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Bridging the circularity gap in the LDPE value chain

A Tetra Pak and PolyPlank case study in Sweden

Margot Brahmi

Supervisors

Julia Nussholz

Katherine Whalen

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Tel: +46 – 46 222 02 00, Fax: +46 – 46 222 02 10, e-mail: iiiee@iiiee.lu.se.

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"The best way to cheer yourself up is to try to cheer somebody else up"

This quote from the American writer Mark Twain can grasp what it has been happening to me at the IIIEE the last few weeks before the final deadline of my Master thesis.

I have moved to Lund the last month of the thesis deadline to benefit from the good work environment at my institute, and I did the best choice. Every day, I had this motivation to come to my school working on my thesis, which I didn't have while I was working on my own in Malmö with nobody to cheer up or even to cheer me up. I could not explained why such a big difference, but now I know. Being surrounded by warm, funny and loving people at the IIIEE was the reason. My two supervisors Julia and Katherine, but also my professors, PhD students, and even the new coming batches gave me the support I needed. But most of all, between classmates working on site, we cheered ourselves up, which gave me more courage and positive energies to continue working on my thesis, and this really confirms the previous given quote from Mark Twain.

This is why, I have so much gratitude towards my classmates who helped me feeling confident, encouraging me in working hard for accomplishing this research. I will miss the cheering up sessions with my co-working classmates, who became true friends.

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Abstract

The consumption of single use and disposable packaging has led to significant amounts of waste. A large share of food and beverage packaging products are multi-layered aseptic cardboard packages laminated with aluminium and principally with the Low-Density Polyethylene (LDPE) plastic material. This multilayer design makes them poorly recyclable and causes that aluminium and LDPE layers are often incinerated after the recycling process of paper. Incineration leads to a significant loss of the material's value and causes substantial emissions of carbon dioxide. In Sweden, the LDPE layers contained in Tetra Pak's carton packaging are incinerated and recovered into energy, creating an important gap in the circularity of the material flow in the value chain. A company interested in using recycled LDPE from post-consumer packaging is PolyPlank AB, manufacturing bio-plastic and wood fiber composite for construction and packaging products. The Tetra Pak and PolyPlank case study of this paper addresses this circularity gap and intends to find solutions by identifying the main actors of the LDPE value chain, examining their main barriers and drivers for bridging the circularity gap of LDPE material and evaluating the existing possibilities to reuse the LDPE waste by performing a simplified Material Flow Analysis. The research employs a literature review and semi-structured interviews with company representatives in the LDPE value chain. Despite many challenging barriers in closing the loop, the findings show that there are possibilities to reuse the rejected LDPE and mixed materials from paper mills into PolyPlank production's processes. This paper is of relevance to food and beverage packaging manufacturers, recyclers, as well as any industries reusing or planning to reuse recycled LDPE.

Keywords: Plastic recycling; Circular economy; Material recovery; Low-Density Polyethylene; Polylaminated food and beverage packaging

Executive Summary

Plastics became one of the most used materials worldwide. They are often used in products with short lifespans, posing substantial environmental problems caused by improper disposal and lead to natural resources depletion if not recycled through effective methods (Van Eygen, Laner, & Fellner, 2018). Plastics production represents today approximately 6% of the global oil consumption and increase the dependency on fossil fuels as 90 % of the plastic materials are derived from virgin fossil fuels sources such as natural gas, oil and coal (European Parliament, 2017a; PlasticsEurope, 2017). Plastics are everywhere and can be imperceptible in daily products like the food and beverage aseptic packaging often laminated with aluminium and low-density polyethylene (LDPE). After the recycling of the cardboard's paper component, those latter materials are often incinerated due to their poor recyclability.

More than 188 billion of packages have been produced for the year 2017 by the well-known packaging manufacturer Tetra Pak (Tetra Laval, 2018). Considering this enormous amount of packages produced each year, we can imagine the important amount of virgin LDPE used in their production leading to even more crude oil dependency. The weight share of LDPE in aseptic carton packages is about 21% (Kaiser et al., 2017). This large fraction of LDPE often ends up being incinerated in waste to energy plants. For the case of the unsorted food and beverages packages mixed with the household waste in Southern Sweden, the incineration occurs at different waste energy plants such as Sysav (waste to energy plant in Malmö receiving waste from its owner municipalities), or at Fiskeby AB, a paper mill in which paper is recycled while the rejected mixed materials (containing mainly LDPE and some other material residues) are incinerated for the energy provision to run the paper mill plant.

In the last few years, the concept of Circular Economy (CE) received an increasing global attention as it contributes to increasing the efficiency of resource use (Ghisellini, Cialani, & Ulgiati, 2016). The EU Action plan, revised in 2018, is an example of how circular economy is becoming a priority for reducing virgin plastics production and waste (European Commission, 2018a). For some companies, circular economy is seen as a business opportunity. It is the case of PolyPlank AB, a manufacturer of products for the construction sector and packaging industries using 100% recycled materials. Part of the project of MISTRA REES in partnership with the IIIEE, this research paper provides a case study in Southern Sweden involving the companies PolyPlank and Tetra Pak both interested in seeking sustainable solutions for bridging the gap of the plastics material flow. Thus, the main objective of this paper was to find possible solutions in helping PolyPlank to reuse the LDPE material contained in Tetra Pak's packaging. In this way, a circular loop in the current linear value chain can be created.

Moreover, the LDPE plastic material, being the main material studied in this paper, had received little attention by the academics. There is a clear knowledge gap on the understanding of the material flow circulating among the LDPE actors in Sweden. Thus, this study intended to create new knowledge for the academics, but most importantly it provides insights into the current LDPE flow system among the actors of the case study as well as understanding their barriers and drivers for closing the loop.

A number of studies have focused on the recycling methods for separating the LDPE and aluminium from aseptic carton packages, but little knowledge exists in regards with understanding what are the main barriers and drivers of the main actor of the LDPE value chain. The study focuses on the waste stream of LDPE derived from the Tetra Pak's post-consumer packaging waste, however, the author extended the research on the plastics packaging stream in Sweden to better understand how the system looks like in a larger context.

Three objectives guided the research: (1) to identify and map the main actors in the LDPE value chain under the case study, (2) to provide an in-depth analysis of the main actors' drivers and barriers to close the loop of the LDPE material flow and (3) to carry out a simplified LDPE material flow analysis in Southern Sweden in order to identify the areas in which possibilities exist to close the loop.

Methods employed:

This exploratory and inductive form of research was carried out on an embedded single case study. The PESTEL analysis implying the political, economic, social *(in terms of communication and interaction among the value chain actors)*, technological, environmental and legislative factors were used for the analytical framework guiding this research. Therefore, it has been useful for the analysis of the barriers and drivers of the different value chain actors. Those actors are categorized into suppliers, converters, recyclers and buyers, which are the units of analysis of the case study.

The author chose a convergent parallel mixed method to approach the research objectives. Both qualitative and quantitative data were collected throughout the study. Data were gathered from secondary sources through a literature review to gain better understanding of the main actors involved in the LDPE value chain as well as the LDPE waste stream and material flow in Sweden *(answering research objective 1)*. In another hand, a total of 11 interviews were conducted through different means in order to collate primary quality data that helped the author to analyse actors' main barriers and drivers *(answering research objective 2)*. The findings were categorized in accordance with the PESTEL analytical framework.

In parallel of the qualitative data collection, the author also gathered quantitative data through interviews and desk research in order to carry out a simplified Material Flow Analysis (MFA) to explore the possibilities to bridge the gap in the material flow of LDPE *(answering research objective 3)*.

Findings summary:

Through this study, the author found a wide range of barriers and drivers to close the material flows of the LDPE flow. Four barriers were deemed the most important under the case study:

1. "*Low market demand of recycled LDPE*" in Sweden and in Europe (economic factor)
2. "*High cost of investment in the technology and the system installation for separating the LDPE into pure fraction*" (economic factor)
3. *"Finding a fuel substitute for the current incineration plant*"(technological factor)
4. "*Lack of communication and material traceability*" (social factor)

From the analysis of the results, the author judged the following four drivers being the most important:

1. *"Circular economy as a business opportunity and competitive edge*" (economic factor)
2. *"Risk avoidance for future stringent regulations and targets*"(legislative factor)
3. "*Technology development increasing the level of purity*"(technological factor)
4. "*Growth in demand of recycled plastics (even with low grades) in various applications*"(economic factor)

Based on the simplified Material Flow Analysis of LDPE in the Southern Sweden, two main opportunities exist at different levels to reuse LDPE from Tetra Pak's packaging waste stream:

- At the company level: the paper mill Fiskeby AB could invest into a recycling system to recover into pure fractions the LDPE and Aluminium contained in the rejected materials from the paper recycling process. Preliminary in-depth market research is recommended to explore all buyers of recycled LDPE and aluminium in the Nordic countries and to evaluate and acknowledge the future trends of the market and policies.
  To support this previous statement, the author identified a legislative trend of stricter regulations regarding plastics use in Europe especially since the beginning of the year 2018. Not only, China's ban on plastic waste import but also the European Commission's higher recycling targets and policies on plastics restrictions could influence the market demand of recycled plastics in Europe.
- At the value chain level: to minimize investment risks being one of the main barrier of Fiskeby AB, the author suggested to sell half of the rejected materials (pre-dried) to a recycler able to separate the materials content into pure fractions (i.e. LDPE fraction to be reused in PolyPlank's composite planks) or to process the mixed materials in order to be reused in PolyPlank's core plugs production.
  Hans Andersson (acquired by Veolia) could be the recycler able to close the loop. This could not be confirmed in this research due to the inability to gather information from this company.

The author's reflections principally highlighted the contradiction among actors' opinions regarding the economic barriers for recycling LDPE. While Fiskeby AB found some market-based challenges to invest into a new recycling line to separate LDPE into pure fraction, the group Borealis in contrast invested millions of euros in August 2018 into the extension of an Austrian LDPE recycling plant. Is there an existing market for recycled LDPE in Sweden and in Europe? New market research studies should be carried out in order to answer this question.

Also, along this study, the author identified new areas for future research. Another main recommendation is to investigate the numerous stakeholders regarding the recycling of LDPE in Sweden. Therefore, an in-depth stakeholder analysis could be performed to explore more solutions for increasing LDPE material circularity in a larger context and finding ways to generate incentives for potential recyclers and converters to drive the LDPE recycled market.

Also, the author believes that future market research could focus on mapping in Sweden and surrounded countries, all the converters of recycled LDPE and mixed rejected materials from paper mills. Evaluating the potential profits generated by re-selling the recovered aluminium could also create a stronger incentive for recyclers and paper mills to invest into new technologies.

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Abbreviations

'CE' – Circular Economy

'HDPE' – High Density Polyethylene

'LDPE' – Low Density Polyethylene

'Al' – Aluminium

'MSW' Municipal Solid Waste

'PE' – Polyethylene

'EOL'- End-of-Life

1 Introduction

1.1 Background and Context

Plastics became indispensable in our everyday world, from single-use packaging to industrial applications such as in the construction sector. Since decades, the plastic production considerably increased with more than 335 millions of tons in 2016 compared to 1.5 millions tons in 1950 (PlasticsEurope, 2017). It is predicted to continue to grow and even double by 2036 (World Economic Forum, 2016; European Parliament, 2017a) generating in this way more plastic waste.

This alarming growth is mainly due to its numerous advantageous properties such as versatility, flexibility and cost effectiveness compared to other material types (European Parliament, 2017a). According to the report in 2017 of Ellen MacArthur Foundation (a foundation working towards a transition to a circular economy) plastics and plastic packaging are a significant force in our global economy due its several benefits, nevertheless, their current linear value chains pose a number of problems to our society and our planet and this is not without consequences. Indeed, plastics production represents today approximately 6% of the global oil consumption and increases the dependency on fossil fuels as 90 % of the plastic materials are derived from virgin fossil fuels sources such as natural gas, oil and coal (European Parliament, 2017a; PlasticsEurope, 2017). Furthermore, plastics production contributes to greenhouse gas emissions with around 390 million tonnes of carbon dioxide reported in 2012 (PlasticsEurope, 2017; World Economic Forum, 2016).

Due to its low recycling rate with 14% of plastic packaging collected for recycling globally, and as a result of its single use, the value loss of plastics is inevitable (Ellen MacArthur Foundation, 2017). Indeed, 80 to 120 billions of dollars (68 to 100 billions of euros) every year are lost in the economy (Ellen MacArthur Foundation, 2017). If not properly disposed for being reused, recycled, or even incinerated, plastics could end up in the natural environment contributing in this way to land and water pollution. Plastic pollution generates therefore negative externalities on society. Clearly, increasing the recycling of plastics is crucial in order to reduce harmful impacts on our planet from increasing oil consumption, greenhouse gas emissions and natural resources depletion.

Current use of existing resources must be modified towards incorporating more circularity of material flows, by creating 'closed-loop systems' in society and industries, in which waste is reduced to a minimum as opposed to the current linear model where material is extracted, consumed and then disposed of (World Economic Forum, 2016; the Ellen MacArthur Foundation, 2017).

In the last few years, the concept of Circular Economy (CE) received an increasing global attention as an approach to replace the current linear economy which is a 'take, make, dispose' model of production with raw material resources dependency. By adopting a closed-loop economic system, CE contributes to increase the efficiency of resource use (with a focus on urban and industrial waste) in order to create a balance between the economy, environment and society (Ghisellini, Cialani, & Ulgiati, 2016). Furthermore, by using fewer resources in a more efficient manner, businesses and industries could gain several economic benefits while protecting the environment.

Recently, plastics became one of the five priority areas in the European Union (EU) action plan for the circular economy in order to encourage European businesses and consumers to utilize resources in a more sustainable way (European Parliament 2017a). The European Parliament recognized in 2017 the urgency to implement special measures on plastic waste in the EU legislation and to value plastics as a resource. It has been stated that in the EU, "the potential for recycling plastic waste remains largely unexploited". In comparison with other materials such as paper, glass or metals, the recycling of the end-of-life plastics is very low. Indeed, in Europe, the average amount of recycled plastics was 36% in 2012, whereas 84% of paper & cardboard and 72% of glass were recycled (European Parliament, 2017b).

The European production of virgin plastics accounted to be over 60 million tonnes in 2016 compared to 58 and 59 million tonnes in 2015 and 2014 respectively, showing a stable production over years (PlasticsEurope, 2017). Therefore, a need for measures is crucial for tackling the impacts caused by future plastics waste generated. According to the organization PlasticsEurope (2017), the production covers the plastic demand from most of the European countries (especially Germany, Italy and France) with the majority used in the packaging sector followed by the building and construction sector being the second largest consumer of plastics. In the same report of PlasticsEurope (2017), more plastics were recycled than landfilled during the year 2016 and this was the first time recycling surpassed landfilling. Among 27,1 million tonnes of post-consumer plastic waste collected in European countries in 2016, 31.1 % was recycled while 27.3% was sent to landfills and 41.6% was used for energy recover, making therefore waste incineration more important than recycling such as it is the case in Sweden (PlasticsEurope, 2017).

Indeed, in Sweden, where this research case study takes place, energy recovery of household waste is largely common. In 2016, 48.5% of the total household waste was recovered into energy compared to 34.6% sent to material recycling while only 0.7% of the total waste was disposed in landfills (Avfallsverige, 2017). Modern combined heat and power plants are numerous within the country in which waste that cannot be sorted is being incinerated in order to produce district heating and electricity. The other diverse sorted materials waste is reused mostly in the construction and building sector (Avfallsverige, 2017).

There are numerous plastics types. In this research paper, the Low-Density Polyethylene (LDPE) being a thermoplastic, is the main type of plastics under study because it is the most representative plastic type in the food packaging industry in Sweden as its chemical properties make it flexible, moisture-resistant, suitable for multi-layered aseptic packaging products for food and beverages (PlasticsEurope, 2017). One of the biggest food-packaging manufacturers is the company "Tetra Pak" located in Southern Sweden in the region of Skåne [Scania]. The case study of this paper focuses on the plastic waste streams from post-consumer Tetra Pak's packaging, and identifying the possibilities to re-use this valuable plastic waste in other companies' production processes such as the PolyPlank AB, a company working mainly in the construction and building sector. In this way, by closing the loop of the current LDPE material flow, those companies may advance towards sustainable solutions to reduce negative impacts on the environment while gaining benefits from an economic perspective further explained along the research.

1.2 Project and Case Study Companies Introduction

Closing the plastic materials flow through recycling and reusing could not only reduce negative environmental impacts but also provide economic benefits and opportunities that have been already understood by some companies in Southern Sweden. Indeed, PolyPlank AB, a company specialized in fabricating composite planks (image 1) for walls, fences, floors sold to the construction industry as well as 'core plugs' (image 2) sold to the paper industry, is reusing 100% recycled materials into the fabrication of their products.

Image 1

Image 2

Image 1: *Composite planks produced by PolyPlank AB (LDPE, HDPE, organic fibres used)*

Image 2: *Core plugs produced by PolyPlank AB (Mixed plastics containing mostly LDPE and other materials residues of aluminium and paper)*

Source: PolyPlank AB Website

One important customer of PolyPlank is Stora Enso, which sells paper rolls containing Polyplank's core plugs to the food and beverage-packaging company Tetra Pak. Therefore, through the intermediary of Stora Enso, Tetra Pak uses PolyPlank's core plugs for the majority of their large rolls of different type of packaging material that goes into their products. Tetra Pak produces large amounts of products containing plastic material, which is of value for PolyPlank. Indeed, Tetra Pak carton packaging contains many layers of polyethylene (type of thermoplastics) such as the low-density polyethylene (LDPE) used for preventing from moisture and contamination. However, in Sweden, most of the LDPE derived from packaging is currently separated from paper before being incinerated for energy recovery.

The research topic has been developed together with Katherine Whalen and Julia Nussholz, PhD students at IIIEE, who are part of the MISTRA REES (Resource-Efficient and Effective Solutions) project, in which PolyPlank AB and Tetra Pak are also involved to seek sustainable solutions in industry. After an initial workshop with the mentioned companies, the researchers at IIIEE tried to map an initial understanding of the current value chain. However, uncertainties related to the plastics material flow from the packaging still persisted. Nevertheless, they identified an existing gap between the packaging end-of-use and the buyers willing to reuse plastic materials that are currently being incinerated for energy recovery.

