario 2	Selling dismantled plastic parts without any size reduction activity	Scenario 1
Simulation Total Revenue	**456,614**	**757,018**	**570,768**	**946,272**
Profit	**328,762**	**545,053**	**303,649**	**503,417**
Profit / kg	**1.53**	**1.53**	**1.41**	**1.41**

The results from the simulation that can be seen in table 5, indicates selling to a domestic customer generates slightly more profit compared to the customer in Germany. Since the differences in profit are not high it is wise to establish business with both customers in Sweden and Germany in order to mitigate the effects from variations in demand.

5.2.2 Case 2 (Selling baled plastic parts)

By utilizing a baler in case 2, it will both solve the problems with low fill rates in transports and meet the demands from the EU-directives of increasing recycling rates of plastics from ELVs. The advantage of having a baler is that the capacity is relatively high with a low investment cost. Also, it doesn't require any high competence to operate and it is cheap and easy to maintain. The disadvantage is that another actor in chain needs to do the shredding activity and simply baling plastics will not replace the activity. So therefore, it can be seen as a non-value adding activity from customer side and therefore the customer will pay less compared to shredded plastics. As mentioned earlier the capacity on a baler is high while each dismantler has limited amounts of plastics. Therefore, having a mobile-baler seems to be a good solution in which several dismantlers can benefit of the investment. By having mobile equipment transports needs to be made between the dismantlers, this will of course mean added emissions which must be taken into consideration when evaluating the case. As former mentioned, the thesis has focus on the economic aspects, therefore the emissions from transporting the mobile baler is considered negligible with consideration of the reduced transports as result of size reduced plastics.

Table 6: Simulation results for case 2 scenarios 1 and 2.

Selling baled plastic parts in separate batches (Stationary Baler)	**Scenario 1**		**Scenario 2**	
	3 Year	**5 Year**	**3 Year**	**5 Year**
Category	Value (SEK)	Value (SEK)	Value (SEK)	Value (SEK)
Costs				
Operator Total Cost	15,867	28,006	15,867	28,006
Transport PP Total Cost	26,348	44,462	53,515	90,306
Transport PE Total Cost	19,764	32,940	40,142	66,903
Baling Total Cost	250,891	251,581	250,891	251,581
Simulation Total Costs	**312,870**	**356,988**	**360,415**	**436,797**
Revenue				
PP to customer Total Revenue	252,000	432,000	315,000	540,000
PE to customer Total Revenue	180,120	306,204	225,150	382,755
Simulation Total Revenue	**432,120**	**738,204**	**540,150**	**922,755**
Profit	**119,250**	**381,216**	**179,735**	**485,958**
Profit / kg	**0.55**	**1.07**	**0.84**	**1.36**

As the results, seen in table 6, from simulation indicates, in case 2 scenario 1 the profit decreases from 1.53 to 1.07 SEK/kg compared to case 1 scenario 1 which represent 30% less profitability. In scenario 2 it can be seen that the profit decreases from 1.41 to 1.36 SEK/kg which shows a 3.5% drop compared to case 1 scenario 2. The reason for the overall profit reduction can be seen in low plastic volumes that the dismantlers receive which results in low utilization rate on the purchased machinery. In order to make purchasing a baler economically justified, the utilization rate should be increased either by increasing the plastic volumes or by using the baler for other parts and items.

Table 7: Simulation results for case 2 scenarios 3 and 4.

Selling baled plastic parts in separate batches (Mobile baler)	**Scenario 3**		**Scenario 4**	
	3 Year	**5 Year**	**3 Year**	**5 Year**
Category	Value (SEK)	Value (SEK)	Value (SEK)	Value (SEK)
Costs				
Operator Total Cost	15,867	28,006	15,867	28,006
Transport PP Total Cost	26,348	44,462	53,515	90,306
Transport PE Total Cost	19,764	32,940	40,142	66,903
Baling Total Cost	11,850	21,020	11,850	21,020
Simulation Total Costs	**73,829**	**126,428**	**121,374**	**206,235**
Revenue				
PP to customer Total Revenue	252,000	432,000	315,000	540,000
PE to customer Total Revenue	180,120	306,204	225,150	382,755
Simulation Total Revenue	**432,120**	**738,204**	**540,150**	**922,755**
Profit	**358,291**	**611,776**	**418,776**	**716,520**
Profit / kg	**1.67**	**1.71**	**1.96**	**2**

In case 2 scenario 3, in which a baler is rented instead of purchasing, it can be seen in table 7 that there will be an increase in profit from 1.53 to 1.71 SEK/kg compared to case 1 scenario 1 which represent 11 % more profitability. In scenario 4 it can be seen that the profit increases from 1.41 to 2 SEK/kg which shows a 42% increase compared to case 1 scenario 2. The reason for the overall increase can be seen in lower transportation cost due to size-reduction. However it has a higher effect on the fourth scenario (selling to a German customer) compared to the third one (selling to a domestic customer) due to longer transportation distance and slightly higher price for the plastics. This seems to be a good solution but the biggest barrier for implementing it is finding a supplier that provides mobile balers that can be used for hard plastics. As mentioned in the empirical data, at this moment there were no suppliers who provide these types of balers for renting and therefore they need to be customized built.

5.2.3 Case 3 (Selling shredded plastic parts)

By utilizing a shredder in Case 3, it will solve the problems with low fill rates in transports since containers can carry eight tons of shredded plastics compared to three tons if they are not size reduced. This will lower both transport costs for the dismantlers as well as reducing number of transports needed and thus decreasing emissions and making less environmental impact. However, there will be more emissions from the scenario with a customer in Germany due to the longer transport distance, but the German customer is willing to pay more than the customer located in Sweden. Further, it will also meet the demands from the EU-directives of increasing recycling rates of plastics from ELVs. The advantages of having a shredder is, compared to Case 1 that the size reduction is a value adding activity and customers are willing to pay more for the shredded plastics. The capacities of the shredders investigated are relatively high with low investment cost and it doesn't require any high competence to operate. Another advantage with shredders is that they are cheap and easy to maintain.

As it can be seen in table 8, in case 3 scenario 1 the profit decreases from 1.53 to -1.3 SEK/kg compared to case 1 scenario 1 which indicates negative profitability. In scenario 2 it can be seen that the profit reduces from 1.41 to 0.89 SEK/kg which shows 37% less profit compared to case 1 scenario 2. However, high operator cost in this case results in negative profitability for dismantlers. If the operate cost can somehow be decreased or even removed by means such as efficient use of already hired staff or designing parallel activities, then the profit will increase and make case 3 an attractive case for dismantlers. Noteworthy is that the utilization rate of the shredder machine is pretty low in this case due to low plastic volumes at dismantlers. If there is a possibility to increase the utilization rate by increasing volumes through combining flows or even utilize the shredder machine for other materials than plastics, then it will become even more attractive and profitable for dismantlers. This will be analysed more closely in case 7.

Table 8: Simulation results for case 3 scenarios 1 and 2.

Selling shredded plastic parts in separate batches (Stationary shredder)	**Scenario 1**		**Scenario 2**	
	3 Year	**5 Year**	**3 Year**	**5 Year**
Category	Value (SEK)	Value (SEK)	Value (SEK)	Value (SEK)
Costs				
Operator Total Cost	123,253	770,895	123,253	218,337
Transport PP Total Cost	26,885	45,369	56,331	95,059
Transport PE Total Cost	20,167	33,612	42,255	70,425
Shredding Total Cost	607,987	552,405	607,987	614,351
Simulation Total Costs	**778,292**	**1,402,280**	**829,826**	**998,172**
Revenue				
PP to customer Total Revenue	320,064	540,108	448,090	756,151
PE to customer Total Revenue	240,084	400,140	336,118	560,196
Simulation Total Revenue	**560,148**	**940,248**	**784,207**	**1,316,347**
Profit	**-218,144**	**-462,032**	**-45,618**	**318,175**
Profit / kg	**-1.02**	**-1.3**	**-0.21**	**0.89**

Table 9: Simulation results for case 3 scenarios 3 and 4.

Selling shredded plastic parts in separate batches (Mobile shredder)	**Scenario 3**		**Scenario 4**	
	3 Year	**5 Year**	**3 Year**	**5 Year**
Category	Value (SEK)	Value (SEK)	Value (SEK)	Value (SEK)
Costs				
Operator Total Cost	123,253	218,337	123,253	218,337
Transport PP Total Cost	26,885	45,369	56,331	95,059
Transport PE Total Cost	20,167	33,612	42,255	70,425
Shredding Total Cost	93,961	168,837	93,961	168,837
Simulation Total Costs	**264,266**	**466,155**	**315,800**	**552,658**
Revenue				
PP to customer Total Revenue	320,064	540,108	448,090	756,151
PE to customer Total Revenue	240,084	400,140	336,118	560,196
Simulation Total Revenue	**560,148**	**940,248**	**784,207**	**1,316,347**
Profit	**295,882**	**474,093**	**468,407**	**763,689**
Profit / kg	**1.38**	**1.33**	**2.19**	**2.14**

Another way of increasing the utilization rate of a shredder is to use a mobile version which can be used by several dismantlers. As shown in table 9, by renting a mobile a shredder in case 3 scenario 3 compared to case 1 scenario 1, the profit decreases from 1.53 SEK/kg to 1.33 SEK/kg which represent 13% less profitability. In scenario 4 it can be seen that the profit increases from 1.41 to 2.14 SEK/kg which shows a 51.7% increase compared to case 1 scenario 2. The reason for the overall increase can be seen in lower transportation cost due to size-reduction. However it has a higher effect on the fourth scenario (selling to a German customer) compared to the third one (selling to a domestic customer) due to longer transportation distance and slightly higher price for the plastics.

5.2.4 Case 4 (Selling washed and granulated plastics)

In this case, besides shredding, the dismantlers will adapt more activities from the value chain in order to produce washed and granulated plastics. In order to do so, a capacity of at least 1000 kg/h needs to be reached to be economically justified which indicates that plastic flows from several dismantlers need to be combined. Three suppliers have been analysed for this case with different prices and machineries. On the one hand, the dismantlers are more comfortable to purchase from a European supplier due to high reputation and close technical support if needed. On the other hand, the price label for Chinese machinery can be attractive for dismantlers, so it is a trade-off that dismantlers should decide which one outweighs the other.