1.3 Problematization and Research Justification

Current plastic production and management are evidently unsustainable. Plastic became one of the most used materials worldwide, is often used in products with short lifespans, and pose substantial environmental problems caused by improper disposal and lead to natural resources depletion if not recycled (Van Eygen, Laner, & Fellner, 2018). Therefore, looking at bringing more circularity into the plastic materials flow through recycling and reusing could solve persistent environmental problems related to the products' lifecycle.

Regarding the circular economy perspective, end-of-life plastics are considered as a resource and not just waste. At their end-of-life, plastics could become valuable resources by being transformed into new products or into energy (PlasticsEurope, 2017).

The Ellen MacArthur Foundation (2017) estimates that with improved design of plastic products and better end-of-life systems, recycling of plastics would be economically attractive for at least 50% of plastic packaging. Furthermore, a study conducted by Norden (2015) took on a broader scope looking at plastic recycling in general, and found that recycling plastic material resulted in 55% less greenhouse gas emissions compared to if plastics were recovered as energy. It is important to add that waste-to-energy could act as a disincentive to develop more sustainable waste reduction strategies (Lloyd, 2016). According to Lloyd (2016), 'preserving material (through recycling and reuse) already in circulation is a key component of sustainable development. Burning finite resources may not be the best approach down the line.'

In a Swedish context, plastics recycling still remain problematic as it is today largely incinerated instead of being recycled. In fact, according to 'Återvinningsindustrierna' [The Recycling Industries] of Sweden, the vast majority of plastics go to incineration (84%), and only the remaining 16% is used for material recovery. The same study estimates that Sweden currently is losing plastics of an original value worth approximately 10 billion SEK (960 million euros) every year. This is mainly due to the inefficient management of plastics. It has been found that 90% of the original value of plastics is lost when recovering plastic waste as energy instead of as material (Återvinningsindustrierna & Re:Source, n.d).

As stated previously, recycling is crucial for reducing dependency on raw materials resources and consumption of fossil fuels. The possibility to recycle LDPE from Tetra Pak packaging is still unclear, as well as the requirements from PolyPlank to reuse recycled materials. As a result, there is a need for finding if a market for recycled LDPE can be created in this situation, thus extraction of virgin material can be avoided.

Despite the increasing number of studies on circular economy and plastic management, there is still no to date studies focusing mainly on LDPE recycling in a Swedish context. Consequently, the main research problem addressed throughout this study is the lack of understanding of the LDPE value chain in this specific Tetra Pak and PolyPlank AB case study in Sweden. In order to find opportunities for PolyPlank to create a closed-loop system of LDPE with Tetra Pak, better understanding of the current situation throughout the value chain is needed.

Moreover, further investigation on the specific LDPE plastic material is deemed important to conduct as differentiation of the types of plastics is still missing in most official data regarding plastic management and recycling. For instance, low-density polyethylene is generally categorized under general plastic or polyethylene. As a result, specific data collection through this research is needed to offer more accuracy in the study of LDPE value chain in Sweden.

1.4 Research Purpose

Based on previous statements in the above section, this study intends to investigate the possibilities and potential approaches for closing the loop of Tetra Pak's packaging waste by reusing the post-consumer LDPE into other companies' production processes, such as for instance into PolyPlank AB's planks products fabrication.

Two main deliverables help the author to reach the research purpose. First, an analysis of the actors in the LDPE value chain under study is carried out in order to map the current relevant actors and their roles in the chain as well as identifying the various barriers and drivers from each actor in closing the loop of LDPE material flow.

Secondly, a simplified LDPE material flow chart within the value chain aims at illustrating the quantities of LDPE with recycling potential.

Thus, the author has the following three objectives:

(1) Map all relevant actors involved in the current plastic material flow system under study,

(2) Analyse in depth their current drivers and barriers to close the loop of Tetra Pak's post-consumer packaging waste, and

(3) Gather quantitative data regarding the amount of LDPE materials used, reused, disposed, and the amount of LDPE required for reuse.

Therefore, the key research aim of this study is to investigate throughout the value chain the existing potentiality and feasibility from PolyPlank AB to reuse plastics materials of Tetra Pak end users products (with respect to LDPE content) in order to bring more circularity into their current business models.

1.5 Research Question

The following research question is guiding the analysis of the study to aim at reaching the research's objectives:

What possibilities exist to closing the loop of LDPE material flow through reusing the post consumer LDPE derived from Tetra Pak's packaging into PolyPlank's production processes?

The following four sub-questions could help answer the main research question*:*

1. Who are the relevant value chain actors around LDPE material flows stemming from Tetra Pak?
2. What are the potential barriers and drivers for each actor to create a closed loop system of LDPE?
3. What is the current LDPE material flow within the system under study?
4. What are the possible solutions that can help companies close material flows of LDPE?

It is important to mention that this study does not aim at proposing specific steps and strategies to close the loop (even though solutions will be proposed after the analysis of the results in *Section 5*) but will be more (1) a foundation for describing what are the actors' opinions and willingness to act towards more circularity for potential future collaboration (through a qualitative analysis) and (2) to map current LDPE material flows for identifying opportunities and future recovery improvements (through gathering quantitative data to create a simplified MFA). The second chapter related to research design and methods will explain the approach used to conduct this research.

1.6 Scope

This paper is focusing on the packaging industry and its downstream flows of the specific type of plastic 'LDPE'. This delimited scope was chosen for the reason that there is currently poor understanding of the LDPE value chain, its current recycling practices and whether there is a market for recycled LDPE in Sweden or abroad.

Even though the scope is limited to the case study of the Tetra Pak cardboard packaging streams and PolyPlank use of the recycled LDPE in their production, the author decided to explore and gather information from other plastics packaging streams for two reasons. First, there is little or no information in regards with the specific food and beverage cardboard packaging consumption in Sweden and its recycling rate. Secondly, looking at other streams could potentially help the author to identify some areas to help close the loop of the LDPE flow in Sweden.

LDPE is a plastic type of special interest as it is the most represented type of plastic in plastics packaging, which makes up the largest fraction of plastic waste (European Parliament, 2017b; Norden, 2014). However, the simplified material flow analysis also traces other material types due to limited information about LDPE fractions in some cases.

It is important to mention that this study focuses on post-consumer waste, which is produced by household and often collected with the municipal solid residual waste (MSRW) (Luijsterburg, 2015). Therefore, the post-industrial plastic waste produced by companies and industries is out of the study scope.

The geographical scope of this case study is in Southern Sweden where the LDPE value chain actors such Tetra Pak and PolyPlank AB is located.

The author assumes that it could exist a larger opportunity for other companies besides PolyPlank to reuse LDPE as Tetra Pak's post consumer packaging generates a large amount of plastic material waste. Therefore, the scope goes beyond PolyPlank production processes in reusing LDPE as other potential companies could also benefit from plastic waste derived from Tetra Pak packaging. Also, other LDPE plastic materials from other industries could be included in some figures and statements as the origins of the LDPE plastics waste is difficult or even impossible to acknowledge from both primary and secondary data.

The following ***table 1.1*** summarizes the scope of this research.

Table 1-1 Scope synthesis for this research

Topic	Scope description
Stakeholders	- Value chain actors (suppliers, converters, recyclers and buyers) taken into account with a special focus on three main actors Tetra Pak, PolyPlank, and Fiskeby
Waste streams	-Focus on food and beverage LDPE laminated cardboard packaging. Other waste streams such as the plastic packaging were covered but not deeply analysed.
Resins	-LDPE is the main type of plastic analysed this research. Also, mixed plastics rejected from paper mill containing LDPE and aluminium is also considered in this research.
Geographical scope	-Southern Sweden
Indicators	-For drivers & barriers, use of the PESTEL analysis factors: Political, Economic, Social (Communication-wise among players), Technological, Environmental and Legislative. -For LDPE Material Flow Analysis: material input, output for production, waste disposal indicators.

1.7 Ethical Considerations

Ethical considerations have been considered throughout the research and interpretation of the results. It is important to highlight that information collected about drivers and barriers as well as their analysis have been interpreted by the author based on her own knowledge even with the efforts to remain objective. The data analyzed in this research were collected from interviewees' answers to specific questions designed and guided by the interviewer. Therefore, companies' drivers and barriers presented in this paper may not necessarily reflect the companies' efforts towards environmental protection or other companies' values.

Some interviewees wished to not share important information and to remain anonymous. Therefore, in this paper, the findings seek to respect the choice of the interviewees. Some information is hidden (highlighted in black) but it does not alter the comprehension of the findings. Also, the author asked beforehand the permission to record the phone call or the discussion (in the case of an interview in person) and the author strived to explain the purpose of the study to the interviewees.

1.8 Audience

As previously stated, this study aims at first to evaluate current situation of the LDPE value chain and actors having potential interest to approach a closed-loop system. In this way, the results of this study could help the actors in the value chain to find solutions for future collaboration for bridging current gap. In addition, the outcomes can form the basis for further investigations for the MISTRA REES and PolyPlank AB project in collaboration with IIIEE researchers.

This research thesis could also exemplify a case study to inspire other similar industries and businesses wishing to follow a circular model and understanding the main barriers and drivers of businesses and organizations towards improving plastics recycling rate. In another way, the study could pretend to offer a solid basis and a case example for future research within the academia in improving LDPE plastic recycling rate from multi-layered food and beverage packaging waste worldwide.

Thus, this paper does not have one specific target audience. Instead, several parties such as the academia, businesses, organizations, or even decision makers could collect information in this paper regarding LDPE material flows and plastic recycling barriers and drivers for their own purposes. However, it is clear that actors in the LDPE value chain under study could benefit from the information generated throughout this paper in order to get a better understanding of the overall situation of the LDPE material flow and what are the main challenges and opportunities to create a more close-loop system.

1.9 Disposition

In **chapter 1**, the background and context regarding the research topic is introduced. The underlying research problem and the research justification are then addressed. Based on the existing knowledge gaps and given the unclear situation of the LDPE value chain in Sweden, the research objectives and the research question are defined. Finally, the scope of the research and the target audience are given.

Chapter 2 describes overall the research approach and the methodology used to conduct this research. The nature of the research is presented as well as the approaches used to address the research questions and objectives. Methods on conducting the literature review, research analysis as well as the interviews are presented in this chapter.

In **chapter 3**, brief background information on the circular economy and plastics streams globally are given followed by the explanation of the current Swedish plastics waste management and treatment systems. Then, the different LDPE value chain main actors in Sweden are introduced as well as the existing barriers and opportunities in recycling plastics. An overview of European and Swedish legislations related to plastics waste treatment is finally given. This chapter provides relevant secondary information before presenting the results collected from primary data in the chapters 4 and 5.

Indeed, in the **chapter 4**, the different actors identified under the case study are described and their main barriers and opportunities are stated through the interviews' results.

The findings are presented in **chapter 5** in which barriers and drivers are further analysed and solutions are suggested for improving the circularity of the LDPE material flow in the system under study. In this chapter, the research method is finally discussed.

Lastly **chapter 6** summarizes the findings and provides concluding thoughts. Some reflections are given regarding the contribution of this study to the research area, as well as recommendations on future researches.

2 Method

This chapter describes and justifies the methodology used in this research. The research design, research process including data collection and analysis throughout this study, are explained in the following subheadings, in this way the reader could follow the methodological process.

2.1 Research Design

This section intends to explain the nature of this research as well as the methods selected by the author for the data collection.

2.1.1 Nature of the research

This research is of exploratory and descriptive nature. Through this study, this research qualitatively and quantitatively investigates the potential and feasibility of reusing plastics materials of Tetra Pak's end users products (with respect to LDPE content) into PolyPlank's production process. With the general research aim in mind, the author formulated the main research question in ***section 1.5*** along with four detailed sub-questions helping to reach the research objectives. Both qualitative and quantitative data were needed through primary and secondary data collection methods to answer the research questions. Therefore, the author will conduct a convergent parallel mixed method data collection with an inductive approach as limited information from the beginning was available and no hypothesis was formulated. This mixed method has been chosen because it was found to be the best approach to illustrate through both numerical figures and opinions the possibilities to reusing LDPE into the value chain.

The author chooses to employ an embedded single case study design to address the main research objectives. The context is geographically limited to Southern Sweden where several units of analysis, being the categories of actors of the LDPE value chain, have been defined throughout the first stage of this research. In comparison with a holistic case study that provides a general analysis on the nature of a global case, the embedded case study, on the other hand, encompasses multiple embedded units of analysis on which attention are given (Yin, 2003).

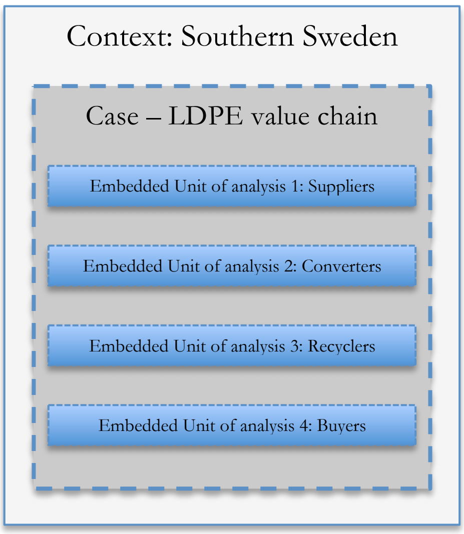

Figure 2-1 Embedded Single-Case Design for this research
Source: Inspired by COSMOS Corporation (Yin, 2003)

The single case of the LDPE value chain, as illustrated in the ***figure 2.1***, is occurring in Southern Sweden and covers several units of analysis. The units of analysis of this case study were categorized into 1) Suppliers, 2) Converters, 3) Recyclers and 4) Buyers. After preliminary research on literature review and the first interview of PolyPlank AB, the categorization of those units has been chosen to reflect the main actors in the value chain. Due to the context of the case study of this research, the converters consist of only one actor "Tetra Pak", and "PolyPlank AB" represents the buyers. Some recyclers of LDPE from other plastics waste streams such as Stena Recycling and Swerec are considered to be contributing to the research as experts and providers of knowledge for understanding the main barriers and drivers for increasing LDPE recycling.

Other recyclers from the plastics packaging waste stream were chosen to not be analysed, as they haven't been found in the earlier stage of this research and were not the actors of the LDPE value chain derived from the Tetra Pak cardboard packaging.

Stakeholders such as public authority and consumers were also excluded from this research, as the author does not intend to analyse in depth the policy and regulations influences and the sorting behaviour of the consumers.

Nevertheless, along this research, the author will reflect upon the role of policy makers in increasing plastics recycling and market demand of recycled plastic. Furthermore, some background information about the European and Swedish legislations on plastics waste are given in the literature review section in ***chapter 3***.

2.1.2 Data collection

A literature review was conducted to gather data from secondary sources to gain understanding of the LDPE value chain in Sweden. Also, primary qualitative data were collected by conducting interviews with the main actors of the LDPE value chain. Through this primary data collection, the author focuses on investigating actors' barriers and drivers towards contributing to more circularity in the system under study. The author used the factors of the PESTEL analysis to categorize the barriers and drivers of the actors. Therefore, barriers and drivers were classified into Political, Economic, Social, Technological, Environmental and Legislative factors.

In parallel, the author has collected primary quantitative data from interviewees to visualize the quantity of the LDPE material flow in the system in order to evaluate possibilities in reusing the material into PolyPlank's production; quantitative data were gathered from secondary sources through the actors' websites and waste managements reports.

Data collection approaches chosen to achieve the research objectives are summarized in the table below.

Table 2-1 Data collection approaches for achieving research objectives

Objectives	Data collection approaches
(1) Mapping all relevant actors involved in the LDPE value chain under study	-Collected information about the actors from secondary sources via a literature review -Getting information about potential actors through interviews (i.e. question asked to interviewees: "who are your main clients and suppliers?"
(2) Identifying LDPE value chain actors' current drivers and barriers to close the loop of post-consumer packaging waste.	-Primary data collection from interviews -Secondary data collection via a literature review -PESTEL factors
(3) Performing a LDPE Material Flow Analysis	-Collect primary quantitative data from interviews -Secondary quantitative data (from companies' reports and via literature review)

2.2 Research Process

The process to collect data for conducting the research consisted of two leading steps, literature review and interviews of different stakeholders.

1) A literature review of numerous academic articles and grey literature related to the theory of the circular economy and on subjects such as plastics recycling was conducted
2) Interviews with LDPE value chain actors and other stakeholders were needed to collect empirical data

2.2.1 Literature review

To conduct the literature review, the author found information through different channels such as LUBSearch, Google scholar and Google, and organizations' websites such as Ellen McArthur Foundation and IVL Swedish Environmental Research Institute. The literature review focused mainly on the opportunities and challenges for plastics recycling globally, giving therefore an overview of similarities in the findings of this research.

Also, drivers and barriers were identified by the PESTEL analysis factors, which are used for the analytical framework of this study. Besides, the literature review helped the author to identify some key actors in the LDPE value chain in Sweden, which was important to reach the research objective 1.

For analysing those data from grey and academic literatures, the data analysis tool called "Nvivo" was used for conducting the literature review. This handy software helped the author to gather information by coding through "nodes" and "cases" for carrying out a more comprehensive analysis and comparison of the exhaustive literature.

The ***table 2.2*** below shows the words and phrases used for the literature research as well as the coding categories for the literature analysis.