Furthermore, the fixed investments cost is high for a complete washing line, indicating that case 4 might not be the best option for dismantlers to implement. From the interviews with recyclers it came clear for the authors that an entire washing line takes up much space as well as it is a noisy process. Even though the dismantlers have space in their existing premises it is not an option to install washing lines due to the impact on work environment. Thus, new buildings would need to be set up to house the washing line, and which costs are not calculated in the simulation.

Table 10: Simulation results for case 4 scenarios 1, 2, and 3.

Selling washed and granulated plastics	**Scenario 1**		**Scenario 2**		**Scenario 3**	
	3 Year	**5 Year**	**3 Year**	**5 Year**	**3 Year**	**5 Year**
Category	Value (SEK)	Value (SEK)	Value (SEK)	Value (SEK)	Value (SEK)	Value (SEK)
Costs						
Size Reduction and metals removal Total Cost	320,394	330,067	2,993,480	3,006,586	605,443	617,800
Washing and drying Total Cost	320,394	330,067	2,993,480	3,006,586	605,443	617,800
Granulating Total Cost	318,693	328,486	2,991,176	3,004,443	603,270	615,780
Operator Total Cost	47,420	82,997	35,007	61,184	47,420	82,997
Transport PP Total Cost	92,400	151,200	92,400	151,200	92,400	151,200
Transport PE Total Cost	51,258	95,193	51,258	95,193	51,258	95,193
Simulation Total Costs	***1,150,559***	***1,318,011***	***9,156,800***	***9,325,192***	***2,005,234***	***2,180,770***
Revenue						
PP to customer Total Revenue	594,000	972,000	594,000	972,000	594,000	972,000
PE to customer Total Revenue	546,191	1,014,355	546,191	1,014,355	546,191	1,014,355
Simulation Total Revenue	**1,140,191**	**1,986,355**	**1,140,191**	**1,986,355**	**1,140,191**	**1,986,355**
Profit	**-10,368**	**668,344**	**-8,016,609**	**-7,338,838**	**-865,043**	**-194,416**
Profit / kg	**-0.05**	**1.87**	**-37.5**	**-20.6**	**-4.04**	**-0.54**

As it can be seen in table 10, the first scenario will be the most profitable scenario in case 4 due to its low investment cost. As the results from simulation indicates, in case 4 scenario 1 the profit decreases from 1.53 to 1.87 SEK/kg compared to case 1 scenario 1 which represent 22.2% more profitability. Economically it seems like scenario 1 is a good choice for dismantlers to implement, however there are many hidden aspects that are associated with buying equipment from China. Aspects and uncertainties such as quality and function of machineries, not having close and near technical support when needed, adaptability to European standards and hidden costs regarding transportation and customs. These aspects and uncertainties can be mitigated by purchasing machineries from a European supplier. In scenario 2, where a European supplier has been selected, it can be seen that due to high investment costs and low volume of plastics the profit decreases from 1.53 to -20.6 SEK/kg which shows negative profitability. Even though this solution prevents the above-mentioned uncertainties, in order to be economically justified higher plastic volume is needed. This can be achieved through establishing a facility which acts as a consolidation point for plastic flows from dismantlers all over Sweden. It may not be feasible to convince all dismantlers to follow this solution, but as many dismantlers as possible especially those with high plastic volumes are needed in order to become a more profitable solution. The next non-profitable scenario in case 4 is scenario 3 which has a Chinese supplier, indicating that the same precautions mentioned for scenario 1 need to be considered. In scenario 3 it can be seen that the profit decreases from 1.53 to -0.54 SEK/kg which shows negative profitability.

In scenario 1 the investment costs will be returned after almost 3 years and can be considered as profit for dismantlers, whereas in scenario 2 and 3 due to their high investment costs and low plastic volume, even after five years the investments will not be returned resulting in 7.3 MSEK and 194 KSEK debt respectively.

As mentioned earlier, in order to have more profit and make these scenarios economically justified, higher plastic volume is needed. All actors in this study were wondering what will happen if hypothetically all plastics in Sweden were processed at dismantlers, reaching the maximum output capacity of each scenario. Therefore it was decided to run simulation for the same case with the only difference being dismantlers process plastic parts from all ELVs in Sweden. In simulations an approximate number of 820 ELVs per day has been considered by CIT. Noteworthy is that the transportation cost for gathering the plastics from all over Sweden to the dismantler's site has not been considered. The results from simulations have been provided by CIT and are as follow (complete results can be found in appendix X.X):

The total revenue and cost for scenario 1 are 140,725,280 SEK and 28,758,289 SEK respectively, resulting in 111,966,991 SEK profit in a five year interval.

The total revenue and cost for scenario 2 are 148,220,618 SEK and 38,220,062 SEK respectively, resulting in 110,000,555 SEK profit in a five year interval.

The total revenue and cost for scenario 3 are 140,725,280 SEK and 30,987,717 SEK respectively, resulting in 109,737,562 SEK profit in a five year interval.

Further analysis and discussion can be found in the discussion chapter, since the focus of this study are the dismantlers, Walters and Eklunds, and their respective plastic volumes.

5.2.5 Case 5 (Selling as pellets)

In Case 5 extrusion and pelletizing are incorporated as value adding activities. By adding extrusion and pelletizing to the previous case, dismantlers will be able to produce plastic pellets which are of higher quality compared to granulated plastics. However, it is evident from observations at Swerea that the extruder requires high competence, especially if additives are to be used to change the plastics qualities. This competence would require investment in personnel, either by educating existing staff or recruiting. The latter is according to the dismantlers as of today, not an option.

Moreover, the price that customers are willing to pay for pellets is higher than previous cases. This together with that there is a wider customer base interested in pellets rather than other forms of plastic makes it an intriguing case. However, case 5 will have the same problems associated with the washing line that has been mentioned in case 4. Furthermore, the extruder machine is complex and requires high competence in order to operate it, especially if different additives are going to be added in order to customize the characteristics of finished pellets.

As it can be seen in table 11, the first and second scenarios will be profitable. In scenario 1 the profit increases from 1.53 to 4.64 SEK/kg compared to case 1 scenario 1 which represent 203% more profitability while in scenario 3 the profit increases from 1.53 to 4.28 SEK/kg which shows 179% more profit. However, the fact that the machineries used in scenarios 1 and 3 are from china cannot be neglected. As mentioned earlier, there are some uncertainties regarding the quality which needs to be investigated furthermore. Besides the quality, dismantlers will not have close and near technical support when needed. Other aspect that needs to be considered is cultural differences, different working environment and the adaptability of the equipment to European standards if it’s decided to select a Chinese supplier. As the simulation indicates, scenario 3 will have a decrease in profit from 1.53 to -53.14 SEK/kg which is an insane negative profit compared to case 1 scenario 1. Even though this scenario mitigates the effect of the uncertainties associated with a Chinese supplier but it would require a lot more plastics in order to become profitable.

Table 11: Simulation results for case 5 scenarios 1, 2, and 3.

Selling high quality plastic pellets	**Scenario 1**		**Scenario 2**		**Scenario 3**	
	3 Year	**5 Year**	**3 Year**	**5 Year**	**3 Year**	**5 Year**
Category	Value (SEK)	Value (SEK)	Value (SEK)	Value (SEK)	Value (SEK)	Value (SEK)
Costs						
Size reduction & metals removal total cost	320,394	330,067	2,993,480	3,006,586	605,443	617,800
Washing and drying Total Cost	320,394	330,067	2,993,480	3,006,586	605,443	617,800
Granulating Total Cost	318,693	328,486	2,991,176	3,004,443	603,270	615,780
Extrusion Total Cost	458,566	600,389	7,352,976	7,383,018	589,607	615,270
Pelletizing Total Cost	461,535	610,325	7,351,589	7,385,662	590,144	617,384
Operator Total Cost	868,676	1,496,931	390,820	676,157	526,899	918,783
Transport PP Total Cost	16,800	28,560	16,800	30,240	16,800	30,240
Transport PE Total Cost	11,764	21,848	11,764	21,848	11,764	21,848
Simulation Total Costs	***2,776,822***	***3,746,673***	***24,102,084***	***24,514,540***	***3,549,371***	***4,054,905***
Revenue						
PP to customer Total Revenue	1,800,000	3,060,000	1,800,000	3,240,000	1,800,000	3,240,000
PE to customer Total Revenue	1,260,441	2,340,819	1,260,441	2,340,819	1,260,441	2,340,819
Simulation Total Revenue	**3,060,441**	**5,400,819**	**3,060,441**	**5,580,819**	**3,060,441**	**5,580,819**
Profit	**283,619**	**1,654,146**	**-21,041,643**	**-18,933,721**	**-488,930**	**1,525,914**
Profit / kg	**1.32**	**4.64**	**-98.44**	**-53.14**	**-2.28**	**4.28**

This can be achieved through establishing a facility which acts as a consolidation point for plastic flows from dismantlers all over Sweden.

Furthermore, in order to reach the maximum output capacity of each scenario a hypothetical case was designed where all plastics in Sweden were processed at one dismantler. In simulations an approximate number of 820 ELVs per day has been considered by CIT. Noteworthy is that the transportation cost for gathering the plastics from all over Sweden to the dismantler's site has not been considered. The results from simulations have been provided by CIT and are as follow (complete results can be found in appendix G).

The total revenue and cost for scenario 1 are 83,172,222 SEK and 23,936,682 SEK respectively, resulting in 59,235,540 SEK profit in a five year interval.

The total revenue and cost for scenario 2 are 373,915,251 SEK and 57,387,458 SEK respectively, resulting in 316,527,793 SEK profit in a five year interval.

The total revenue and cost for scenario 3 are 254,737,548 SEK and 24,222,178 SEK respectively, resulting in 230,515,370 SEK profit in a five year interval.

Further analysis and discussion can be found in the discussion chapter, since the focus of this study are the dismantlers, Walters and Eklunds, and their respective plastic volumes.

5.2.6 Case 6 (Selling as pellets and filament)

In Case 6 the pellets are further processed into filament that can be used in 3D printers. This is an activity that would increase the value of the recycled plastics by approximately 134 SEK/kg. The market research did not result in any customers interested to buy filaments of the specific quality. Moreover, due to the low capacity of the machine that produces filaments it is not be possible to sell in large quantities; therefore it is assumed that the dismantlers would sell them over counter or on their website. The case might not be feasible, but is considered to be interesting to show the possibilities of value creation through processing recycled plastics.

Table 12: Simulation results for case 6.

Selling pellets and filaments	**Case 6**	
	3 Year	**5 Year**
Category	Value (SEK)	Value (SEK)
Costs		
Size Reduction and metal removal Total Cost	320,394	330,291
Washing and drying Total Cost	320,394	330,291
Granulating Total Cost	320,716	330,394
Extrusion Total Cost	455,913	603,498
Pelletizing Total Cost	464,986	604,162
Filament production Total Cost	223,965	233,367
Operator Total Cost	3,624,669	6,112,400
Transport PP Total Cost	14,784	24,192
Transport PE Total Cost	11,764	21,848
Simulation Total Costs	**5,757,585**	**8,590,441**
Revenue		
PP to customer Total Revenue	1,584,000	2,592,000
PE to customer Total Revenue	1,260,441	2,340,819
Filament customer Total Revenue	3,780,000	6,660,000
Simulation Total Revenue	**6,624,441**	**11,592,819**
Profit	**866,856**	**3,002,378**
Profit / kg	**4.05**	**8.42**

As the results from simulation indicates, in case 6 the profit increases from 1.53 to 8.42 SEK/kg compared to case 1 scenario 1 which represent 450% more profit. As mentioned in case a description, the filament machine was added to see how much will the value be affected by processing pellets to filament. The results clearly show that the effect is significantly high, however the huge barrier here is limited customer demand. In fact, no study has been conducted in this thesis regarding the market demand of filaments produced of recycled plastic pellets from ELVs. If a market with constant demand could be identified for the plastic types mentioned in the beginning of analysis, then this scenario will become attractive not only for dismantlers but also every single actor in the recycling chain.

5.2.7 Summary of results from Case 1 to 6

Results from cases 1 to 6 from simulations and their feasibility according to dismantler's conditions have been summarized in table 13. All cases have been compared to Case 1, Scenario 1, to show how much profit every value adding activity will generate.

Table 13: Summary of results from cases 1 to 6.

Case/Scenario	Description	Profit SEK/kg	% difference in profit compared to case 1	Feasible according to dismantler's conditions
Case1-scenario1	Selling PP and PE to domestic customer without any further processing	1.53	0	YES
Case1-scenario2	Selling PP and PE to German customer without any further processing	1.41	0	YES
Case2-scenario1	Selling baled PP and PE to domestic customer utilizing a stationary baler	1.07	-30%	YES
Case2-scenario2	Selling baled PP and PE to German customer utilizing a stationary baler	1.36	-3.50%	YES
Case2-scenario3	Selling baled PP and PE to domestic customer utilizing a mobile baler	1.71	11%	YES
Case2-scenario4	Selling baled PP and PE to German customer utilizing a mobile baler	2	42%	YES
Case3-scenario1	Selling shredded PP and PE to domestic customer utilizing a stationary shredder	-1.3	-185%	YES
Case3-scenario2	Selling shredded PP and PE to German customer utilizing a stationary shredder	0.89	-37%	YES
Case3-scenario3	Selling shredded PP and PE to domestic customer utilizing a mobile shredder	1.33	13%	YES

Case3-scenario4	Selling shredded PP and PE to German customer utilizing a mobile shredder	2.14	52.70%	YES
Case4-scenario1	Selling shredded PP and PE to domestic customer utilizing a washing-granulating line provided by supplier1 from China	1.87	22.2%	NO
Case4-scenario2	Selling shredded PP and PE to domestic customer utilizing a washing-granulating line provided by supplier2 from Europe	-20.6	-1446%	NO
Case4-scenario3	Selling shredded PP and PE to domestic customer utilizing a washing-granulating line provided by supplier3 from China	-0.54	-135%	NO
Case5-scenario1	Selling PP and PE pellets to domestic customer utilizing a washing-granulating line and extrusion-pelletizing line provided by supplier1 from China	4.64	203%	NO
Case5-scenario2	Selling PP and PE pellets to domestic customer utilizing a washing-granulating line and extrusion-pelletizing line provided by supplier2 from Europe	-53.14	-3573%	NO
Case5-scenario3	Selling PP and PE pellets to domestic customer utilizing a washing-granulating line and extrusion-pelletizing line provided by supplier3 from China	4.28	179%	NO
Case6	Selling PP and PE pellets and to a small extent filaments to domestic customer utilizing a washing-granulating line and extrusion-pelletizing line provided by supplier3 from China completed with a low capacity filament machine from Europe	8.42	450%	NO

As can been seen in table 13, the most profitable case while also being feasible is Case 3 Scenario 4. Case 3 Scenario 4 is where a mobile shredder is being utilized and the shredded plastic is sold to a German customer.

5.2.8 Environmental analysis for cases 1 to 6

In this project, a number of cases and scenarios have been developed in order to increase the recycling rate of plastics from ELVs. The environmental analysis for all cases related to plastic recycling, which are 1 to 6. The information needed for the environmental analysis are plastic type of each plastic part, all presented cases in this study, transportation distance for each case, and how much energy is consumed in each scenario and processing step. What can be said based on the information we have (plastic type of each plastic part, transportation distance for each case, and how much energy is consumed in each scenario and processing step) is that as the environmental impact increases with longer transport distances and higher energy consumption, it is difficult to assess how environmental impact looks for the different cases. However, in cases where dismantlers processes the plastic, a higher degree of resource efficiency is achieved while also the plastic is going to be recycled instead of sent to incineration. Furthermore, dismantlers adopting the different recycling processes, indicates that some or all recycling activities will be done at their location resulting in lowering the number of current transportations.

5.2.9 Case 7 - Exclusive, Selling granulated copper and shredded plastic parts

As mentioned in the analysis of Case 3, the profit can be achieved through increasing the utilization rate of the shredder. One identified material that can help reaching this purpose is cable. Cables will be size reduced with help of the shredder and further processed in a cable granulator in order to retrieve pure copper. Even though Case 3 Scenario 2, where a stationary shredder is being utilized, has a profit 1.36 SEK/kg representing 3.50% reduced profit compared to Case 1 Scenario 2, the authors have decided that simulation for Case 7, which is a combination of plastics and cables, should include both stationary and mobile solutions in order to see the effect of increasing utilization rate on both scenarios. In both scenario 2 and 4 in case 3, the plastics are sold to the German customer, thus the simulations will be based on only this customer.

Case 7 is an interesting solution since it will help the dismantlers to both size reduce the plastic and granulate the cables. The results from this process will be shredded plastic and pure copper which can be sold directly to customers. The value for plastic will increase to 3-4 SEK/kg and for copper it can be said that it has a high value, but the exact prices that were given are classified and is not allowed to be published. According to the results from the simulation, which can be found in table 14, it seems like this case has the best results and provides significantly more economical profit compared to other cases. It has also come to authors understanding that the dismantlers are leaning more towards this solution than others and claim that this is where their competence and interest lies.

Table 14: Simulation results for case 7 scenario 1.

Selling shredded plastics and pure copper (Stationary shredder and cable granulator)	**Case 7 Scenario 1**	
	3 Year	**5 Year**
Category	Value (SEK)	Value (SEK)
Costs		
Size reduction and metal removal Total Cost	621,685	636,698
Operator Total Cost	379,347	640,329
Copper processing Total Cost	406,660	411,061
Copper transport Total Cost	11,180	18,628
Transport PP Total Cost	56,331	95,059
Transport PE Total Cost	38,734	66,903
Simulation Total Costs	**1,513,936**	**1,868,679**
Revenue		
PP to customer Total Revenue	448,090	756,151
PE to customer Total Revenue	308,108	532,186
Copper customer Total Revenue	2961824	4936374
Simulation Total Revenue	**3,718,021**	**6,224,711**
Profit	**2,204,085**	**4,356,033**
Profit / kg plastic	**2.17**	**2.57**
Profit / kg copper	**18.70**	**22.17**

Table 15: Simulation results for case 7 scenario 2.

Selling shredded plastics and pure copper (Mobile shredder and stationary cable granulator)	**Case 7 Scenario 2**	
	3 Year	**5 Year**
Category	Value (SEK)	Value (SEK)
Costs		
Size reduction and metal removal Total Cost	178,247	303,680
Operator Total Cost	379,347	640,329
Copper processing Total Cost	406,660	411,061
Copper transport Total Cost	11,180	18,628
Transport PP Total Cost	56,331	95,059
Transport PE Total Cost	38,734	66,903
Simulation Total Costs	**1,070,498**	**1,535,660**
Revenue		
PP to customer Total Revenue	448,090	756,151
PE to customer Total Revenue	308,108	532,186
Copper customer Total Revenue	2,961,824	4,936,374
Simulation Total Revenue	**3,718,021**	**6,224,711**
Profit	**2,647,523**	**4,689,052**
Profit / kg plastic	**2.60**	**2.76**
Profit / kg copper	**22.46**	**23.86**

Results from simulations of case 7 scenario 1 shows that in this scenario the profit increases from 1.53 to 2.57 SEK/kg for only plastics compared to case 1 scenario 2 which represents 68% more profitability. For case 7 scenario 2 the results shown in table 15, indicate that the profit increases from 1.53 to 2.76 SEK/kg for only plastics compared to case 1 scenario 2 which represents 80% more profitability

However, in order to understand the effect of increasing utilization rate on profit for these scenarios, they need to be compared to their respective scenarios. For case 7 scenario 1 the respective scenario is case 3 scenario 2. By comparing case 7 scenario 1 with case 3 scenario 2 it can be seen that the profit per each kilogram plastic has increased from 0.89 to 2.57 SEK/kg which is an increase of 189%. It can be seen that by adding cables as another material to this scenario, the utilization rate of shredder has increased significantly and thus generating more profit. Case 3 scenario 4 is the respective scenario for case 7 scenario 2 and by comparing them it could be seen that the profit per each kilogram plastic has increased from 2.14 to 2.76SEK/kg showing an increase of only 29%. It can be seen that increasing utilization rate in the second scenario does not have the same effect as the first one in case 7. The reason is that in second scenario a rental shredder is utilized which the payment is based on the capacity and no fixed investment cost has been dedicated to shredder machine.