Table 2-2 Literature research words and sentences and Nvivo coding categories

Research of Literature		*Literature Analysis*
Words Search	**Sentences Search**	**Coding Categories**
-LDPE -Plastics Recycling -LDPE reusing -LDPE in Sweden -Polyethylene recycling	- LDPE value chain in Sweden -Plastics Recycling barriers and drivers -Barriers and Drivers of plastics material circularity -LDPE recycling process -Opportunities and challenges of plastics recycling -Swedish plastics waste management system -European plastic waste policies -Swedish legislation on plastic waste	**Barriers**: *Political, Economic, Social, Technological, Environmental, Legislative factors* **Drivers:** *Political, Economic, Social, Technological, Environmental, Legislative factors* **Plastics Recycling:** *-LDPE recycling methods* *-LDPE recycling technologies* **Plastic streams in Sweden:** *-Plastics recycled* *-LDPE consumption and recovery*

Source: Table developed by the author

2.2.2 Interviews

At the first stage of this thesis, the author knew only few actors to contact such as Tetra Pak, PolyPlank AB and Sysav (the company that runs the waste-to-energy plant in Malmö). The strategy was to get an initial interview with PolyPlank AB to get to know better the situation and gathering names of the company's suppliers and other stakeholders.

This strategy was applied to other interviews by getting informed of actors' suppliers and clients. Not only the author could conduct interviews by contacted those suppliers and clients but also the LDPE value chain started to be more clear.

People who were interviewed were working in one way or another in relation with plastics waste. In total, the author conducted a total of 11 interviews using different means such as phone call, meeting in person, questions answered through e-mail and one visit on site of the waste recycling centre at Sysav in Malmö. In some cases, interviewees suggested to contact other persons, which allowed interviewing additional people.

The following ***table 2.3*** lists and provides details on the interviews conducted in this research.

Table 2-3 List of interviews conducted for this research

Company/Industry	Type of Actors	Medium	Interview Date
PolyPlank AB	Buyer	In person	June 20th, 2018
Fiskeby AB	Recycler	Phone call	July 4h, 2018
Sysav Utveckling AB	Recycler/Collector	In person	July 6th, 2018
Tetra Pak	Converter	Phone call	July 11th, 2018
PolyPlank AB	Buyer	Email response	June 18th, 2018
Stena Recycling AB	Recycler	Email response	N/A
Swerec	Recycler	Email response	N/A
Swerec	Recycler	Email response	N/A
Fiskeby AB	Recycler	Email response	N/A
FTI AB	Recycler	Email response	N/A
Borealis	Supplier	Email response	N/A
Total of Interviewees: 11			

A more detailed list of interviewees is available in ***appendix 7*** with referring interview number (i.e. I3 for interview 3) being used in the results and discussion chapters.

First of all, before conducting interviews, the author started with creating interview guides. The first interview, which was with PolyPlank, has been created in a semi-structured way in order to discover, at this stage of the study, unknown areas for this research. This initial interview helped at designing the next interviews guides as better knowledge of the situation was acquired thanks to the information collected in advance.

Besides, exploring literature on key concepts for this research and having in hand the paper of the IIIEE master student Hanna Angel about the LDPE waste streams in Sweden, helped the author to formulate questions in order to get the answers needed for this research.

Previous to drafting guides, the author did some grey research on the interviewees' company and acknowledged the position of the person being interviewed. In this way, the interview design aimed at fitting the interview person by adjusting the questions to the respective interviewee.

Also, to make it more convenient for the person interviewed, samples of interview questions were sent out beforehand, thus, giving the possibility to the person contacted to comment and be prepared. In some cases, interviewees were not able to answer; therefore, other contact persons were suggested.

Each category of actors from the LDPE value chain was contacted as well as plastics recycling experts. Therefore, two LDPE suppliers (for virgin and recycled material), one converter of the case study (Tetra Pak), five recyclers, and one buyer of the case study (PolyPlank AB) were interviewed. In some cases, several employees from the same company were consulted to complete information needed.

The author conducted semi structured interviews, allowing more flexibility and adding a natural flow to the discussion but mostly due to the fact that depending on the answers from the first main questions, the author could use new follow up questions and be prepared to go to another direction. Indeed, semi-structured interviews allow the researcher to come up with new follow up questions being outside of the original interview design (Bellamy, 2012).

The author used mostly open-ended questions as they provide rich qualitative data for answering mainly research objective 2. The author used an interviewing technique recommended in the literature called "funnel approach" which consists of having first a general perspective on the topic with open ended questions, and then going towards more targeted questions (Kvale & Brinkmann, 2009). On the contrary, to answer research objective 3, closed-ended questions were needed to collect quantitative data representing hard facts.

Questions were principally trying to find out the current situation of the actors regarding their relation with the LDPE recycling or reusing or neither both, and why by focused on barriers and drivers, finally some questions aimed at understanding the LDPE flows (see ***appendix 9*** for accessing the interviews designs).

The length of interviews varied from 30 minutes to more than an hour. The first interview with PolyPlank was important to start the research, as it is one of the main companies under the study case. Consequently, the length of the meeting was about 75 minutes compared to an average of 30 minutes with other actors, except for the visit of Sysav. Indeed, the visit of one of the main waste recycling centre in Malmö managed by Sysav lasted for 40 minutes and 30 minutes extra for the interview with a representative.

Interviews were transcribed for making it easier for the author to go through a coding strategy. The coding helped identify similarities and common themes among the interviews scripts. The coding processed the answers through different categories such as barriers, drivers, LDPE amount of inflows and outflows by creating a coding matrix on an excel sheet. The categories created for the coding of the interviews analysis are listed in the previous *table 2.2*.

2.2.3 Material Flow Analysis

The third research objective is to create a simplified Material Flow Analysis (MFA) to give an illustrated overview of the LDPE inflows and outflows at different stages of the value chain in the case study. Indeed, a MFA is a type of method used for evaluating materials circulation in a system (Van Eygen et al., 2018). The MFA method from the academic paper "Circular economy of plastic packaging: current practice and opportunities in Austria" by Van Eygen et al. is used as a model for this study. This simplified MFA research mainly focuses on LDPE material input, consumption and output indicators. However, in the simplified MFA perfomed for this master thesis other plastic types are mentioned when LDPE information is unknown. Therefore, the MFA could be also called "plastics material flow" in Southern Sweden with a focus on LDPE, but the author chose to refer to it as the MFA for creating less confusion for the readers. The main intention from the author is to present, through this analysis, a mapping of material flows as an illustration of approximate volumes and directions of flows.

While conducting interviews, quantitative data is collected in parallel of the qualitative data in order to perform the simplified MFA and support the research aim. Each figures and numerical data given by interviewees are represented in units of tons per year. Units of analysis will be inflow, outflow, consumption and disposal.

2.2.4 Data analysis

In order to complete an in-depth analysis of the main drivers and barriers of the LDPE value chain actors to answer research sub-question 1, results from the literature review had a significant role in analysing data collected from interviews. The PESTEL analytical framework was used for the analysis of the findings to get a more holistic perspective on the actors' drivers and barriers. Therefore, the data gathered from interviews were analysed and divided into Political, Economic, Social (in terms of communication and interactions among actors), Technological, Environmental and Legislative factors.

In order to summarize this chapter, the below ***figure 2.3*** gives to the reader a clearer picture of the entire research process and methods chosen to conduct this study:

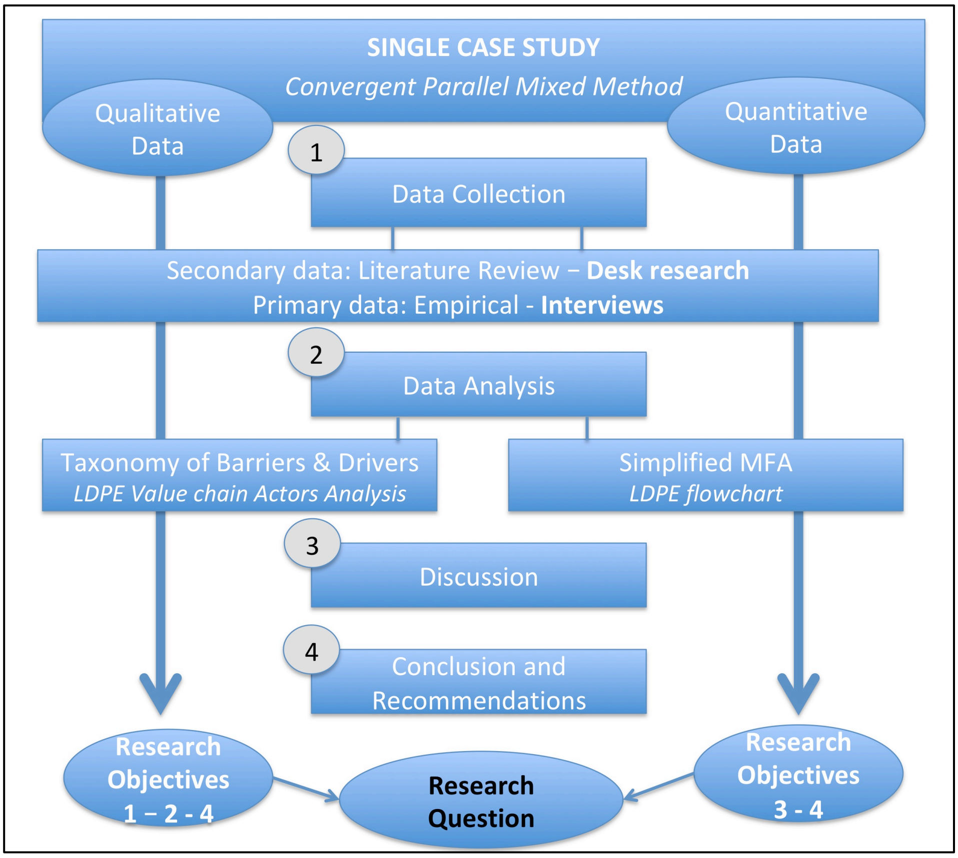

Figure 2-2 Research process and methods of this study – Own source

2.2.5 Data limitations

Challenges may occur in carrying out a master thesis. In this study, the author faced some limitations from data collection to research process.

First of all, LDPE is not a common plastic material independently studied in the academic field. Consequently, desk research for background information on LDPE recycling was challenging for this study. However, this challenge became one of the main reasons of this research focus as it was considered as a research gap.

Secondly, the research was limited in terms of the difficulty to obtain exact numbers and business operations' information due to confidentiality matter. Few exact prices of technology and operations investments were revealed due to either disclosure reason or lack of market study caused by uncertainties. Besides, the author faced some challenges in getting information on precise LDPE material fraction for some statistics in waste management reports. Most of the reports do not divide each type of plastics. Therefore gathering information on exact figures regarding LDPE material recovery was difficult and influences the accuracy of the LDPE Material Flow Analysis presented in the *figure 5.6*. Also, some numerical data regarding LDPE consumption and disposal were unknown by the companies' representatives interviewed. This was another limitation for performing the Material Flow Analysis.

Furthermore, the study was limited due to the time constraint of a master thesis and the availability of interviewees during the summer vacations. Indeed, the author of this study reached more than 30 people through e-mails and phone calls, however, less than 30% answered back with a positive answer to an interview request. Therefore, summer vacations did influence the collection limit of empirical data.

Regarding the gathering of sources, some are somewhat out-dated (i.e. SMED report of the year 2012) as no recent information and studies could be obtained about the LDPE applications and general plastics streams in Sweden.

Lastly, the author is a non-Swedish speaker; therefore, it was difficult to translate some reports and process the information from Swedish documents.

3 Literature Review

In this section, literature findings help answer the research objectives 1, 2 and 3. In a first place, this chapter defines different terms related to waste management, plastics and circular economy. Then it provides a general background of the current situation of plastics recycling in Sweden including the actors involved and the market segments as well as information regarding LDPE in the Swedish market.

In a second part, the findings of the literature review will be categorised into barriers and opportunities for increased plastics recycling in accordance to the PESTEL analytical framework: Political, Economic, Technological, Social (communication wise), Environmental, Legislative factors.

It is important to mention that this literature review could be perceived too general regarding plastics and not limited to LDPE. This can be explained by the fact that there is a lack of academic literature on LDPE recycling. Therefore, literature on plastics recycling and plastic material recovery has been deemed to be the closest and most relevant available literature to this research. Further in this paper, empirical data collection will help bridge the knowledge gap regarding LDPE material, thus acting as the key contribution of this research.

Moreover, some inconsistency and contradiction persists on some figures and estimations found in various waste management reports and documents from Swedish organizations. As a result, some primary data collected by the author is of importance for more accurate representation of LDPE material flow in the value chain.

3.1 Definition of Terms

Some terms and the concept of circular economy used in this study are described in this section. Definitions regarding plastics and recycling methods are first given before describing the concept of the circular economy.

The author believes that defining words and concepts are important for potential reader with limited plastics recycling knowledge in order to understand the findings of this study. Important definitions regarding waste treatment are given at the end of this paper in the glossary section.

3.1.1 Plastics

Plastics are various and designed to meet the different requirements of thousands of end products (PlasticsEurope, 2017). Plastics are considered to be a group of materials (synthetic or natural) called polymers ("Science of Plastics," 2016). There are two categories of plastics: the "thermoplastics", which consist of plastics with the properties to be heated, reheated and reshaped and hardened when cooled (such as the LDPE) while the other category named 'thermosets' cannot be re-melted and reformed when heated (Avfallsverige, 2017).

Resin (mixed of organic compounds) is the raw material used for manufacturing plastic products. One of the most common resins is the polyethylene, a synthetic polymer often made from natural gas or crude oil and famous for its wide range of properties. Polyethylene is one of the most used polymers in the world and is produced into three main types: Low-Density Polyethylene (LDPE), High-Density Polyethylene (HDPE) and Linear Low Density Polyethylene (LLDPE). (Lazonby, n.d.).

3.1.2 Plastics recycling and recovery

There are different methods to recover plastics:

1) Mechanical recycling is a physical method and consists of several steps such as cutting, shredding into granulates, flakes or pellets of the required quality, contamination separation, floating and is finally melted into a new product by extrusion. There is no alteration of the polymer during the mechanical recycling process. (Grigore, 2017; (Luijsterburg, 2015). This method occurs when the materials are converted into "new"(secondary) raw materials without modifying the structure of the material. It is also called material recycling, material recovery and back-to-plastics recycling in the case plastics are involved (European Bioplastics, 2015).

2) Chemical recycling or **feedstock recycling** occurs when there is an alteration of the structure of the polymer through a chemical reaction. In other terms, the polymers are partly depolymerized or converted into monomers (single molecule), and then, those obtained monomers can be bonded to other identical molecules to form a new polymer. Therefore, this method could convert the plastic material into smaller molecules, and be used as feedstock material (Francis, 2016; Olga & al., 2008). There are several chemical reactions employed to decompose polymers into monomers, however, this chemical recycling method is still under study and not widely used, as it needs a lot of investment and expertise. (Grigore, 2017)

3) Energy recovery consists of recovering the plastic's energy content. The incineration is one of the most effective methods to recover plastics into energy. Electricity or steam is produced when the plastic waste is burnt at high temperature. As a significant amount of energy is generated from polymers, this method could be considered a good solution however it could cause health risk due to the airborne toxic substances. (Grigore, 2017)

Those methods are usually divided into **primary** (mechanical recycling which is also named "closed-loop recycling"), **secondary** (another mechanical recycling process but also named "open-loop recycling") **tertiary** (chemical recycling) and **quaternary** recycling is when the energy is recovered (Hopewell et al., 2009).

The **closed-loop recycling** means that a material can be recycled over and over again without degrading its properties. The recycled material could substitute the virgin material and used in the same way. It is considered a more sustainable way compared to the **open loop recycling** often called "downcycling" in which the material cannot be recycled indefinitely and at some point, will become waste. In this latter process, the recycled material properties are reduced or modified (i.e. degradation of the quality), as a result, the inherent properties differ from the ones of the virgin material. (Nakatani, 2014; Williams et al., 2010;Huysman et al., 2015)

3.1.3 Circular Economy concept

Circular Economy (CE) is the main central concept for conducting this project to answer the core research question. The Ellen MacArthur Foundation (2016) defines it as "an industrial system that is restorative and regenerative by design. It rests on three main principles: preserving and enhancing natural capital, optimizing resource yields, and fostering system effectiveness". A central theme of the Circular Economy concept is "the valuation of materials within a closed-looped system with the aim to allow for natural resource use while reducing pollution or avoiding resource constraints and sustaining economic growth" (Winans, Kendall, & Deng, 2017). Therefore, CE could be referred to a "closed- loop economy", which "does not generate excessive waste and whereby any waste becomes a resource" (Wysokinska, 2016; Geisendorf & Pietrulla, 2018).

Another definition was given by the European Union Action Plan for the Circular Economy: "in a circular economy the value of products and materials is maintained for as long as possible; waste and resource use are minimized, and resources are kept within the economy when a product has reached the end of its life, to be used again and again to create further value" (European Commission, 2015). It is clear that this concept relates to the case study of this paper in which a gap persists in the LDPE value chain. Therefore, this concept is used as a guideline to identifying possible approaches for more circularity of the LDPE material flow in the value chain under study.

3.2 Global Plastics and Circular Economy

3.2.1 Circular Economy background

The idea of the Circular Economy evolved along decades since late 60's and has been developed by different schools of thought. CE has been recognized to be a possible solution to replace the current unsustainable linear economic system with the traditional industrial mantra of "take, make, dispose" (Geisendorf & Pietrulla, 2018). Indeed, CE aims to reduce dependence on oil, minimize resource input, waste, emission out of the system (see the CE system diagram in ***appendix 1***). Therefore, this model strives to shift towards a low carbon economy without jeopardizing economic growth. Besides, the Ellen MacArthur Foundation stated: "while great strides have been made in improving resource efficiency, any system based on consumption, rather than on the restorative use of resources, entails significant losses along the value chain" (Ellen MacArthur Foundation, 2015).

Retaining materials within a recirculation loop while re-making new added value products could not only reduce the use of virgin materials but also eliminate the generation of waste (Kaur, Uisan, Ong, & Ki Lin, 2018). This idea of material recirculation loop has been proposed by one of the CE's roots called "Cradle to Cradle" (C2C), a school of thought developed by the chemist Braungart and architect McDonough (Geisendorf & Pietrulla, 2018). C2C refers to a closed-loop supply chain in which the material recycled at a product's end of life is re-used into the production of a new product for either the same or a different purpose. (De Pauw, Karana, & Kandachar, 2013; Huang, Bird, & Heidrich, 2007)

This below ***figure 3.1*** illustrates the C2C concept of the materials circulation loop after the production to avoid waste generation and minimize raw resources use.