In general, for 5 years the profit generated in case 7, scenario 1 is 4,356,033 SEK and in case 7, scenario 2, it is 4,689,052 SEK so the profits are close to each other and the dismantlers need to take other considerations into account and choose the one that suits them. A summary of results can be found in table 16.

Table 16: Summary of results for case 7.

Case/ Scenario	**Description**	**Profit SEK/kg for plastic**	**Profit SEK/kg for copper**	**% difference in plastic profit compared to case 1**	**% difference in plastic profit compared to case 3**	**Feasible according to dismantler's conditions**
Case7-scenario1	Selling shredded PP and PE and pure copper to German customer utilizing stationary shredder and cable granulator	2.57	22.17	68%	189%	YES
Case7-scenario2	Selling shredded PP and PE and pure copper to German customer utilizing mobile shredder and stationary cable granulator	2.76	23.86	80%	29%	YES

6 Discussion

In this chapter, based on the results and analysis for all presented cases, a chosen case will be selected and further discussed in regards to value adding activities, customer demands, and equipment and machinery.

6.1 Best case for small scale actors such as Walters and Eklunds

As argued by Lieder and Rashid (2016) it is of importance for the individual company to make profit if CE is to be reached. It is therefore considered to be more relevant to evaluate the profit dismantlers can make from each case rather than the environmental effects. Several of the cases result in revenue and could theoretically be implemented by the dismantlers. However, the qualitative information gathered indicates that e.g. space and work environment are highly important to take into consideration when evaluating the cases.

The case that shows best results and is considered feasible for the dismantlers is decided to be case 7. By adding copper to the shredding process, the investment cost can be shared by two materials instead of being carried by only plastics. As stated by Duval & MacLean (2007) one of the barriers is lack of profit which is a solid argument for making as much use as possible of the machinery invested in. It is evident that it is possible to make revenue from only recycling plastics, but by also recycling copper the dismantlers can use the equipment to increase the overall recycling from ELVs. The focus of the master thesis lies within plastics recycling but the recycling of copper shows that in order to reach a CE for one material, it might be necessary or at least favourable to combine the RL of several materials.

Furthermore, by shredding the plastics the dismantlers will be able to send containers with eight tons of plastic to their customers. Compared to case 1 with sending the plastics ATA with three tons of plastics in the containers this is considered as a great improvement for transports. The increase in weight sent in one container will reduce the number of transports needed. Depending on customers locations the emissions and its environmental impact can be reduced.

6.2 Value adding activities

The identified value adding activities in case 7 is size reduction of plastics and copper. Considering the fact that dismantlers need to increase recycling rates of plastics, together with the results from the simulation, an investment in a shredder is a good opportunity for dismantlers to perform a value adding activity. Shredding plastics is one vital step in recycling plastics, and the earlier in the RL system it is done the better it is. By shredding the plastics, the dismantlers will have the opportunity to make profit of the plastics at the same time as fewer numbers of transports will be needed.

6.3 Customer demands

The market research shows that several customers are interested in buying shredded plastics. The customers identified are interested in buying shredded plastics in large volumes and with frequent deliveries. One of the deal breakers for the customers is a steady supply of plastics, this to secure that the production keeps even quality and is secured for future demands. Both dismantlers have steady supply of ELVs which can ensure that the customers receive the quantities asked for. This indicates that the dismantlers can cope with the barrier of high uncertainties identified by Tibben-Lembke, (2002). The dismantlers can have seasonal variations in supply due to higher amount of car accidents during winter. According to Andersson[3] this is not a problem since they have a stock with ELVs to cope with variations and have a levelled amount of work.

Gerrard and Kandlikar (2007) argues that automotives are not designed to be easy dismantled, which indicate that it takes time to dismantle and to get the plastics clean from metal and other unwanted materials. The German customer have other, lower, demands compared to the domestic customers, e.g. it is ok with small metal parts on the plastics which means that the dismantlers do not need to spend time on cleaning the plastics. This is one positive aspect with the German customer since labour costs are considered high relative to the price of plastics. High labour costs are identified by Dodbiba and Fujita (2004) as one major barrier with dismantling plastics from ELVs for recycling. If the dismantlers can reduce amount of labour needed for the dismantling they will be able to make more revenue. This will also mean that it will not be necessary to hire more personnel which are one of the desires from dismantlers.

6.4 Equipment and machineries

The machinery in Case 7 consists of a shredder and a cable granulator. The shredder has fairly low needs for service and it is assumed that the dismantlers can handle some of the maintenance themselves. The shredder will need an operator at certain times, and it is assumed that the dismantlers can do improvements in their way of working when dismantling, in order to free up time for operating the shredder. During the observations at the dismantlers it was noted that they both have excavators to dismantle some materials from the ELVs. If they can find a way for the excavators to fill the shredder with plastics during e.g. waiting times for new ELVs, they will increase up time for the excavators at the same time as they can effectively fill the shredder. If they do this, they will have good opportunities to cope with the barrier of high labour costs argued by Dodbiba and Fujita (2004).

By utilizing a cable granulator together with the shredder, the investment cost for the shredder will be shared by two materials. For copper, the major cost is the first size reduction which separates the cables from cable holders and other products that are related to the cables. Off course there is an investment cost in the granulator, but the price customers are willing to pay for copper is considered to quickly payback the machine. This combination of recycling materials will make it easier to make profit from plastics and thus be an incentive for dismantling more plastics from ELVs.

All machinery looked into in the thesis are new. However, there are possibilities to buy used machinery from certain companies dealing with this kind of equipment which will result in

[3] Joakim Andersson, Workshop Manager at Walters Bildelar, [2017-12-14).

lower investment costs and therefore more profit can be made from each kg of plastics that are recycled. However, with used machinery there are uncertainties with how long they can function and whether or not there are guaranties. The authors have chosen not to look into these machineries due to uncertain supply and conditions, but the dismantlers will be informed of the possibilities to buy machinery second hand.

6.5 National solution

In results and analysis, it was mentioned that higher plastic volumes are needed for cases 4 and 5 in order to make them economically justified and simulation results on a national scale were presented. In table 17 a summary of results from appendix X and their comparison to case 1 scenario 1 can be seen.

Table 17: Summary of results for cases 4 and 5 on a national scale.

Case/Scenario	Profit SEK/kg	% difference in profit compared to case 1	Bottleneck / degree
Case4-scenario1	4.4	187%	YES / Low- can be solved by optimizing batch size
Case4-scenario2	4.32	182%	NO
Case4-scenario3	4.31	181%	YES / Low- can be solved by optimizing batch size
Case5-scenario1	2.32	52%	YES / High- Higher capacity is needed
Case5-scenario2	12.44	713%	NO
Case5-scenario3	9.06	492%	YES / High- Higher capacity is needed

As it can be table 17, all scenarios in case 4 will have more than 180% higher profitability compared to case 1. In case 4 scenario 1, the profit for each kilo plastic increases from 1.53 to 4.4 SEK/kg compared to case 1 scenario 1 which represent 187% more profitability. When running the simulation for scenario 1, even though 3 shifts per day was considered, it could be seen that a small bottleneck was created which was a minor issue and can be solved through optimizing the batch sizes. In next scenario, case 4 scenario 2, the profit for each kilo plastic increases from 1.53 to 4.32 SEK/kg compared to case 1 which represent 182% more profitability. There was no bottleneck during simulation of scenario 2 and it only requires two working shifts. In case 4 scenario 3, the profit for each kilo plastic increases from 1.53 to 4.31 SEK/kg compared to case 1 representing 181% more profitability. Since this scenario has the same capacity as the first one, minor bottlenecks could also be found here during the 3 shifts per day simulation. The bottlenecks are not a huge problem and can be solved through batch size optimization. Noteworthy is that the labour cost for the three working shifts in a day have been considered to be the same. So even though the profit for each kilo plastic in all scenarios are around 4.3 SEK/kg, if the costs for night shift personal are normalized, then scenario 2 will be a winner considering the fact that it only requires two working shifts due to its higher capacity.

In case 5 there is a whole different story. In scenarios 1 and 3, when running the simulation, it could be seen that the extruder is a huge bottleneck, having 200 kg/h and 800 kg/h capacity respectively. In scenario 1 of case 5 it can be seen that the profit for each kilo plastic increases from 1.53 to only 2.32 SEK/kg compared to case 1 which represents 52% more profitability whereas in scenario 3 the profit for each kilo plastic increases 9.06 SEK/kg showing a 492%. However, the bottleneck cannot be solved by normal means in these two scenarios and the only way to overcome it, is through increasing capacity. On the other hand, there will be no bottleneck in scenario 2 due to its higher (1500 kg/h) extruder capacity. In this scenario the profit for each kilo plastic increases from 1.53 to 12.44 SEK/kg showing a great profit increase of 713% compared to the first case, making it the best solution for plastic recycling on a national scale.

7 Conclusion

In this chapter, the most important findings are summarized with a perspective of the research questions. Each research question and its highlights will be concluded with the most important findings. Firstly findings regarding activities will be presented, followed by findings of customer demand and machineries. Lastly implications for practitioners and scholars are described.

7.1 Findings regarding activities in reverse logistic chain

A mapping of a general plastic recycling process was performed at Swerea by the authors in order to understand what activities are needed for plastic recycling and what difficulties they might imply. The main purpose of the mapping was to make sure of what steps of recycling that needs to follow each other in order to construct the different cases.

The value adding activities that are identified, after the dismantling and separation of plastics, are size reduction, washing and drying, granulation, extrusion, and pelletizing which are illustrated in figure 17. The size reduction process, which is done with a shredder, is considered to be most feasible activity for dismantlers to perform due to several reasons such as relatively low investment cost, increase in transportation fill rates of plastics, being able to utilize the shredder for other purposes, and relatively high customer demand for the shredded plastics. Further refinement such as washing, granulating, and extrusion requires high investments in machinery and also competence which is not considered as an option for the dismantlers. Furthermore, the high capacity of these machines would require that a considerable number of all ELVs in Sweden were to be recycled.