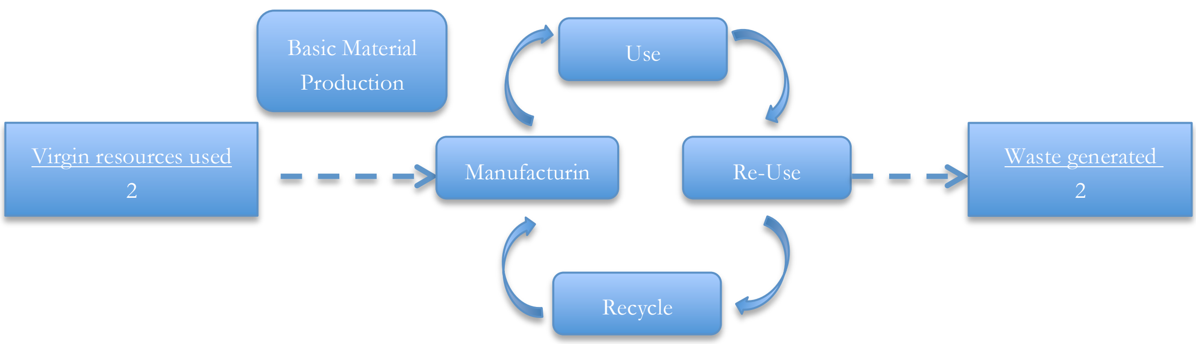

Figure 3-1 Cradle to cradle system
Source: Adapted from Product-Life Institute, Geneva, 2013

3.2.2 Plastics and plastics packaging overview

Plastic has received a lot of attention in terms of rethinking its current unsustainable use affecting negatively human health and the environment. The renown Ellen MacArthur Foundation many times cited in this paper, created a report offering strategies aligned with CE principles to improve the plastics economic system by providing examples from the plastic packaging value chain.

This report "New Plastics Economy" (2016) proposes a new way of thinking to increase the circularity of the global plastics material flow and presents alarming statistics regarding the current consumption of plastics worldwide. In fact, this report states that the plastics production drastically increased in the last 50 years by 20 times and may even double within the next 20 years as plastics are used in numerous sectors and applications.

From the yearly 78 millions tons plastics production in the world, 40% is landfilled, 32% ends up in the nature, 14% is recovered into energy or incinerated while only 14% is collected for recycling. This plastic recycling rate (14%) is by far lower than the ones from other materials such as paper (58%), iron and steel (70% and 90% respectively). Consequently, the reuse, recovery and recycling of plastics are extremely needed. In the global plastics economy, the plastics packaging value chain exemplifies a linear system using 98% of fossil feedstock in which only 2% of the plastics packaging material is recycled into a closed-loop system (see diagram ***appendix 2***). (Ellen MacArthur Foundation, 2016)

Packaging (mostly single use) is the main sector for plastics applications with a total of 40% from the total plastics consumption in Europe (PlasticsEurope, 2016) and the vast majority (70%) comes from household waste (ACRR, 2004).

As the authors Piringer and Baner (2008) mentioned, polyethylene is the most used plastic for packaging. Among the polyethylene family, LDPE is the most prominent plastics in the packaging products (Kaiser, Schmid, & Schlummer, 2017) (see graph about plastics applications fields in ***appendix 4***). The reason why LDPE is largely used is because of its special molecular structure and its density range of 0.910–0.940 g/cm3 as well as its numerous properties such as moisture resistant and flexibility (PlasticsEurope, 2017).

Those characteristics make LDPE the most suitable material for multi-layered aseptic food and beverages packaging products. LDPE is also the main material for the production of shopping plastic bags and other applications such as for the inner lining of cardboard packaging in the food and beverage industry, which is the case of the Tetra Pak packaging under this study (see picture illustrating the layers of carton packaging of Tetra Pak in ***appendix 3***). Liquid packaging board (LPB) is a multi-layered packaging consisting of mainly cardboard (75%) for giving stability of the package, polyethylene mostly LDPE (21%) preventing from moisture, and 4% aluminium acting as a gas barrier (Kaiser et al., 2017) .

3.3 Plastics and LDPE Recycling

To avoid dependency on non-renewable resources of petroleum, a circular plastics economy is evidently needed, and this could be done through an efficient waste management and especially through recyclability (Geisendorf & Pietrulla, 2018). According to Ellen MacArthur Foundation (2016) the low 5% of the after-use plastic packaging material value gives thus space for large possibilities to capture more material value by significantly improving recycling, quality and uptake.

Plastic recycling is more cost-effective when the recycled material is kept as pure as possible, meaning that it contains the same polymer and has low levels of impurities. Compared to household waste being mixed with various sources, the industrial plastic waste is easier to achieving higher recycling rates due to more homogeneity of the industries' plastic streams. Nevertheless, it is important to focus on the households waste as it generates the largest amounts of plastic waste. (Hopewell et al., 2009).

Savings from primary energy use is one of the main benefits of plastics recycling. The production of polymers represents the largest amount of resource use. The energy use for LDPE/LLDPE production in Europe accounts for 78 GJ/tons and 1,8 tons CO2 (ACRR, 2004). Therefore, recycling of LDPE could save energy consumption for its production and reduce the release of CO2 emissions.

However, LDPE faces some challenges for its recycling as it is not so widely recycled except for the production of stretch wrap film in transport packaging and agricultural film (ACRR, 2004). Some recycled LDPE, with the recycle code "4", are also used in the production of garbage bags, floor tiles and in the construction sector in planks composite as it is the case for the company PolyPlank AB.

There are different methods for recycling plastic materials, and the ease of recycling depends on the type of polymer, the design and product type. Mechanical or chemical recycling are the two most suitable processes to keep the quality of the plastics polymer. Thermoplastics with higher mechanical recycling potentiality are the PE (including LDPE), PET (polyethylene terephthalate) and PP (Polypropylene). In some cases, plastics (including plastics contained in some products) which cannot be effectively or sustainably recycled through the mechanical method to provide economic or environmental incentives are recovered in other forms such as feedstock recycling and energy recovery.

3.3.1 LDPE recovery from multi-layered packaging

For thermoplastics such LDPE, both recycling and incineration are the common recovery methods. However, there are some issues related to the incineration of thermoplastics such as the release of toxic gases and in some cases, the ash created from burning may contain lead and cadmium. In contrast, choosing the recycling method reduces environmental issues, as it not only saves raw material resources but also energy. (Mohammadzadeh, 2009; Francis, 2016; Favis & Le Corroller, 2017).

Some packaging products contained not only plastics but also all kinds of materials such as paper, metals, other polymers and additives (i.e. ink and adhesives). In this case, separating plastics from those materials is often expensive and difficult (SMED, 2012). Due to their poor recyclability of this complex type of packaging, those multilayers are therefore recovered into energy by incineration or landfilled, which are obstacles to advance towards a circular economy and reduce crude oil independency. (Kaiser et al., 2017)

Recovering polymers into energy could be considered advantageous if we look at their calorific value (energy content). Among the plastics types, LDPE, HDPE and PP have one of the highest energy content with a 45 net calorific value (Mj/Kg) compared to PVC with a low calorific value of 22 Mj/Kg (ACRR, 2004). Kaiser & al. stated in their study "most polymers have a caloric value in the same range as that of crude oil (~40 MJ/kg)" therefore plastic waste could be considered as a substitute of crude oil. Nevertheless, the energy needed for producing virgin plastic can not be recovered (Kaiser et al., 2017).

Many studies such as the one on "Recycling of Polymer-Based Multilayer Packaging" by Kaiser et al. (2017) presented some methods for recycling LDPE and separating materials from liquid board packaging such as the one used in Tetra Pak. The following sub-chapter will describe the methods.

3.3.1.1 LDPE recycling stages and methods

Generally, there are several stages for treating postconsumer waste and recycling thermoplastic polymers: first, the waste is collected from households or recycling centres to be sent then in sorting or recycling facilities in order to separate different types of materials and then the material is reprocessed (manufacturing stage) for being sold again on the market.

There are several technologies for recovering the separated materials, some involves mechanical and chemical recycling techniques and vary in terms of complexity and cost. Generally, when the technology is more complex and expensive, the material recovered is more pure. There are still many studies and on-going experiments regarding chemical recycling with complex processes such the "pyrolysis" consisting of degrading polymeric materials by heating in the absence of oxygen (Kaiser et al., 2017). Studies of Achilias, D. et al. on LDPE, HDPE and PP recycling did some experiments with both mechanical and chemical recycling. The first one used the dissolution/re-precipitation technique (mechanical recycling) while the last consisted of the pyrolysis (chemical recycling). They concluded that despite using consequent amount of organic solvents, the mechanical recycling succeeded to obtain a high recovery of pure polymer. In parallel, the results of the chemical recycling were considered the "most promising technique".

3.3.1.2 LDPE recycling methods from plastic-coated cardboard packaging

LDPE contained into carton packaging could be separated by several methods. One of the techniques to separate plastics materials from other types of materials such as paper is called the "hydro-pulping". This technique consists of agitating water in a tank (a "pulper") in which a rotor (working as a blender) rotates repetitively. The rotor separates composite materials apart such as paper fibres, plastics and aluminium. (ACRR, 2004)

The different types of materials contained in liquid packaging boards (LPBs) and plastic-coated cardboard packaging could be separated by another method. First, this type of packaging is sorted from other types of materials by using reflection measurements through the NIR (near infrared) and using compressed air pulses. Then, the sorted LPB is shredded for separating the fibres being dissolved through a specific paper treatment in which plastics and aluminium are separated. The fibres will be added to the fibre preparation while the rest, which often consists of LDPE and the aluminium, will separately be processed. This later output is called LDPE-Al reject and will be further processed into a selective dissolution in order to be reused in many other applications to replace for instance raw materials in the construction sector. In some cases, the LDPE-Al reject is incinerated for energy recovery. (Kaiser et al., 2017)

3.4 Swedish Plastics Waste System Flows and Treatments Methods

This study is dealing with the postconsumer waste of cardboard packaging containing polyethylene layers (such as Tetra Pak's products), however, no data could be found in a Swedish context on the multi-layered food and liquid packaging board. The plastics packaging is chosen to represent this missing sub-category of packaging waste. Despite being somewhat out-dated, a detailed report in 2012 on Swedish plastic waste streams (created by

SMED, on behalf of the Swedish Environmental Protection Agency) will be used for providing an overview of the waste streams and the recovery methods employed in a Swedish context in the year 2010. No more recent detailed studies were found for Sweden.

According to the statistics from "FTI" (the largest paper and packaging collector in Sweden) plastics remain in Sweden one of the lowest recycled materials representing only 40% in 2017 compared to 80% for cardboard and 93% for glass (FTI Statistics, 2017). Those figures are similar to those in Europe. It has been argued that material recycling for plastics is more difficult mainly due to the numerous material composites contained in plastics and the fact that there are several different types of plastics (Avfallsverige, 2017).

Naturvardskerket (2018, February), the Swedish Environmental Protection Agency, reported that in 2016, the quantity of plastic packaging on the Swedish market corresponded of 212 500 tons from which 47% were recycled.

Regarding the SMED report on plastics streams in Sweden, other figures were found. This report stated that in 2010 household plastic waste (being the largest fraction of plastic waste followed by the construction sector) represented 298 000 tons a year. From this amount, 37% materials were recovered in both Sweden (45 000 tons) and abroad (23 000 tons). The rest (230 000 tons) was recovered into energy through incineration in Sweden. It is important to notice that from this total household plastic waste, the sorted plastic packaging is fully recovered either in Sweden or abroad (46 000 tons/year). On the other hand, 151 000 tons of the non-sorted plastics packaging from mixed household waste were sent to waste-to-energy incineration plants (see table of the plastics waste flows in Sweden in the year 2010 in ***appendix 5***). Therefore, the non-sorted plastics in the mixed waste considerably decreases the plastics material-recycling rate. Indeed, according the same SMED report, 77% of the household waste was directly incinerated in the year 2010. Consequently, this large amount of waste incinerated contributes to the loss of the plastics original value.

A report from the Recycling Industries of Sweden, 'Återvinningsindustrierna', and Re:Source, (n.d.), estimated that every year Sweden is loosing SEK 10 billion (960 million euros) worth of original plastics value caused by the inefficiency in waste management. One reason for this important economic loss is when plastic waste is recovered for energy instead of as material. In this case 90% of its original value is lost. Inefficient sorting of plastics is another reason of this value loss. Indeed, when sorted wrongly, the plastics are mixed with the combustible household waste. (Återvinningsindustrierna & Re:Source, n.d.).

Other reasons why large amount of plastics waste is incinerated instead of being recycled is explained by the lack of an attractive market for recycled plastics along with challenges to separate some polymers from other types of materials and impurities (Hopewell et al., 2009; Miljönytta, 2013).

According to the report of SMED (2012), LDPE and LLDPE together represent the largest portion of the plastics used in Sweden with 17% of the total use after the Polypropylene (19%) (see table of plastics categories used in Sweden in ***appendix 6***). From the same study, in 2010, 17 000 tons of plastics waste from the PE (high and low density together) were imported which represented 6% of the total plastic import in 2010. In comparison, 37 000 tons of PE were exporting (41% of total plastic export) showing that PE are widely produced in Sweden.

3.4.1 Legislations and targets background

There are several directives and regulations regarding waste both at the European and national level. The European directives usually shape the national legislation. In the case of Sweden, recycling targets are even higher than the European ones. The author judged important to present a brief description of the most relevant European and Swedish legislations related to packaging waste to give a better understanding to the reader about the current situation and future targets.

3.4.1.1 European level

The European Waste Framework Directive (WFD 2008/98/EC) is one of the main European directives related to the reduction of waste. The main purpose of the WFD 2008/98/EC is that EU should become more of a 'recycling society', in the objective to use waste as a resource by avoiding waste generation (European Commission, 2012). Another one is the packaging and packaging waste directive (94/62/EC) with a 50% plastics recycling target by 2025 (as previously mentioned, the current plastics recycling in Europe is around 30%). To attain this target, the Plastic Recyclers Europe organization (2017) estimates that the use of recycled LDPE in packaging should increase by 18 times more than the current use.

Recently, the European Commission (2018) revised recycling targets in the Circular Economy Action Plan. The common EU target for recycling all packaging waste is 75% by 2030, which slightly differ from the Swedish target described in the next section. From the same action plan, the EC mentioned that by 2030 all the plastics packaging should be recyclable.

3.4.1.2 Swedish level

Swedish legislation on waste has been revised after the EU directives. Regulations in the WFD are implemented into the existing environmental legislation called Miljöbalken (The Swedish Environmental Code). Some examples of those regulations are the waste regulations, the regulations on producer responsibility and the regulation on landfill.

The producer responsibility ordinance for packaging SFS 2014:1073 (Ministry of the Environment and Energy, 2014) imposes a recovery target of 55% for all packaging waste by 2020, after this year the recovery target should be 65% (SFS 2014:1073, Section15). Regarding the plastic packaging (excluding packaging for beverages) the target is 30% by 2020 and 50% after 2020 (SFS 2014:1073, Section15).

Despite the ambitious EU target of 75% by 2030 for all packaging waste, the Swedish targets at the national level are higher than the European ones.

3.5 Actors of Plastics Value Chain

Households and commercial businesses generate plastic packaging waste, which will partly end up in municipal solid waste for disposal or incineration. The remained part of the waste is collected and sent to sorting facilities. In those facilities, the waste is pre-treated and plastic resins are separated by categories. Then, those separated plastic resins are sent to specific recycling facilities to be further processed into new products. Finally, brand owners and manufacturers would put into the market those new products (NewInnoNet, H2020, 2016).

The main actors of the LDPE value chain identified in the literature are divided in three categories: Producers, Converters, Buyers and Collectors & Recyclers. There is limited data regarding LDPE in Sweden but general background of those categories is given in the following sub-chapters.

3.5.1 Producers

In Sweden, there is only one raw polyethylene producer called "Borealis AB" being also the second largest polyethylene producer in Europe (followed by the companies Dow Chemical and Lyondell Basell) (Borealis, Annual Report 2017; PlastForum, 2006).

Borealis AB plant renovated in 2010, located in Stenungsund (Sweden), has an annual production capacity of 680 000 tons for LDPE, 1.01 million tons for LLDPE and 1.075 million tons for HDPE (Chemicals Technology Website, n.d; PlastForum, 2006).

3.5.2 Converters

Plastics converters have a crucial role in the plastics industry. Plastics converters (sometimes called "processors") manufacture plastics semi-finished and finished products for an extremely wide range of industrial and consumer markets. Raw materials for the plastic converting industry include both virgin plastics, provided by large chemical companies which are transforming a carbon based material into a polymer by a polymerization process, as well as recycled plastics from plastic recyclers.

The NewInnoNet's study (2016), funded by the EU's Horizon 2020 programme, describes plastics converters as follow: "Plastics converters buy in raw material, granular or powder form and process involving pressure, heat and/or chemistry and apply design expertise to manufacture their products. They often undertake additional finishing operations such as printing and assembly work to add further value to their activities."

According to SMED (2012), plastics converters are around 1200 in Sweden.

3.5.3 Buyers by segments

There are different market segments that use virgin plastics. According to PlasticsEurope (2017) the following are the main ones: packaging (39.9%); building and construction (19.7%); automotive (10%); electrical & electronics (6.2%); household, leisure and sports (4.2%); agriculture (3.3%); and 'others' (16.7%).

Regarding the virgin LDPE, the packaging sector is the main one for its application, followed by the construction sector and the agricultural sector (PlasticsEurope, 2017).

In Sweden, from the report of SMED (2012), around 150 000 tons of LDPE and LLDPE is used every year (see table in ***appendix 6***), representing 17% of the total plastic consumption in Sweden. Applications of LDPE by market segments could not be found.