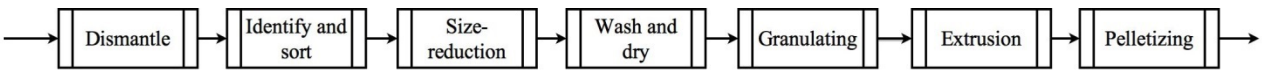

Figure 17 : Identified value adding activities in a recycling chain of plastic parts in ELVs.

7.2 Findings regarding customer demands

A market research was conducted in order to identify potential customers and their requirements on recycled plastics. The customers were categorized based on the findings regarding quality, shape, volume, and price. The categories were then used to create the different cases that are needed to evaluate whether or not it would be reasonable to implement a RL system aligned towards the customer category.

The main finding was that customer requirements (e.g. quality, condition, volume, etc.…) become, to a large extent; higher and stricter the further in plastic recycling chain the customer is located. This indicates that if dismantlers want to sell plastics to a customer locating in the end of recycling chain, a very detailed research needs to be conducted to understand a wide range of aspects regarding customer requirements.

7.3 Findings regarding equipment and machineries

In order to implement the different value adding activities that were presented earlier and retrieve plastics with different value accordingly, certain machineries are required. The size reduction process, which will enable the option of selling shredded plastic for dismantlers, requires a shredder which is relatively cheap, has low service cost, and requires minimum competence. In order to sell washed and granulated plastics, a complete washing and granulating line is needed which is associated with high investment for equipment, high service costs, occupying a large amount of space, and being noisy process resulting in bad working environment. In order to produce pellets, the dismantlers need to invest in extrusion-pelletizing line in addition to previous equipment. Besides being significantly more expensive and having high service cost, the extrusion machine requires a higher degree of competence. Considering these aspects and the results from simulations, large volumes of plastics are needed in order to overcome the economical barrier and investing in such machineries. Moreover, the dismantlers can produce filament from pellets by adding a filament machine which varies depending on its capacity. In this thesis a relatively cheap low capacity filament machine has been considered in order to understand the added value compared to pellets, which requires no special competence and has very low service cost.

7.4 Implications for practitioners

The results from the study show that there are several possibilities to design a RL system for recycling plastics from ELVs. As can be found in the analysis it is possible that the best way to design a RL system is to combine the recycling of several materials by finding equipment that can handle these.

The suggested design for RL system can be seen in figure 18. After the collection process, dismantlers should identify and separate the parts to three different flows. The first flow is the reusable parts which are being separated and stored in order to later on selling them to customers. The second flow is the recyclable items, which are the identified plastics and cables in this case, which will be separated and afterwards size reduced by a shredder. As mentioned in the analysis of case 7, both a stationary or a mobile version could be used, which should be decided based on the dismantlers' preferences. The shredded plastic will be sold directly to customer whereas the cables will be further processed in a cable granulator in order retrieve pure copper. The third flow is the parts that could not be reused or recycled and need to be disposed. These parts should be put back into ELV`s chassis and following it to recycling centres for fragmentation, where it becomes ASR, which will to a large extent be used for energy recovery.

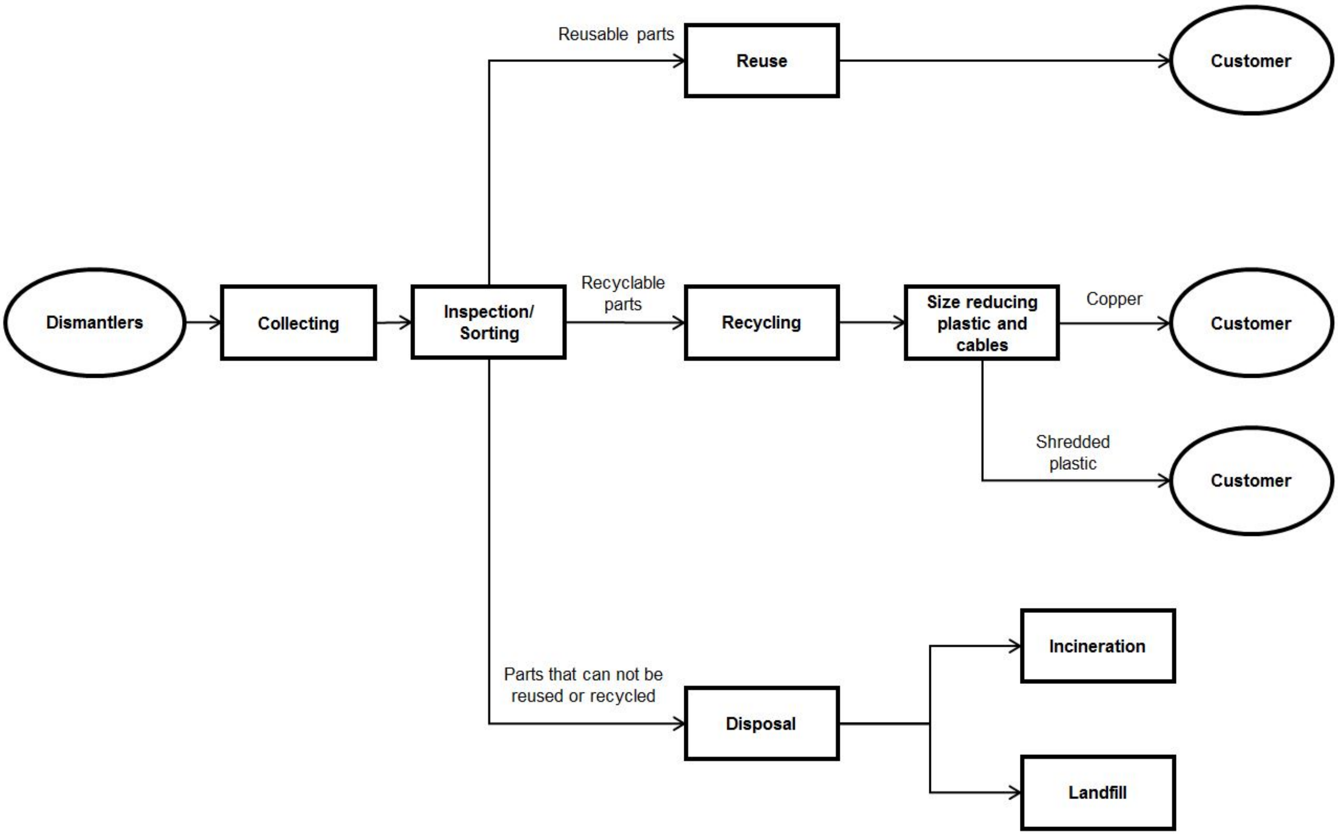

Figure 18: Suggested RL system for dismantlers.

Walters and Eklunds are considered as two of the larger dismantling firms in Sweden. Hence, for other smaller practitioners it could be beneficial to cooperate with each other to have volumes of material big enough to make size reduction a feasible option. Moreover, the presented RL design has been tailored according to the needs of Walters and Eklunds; however, if any dismantler decides to follow the path of Walters and Eklunds, they could use all information provided in this thesis and select a proper strategy that suits them and their conditions.

Furthermore, since there is a demand for different recycling machineries from the dismantler's side, then probably it could be interesting for a service provider to rent some of the demanded equipment, especially when it comes to mobile solutions. Mobile solutions such as mobile baler and mobile shredder can be designed to be applicable for different types of materials other than plastic. This will enable a wider market for the service provider and making it an economically attractive business model.

On a national scale and level, besides the alternative that all dismantlers can go together and start a recycling company, it could be suggested that a bigger actor who is specialized in recycling gets involved and collects all plastics from dismantlers. This big actor can provide mobile size-reducing solutions to dismantlers while simultaneously collecting the plastics from their sites and transporting them to actor's central recycling facility where the plastics will be further processed. Since all plastics will be processed on a centralized location, the overall costs are being reduced due to high volumes, a higher profitability can be reached thus making it an interesting and attractive business model.

The authorities are also able encourage plastic recycling through several different acts. They could offer huge tax cuts for actors working with plastic recycling. On the other hand, there should be higher taxes on incineration, which is a leakage from circular economy, to prevent plastics ending up in this process and instead being recycled as a more attractive solution. They could also have stricter rules and legislatives for manufacturers regarding the recyclability of produces produced. As an example, in car industry, it should be easy to dismantle the plastic parts from the cars and identifying the different parts with their respective material. The parts should also contain materials that make the recycling process feasible and easy. Implementing these changes will make plastic recycling a more favourable process.

7.5 Implications for scholars

This thesis provides a wide range of data that have been collected and analysed to reach its purpose. There are some aspects that the authors find interesting for further studies and investigations.

One interesting proposition for further research is if it is possible to reach CE of other materials that are suitable to combine in the identified RL system. There are parts in ELVs that are made of aluminium which according to suppliers of recycling machinery is possible to process in a shredder. Several known barriers are of economic character which could be overcome by considering possibilities of other materials, such as soft metals, in ELVs. By investigating these options, it could be possible to make it more attractive for dismantlers to recycle additional parts from ELVs and reach CE for several materials.

One other suggestion of future research is to investigate other industries; to recycle white goods, tires, or soft plastics from e.g. farming industry. This to see if the proposed RL system is a good method to be used in other recycling chains. As the thesis shows it is possible to make profit from recycling certain plastics from ELVs. There is high potential of increasing recycling rates by having effective RL systems for recycling plastics in other industries.

This thesis is limited to studying the recycling activity within RL. As mentioned there are several other activities identified in RL, and further studies could consider the possibilities of developing ways of sorting or inspecting materials which can contribute with higher recycling rates and thus reaching CE. On a nationwide scale, research regarding collection of material could contribute with effective RL systems. By collecting on a nationwide scale, it could be possible to find economies of scale and other beneficial aspects that could increase recycling rates and help to strive towards CE.

One suggestion of future research is to make a deeper environmental analysis. The scope of this thesis is to look into economic aspects, which is why the environmental analysis is not given that much attention. To make the RL system a truly sustainable solution, aspects of energy consumption needs to be taken into consideration. Therefore, research of how much raw material (oil) that is used e.g. to transports and energy, compared to how much raw material is “saved” by recycling needs to be looked into. One might also consider the question whether or not it is a good option to recycle plastics if more raw material is needed for the incineration when the plastics are used elsewhere.