3.5.4 Collectors and recyclers

There are different holders of the waste: households, industrial and commercial users of packaged products, and retailers. Households, who are not study in depth in this study, are private consumers having different possibilities to discard their plastic packaging waste depending on the local collection systems available. (NewInnoNet, 2016).

In Sweden, there are two collection systems. Households' plastic waste is mostly collected through the "bring-system", the consumers (households) dispose the waste in one of the 6 000 recycling stations located at different convenient areas of the cities in Sweden (SMED, 2012). The other "kerbside system", occurs when the households have the possibility to separate their waste near their residency. Through this system, the waste streams are generally purer; as a result it is becoming more popular (Norden, 2014). Those collection systems are managed and financed by municipalities or the housing's landlord, and from this financing, a certain amount goes to the packaging and paper collector called in Swedish "Förpacknings- och Tidnings Insamlingen" [Packaging and Newspaper Collection] (FTI). FTI is responsible for the collection and the recycling of all kinds of packaging in Sweden and send the plastic waste to four different recyclers through contractors. Three of those recyclers are German, and the fourth one is Swerec AB, a Swedish plastic recycler. (Norden, 2014).

Swerec sorts, washes and grinds plastics, and in some case sends the baled plastics to German producers for further process the sorted plastics into granules. Fifty per cent of the collected waste is treated by Swerec and the remaining waste is sent to Germany (SMED, 2012). LDPE is one type of polymers being sorted out at Swerec's facility (Norden, 2014). It represents about half of the incoming plastic packaging waste. Swerec receives around 5 000 tons of bulky industrial plastic waste per year coming from 15 Swedish municipalities. (Norden, 2014).

On top of the 'bring-system', around 580 recycling centres are available in Sweden for household to bring their bulky waste (Avfall Sverige, 2017). The plastic fraction sorted in those centres represents about 30% of the total waste generated by households. Moreover, it is estimated that 30% of this sorted plastic corresponds to polyethylene (PE). There are other recyclers contracted with municipalities, which includes Ragn-Sells, Hans Andersson's Recycling and Stena Recycling. At Ragn-Sells, depending on the degree of pigmentation, the LDPE is separated and sold to Germany for material recovery. The more pigmented LDPE is sent for energy recovery due to its low economic value. (IVL, 2017).

The ***table 3.1*** below gives a general overview of the LDPE recycling plants and the amount recycled in Sweden for the year 1999.

Table 3-1 Plastics recycling plants and LDPE recycled in 1999, Sweden

Recycling stations	LDPE (tons)	Sources	Products
Sweden			
Miljöresurs, Östersund	200	Trade and business	Plastic planks
Miljösäck AB, Norrköping	7 000	Industry and trade	Bin bags
Plastic Recycling RLS AB, Röstånga	4 000	Industry and trade	Regranulate (to bin bags)
Plaståtervinning i Arvika	7 200	Industry and trade	Bin bags, flower pots, dish brushes
Abroad			
Plasta, Latvia	3 000	Industry and trade	
Total	**21 400**		

Source: IVL, 2002 – adapted from (Angel, 2018)

This table may not represent what the current LDPE recycling system actually is in Sweden as the sources come from the year 2002 (no recent information from literature could be obtained). Indeed, the company Fiskeby, a large producer of cardboard made out of recycled fibres, is also recovering LDPE, (however only in terms of energy), but was excluded from the IVL report. Fiskeby is currently the only company in Sweden having the capacity to handle packaging products consisting of a mix of paper, plastic and aluminium (typical for food and beverage packaging) (Fiskeby, n.d.). Tetra Pak is a large supplier of the cardboard packaging products that are treated at Fiskeby (IVL, 2013).

3.6 Barriers and Opportunities for Increasing Plastics Recycling

Some studies have identified some challenges to increase recycling of plastics and some barriers for increasing market demand of recycled plastic persist. However, there are still opportunities to advance towards a more circular plastics economy, which will be further described in the next sections. The PESTEL factors are used for the taxonomy of the barriers and opportunities.

3.6.1 Analytical framework

In order to assess the barriers and drivers of the different actors of the LDPE value chain, the PESTEL analysis has been chosen by the author. It is used to get a holistic view on the actors' opinions, and is often used in business sector. PESTEL stands for the analysis of Political, Economic, Social, Technological, Environmental and Legal factors. In this research, the social aspect encompasses the communication and interaction among the business partners in the value chain. This analytical framework will be further used in the results and empirical data analysis sections.

3.6.2 Barriers

The transition towards more circularity in the plastics value chain implies some challenges. In the literature, the most recurrent issues mentioned for closing the materials loop of plastics (in regard with LDPE whenever information was found) are related to the economic (market-based) and technological aspects. All those barriers are affecting the producers, buyers, waste handlers and recyclers. The political, economic, social, technological, environmental and legislative barriers identified in the literature are covered in the next sub-chapters.

3.6.2.1 Political factor

China was the first importer of plastic waste for decades. Around 87% of European plastic waste used to be sent to China (Velis, 2014). However, China imposed a ban of foreign waste import (24 categories of solid waste such as plastics), which came into force in January 2018 (Benson, 2018). This ban was mentioned in some newspaper articles; however, it wasn't recognized as a barrier for recycling plastics. Nevertheless, the author identified this ban as both a potential barrier and a driver discussed in the next 'Opportunities' section.

3.6.2.2 Economic factor

The low demand for recycled plastic is explained by many factors such as the higher prices for recycled plastics compared to the virgin plastics and the quality variations and uncertainties of recycled plastics.

Virgin plastic price influences the demand for recycled plastics. It has been found that, in general, recycled plastic is cheaper than virgin plastic. The price difference between recycled plastic and virgin plastic is argued to play a key role in the plastics converters' demand for recycled plastics. From the report on Plastic Waste Market of the Nordic Council of Ministers (NCM) (2018), it has been estimated that recycled plastic is 15-30% cheaper than virgin plastic. The oil prices contribute to the price volatility of the virgin plastic. Currently the price of crude oil is very low; as a result, recycled plastics encounter difficulty for competing over cheaper virgin plastics. (Nordic Council of Ministers, 2018)

Another barrier could occur at the consumer decision level, when there is a lack of interest to buy products containing recycled plastics. Therefore, not only this lack of demand but the overall plastic prices differences (virgin vs. recycled) contribute to disincentivizing producers from using recycled plastics instead of virgin ones. (Nordic Council of Ministers, 2018)

One of the main economic barriers for increasing the plastics recycling is the important amount of money to be invested towards innovation (research and development) regarding recycling technologies. According to a study by Technopolis Group et al. (2016), "billions of euros" need to be invested in order to create a circular economy in the plastic packaging sector.

One factor contributing to the economic barriers is the oil price being currently low. If it remains low, there would not be any financial incentives for investing into new infrastructure and technologies to recycle LDPE. Another factor is the lack of economic incentives for end-users to sort out the waste into different materials (except some beverage bottles with an effective system) leading to a low quantity of material collected. (European Parliament, 2017a)

3.6.2.3 Technological factor

The quality of the feedstock material is a major technological barrier. Most of the time, the plastics waste collected consists of different materials types mixed together with other contaminants. Some packaging is multi-layered containing paper and aluminium. This mixed waste of different materials increases the challenge in treating separately those materials. Furthermore, the challenge persists due to the multiple treatments methods for each type of polymer, which depends also on the composition of the product and the contamination degree (European Parliament, 2017a; Hopewell et al., 2009; Plastics Recyclers Europe, 2017).

Also, most of the polymers being recycled present lower quality characteristics than the virgin plastic, and the quality of recycled plastics decreases even more after repetitive recycling processes of the plastic material, which is not the case for materials such as glass and metal (Nordic Council of Ministers, 2018).

Depending on the final products purpose, requirements for the quality of the recycled materials vary among sectors. For instance, recycled plastics destined to be in contact with food or liquid have the highest requirements to avoid health issues. Therefore, current plastics recycled mechanically are not suitable for being in direct contact with the food and beverages due to high risk of contaminations. Despite chemical recycling being able to remove contaminants such as additives, nutrients and other types, this technique is still not economically viable for recycling plastics in a larger extent. (World Economic Forum, 2016; Plastic Recyclers Europe, 2017). Therefore, current mechanical methods for plastics recycling are not suitable for all type of sectors.

One indirect barrier is the lack of design for recycling. Some products designs are not taking into account the recycling of the products at their end-of-life. Therefore, this aspect creates challenges for waste handlers and recyclers to further separate materials.

Some other technical problems are caused by the undeveloped technologies for sorting and recycling plastics more efficiently to increase the quality of the recycled plastic. The logistics for collecting materials at the sources are considered crucial for improving recycling rate. Therefore, it is evident that not only the "market needs the technology innovation but the technology innovation needs the market" (Nordic Council of Ministers, 2018).

3.6.2.4 Environmental factor

From the literature, environmental challenges were not clearly stated. Nevertheless, the author believes that high water and energy consumptions (mechanical recycling) as well as usage of chemicals (chemical recycling) could be contributing to environmental impacts but they are not considered as barriers for recycling plastics in this research.

3.6.2.5 Social factor

As the plastic value chain is rather fragmented, this could lead to a lack of communication and coordination among actors. Those are examples of barriers to increase the efficiency of plastics recycling not only in terms of quantity but also in quality.

Poor communication can be justified by the lack of knowledge to sort waste properly (Plastic Recyclers Europe, 2017). In Sweden, it was estimated that 40% of the waste was unsorted or materials were sorted wrongly at recycling centres (IVL, 2017). The value of the material is therefore lost as well as high contamination in the recycled plastics can be created.

Besides, the organization Plastic Recyclers Europe (2017) further pointed out the lack of disclosure of information from manufacturers regarding the degree of recycled materials content in their products which otherwise could be perceived as low quality products.

3.6.2.6 Legislative factor

In Europe, the lack of landfilling bans in some countries can act as a barrier for improving recycling rates (Plastic Recyclers Europe, 2017). Moreover, the lack of standards regarding the plastic packaging material type, quality, design and labelling as well as standards for sorting the type of plastics waste and the reporting plastic flows could also act as a barrier for the efficiency of recycling (World Economic Forum, 2016).

The waste policy and implementation is very diverse among Nordic countries and it is seen in Sweden as a barrier to improve collection and sorting of plastic waste. In fact, countries do not have the same practices and waste streams meaning that waste management companies and plastics producers from other countries have to acknowledge and manage those differences. (McKinnon et al., 2018)

In Sweden, those different practices also occur at the municipal level in which policies implementation differs widely from one municipality to another. There are different methods of collection, waste fractions leading to multiple plastic waste qualities. As a result, there is a lack of criteria standardization for defining waste plastics into different recycled polymers, being an important market barrier. Therefore, the current legislation and the different instructions in Swedish municipalities are not helping producers and waste management companies to improve recycling practices. (McKinnon et al., 2018)

Recycled plastic in the food and packaging industry is regulated for food safety concerns, which may act as a barrier for reusing plastics. The Regulation (EU) No 10/2011 states that the recycled plastic must not be in direct contact with the food. However, in some applications, recycled plastic is allowed only for the centre layer of the multiple laminations in the packaging (having no direct contact with the food). (Kaiser et al., 2017)

The following ***table 3.2*** summarizes the barriers found in the literature by type of factors.

Table 3-2 Barriers of closing the plastics flow loop identified in the literature

Factor type	Barriers
Political	China's ban on import waste
Economic	• Low market demand of recycled plastics • Virgin plastics cheaper than recycled plastics • Oil price volatility – low prices • Lack of end-users interest for products containing recycled materials • Lack of economic incentives for end-users to sort out the waste • High investment costs towards research and development • Expensive sorting • Material value loss due to impurities and mixed content
Social ***(Communication-wise)***	• Lack of communication across value chains • Lack of knowledge among actors • Disclosure of recycled materials in products may create a negative image regarding the quality
Technological	• Complexity in separating mixed materials content and impurities from multi-layered packaging • Quality requirements • Lack of consideration of the end-of-life treatment in the product design
Environmental	• Unidentified
Legislative	• Lack of landfilling bans in some countries in Europe • Unclear criteria standardization of plastic waste • Lack of policy and implementation instructions harmonization among Swedish municipalities and Nordic countries • Food safety regulation for using recycled plastics in food packaging

3.6.3 Opportunities

Despite challenges in closing plastics material loop, there is a large potential for advancing in a circular plastics economy. Vast opportunities are revealed in the literature and many studies mention benefits and solutions for improving recycling and closed-loop systems. Those opportunities are categorized using the PESTEL factors.

3.6.3.1 Political factor

Already mentioned as a barrier, the China's ban on import waste can be considered also as a driver since it obliges Europe to act urgently to handle enormous plastics waste. In this way, new solutions, targets and management strategies need to be implemented.

3.6.3.2 Economic factor

The negative externalities implied with plastics production and littering have been estimated to attain 40 billion US dollars (around 35 billion euros) annually (World Economic Forum, 2016). Therefore, by implementing a better system for handling plastics waste, this significant cost could be avoided while preserving the environment.

Also, a study of Technopolis Group et al. (2016) mentioned that in Europe if the recycling rate for plastic packaging attains 80%, it would save 700 million of euros annually from primary production (estimation based on recycled plastics prices being approximately 10% cheaper than of virgin material).

Furthermore, in Sweden, the material value loss of plastics materials represents nearly 10 billion SEK (960 million euros) annually (Återvinningsindustrierna & Re:Source, n.d) which could be drastically reduced by bringing more circularity into the plastic material flow. The Swedish Environmental Protection Agency [Naturvardsverket] mentioned in its report on the potential for increased material recycling of plastics in Sweden (2018) that the "total recycled plastic raw material is estimated to be up to 300 million Swedish Crowns [nearly 30 million euros] per year based on available data on volumes and prices, suggesting an opportunity for investments to yield significant benefits" (Naturvardsverket, 2018).

According to the World Economic Forum (2016), the growing of stringent regulations and recycling targets as well as the increasing public awareness towards issues related to unsustainable waste management, companies are urgently in need to revise their business models for avoiding economic, legislation and reputation risks. In addition, there is a high economic risk for companies caused by the virgin materials supply fluctuation due to the oil price volatility (European Parliament, 2017a; World Economic Forum, 2016). Therefore, by bringing more secondary materials into their production, companies could prevent from those listed risks.

In 2014, 3% of LDPE was recycled from plastic packaging but it is much more recycled in the construction sector with a rate of 26.5 % (Plastic Recyclers Europe, 2017). It has been estimated that by 2025 with the recycling rate target of 55% for plastics, the penetration rate of LDPE recyclates will be 24.2% for the packaging industry while 75% for the construction industry. Therefore, recycled plastics market exists and will increase by 2025. Compared to the high requirements for recycled materials use in the food packaging industry, the construction sector have lower quality requirements for reusing recycled plastics into their materials composite which explains the high recycling rate estimation (Nordic Council of Ministers, 2018).

In Sweden, Swerec, a plastic recycler, has the capacity to recycle much more plastics and sell the double of what they are currently selling. However, the market demand for recycled plastics remains low even in Sweden, but an increase of this targeted market has been noticed in some European and in US (Miljönytta, 2013).

A report on the plastic waste market in Nordic countries presents the situation of the plastics waste generated and the demand for plastics (including virgin plastics) in Sweden. The following *figure 3.2* shows a large difference between the plastics waste generated compared to the plastics demand on the market. This report is however unclear on the parameters to evaluate the market demand and does not provide details on different plastic types to carry out more comparison for LDPE.

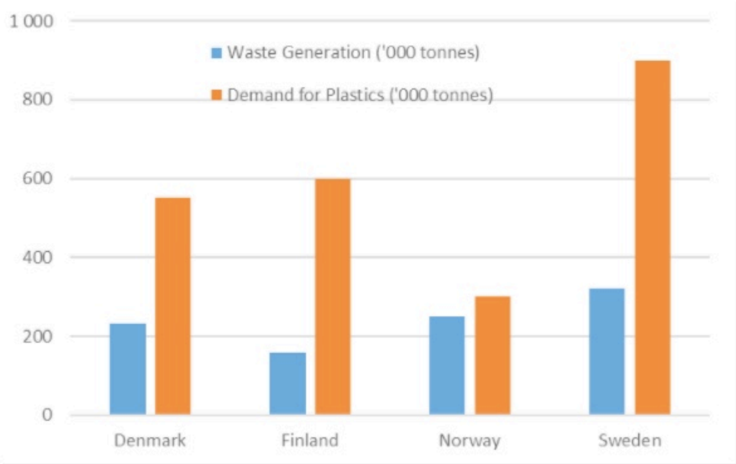

Figure 3-2 Plastic waste generated vs. plastics demand in Nordic countries
Sources: Adapted from the report « Plastic waste markets » by Nordic Council of Ministers (2018) using sources from Eurostat, Plastic Europe 2015

It is clear on this ***figure 3.2*** that the demand is much higher than the plastic waste generated offering large opportunities to cover the demand by improving the recycling of the waste, even though it would not cover the entire demand if all plastics would be recycled.

3.6.3.3 Social factor

The author could not identify social factor as a driver for increasing plastics recycling rate.

3.6.3.4 Technological factor

Several studies found that new technologies have increased the level of purity of the material allowing recycled plastics to have properties that could compete with the virgin plastics but those technologies are still on pilot stage and not yet commercialized.

The studies of Achilias, D. et al. (2007) concluded after experiments of recycling LDPE that the dissolution and re-precipitation technique (mechanical recycling) and the pyrolysis (chemical recycling) succeeded to obtain a high recovery of pure polymer. Furthermore, Kaiser & al. (2017), added "the dissolution–reprecipitation method could be available for the recycling of existing recycling streams in the near future" and "it could be an attractive alternative to incineration or to the production of low-quality recycled materials".

3.6.3.5 Environmental factor

Many studies have pointed out the environmental benefits of recovering plastics materials. The most commons are the opportunity to significantly decrease the release of greenhouse gas emissions into the atmosphere and the reduction of energy consumption from both primary production of plastics and incineration with energy recovery (IVL 2002, 2013; Olofsson, 2014; Återvinningsindustrierna & Re:Source, n.d.). Besides, the increase of plastics recycling will reduce negative externalities generated from littering and consequently, it will avoid plastics leakage into marine and terrestrial ecosystems contributing to biodiversity loss (Technopolis Group et al., 2016).

3.6.3.6 Legislative factor

As previously mentioned, legislations can influence the market demand for recycled plastics. With more landfilling banning, taxes and stricter regulations on producer responsibility as well as higher recycling rates, companies and producers would have to shift towards more circular business models (World Economic Forum, 2016).

The ***table 3.3*** below summarizes the opportunities found in the literature.

Table 3-3 Opportunities of closing the plastics flow loop found in the literature

Factor type	Drivers
Political	• China plastic waste import ban
Economic	• Captured value of resources • Reduced risks of uncertainties regarding virgin supply and oil price volatility • Avoided costs for negative externalities • Recycled plastics higher in the construction sector
Social	• Unidentified
Technological	• New recycling techniques (chemical and mechanical) with high purity of recycled plastic • Dissolution–reprecipitation method could be attractive in the future
Environmental	• Avoided greenhouse gas emissions • Large energy savings • Reduced littering • Less pollution from incineration
Legislative	• Stringent targets and regulations

4 Description of the current LDPE Value Chain

This chapter presents the empirical data collected from interviews combined with information from desk research. The author will describe first the key actors of the LDPE value chain in the case study of this paper. In a second part, the data will be categorized into barriers and drivers in accordance with the PESTEL analytical framework.

4.1 LDPE Value Chain Actors

This section helps reach the research objective 1 and 3. The different actors identified in the LDPE value chain under study will be introduced with companies' overview along with figures representing the production volumes, inflows and outflows of plastics materials and LDPE.

4.1.1 LDPE Suppliers

4.1.1.1 Virgin LDPE: Borealis AB

Borealis AB is the largest supplier of virgin LDPE in Sweden. With its headquarter in Vienna, Austria, it is the second producer of polyethylene in the European market. Borealis, the only producer of PE in Sweden, inaugurated in 2010 a LDPE production plant in Stenungsund (Sweden) with the annual capacity to produce more than **350 000 tons of LDPE** (Chemicals Technology Website, n.d.).

Borealis is the main supplier of LDPE for the Fiskeby AB. Besides, it is assumed that Tetra Pak's LDPE comes from Borealis as well (the interviewees could not confirm it for confidentiality reason).

According to Mr Patrick Laurays, Senior External Communications Manager at Borealis, the group invested in mechanical plastics recycling in two European recycling companies: the German plastics recycler 'MTM plastics' and the recently acquired Austrian plastics recycler called 'Ecoplast Kunststoffrecycling GmbH' (Ecoplast) (I11, personal communication, 2018; Borealis Press Release, August 2018). Ecoplast can process around 35 000 tons of post-consumer waste annually (both households and industrial waste) to recycle high-quality LDPE and HDPE mostly for the plastic film market.

Next year, Ecoplast will be able to increase capacity to process 65 000 tons of waste due to an on-going extension project (I11, personal communication, 2018). MTM is mainly focused on right injection moulding solutions while Ecoplast principally recycles LDPE from household and commercial waste to create a fraction suitable for thin film production (I11, personal communication, 2018).

Borealis works closely with circular economy and encourages industries actors to improve recyclability of plastics packaging materials.

4.1.1.2 Recycled LDPE: Hans Andersson (Veolia)

On the other hand, **Hans Andersson** is one of the suppliers of **recycled LDPE** and mixed plastics containing some small aluminium and paper fractions (called "**PolyCell**") for the company PolyPlank AB. It can also be considered as a recycler but under this specific case study, the author has chosen to define this company under suppliers to differ from other recyclers with different purposes and it is the main supplier of PolyPlank.

Hans Andersson Recycling AB, recently acquired by the Veolia, the world leading environmental management company, is located in Trelloborg in the South of Sweden and in Kiruna in the North of Sweden. It is one of the leading recycling companies in Sweden. With a capacity of handling 750 000 tons of waste including paper, plastics, metals, wood, batteries and hazardous waste, the company is trying to prevent valuable materials from being incinerated or disposed in landfills ("Veolia Recycling Plastics Sweden AB," n.d.). No figures could be found or gathered regarding LDPE fraction in the plastics waste recycled in Sweden.

According to Anna-Lena Elmeklo's news report of Hans Andersson in August 2018, the price for raw LDPE in August went down by 30 euros per ton (which is a common decrease in the summer period). According to the same report, the price of raw LDPE material fluctuates among the year 2018 from an increase of 40 euros/ton in July to a decrease of 30 euros/ton the next month (Elmeklo, 2018).

4.1.2 Primary LDPE converter: Tetra Pak

Tetra Pak in Sweden is the converter using **virgin LDPE** from a confidential supplier; however, the author of this paper assumes that Borealis could be the main supplier of virgin LDPE.

Tetra Pak is one of the largest food packaging company in the world with more than 188 billion packs produced each year (Tetra Laval, 2018), and 78.2 billions of litres of food products delivered in more than 170 countries (Tetra Pak, 2015). The largest company site is located in Lund, Sweden, but the company has three other converting plants in Sweden: Fjällbacka, Sunne, and Skoghall (Tetra Pak, 2015).

Every year, the volume of packaging being produced in Sweden represents approximately 6.4 billions tons (Tetra Pak, 2015). Tetra Pak, in Sweden, uses each year **21 040 tons** of polyethylene for both the packaging caps (HDPE) and the laminating inner LDPE layers of cardboards (Tetra Pak Nordics, 2015). The fraction for the LDPE is unknown. In Europe, 47% of Tetra Pak packaging is recycled (I4, personal communication, July 11th 2018); no official figures for Sweden were found.

Tetra Pak identified three main directions for recycling plastics from their packaging (I4, personal communication, July 11th 2018):

1) **Agglomeration**: a pallet of plastics aluminium composite that can go into material production (i.e.: PolyPlank AB reusing mixed material composite for their products)
2) **Chemical separation:** chemicals can separate plastics and aluminium and separate the two fractions into different materials
3) **Thermal processing:** The product is heated either through a **gasification process** or **pyrolysis** process by using heat and pressure to separate the materials contained in the packaging board.

According to the interviewee of Tetra Pak, the first one is more advantageous at this moment as homogenous composite materials could be applied in different sectors such as in the construction of building, furniture's production, etc. (I4, personal communication, July 11th 2018) without degrading the product's functionality.

4.1.3 Recyclers and Collectors

There are several recyclers of plastics in Sweden; however, some are also collectors who sort plastics materials rather than processing or recycling materials to be ready for reuse.

4.1.3.1 Fiskeby AB

Fiskeby AB located in Norrköping, is a paper mill manufacturing paper and cardboards. In their facilities, the company receives packaging waste (mostly cardboard packaging containing all types of plastics) and recycles the paper from those packaging. The reject from the separation of paper fibres consists of different types of plastics such as LDPE but also contains some aluminium from the liquid cardboard packaging.

According to one of the interviewees from Fiskeby AB, the paper recycled is mostly derived from end-of-use Tetra Pak's packages. Any contaminant or unwanted material is rejected as a combined waste. In this waste, PE is a fraction. The factory has not been designed for separating materials into fractions but instead has been adapted to handle the materials rejected so that they can be recovered into energy. The energy in the PE molecules is partially turned into electricity and the rest provides heating. (I9, personal communication)

The other interviewee from Fiskeby (I2) explained the process of the paper fibres recycling: [packaging waste is received (i.e. juice packaging, etc.) and put into a big drum filled with water being poured slowly. The paper fibres are separated from plastics for making new carton board. The mixed plastics (all kind of plastics but mostly PE and some aluminium) are then separated and being burnt to fuel the energy plant]. (I2, personal communication, July 4th 2018)

The paper mill produces each year **170 000 tons** of boards, from this number **40 000 tons** contain LDPE or HDPE. For being able to produce this amount, a minimum of **190 000 tons** of packaging waste are needed. From this packaging waste, 45 000 tons of mixed plastics and aluminium are separated from the paper fibres. However, 50% of these rejected materials contained water used for the separation process. Therefore, it is assumed that around **22 500 tons** of mixed plastics and aluminium are being rejected for further energy recovery. (I2, personal communication, July 4th 2018). If we refer to Kaiser et al.'s estimations on the fractions of material use in a laminated packaging board (75% paper, 21% LDPE and 4% aluminium), from the total 22 500 tons, LDPE's weight share is about **18 900 tons** and 3600 tons for the aluminium (rough estimations made by the author as residual impurities from paper and remaining water may still be a representative amount remaining in the final "dried" reject).

Furthermore, the latter interviewee mentioned that aluminium is a problem for Fiskeby to be incinerated: [That is a problem for us as we don't really want aluminium in our incinerator] (I2, personal communication, July 4th 2018).

Market studies have been done by Fiskeby experts for evaluating the cost of investment for putting in place the right technology to further separate the rejected materials into fractions. According to Mr Johansson, M. (I9), the cost of **50-60 million SEK** (around 5 to 6 million euros) to invest into a new recycling system (technology is not the big part of this cost) is a [high investment for the company without a very strong sustainable business case]. These economic barriers from this market study will be explained in the next barriers section 4.2.

4.1.3.2 Sysav waste-to-energy plant & Sysav Utveckling AB

In the other hand, the waste management group called **Sysav** owned by 14 municipalities in the region of Skåne [Scania] (I4, personal communication, July 6th 2018) is a company running a waste-to-energy plant and treating waste from the region and licensed to incinerate 630 000 tons of waste per year (Sysav, 2017). **Sysav** produces energy from incinerating waste to generate electricity and district heating. The group also owned subsidiaries such Sysav Utveckling AB, working with research and development for improving waste management, and Sysav Industri AB handling industrial and operational waste. Sysav is responsible for handling, recycling and treating the region's household's waste in the best possible way (Sysav annual report, 2017). The majority of the collection and transportation of the household waste to Sysav facilities are handled by some owner municipalities or their contractors. Sysav has 16 recycling centres in which waste are sorted from households and small businesses (Sysav, 2018).

Sysav in this study is categorized under collectors and recyclers for receiving LDPE plastics film recycling received on their recycling sites (such as bags, film wrapping being recycled by another actor). But Sysav can be outside of the actors' categorization as it receives mixed of non-sorted waste from household to be burned into the waste to energy plant. Mixed household waste may contain multi-layered packaging derived from Tetra Pak (being the type of packaging analysed in this study), therefore, Sysav is deemed to be an interesting actor to investigate the company's barriers and drivers for closing the loop of plastic material flow.

The visit of Sysav Utveckling AB with the representative Ellen Lindblad (project leader for research and development of plastics recycling), helped the author to better understand the recycling capacity and opportunities for plastics.

Beside the waste-to-energy plant, Sysav group also runs the **Sysav Utveckling AB** recycling centre. The centre does not recycle the plastic material collected but instead sort the plastic waste before being sold to other recyclers. In fact, the interviewee Mrs Lindblad Ellen (I4, personal communication, July 6th 2018) confirmed that "*all the packaging is collected within the producers responsibility organisation FTI [förpacknings-och tidningsinsamlingen], and even though some of this collection takes place in Sysav recycling centres we do not own, collect, sort or handle the material in any way ourselves*" (I4, personal communication, July 6th 2018). The interviewee further added: "*wrongly sorted packaging in the household waste (from the waste bin) goes directly to incineration and is not sorted out*". Even though Sysav collects separately non-packaging plastic (called mixed plastic or municipal plastic) and plastic bags in their recycling centres in Malmö, those materials are not recycled by Sysav but instead they are collected to be then sold to other parties (I4, personal communication, July 6th 2018).

In 2017, Sysav handled a total of 841 400 tons of different waste streams in which **408 900 tons** of waste were from households. From the former total amount, 47.4% was recycled, 55.8% was incinerated for energy and 2.8% was sent to landfill (I4, personal communication, July 6th 2018; Sysav annual report, 2017).

4.1.3.3 FTI AB

FTI AB (Förpacknings och tidningsinsamlingen) [Packaging and Newsletter Collection] collects some plastics materials pre-sorted at the Sysav's recycling centres (brought by households) and then sends those materials to other different recyclers to further sort the plastic into purer fractions. It is a recycling company that collects and recycles packaging and newspapers in Sweden. Owned by five material companies: MetallKretsen, Plastkretsen, Pressretur, Returkartong and Swedish Glass recycling, FTI is nevertheless a non-profit company.

Plastkretsen, one of the owners of FTI, believed that the whole Europe was and still is lacking of sorting capacity for plastic packaging (FTI, 2017). Therefore, Plastkretsen is building one of the most modern recycling plants in Motala, Sweden that is expected to be fully operational by 2019 with a sorting capacity for plastic packaging of **120 000 metric tons a year** being roughly the amount of the Swedish household consumption of plastic packaging per year (I10, personal communication, 2018). It will be mostly focusing on plastic packaging recycling in which LDPE will be one of the fractions sorted out in Motala (I10, personal communication, 2018). Furthermore, according to the interviewee I10, "*the facility is designed for reaching 95% of purity in the recycled material*".

According to the FTI Annual Report of the year 2017, once the Motala facility will start operating in 2019, "Sweden will be self-sufficient in terms of its plastic packaging sorting needs for many years to come". Therefore, the collected plastic packaging from households and businesses will no longer be exported to Germany for being sorted, cleaned and granulized (FTI, 2017).

4.1.3.4 Swerec AB

FTI collects plastic packaging waste and then sends the sorted plastics materials to four recycling facilities, one in Sweden called "**Swerec AB**" processing 50% of the collected plastics packaging in Sweden and the rest is sent to three recycling facilities in Germany (FTI AB, n.d). Swerec AB located in Lanna, in Sweden, is the only plant in the country to sort and process plastic packaging from households and prepares LDPE for recovery**.** Every year Swerec received around **50 000 tons of plastics** and about **1 000 tons of LDPE** is sorted and sold each month (or **12 000** a year) and sold mainly to German recyclers to produces recycled LDPE in the form of granules (I7&I8, personal communication, 2018). Swerec recycling facility focuses only on recycling plastic packaging from households having a content of 65-67% recoverable plastic (I7&I8, personal communication, 2018). From the plastics packaging received in Swerec's facilities, 50% are rigid plastics (i.e. HDPE), and the remaining 50% are flexible plastics (LDPE) (Castell-Rüdenhausen et al., 2014).

The plant in Lanna runs a mechanical recycling system in which the sorted plastic materials are washed and grinded into flakes and separated into different types and grades fractions. A remaining of mixed plastics is used for products applications in the construction sector for instance (i.e. manufacturing of floors, fences etc.). (Anderberg & Thisted, 2015)("Recycling plants - FTI AB," n.d.).

One of Swerec's customers is PolyPlank for recycled HDPE only.

4.1.3.5 Stena Recycling

Stena Recycling is another player for plastic recycling in Sweden and receives also household's plastic packaging from the collector FTI AB (and other commercial waste). Some information gathered in the interview was confidential; therefore some figures as well as business information are hidden in the next paragraph.

Stena Recycling group operates in the Nordic countries, Poland, Germany and Italy and recycles different types of waste. In Sweden, Stena Recycling has 90 facilities ("Stena Metall - Recycling," n.d.). The entire group collects [redacted] tons of plastics from industries, retailers and households. The Stena Recycling plastic department for the whole business area is centralized and located in Gothenburg and right now "*the company is investing a lot to take further steps in plastic recycling,* [redacted]" (I6, personal communication, 2018).

Stena Recycling representative interviewee (I6) defines recycling as "*a mechanical process making the plastic material ready for final production in an extruder or a molding machine*". Therefore, the interviewee concluded that Stena Recycling in Sweden does not recycle plastics but instead "*collect, control, pack and sell*" the plastics material. (I6, personal communication, 2018)

The company does not separate LDPE from other types of cardboard packaging, and does not see any value for the business for doing so. Instead, the interviewee said "*this shall be made in an integrated process at a paper/board mill*" (I6, personal communication, 2018)

Also, according to the Stena Recycling interviewee, LDPE has one of the highest recycling rates among plastics, and the remaining LDPE streams are incinerated due to economic, practical and quality factors further explained in the barriers ***section 4.2.***

The author can conclude from this interview that Stena Recycling does not play right now an important role for recycling plastics and LDPE specifically at the moment, but in the future it is worth to include Stena Recycling as a one player for recycling LDPE.

4.1.3.6 Other collectors and recyclers out of the research analysis

It is important to acknowledge other recyclers and collectors part of the LDPE value chain in Sweden. Among those actors, Ragn-Sells, IL Recycling and Sita are collectors who sort plastics waste into different polymer fractions and deliver the sorted LDPE fraction to Swerec and to Plaståtervinning i Wermland (PiW) being another LDPE recycler in Sweden.

4.1.4 Buyer and secondary LDPE material converter: PolyPlank AB

PolyPlank AB is the end buyer of recycled LDPE under this case study. It can also be considered as a converter of recycled LDPE material. PolyPlank AB was founded in 1994, and since 2004, the company started to manufacture products for the real estate sectors ("PolyPlank AB | History," n.d.).

The company has two main products: planks products made out of 100% recycled composite materials such as LDPE and HPDE and organic fibres for the real estate sector; and core plugs made of mixed plastics (without high quality requirements) representing about one third of the sales volume in 2017. The core plugs are used for the paper rolls in the paper and packaging industry such as for Tetra Pak. However, Tetra Pak is not a direct client of PolyPlank. Instead, PolyPlank's core plugs are sold to Stora Enso, a packaging and paper company in Sweden, which are then used for Stora Enso's carton board rolls sold to Tetra Pak. (I1, personal communication, June 20th 2018)

The interviewee of PolyPlank AB, Annika Fernlund, Board Director of PolyPlank AB, is active in finding circular solutions into the company business model. PolyPlank AB has been working ahead of its competitors in terms of circular economy business models, and they have a unique selling point with 100% recycled materials used in their production. Indeed, they have the knowledge and experience with integrating into the core business model material flow circularity.