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Appendices

Appendix A

Images of different plastic parts discussed in this thesis:

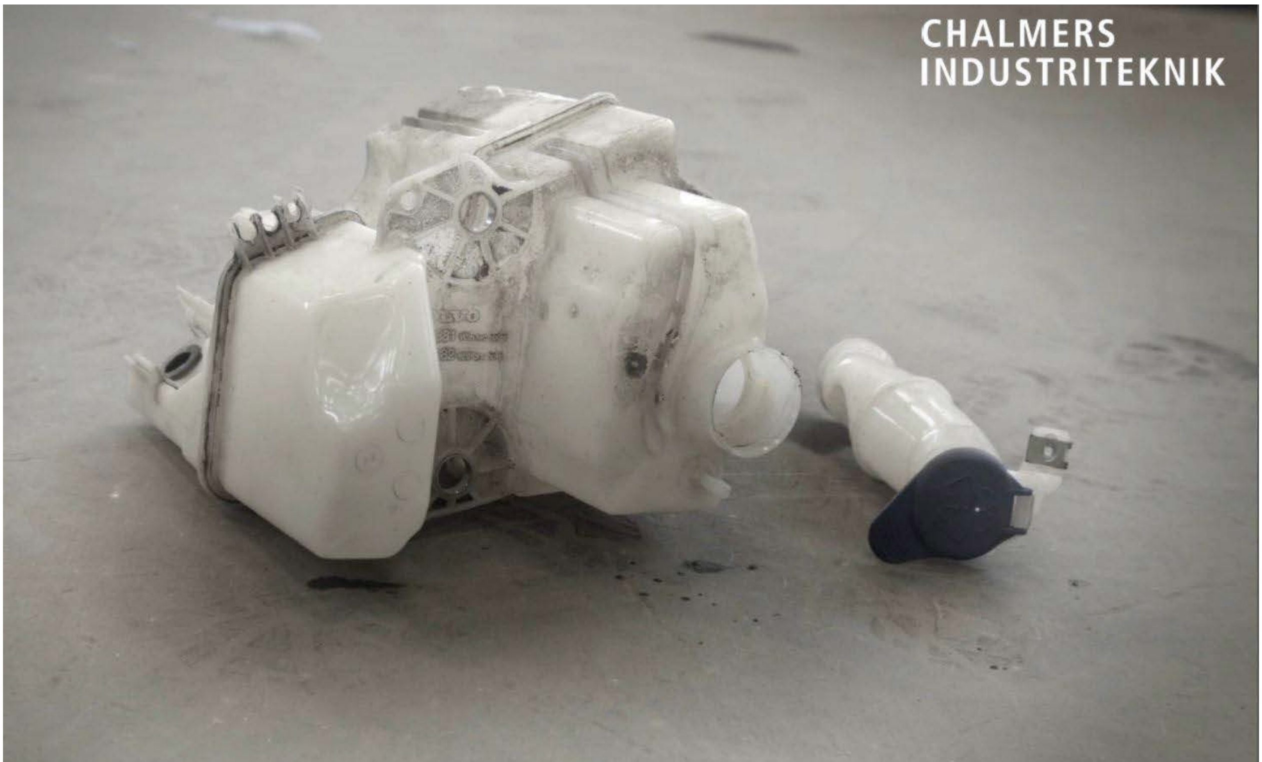
Bumper

Bumper

Fuel tank

Wheelhouse

Skid plate



Washing fluid tank

Expansion tank

Expansion tank

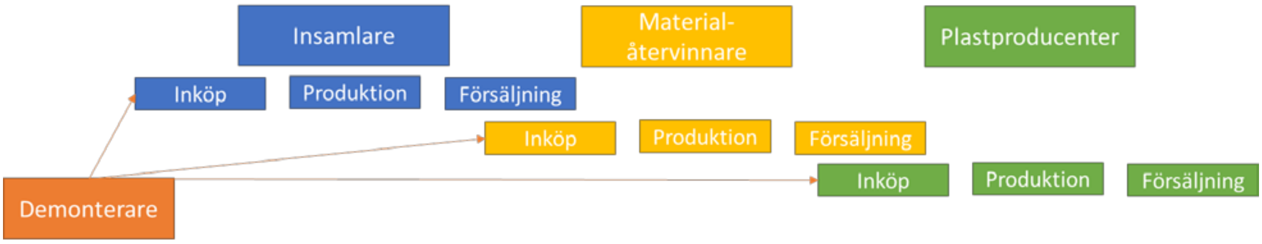
Appendix B

Intervjuer av potentiella kunder för demonterare

Intervjuer av potentiella kunder för demonterare

Tre grupper av potentiella kunder kommer att intervjuas: Insamlare, materialåtervinnare och plastproducenter.

För att förstå hur flödet fungerar från inköp av plast hos insamlare till försäljning av plastprodukter är alla intervjuer strukturerade med tre avsnitt: Inköp, produktion och försäljning. Inköp och försäljning blir det överlappande steget mellan de olika stegen i försörjningskedjan och stärker validiteten genom att samla in data om samma process från olika steg i kedjan.



Insamlingsföretag

Mottagande av plast

1. Vilka industrier tar ni emot plast från?
    a. Var finns dessa industrier (Sverige, utomlands?)
    b. Vilka typ av produkter och plastsorter
    c. Köper ni idag/får ni in plast från bildemonterare?
2. Hur kommer plasten in till er?
    a. Rena plastfraktioner
        i. Hur sorterad är plasten i denna fraktion i så fall?
    b. Brännbart
    c. Blandat/osorterat
3. Hur långt i kedjan har plasten kommit?
    a. Produktionsspill
    b. Installationsspill
    c. Använda produkter
4. I vilken form köper ni in återvunnen plast (pris/form)?
    a. Hela delar
    b. Balpressade delar
    c. Shreddat
    d. Kvarnat
    e. Tvättat
5. Vad får företag betala/vad betalar ni för inlämnad plast? (beroende på fraktion, sortering osv)?

’Produktion’

6. Vilka aktiviteter utför ni för plast?
    a. Sorterar
    b. Tvättar
    c. Förvarar
    d. Storleksreducering (balad, shredder, kvarn etc.)
    e. Regranulerar
    f. Transport

g. Övrigt
7. Har ni funderingar på att ändra vilka aktiviteter ni utför i framtiden (tex utföra fler)?

Försäljning av insamlad plast

8. Vilka är era kunder av plastdelar/storleksreducerade/osv plast?
9. Vad har era kunder för krav för följande aspekter?
    a. Ty av plast (PE/PP/Mixed)
    b. Storlek
    c. Tvättad?
    d. Hur ren måste plasten vara (andra material, damm och smutspartiklar...)?
    e. Form? (Flake, Granulate, Filament, etc.)
    f. Kvalitet
    g. Volym
    h. Färg och lack
    i. Frekvens på leveranser
10. Vad är priset på plasten (beroende på typ, form osv)
11. Hur har efterfrågan på plast ändrats de senare åren? Vad tror ni kommer att hända de kommande åren?

Materialåtervinnare

Inköp av återvunnen plastråvara

1. Vilka industrier tar ni emot plast från?
    a. Var finns dessa industrier (Sverige, utomlands?)
    b. Vilken typ av produkter och plastsorter (PP, PE etc.)
2. Hur långt i kedjan har plasten kommit?
    a. Produktionsspill
    b. Installationsspill
    c. Använda produkter
3. Köper ni bara återvunnen plast eller också jungfrulig plast?
    a. Hur stora volymer av respektive kategori köper ni varje år?
    b. Har ni problem att få tillräckliga volymer med återvunnen råvara?
4. Hur många råvaru-leverantörer har ni? (återvunnen och jungfrulig)
5. I vilken form köper ni in återvunnen plast (pris/form)?
    a. Hela delar
    b. Balpressade delar
    c. Shreddat
    d. Kvarnat
    e. Tvättat
6. Vad är era krav för följande aspekter?
    a. Ty av plast (PE/PP/Mixed/osv)
    b. Storlek
    c. Tvättad?
    d. Hur ren måste plasten vara (andra material, damm och smutspartiklar...)?
    e. Form? (Flake, Granulate, Filament, etc.)
    f. Kvalitet
    g. Volym
    h. Färg och lack
    i. Frekvens på leveranser
7. Hur transporteras råmaterialet till er?
    a. Typ av lastbärare
    b. Fyllnadsgrad
    c. Kostnad
    d. Vem ansvarar och betalar för transporten?
8. Beskriv de fraktioner vi gör tester på nu och fråga om de skulle vara intresserade av att ta emot de analyser vi kommer att utföra eller om de skulle vilja ta emot testfraktioner för egna tester.

Fraktioner	Delar	Identifiering
1	Bränsletank	PE
2a	Expansionskärl & Spolarvätskebehållare	PE
2b	Expansionskärl & Spolarvätskebehållare	PP/PE
3	Stötfångare	PP
4	Hasplåtar och Inneskärmar	PP

Materialåtervinningen

9. Var finns er produktionsanläggning?

10. Vad gör ni med plasten?
    a. Samlar in
    b. Sorterar
    c. Shreddar
    d. Tvättar
    e. Kvarnar
    f. Regranulerar
    g. Transporterar
    h. Övrigt
11. Vad har ni för utrustning för att återvinna och/eller mala/kvarna samt tvätta plasten och hur går detta till?
12. Hur genomförs tester av plasten gällande densitet, renlighet och smältindex?

Försäljning av återvunnen förädlad plastråvara

13. Hur ser efterfrågan ut på återvunnen plast idag?
14. Vad är kostnaden för den återvunna plasten/jungfrulig plast?
15. Vilka kunder har ni? (antal och typ av industri)
16. Vad har era kunder för krav på plasten?
    i. Ty av plast (PE/PP/Mixed)
    j. Storlek
    k. Tvättad?
    l. Hur ren måste plasten vara (andra material, damm och smutspartiklar...)?
    m. Form? (Flake, Granulate, Filament, etc.)
    n. Kvalitet
    o. Volym
    p. Färg
    q. Frekvens på leveranser
17. Vad använder era kunder plasten till för typ av produkter?
18. Hur transporteras plasten till kunder?
    a. Typ av lastbärare
    b. Fyllnadsgrad
    c. Kostnad
    d. Vem ansvarar och betalar för transporten?