The recycler Hans Andersson (Veolia) is their main supplier of recycled materials for both LDPE and mixed plastics (being kind of a polluted mix containing mainly low density polyethylene). Every year, they purchased **400 tons** of the mixed polluted plastics called "Polycell" which is cheap (I1, personal communication, June 20th 2018). Regarding the recycled LDPE called "Scandinatene", PolyPlank purchases around **200 tons** of this material every year (depending of the year). LDPE represents 40% of the material used for the planks production, and all materials are 100% recycled. However, PolyPlank AB requires a certain level of purity to purchase recycled LDPE and should be sold in granules (I5, personal communication, 2018).

4.2 Barriers for Closing the Loop

Among the data collected through interviews conducted for this research, several barriers have been identified for closing the loop of LDPE material stream. Some are specific to one particular value chain actor while others are shared among all actors.

The findings are analysed and integrated using the PESTEL framework. Therefore, barriers are categorized in accordance with the PESTEL analysis of political, environmental, social, technological, economic, legislative aspects for closing the loop of plastic material flow in Sweden and sometimes given in a larger context of Europe. However, it is important to note that some of the barriers factors could not be applied in this specific study or were not mentioned by the interviewees.

4.2.1 Political factor

One recurrent political factor was mentioned among four actors of the value chain. Indeed, many times China's ban on plastic waste import was a concern of the supplier Hans Andersson, the recycler Swerec, the buyer PolyPlank and the converter Tetra Pak.

The supplier of PolyPlank, Hans Andersson (Veolia), mentioned in a press release from August 2018: *"it will be harder and harder to allocate a lot of recycled material as a result of China's earlier closure of its imports of plastic waste. Countries like Vietnam, Thailand and Malaysia have also closed all imports during the summer"* (Elmeklo, 2018).

According to another supplier of Polyplank, the recycler Swerec's representatives stated that "*a big challenge was to sell the out sorted LDPE fraction (about 70-75 pureness), after China stopped to allow import of waste, which really hit LDPE", "we were forced to store this material or send to incineration due to overfilled stock*" (I7&I8, personal communication, 2018). The same interviewees shared their opinions on why plastics are largely incinerated in Sweden and said "*China stopped waste stream import. Before this all LDPE was sent to China for recovery. So, this is just temporary solution to incinerate*".

PolyPlank shared similar thoughts as Swerec. PolyPlank's interviewee supposes that China ban on import waste might have forced Sweden to burn the plastics waste until a solution could be found (I1, personal communication, 2018).

For the converter Tetra Pak, the reason why we haven't develop local recycling capacity in Europe is due to the fact that "*we have exported a lot of the plastics waste to China for many years*" and "*now when China has closed their borders, suddenly we have a lot of plastics in Europe and we don't know really what to do with it*"(I5, personal communication, July 11th 2018).

It is important to note that China ban on plastic import has been seen also as an opportunity to improve recycling capacity in Europe and in Sweden in particular. This opportunity will be covered in the drivers' ***section 4.3***.

4.2.2 Economic factor

Economic barriers for recycling LDPE and plastics in general are predominant in this case study. All the actors of the value chain, except FTI AB, identified financial challenges for investing into LDPE recovery.

Three actors mentioned the bankruptcy case of the former plastics recycling plant Miljösäck AB in Norrköping, Sweden. Miljösäck were able to buy sorted LDPE material from Swerec for further recycling washing and processing until the company went bankrupt in the summer 2017 (I7&I8, personal communication, 2018).

PolyPlank AB confirmed that in Sweden the only actor who could wash the LDPE wrapping plastic in the building sector was Miljösäck, and therefore now "*it is burnt or sold to Northern Europe*" (I1, personal communication, June 20th 2018). Fiskeby AB explained that [Miljösäck went bankrupt because of the low demand and it was hard to compete with so much other plastics] (I2, personal communication, July 4th 2018).

According to PolyPlank's representative, another economic barrier mentioned for the building materials collectors is the high cost of transporting collected LDPE wrapping film from the construction sector: [collectors of LDPE film from construction sector could sell it but first they have to collect a large amount of materials to fully fill trucks before exporting the sorted materials all around Europe, but the transport is expensive] (I1, personal communication, June 20th 2018). Stena Recycling representative also confirmed that if LDPE is incinerated today in Sweden, it could be due that it does not worth to transport it (I6, personal communication, 2018).

For Tetra Pak, one of the problems for plastic recycling is in terms of having enough volume and "*to make sure there is a market for it*"; "*that is the big challenge when it comes to plastics*" (I4, personal communication, July 11th 2018). The same Tetra Pak's interviewee added that there is today a weak end-market of recycled plastics in Europe; the reason is due to the export of European plastics waste in China for many years, which prevented Europe to developing local recycling facilities. Regarding the situation here in Sweden, the interviewee believed that the big challenge for Fiskeby to clean up the reject (separating for instance LDPE material into a pure fraction) is to not have an end-market for this type of recycled plastic (I4, personal communication, July 11th 2018).

Stena Recycling's representative gave an approximate cost of 4 million euros (nearly 40 million SEK) to build a recycling line equipment without counting the cost of the facility building, installation etc. (I6, personal communication, 2018).

Fiskeby AB's both representatives agreed on the fact that there is not enough demand for recycled plastics for the company to invest into installing new separation system to clean up the reject. Magnus Johansson, Quality Management Manager at Fiskeby AB, mentioned that after carrying out a market study for recycling the reject materials at the paper mill, the company identified "*small and eager actors but didn't find reliable business cases*", he further added: "*there is no market and thus no pay-back*".

The same Fiskeby's interviewee (I9) gave a range of 50-60 million SEK (around 5 to 6 million euros) for integrating to the existing system, a new recycling equipment and facility (comprising the process changes, new equipment, adaptations to other systems, new buildings, handling and storage facility, water handling, safety arrangements, quality control and logistics). The equipment itself is not the biggest part, and this amount does not count the fixed maintenance costs, the extra work hours in the production, market and sales (I9, personal communication, 2018).

The company representative also stated that there is a huge market for film blowing plastic grades but also a strong competition with other recycled material and virgin plastics, furthermore, "*with a plastic ban arising the virgin plastic market's actors will be even more aggressive*". In another hand, the interviewee said: "*for low quality grades (mixture of plastic and wooden fibre) there are very low market demands and thus very low prices (some get the material for free)*"(I9, personal communication, 2018). The same interviewee affirmed that "*the demands on plastics are sometimes hard to meet by the virgin plastic industry and no one would think of using not fully defined recycled material instead*".

4.2.3 Social factor

PolyPlank AB's interviewee didn't explicitly mentioned social factors affecting the plastics recycling. However, PolyPlank representative mentioned several times some miscommunication aspects regarding the lack of material traceability among partners and actors in the value chain needed for finding solutions towards closing the loop (I1, personal communication, 2018).

4.2.4 Technological factor

Some barriers could be related to technological aspects of recycling plastics. PolyPlank AB explained that the company could not collect and clean LDPE in their facilities, and need middle actors for doing it. One of the PolyPlank's biggest problems in the building sector was that "nobody could wash the LDPE wrapping plastics as the only one who could do that was Miljösäck who went bankrupt" (I1, personal communication, 2018). Another PolyPlank's employee explained that it is hard to reach high purity in recycled LDPE material, and there is a maximum of 3 to 4 times to recycle LDPE to be reused into products, as the quality get affected after several times the same material is recycled (I5, personal communication, 2018). The same interviewee explained that PolyPlank has certain requirements from their supplier. In fact, in order to reuse LDPE into their products, the material should be a recycled and transparent plastic with the correct MFI (Melt Flow Index) and sold in granules.

In the food packaging industry, the risk of contamination is an issue due to impurities present in recycled LDPE. This is why virgin plastics are used at Tetra Pak. Also, even though there is a possible technology in Sweden, which completely disintegrates recycled plastic into molecules for having pure LDPE for instance, this technology is not yet commercialized but instead it is in a pilot scale. (I4, personal communication, July 11th 2018)

For Fiskeby, today the waste reject containing plastic is converted into energy for running the paper mill. It will be hard to beat in another way the high efficiency of thermal energy currently produced thanks to burning the rejected waste from the paper recycling process. Therefore, the possibilities of replacing the plastic with another fuel will need to be addressed by the company. (I9,personal communication, 2018).

Besides, the same interviewee from Fiskeby mentioned that the company is not expert in recycling plastics and there is already a whole industry that already profits from doing it; the following quote from Alfred Nobel was given by the interviewee: "Never try something, someone else already does so much better" (I9, personal communication, 2018).

For Stena recycling, one reason why Sweden incinerates plastic can be due to the fact that this plastic is contaminated or it is a mixed of polyethylene laminated with other materials (I6, personal communication, 2018) which requires the adequate technology to be further separated into pure fractions.

Another recycler, Swerec, confirmed that the pureness of the material is a challenge for selling sorted material. The material received in their facilities is contaminated with all sorts of fluids. Therefore, the buyers would need to wash it themselves or through another actor as they do not wash plastics in the company's sorting facilities (I7&I8, personal communication, 2018).

4.2.5 Environmental factor

No environmental challenges for recycling LDPE have been mentioned among the interviewees.

PolyPlank AB didn't mention a direct barrier regarding environmental aspect but according to the representative's opinion on strict laws about handling waste, some indirect environmental barriers regarding the storage of waste regulation on site is limited due to the fact that some leakage could occur when plastics are stored on a land for a long time which may cause soil and water bodies contaminations through rainwater runoff (I1, personal communication, 2018).

4.2.6 Legal factor

PolyPlank has pointed out some legal barriers in terms of policies interpretation issues. Even though, the EU Commission regulations defined "end-of-waste", in Sweden the definition is stricter and different than other countries such as in Denmark. When a waste becomes another product at its end of life, it should be under another regulation. For instance, in Sweden, it is not allowed to use a waste as a raw material for making another product. That could be a barrier for collectors and producers to define the waste to be able to sell it under a raw material instead of a waste (I1, personal communication, 2018).

Another barrier identified by PolyPlank is the Swedish regulation regarding the limited time of stored material on a land and other strict laws about handling waste materials in Sweden.

For Tetra Pak, today's main challenge is the fact that food-packaging industry is not allowed to use recycled material into the packaging material due to food safety and legal reasons. Besides, Tetra Pak representative believed that from a legislative side, banning and taxing plastics might not be the best solution for advancing plastics recycling but instead we should find other ways to increase the demand for recycled plastics and create incentives to drive the end-market. (I4, personal communication, 2018)

The ***table 4.1*** below provides a summary of the barriers for recycling plastics and LDPE among each actor's categories in the value chain under the case study.

Table 4-1 Summary of the barriers identified in LDPE value chain actors' interviews

Barriers	Suppliers	Buyer – *PolyPlank*	Converter – *Tetra Pak*	Recyclers & Collectors
Political	-China plastics waste import ban and Vietnam, Thailand and Malaysia closed waste import in summer 2018 – *Hans Andersson (Veolia)*	-China ban on plastics waste: temporary solution to incinerate in Sweden	-China import plastics waste ban	-China import plastics waste ban (before the ban, LDPE was sent to China for recovery) – *Swerec*
Economic	-Sometimes difficulties to supply enough recycled materials to clients – *PolyPlank mentioning it for its supplier Hans Andersson (Veolia)*	-Bankruptcy of a plastics recycling plant in Norrköping (the only one who could wash LDPE film wrapping from construction sector) -High transportation cost	-No real end market for recycled plastics	-No real end-market for recycled plastics & no reliable business case – *Fiskeby* -Miljösack's bankruptcy: before buyer of sorted LDPE from Swerec – *Swerec* -Low demand of recycled plastics & hard to compete with virgin plastics – *Fiskeby AB* -Possible high transportation cost– *Stena Recycling* -High investment cost for installing LDPE recycling line – *Sysav, Fiskeby & Stena Recycling*
Social		Miscommunication/lack of material traceability among actors & business partners		
Technological		-Inability to wash, clean and collect the sorted LDPE waste within the company's facilities (middle actors with the expertise and technology are needed) -Depending on the plastic's quality: maximum of 3 to 4 times for the same LDPE material to be recycled into products. -Material requirements: recycled, correct MFI, transparent plastic and in granules	-Current low plastics recycling capacity in Sweden and Europe -Contaminations from impurities present in recycled plastics. -Technology able to completely disintegrate recycled plastics into molecules still not commercialized (pilot scale).	-No expertise in recycling plastics, not core business – *Fiskeby* -Replacing plastics with another fuel as already high thermal energy efficiency by burning current plastics waste– *Fiskeby* -Contaminations & impurities in recycled plastics – *Stena Recycling & Swerec* -No washing technology at the sorting facilities – buyers have to wash themselves contaminated sorted LDPE. – *Swerec*

Environmental		-Indirect barrier caused by stored plastic waste on land: leakage and water bodies' contamination due to rainwater runoff.		
Legislative		-End-of-waste definition interpretation difficulties - "waste" can not be used as raw material in some cases in Sweden -Strict regulations on handling and storing waste in Sweden	-Safety regulations for food compact industry (only virgin plastics used to avoid food contamination risk with recycled plastics) -Banning and taxing plastics may not be the best solution to pushing forward the market demand on recycled plastics	

4.3 Drivers for Closing the Loop

Even though the actors of the LDPE value chain have largely mentioned barriers, some drivers to close the loop of LDPE material flow were also revealed in the empirical data collection. This section helps to answer the research objective 2.

4.3.1 Political factor

Tetra Pak and PolyPlank AB have perceived the former export of plastic waste to China as a cause for low recycling plastics in Europe. However, the recent China ban on plastic waste in January 2018 has also been seen as an incentive to find new solutions to handle the waste in Europe and increase recycling capacity (I1&I4).

4.3.2 Economic factor

FTI AB with the new Motala recycling plant project has identified mainly economic incentives for recycling plastics. The collector drew the conclusion that Europe was lacking of sorting capacity for plastic packaging for many years until today, therefore "*Sweden needs to be self-sufficient when it comes to sorting capacity for plastic packaging*". In fact, the Motala recycling plant will be able to process 120 000 tons of plastics households waste', which represents the total average of Swedish households plastics waste per year. According to the FTI AB representative, the "*LDPE-film is both sortable, treatable and there are buyers for the recycled material*" (I10, personal communication, 2018).

The virgin LPDE supplier in Sweden, Borealis, has invested into mechanical plastics recycling to expand two European companies MTM and Ecoplast. Borealis group has the vision that "*one day we will be able to use plastic waste as just another feedstock*" (I11, personal communication, 2018).

Furthermore, Borealis Chief Executive Alfred Stern said: "*Borealis recognises the increasing need for plastic recycling and sees the Circular Economy as a business opportunity*"(Borealis Media Release, August 2018).

According to Borealis group's interviewee, "*there is a recognizable growth in demand for recyclates in Europe not only in terms of quantities, but as well regarding the variety of possible product application*s". Furthermore, the same person added: "*Sweden has its own plastics recycling industry and shows significant demand increase as well*". (I11, personal communication, 2018)

For PolyPlank AB, material circularity is an important driver for the business's competitive edge. The company believes to be a front-runner with their products made of 100% recycled materials and uses this unique selling point to differ from their competitors. (I1, personal communication, 2018)

4.3.3 Social factor

In the interview data collection and desk research in companies' websites, the author could not collate the social factors as drivers for closing the loop of LDPE material flow.

4.3.4 Technological factor

Among the drivers for closing the material loop, three actors (recycler, converter and supplier) stated technological aspects in the interviews.

The recycler Swerec's representative believes that recycled plastics market will grow in Sweden as [technical development will provide more sophisticated applications that will increase the pureness which will increase the demand] (I7&I8, personal communication, 2018).

Regarding the converter Tetra Pak's opinions, the technology for increasing the purity of recycled plastics material exists and there are many possibilities to recycle plastics materials. Even for low level of mixed plastics grades, applications are several in sectors such as in the construction sector and furniture's production. (I4, personal communication, 2018)

The Borealis group's Chief Executive Alfred Stern stated "*the company puts a lot of efforts in Research and Development into improving mechanical recycling and exploring other recycling technologies*" (Borealis Media Release, August 2018).

4.3.5 Environmental factor

PolyPlank AB's main interest is to take care of the environment. The representative (I1) acknowledged that if the company could reuse the post-consumer households waste, then it would have greater impact on the environment. In this way, plastics leakage in the nature could be avoided, knowing that it is mostly caused by households' waste and not industrial waste. If the company is able to reuse 100% recycled plastics from post-consumer households waste and promotes this effort, it will have a better impact for the company. (I1, personal communication, 2018)

In another hand, Borealis Chief Executive stated that: *"Ecoplast will help us address critical sustainability challenges"* (Borealis media release, August 2018).

4.3.6 Legal factor

According to PolyPlank, using 100% recycled plastics in their production will reduce the risk of future stringent regulations on plastics waste (I1, personal communication, 2018). Beside PolyPlank mentioning the future risk of stringent regulations for plastics converter industry, no other legislative drivers have been identified among the actors. The ***table 4.2*** below summarizes the drivers per categories of the LDPE value chain actors.

Table 4-2 Summary of the drivers identified in LDPE value chain actors' interviews

Drivers	Suppliers	Buyer	Converter	Recyclers/Collectors
Political		-China plastics waste import ban as an incentive to find new solutions and increase recycling capacity in Europe	-China plastics waste import ban as an incentive to find new solutions and increase recycling capacity in Europe	
Economic	-Large extension of plastics recycling facilities – *Borealis group* -Increasing need and demand for plastic recycling in Europe and in Sweden and Circular Economy as a business opportunity – *Borealis group* -Growth in demand in terms of product applications variety– *Borealis group*	-Material circularity as a business's competitive edge -Unique selling point to differ from competitors	-Homogenous composite materials could be applied in different production sectors such as in construction and furnitures manufacturing	-Sweden was lacking of recycling capacity facilities for many years: new Motala recycling plant project will help Sweden to be self-sufficient. – *FTI AB* -There are buyers for the LDPE recycled material – *FTI AB*
Social				
Technological	-Research and development investment into new recycling technologies – *Borealis group*		-Many possibilities of recycling exist, as well as many applications for low grades mixed plastics.	Technology development will provide more sophisticated applications and increase level of purity - *Swerec*
Environmental	-Ecoplast recycling plant could help address sustainability challenges – *Borealis group*	-Reusing plastics waste from households: plastic leakage avoided and better impact on the environment.		
Legislative		-Reducing risk of future stringent regulations		-Reaching the increased recycling targets in Sweden – FTI AB (Motala sorting plant)

5 Findings and Discussion

In this chapter, the author will first present the findings on the current system of the LDPE value chain under study and the different waste streams in order to understand the LDPE material flow in a larger context.