Plastproducenter

Inköp av plastråvara

1. Vilken typ av plast köper ni in? (PP, PE..)
2. Köper ni in återvunnen plast idag? Om inte varför då och vad skulle krävas för att ni började köpa återvunnen råvara?
3. Förutsatt att ni köper återvunnen plast, hur stora volymer jungfrulig kontra återvunnen råvara köper ni in?
4. Hur många råvaruleverantörer har ni och var finns de? (återvunnen och jungfrulig)
5. Vad är priset på jungfrulig och återvunnen plast?
6. För återvunnen plastråvara:
    a. Har ni problem att få tillräckliga volymer med återvunnen råvara?
    b. Vill ni på sikt köpa in mer återvunnen plast? Om ja, vad finns det för hinder för att ni inte gör det idag?
    c. Skiljer sig inköpsprocessen för återvunnen och jungfrulig plast? (tex inköpsvolymer, frekvens, osäkerheter, antal leverantörer osv)
    d. Har ni krav på vilken typ av återvunna produkter som den återvunna plasten ska vara gjord av? (closed-loop)
7. Vad är era krav för följande aspekter (både för jungfrulig och återvunnen)
    a. Storlek
    b. Tvättad?
    c. Form? (Flake, Granulate, Filament, etc.)
    d. Kvalitet
    e. Volym
    f. Färg
    g. Frekvens på leveranser
8. Hur transporteras råmaterialet till er?
    a. Typ av lastbärare
    b. Fyllnadsgrad
    c. Kostnad
    d. Vem ansvarar och betalar för transporten?

Produktion

9. För vilka produkter använder ni återvunnen plast?
10. Hur har produktionen påverkats av att ni använder både jungfrulig och återvunnen plast?
11. Vad använder ni för utrustning för tillverkning av plastkomponenter (formblåsning, formsprutning etc.)

Försäljning av produkter innehållande återvunnen plast

12. Vet era kunder om att ni har återvunnen plast i era produkter?
    a. Hur tar de i så fall emot det?
13. Berättar ni att ni använder er av återvunnen plast i era produkter i marknadsföringssyfte?

Appendix C

List of when potential customers were interviewed.

Type of company	Customer	Location	Respondents position in company	Date of interview
Collector	A	Göteborg	-	10/31/2017
Collector	B	Malmö	CEO	11/2/2017
Recycler	C	Göteborg	-	10/31/2017
Recycler	D	Karlskoga	Founder	10/28/2017
Recycler	E	Malmbäck	Founder	10/24/2017
Recycler	F	Lerum	-	10/27/2017
Recycler	G	Röstånga	Sales/Marketing	10/24/2017
Processor	H	Gislaved	Technical supervisor	10/24/2017
Processor	I	Arvika	CEO	10/31/2017
Processor	J	Strömsbruk	CEO	10/17/2017
Processor	K	Knivsta	CEO	10/27/2017
Processor	L	Anderstorp	CEO	10/31/2017
Processor	M	Tranås	Sales/Marketing	10/16/2017
Processor	N	Gislaved	Sales/Marketing	10/16/2017
Processor	O	Ingmarsö	Sales/Marketing	10/17/2017
Processor	P	Landskrona	Sales/Marketing	10/31/2017
Processor	Q	Älghult	CEO	11/2/2017
Processor	R	Nyköping	CEO	10/17/2017
Processor	S	Bromma	-	11/2/2017
Processor	T	Göteborg	Sales/Marketing	10/16/2017
Processor	U	Göteborg	-	10/16/2017
Processor	V	Ystad	Sales/Marketing	10/4/2017
Processor	W	Färjestaden	Sales/Marketing	10/4/2017
Processor	X	Tyskland	Sales/Marketing	11/15/2017
Processor	Y	Anderstorp	CEO/Sales	11/28/2017

Appendix D

Company	Focus	Location.	Date of RFQ Sent
Supplier 1	Shredder, Polystyrene Shredder, Bale-Breaker, Screw Shredder, Guillotines, Grinders, Granulators, Pipe-Granulators, Profile-Granulators, Hammer-Mills, Fine-Grinders, Pulverizers, Pulverisers, complete Washing Lines	Germany	20171107
Supplier 2	Plastic Grinder, Plastic Recycling Machine, Plastic Granulator	USA	20171107
Supplier 3	Specializes in manufacturing single-shaft shredders, four-shaft shredders, and briquette presses that are built to handle a variety of applications. These applications include-- but are not limited to-- plastic, paper, wood, metal, and biomass.	Germany	20171106
Supplier 4		China	20171107
Supplier 5	Offers a complete line of plastic recycling machines required for packaging, size reduction, separation, washing, drying, and pelletizing.		20171107
Supplier 6	Shredder technologies	Austria	20171107
Supplier 7			20171107
Supplier 8			20171107
Supplier 9		Sweden	2071107
Supplier 10	They are specialized in developing, manufacturing and selling End-of-Life Vehicle de-pollution technology, stations	Austria	20171106

Appendix E

Hi,

It is of interest to buy machinery and equipment suitable for recycling plastics from ELVs.

Plastic parts that are currently being considered are Bumpers, Fuel tank, Wheelhouse, Expansion tank, Washing fluid tank and Skid plate. The max size for all parts is 1700mm*800mm*600mm which indicates that the minimum hopper size required is 800 mm*600 mm.

In the attachment, you'll find pictures of the different plastic parts and a process flow map of how the recycling process should look like.

The plastic types are as follow:

PP (PP, PP+EPDM, PP+Talc)

PE (PE, LDPE, HDPE)

PP/PE

I'll provide some of the important aspects:

The shredding machine should not be sensitive to metal parts such as screw, clips, etc. Also, it needs to be able to shred wet plastic materials Feeding could be done both manually and with help of conveyor belts. Please quote both.

Shredding output should be between 15-50 mm.

Granulating output should be between 8-13 mm.

All solutions are going to be installed inside the customer's building (indoor).

There should be a "Magnet" after the shredder in order to remove ferrous metals and a "Metal detector" should be installed before granulator in order to prevent non-ferrous metals entering and damaging the machine.

Regarding the washing line, we know that there is a risk with PP+EPDM and PP+Talc sinking, however the assumption is that they will not sink and can be treated as pure PP.

For the extruder, no additives will be added in this stage of the project, so standard version will suffice for the quote. I'll inform if the client decides on what type of additive they want to add.

The required capacity varies between 100 to 1000 kg/h depending on which scenario our client select.

Please quote your best price for the following scenarios

Each machine

A stationary solution for 100 kg/h capacity (Stop after granulating)

A mobile shredding solution for 100 kg/h capacity

A complete solution for 2000 kg/h capacity (Output of this process will be pellets)

Also, please provide annual operation cost and maintenance cost for each suggested machine.

Keep in mind that the solutions you provide should also be suited for cables. The capacity for the cables is estimated to vary between a minimum of 45 kg/h and a maximum of 1300 kg/h.

If you have any further questions, please feel free to contact me.

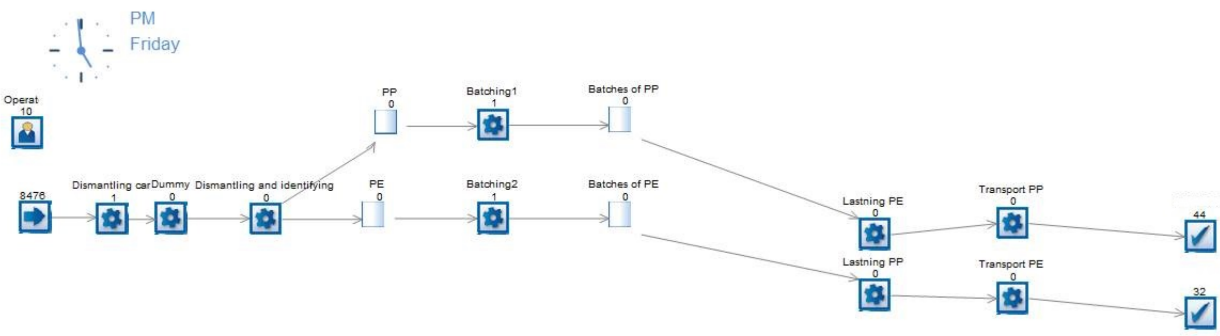
Thanks in advance

Best Regards

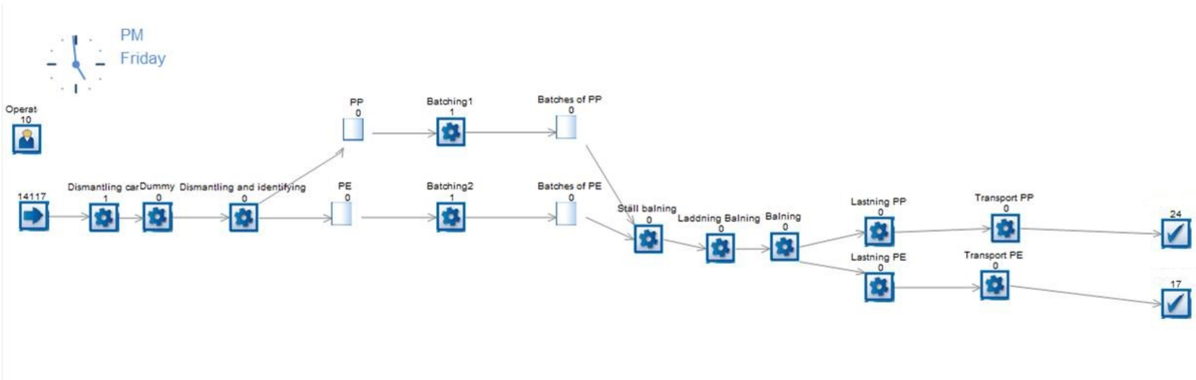
Appendix F

In Appendix F all layouts for the simulations in Simul8 are visualized.

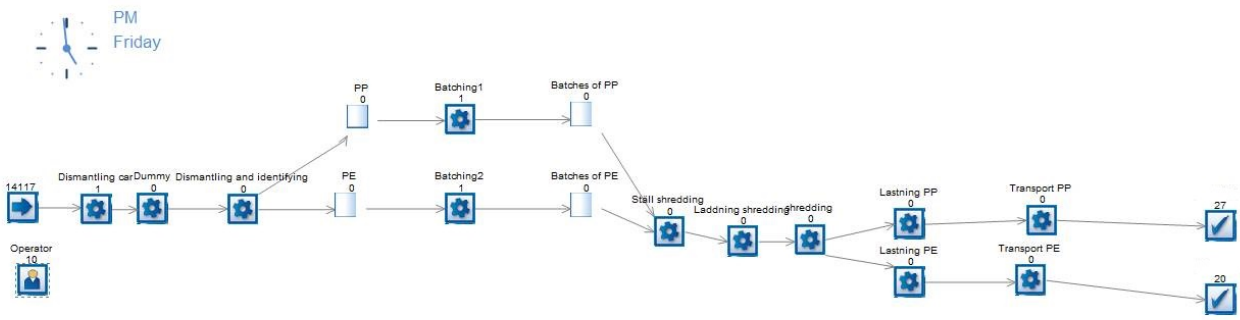
Simulation layout for case 1:



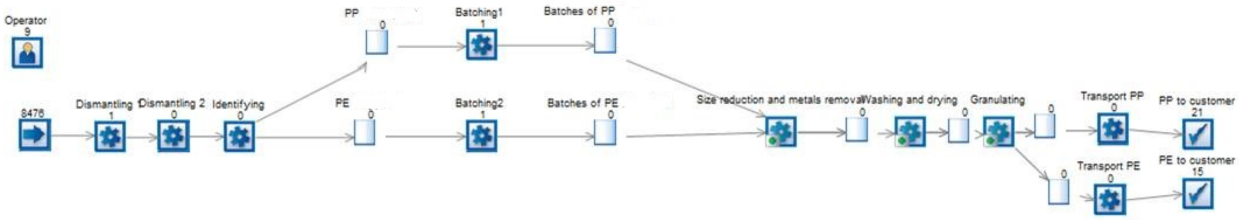
Simulation layout for case 2:



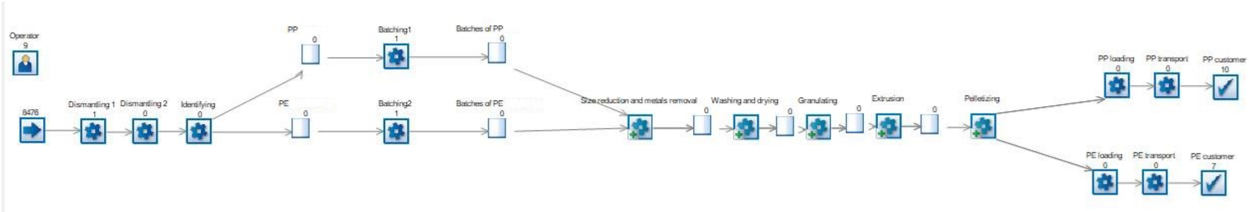
Simulation layout for case 3:



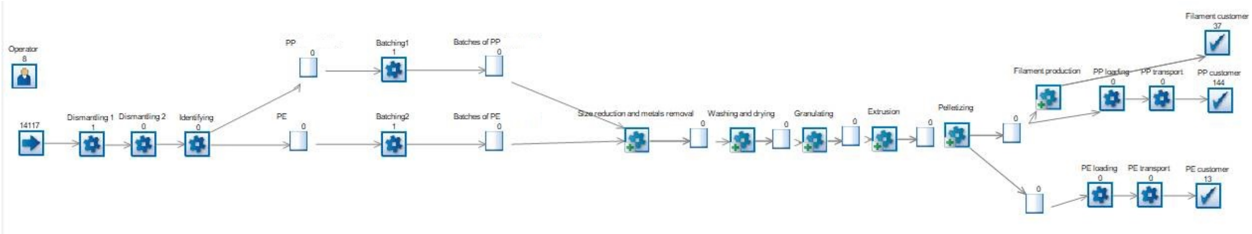
Simulation layout for case 4:



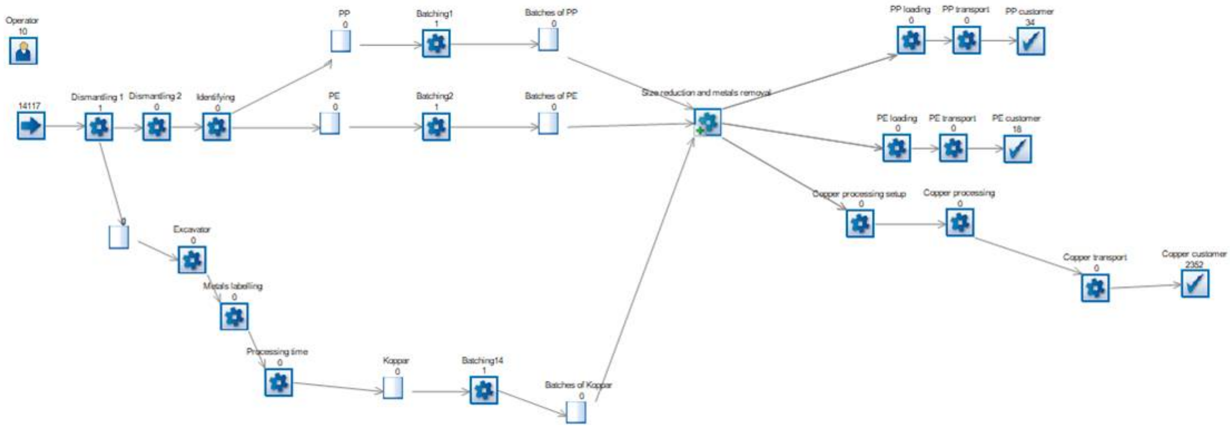
Simulation layout for case 5:



Simulation layout for case 6:



Simulation layout for case 7:



Operator
10
14117
Dismantling 1
1
Dismantling 2
0
Identifying
0
PP
0
Batching1
1
Batches of PP
0
PE
0
Batching2
1
Batches of PE
0
0
Excavator
0
Metals labelling
0
Processing time
0
Koppar
0
Batching14
1
Batches of Koppar
0
Size reduction and metals removal
PP loading
0
PP transport
0
PP customer
34
PE loading
0
PE transport
0
PE customer
18
Copper processing setup
0
Copper processing
0
Copper transport
0
Copper customer
2352

Appendix G

Simulation results for case 4 on a national scale

Selling washed and granulated plastics	**Scenario 1**		**Scenario 2**		**Scenario 3**	
	3 Year	**5 Year**	**3 Year**	**5 Year**	**3 Year**	**5 Year**
Category	Value (SEK)	Value (SEK)	Value (SEK)	Value (SEK)	Value (SEK)	Value (SEK)
Costs						
Size Reduction and metals removal Total Cost	1,338,336	2,028,111	4,372,627	5,307,182	1,905,060	2,785,646
Washing and drying Total Cost	1,286,840	1,940,992	4,372,508	5,306,926	1,839,998	2,675,625
Granulating Total Cost	1,289,895	1,954,170	4,377,933	5,321,517	1,843,901	2,692,459
Operator Total Cost	3,234,203	5,403,124	2,348,695	3,922,539	3,233,655	5,402,096
Transport PP Total Cost	6,392,400	10,651,200	6,728,400	11,222,400	6,392,400	10,651,200
Transport PE Total Cost	4,056,699	6,780,692	4,276,376	7,139,498	4,056,699	6,780,692
Simulation Total Costs	**17,598,373**	**28,758,289**	**26,476,539**	**38,220,062**	**19,271,714**	**30,987,717**
Revenue						
PP to customer Total Revenue	41,094,000	68,472,000	43,254,000	72,144,000	41,094,000	68,472,000

PE to customer Total Revenue	43,227,124	72,253,280	45,567,943	76,076,618	43,227,124	72,253,280
Simulation Total Revenue	**84,321,124**	**140,725,280**	**88,821,943**	**148,220,618**	**84,321,124**	**140,725,280**
Profit	**66,722,751**	**111,966,991**	**62,345,404**	**110,000,555**	**65,049,411**	**109,737,562**
Profit / kg	**4.37**	**4.4**	**4.08**	**4.32**	**4.26**	**4.31**

Simulation results for case 5 on a national scale.

Selling high quality plastic pellets	**Scenario 1**		**Scenario 2**		**Scenario 3**	
	3 Year	**5 Year**	**3 Year**	**5 Year**	**3 Year**	**5 Year**
Category	Value (SEK)	Value (SEK)	Value (SEK)	Value (SEK)	Value (SEK)	Value (SEK)
Costs						
Size Reduction and metals removal Total Cost	1,337,771	2,027,118	4,372,583	5,306,174	1,606,729	2,288,580
Washing and drying Total Cost	1,193,386	1,785,616	4,371,312	5,305,165	1,606,273	2,287,899
Granulating Total Cost	1,194,042	1,798,390	4,377,002	5,319,350	1,604,826	2,302,009
Extrusion Total Cost	3,407,225	5,517,324	10,480,885	12,617,925	2,289,888	3,446,546

Pelletizing Total Cost	3,372,325	5,527,419	10,498,449	12,654,565	2,290,892	3,470,677
Operator Total Cost	3,899,062	6,504,541	7,607,806	12,694,403	4,806,879	8,048,915
Transport PP Total Cost	268,800	450,240	1,206,240	2,016,000	818,160	1,375,920
Transport PE Total Cost	194,948	326,034	877,267	1,473,876	596,609	1,001,630
Simulation Total Costs	**14,867,558**	**23,936,682**	**43,791,543**	**57,387,458**	**15,620,257**	**24,222,178**
Revenue						
PP to customer Total Revenue	28,800,000	48,240,000	129,240,000	216,000,000	87,660,000	147,420,000
PE to customer Total Revenue	20,887,308	34,932,222	93,992,886	157,915,251	63,922,365	107,317,548
Simulation Total Revenue	**49,687,308**	**83,172,222**	**223,232,886**	**373,915,251**	**151,582,365**	**254,737,548**
Profit	**34,819,750**	**59,235,540**	**179,441,343**	**316,527,793**	**135,962,108**	**230,515,370**
Profit / kg	**2.28**	**2.32**	**11.76**	**12.44**	**8.9**	**9.06**