Figures and flowcharts will be provided in order to illustrate the Swedish current situation of: 1) the LDPE flow from plastics packaging waste streams; 2) the LDPE flow from the laminated cardboard packaging of Tetra Pak and 3) the LDPE flow from PolyPlank products (including the LDPE contained in the "mixed plastics/materials" use for the core plugs).

In a second part, a simplified LDPE material flow analysis will be presented along with the identifications of the areas in which the material can be reused. Barriers and drivers will be analysed and compared across both the literature and the interviews. Then, solutions are proposed to overcome the main barriers under the case study. And finally, the author will discuss and reflect on the methods chosen for this research.

5.1 Analysis of the LDPE Actors' Roles into Visual Mapping

This section gives a clearer picture of the LDPE flows examined in this paper. The results are used for mapping the actors, their interconnections and the LDPE's lifecycle.

The sub-research question 1: *"Who are the relevant value chain actors around LDPE material flows stemming from Tetra Pak?"* is addressed in this section. However, the players in the LDPE value chain of the plastics packaging streams in Southern Sweden are also explored to provide a larger range of opportunities to reuse plastics. The key actors of the LDPE value chain derived from Tetra Pak packaging will be finally identified.

5.1.1 Mapping the actors of the LDPE value chain in Southern Sweden

The following map is illustrating the different actors in the LDPE value chain in Sweden. However, it is important to note that many uncertainties still persist and the author had difficulties to gather information from the origins of the LDPE in some cases. The author was unable to find some information regarding the relationship among the actors and in some cases the origins of the LDPE were confidential.

Nevertheless, the author tried according to her current knowledge and assumptions to map and connect the actors in the LDPE material flows from both the plastic packaging streams and from the LDPE laminated cardboard packaging (case study of Tetra Pak packaging waste and the reusing of recycled plastics in the products of PolyPlank).

The author recommends further investigation among the actors to confirm the following chart flow *figure 5.1*. This map may be even modified after the future plastics recycling plant project in Motala, which may become a key supplier of recycled plastics material, such as LDPE in Sweden. However, in this specific case study research, the Motala plant does not play a role in recycling cardboard packaging to separate into pure fraction the laminated LDPE film protection in the cardboard packaging (I10, personal communication, 2018).

In the following actors map, the blue arrows represent the LDPE derived from Tetra Pak's packaging waste stream while the purple arrows indicate the flows of LDPE from households plastic packaging waste stream.

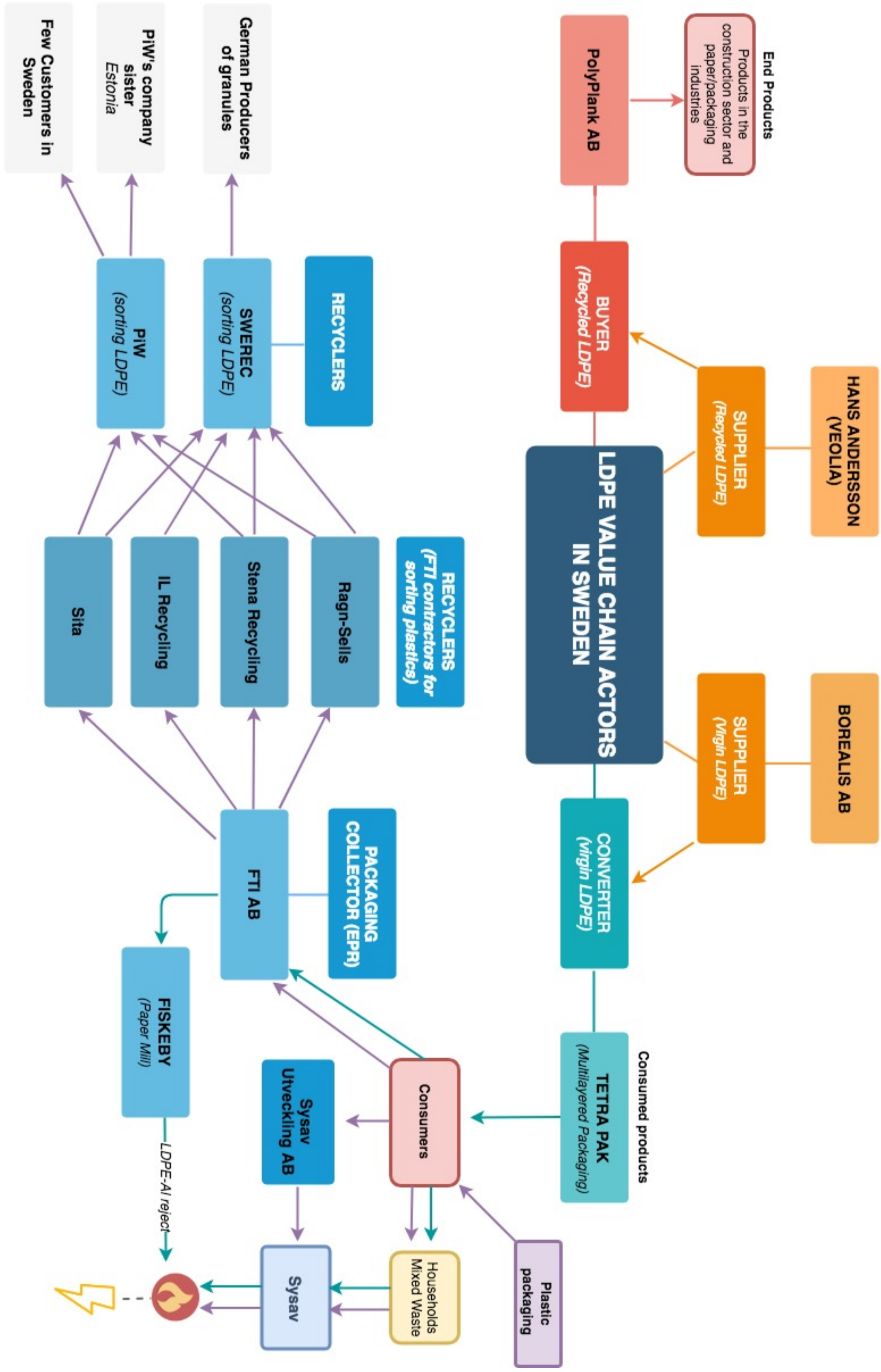

Figure 5-1 LDPE value chain players in Southern Sweden
Source: Own source based on desk research, interviews and author's assumptions

5.1.2 Understanding the LDPE's lifecycle in a larger context

Tetra Pak's packaging discarded products from households represent the main waste stream analysed in this research. Nevertheless, the author chose to extend the research to other possibilities of LDPE recycling from plastics packaging streams to better understanding the current LDPE flow in a larger context. Also, due to the lack of information and figures regarding LDPE laminated cardboard packaging disposal and recycling rate, the author used along the research plastic packaging consumption and recycling rate figures as a guideline for giving an overview of the LDPE recycling situation in Europe and in Sweden. Therefore, the author judges to be relevant to provide information about the LDPE derived from plastics packaging waste in order to better contextualize the specific case study of the LDPE derived from Tetra Pak cardboard packaging.

Before going into detailed of the case study's LDPE flow, the following ***figure 5.2*** below depicts the different stages and categories of actors in the entire LDPE value chain in Sweden from all plastics streams.

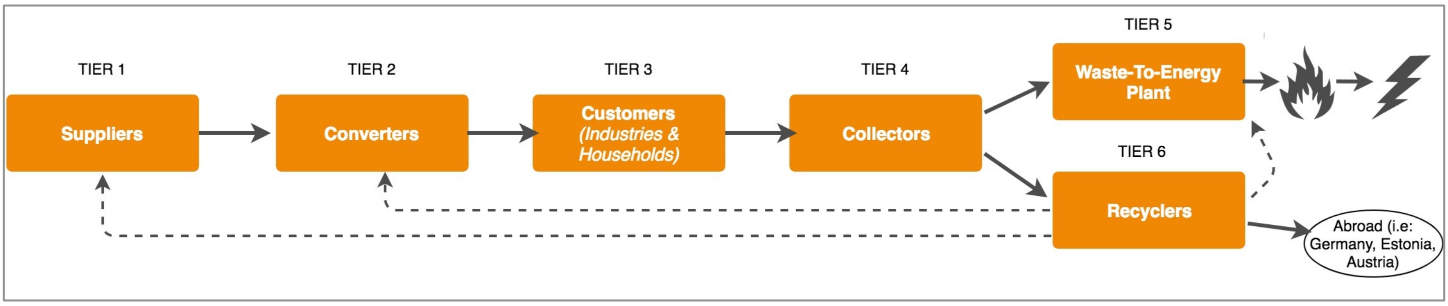

Figure 5-2 LDPE flow from all type of plastics waste streams in Sweden
Source: Own illustration based on the author's analysis

In this ***figure 5.2***, the suppliers provide virgin or recycled LDPE to converters who use the LDPE material to manufacture products for households or industries' business purposes. At their end of life, those products are then disposed and collected by different companies hired by the municipality and sent either to waste-to-energy plants or to recyclers (in Sweden or abroad). The author assumes that some recyclers (who offer material sorting services rather than more complex recycling processes) provide sorted LDPE material to some suppliers (in the form of baled plastics for further recycling process of LDPE material) or in some cases, directly sell recycled LDPE in the form of granulates to converters. The author could not confirm if in Sweden that was the case, as one of the suppliers didn't provide information regarding the origins of their LDPE materials. Therefore, in this ***figure 5.2*** the two arrows coming from recyclers to converters and to suppliers could be confirmed by further research in the future.

The author also believes that other European recyclers sell the recycled LDPE (in the form of pellets and granules) to Swedish suppliers and converters. For instance, Ecoplast in Austria (recently acquired by Borealis) could be one recycled LDPE supplier in Europe including Sweden. Besides, the Swerec's representative confirmed that the sorted baled LDPE is sold to German producers of LDPE granules (I7&I8, personal communication, 2018), but the Austrian recycling plant Ecoplast wasn't mentioned.

In the same ***figure 5.2*** above, the arrow coming from the recyclers to the waste-to-energy plant represents the undesired and non-recyclable plastics materials being sent for incineration. For instance, around 15-20% of the plastics material waste received at Swerec is sent to energy recovery due to low recyclability (Anderberg & Thisted, 2015). Same as Swerec, PiW sends the incorrect sorted plastic type to energy recovery as well as the recycling process's reject representing 10-20% of the plastics waste collected (Anderberg & Thisted, 2015).

5.1.3 Flowchart of LDPE from Tetra Pak packaging

For this research, Borealis AB is assumed to be the virgin LDPE supplier for Tetra Pak. Tetra Pak is the converter of this LDPE for laminating the cardboard of the company's food and beverages packaging. At the consumer stage, Tetra Pak's products are either disposed in the mixed waste (non-sorted), or properly sorted in the cardboard packaging waste bin. Förpacknings-och Tidningsinsamlingen AB (FTI AB) responsible for organising collection and recycling of the different packaging materials will deliver the cardboard packaging (from Tetra Pak) to the paper mill "Fiskeby AB". In their facilities, Fiskeby AB recycles paper in which other materials contained in the packaging are rejected such as LDPE and aluminium being currently burnt for providing energy to the paper mill. The burning stage of the rejected LDPE-Al is the critical area of this study as it ends the circularity of the LDPE material loop. The mixed household waste is collected by contractors (i.e. Ragn Sells) hired by the municipality or by the intermediary of FTI AB, and it is sent to Sysav to be converted into energy through incineration.

The following ***figure 5.3*** summarizes the current situation explained above:

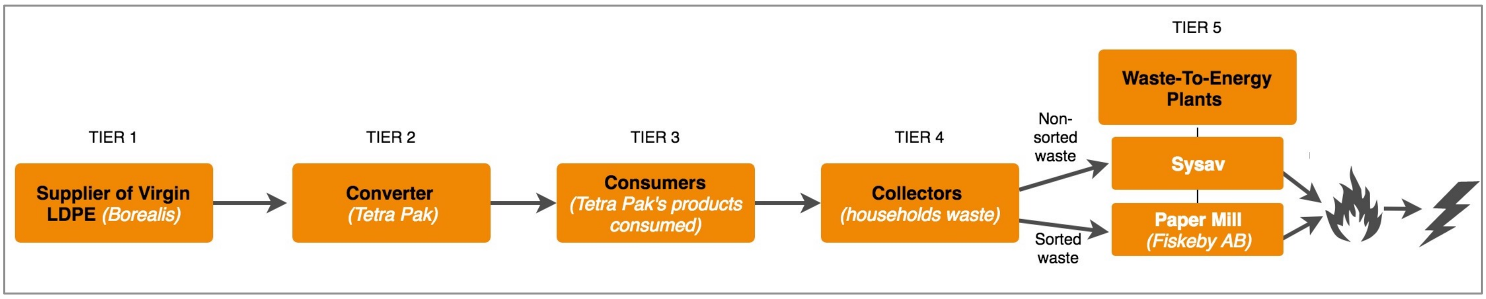

Figure 5-3 Flow of the LDPE from Tetra Pak Packaging in Sweden
Source: Own illustration based on the author's analysis and assumptions

5.1.4 LDPE flow from PolyPlank products

PolyPlank AB's main supplier for recycled LDPE and for mixed plastics "Polycell" is Hans Andersson (Veolia).

PolyPlank AB manufactures two types of products using LDPE and mixed plastics. One product category is the planks sold to the construction sector (containing both LDPE and HDPE); and the core plugs represent the second product category (mixed plastics used in their production process) being sold to packaging and paper industries (i.e. Stora Enso selling the paper rolls containing core plugs to Tetra Pak).

The LDPE, used for the planks' material composite, ends up in fences, housing structures, and other applications, from which LDPE contained in the construction material is then disposed or reused at the demolition of such materials or buildings.

On the other hand, for some cases, the core plugs are sent back to PolyPlank. However, the core plugs' end of life is unknown (they are sent all around the world in the paper and packaging industries). Due to miscommunication or lack of material traceability among partners, PolyPlank AB does not know who are responsible for sending back those core plugs to the manufacturer (back to PolyPlank) (I1, personal communication, 2018). Regarding the LDPE contained in the planks composite for the construction sector (40%), it is assumed that it ends up as an industrial waste to be either recycled at a recycling facility (therefore, the recycled LDPE could be returned to the supplier of this chain) or it is sent to landfill, or incinerated (which is the most probable case in Sweden according to the author's current understanding).

The following ***figure 5.4*** depicts the flow of the LDPE and mixed plastics used into the PolyPlank's production:

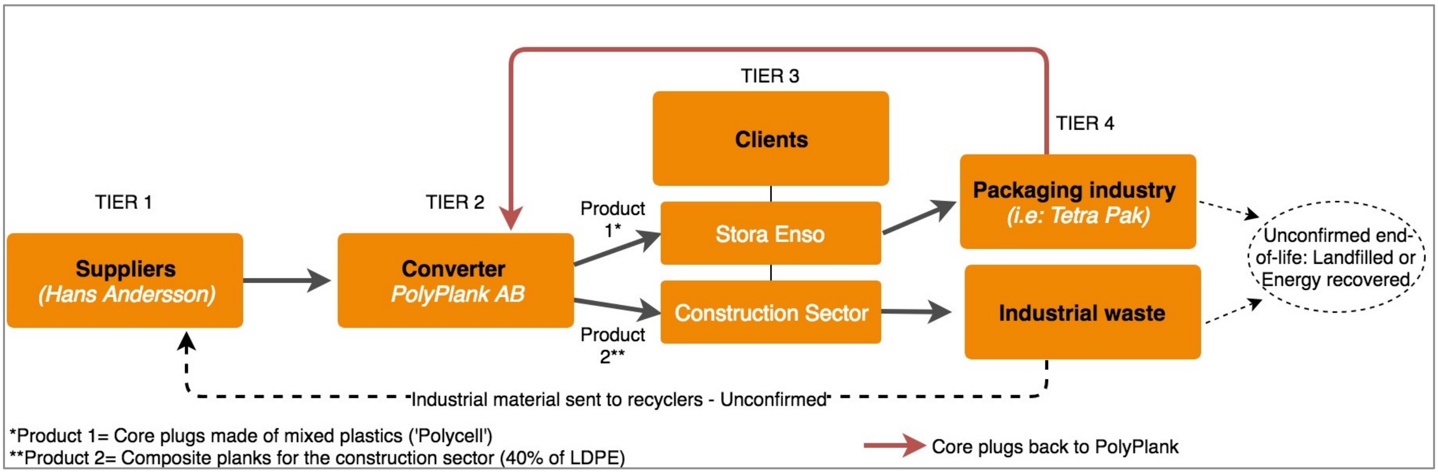

Figure 5-4 Flow of LDPE and "mixed plastics" from PolyPlank's products
Source: Own illustration based on the author's analysis and assumptions

5.1.5 Quasi-linear LDPE material flow system under the case study (Tetra Pak & PolyPlank AB)

From those previous illustrations representing the situation of the LDPE from different perspectives, the following ***figure 5.5*** attempts to summarize through a chart flow the core problem that this paper is addressing. It shows the current LDPE material flow among the actors including the LDPE contained in the core plugs (produced by PolyPlank and used by Tetra Pak) but also the LDPE derived from Tetra Pak's packaging.

However, it important to remember that this paper looks at the LDPE from the Tetra Pak's post-consumer packaging that can be reused into the production of PolyPlank's core plugs and composite planks.

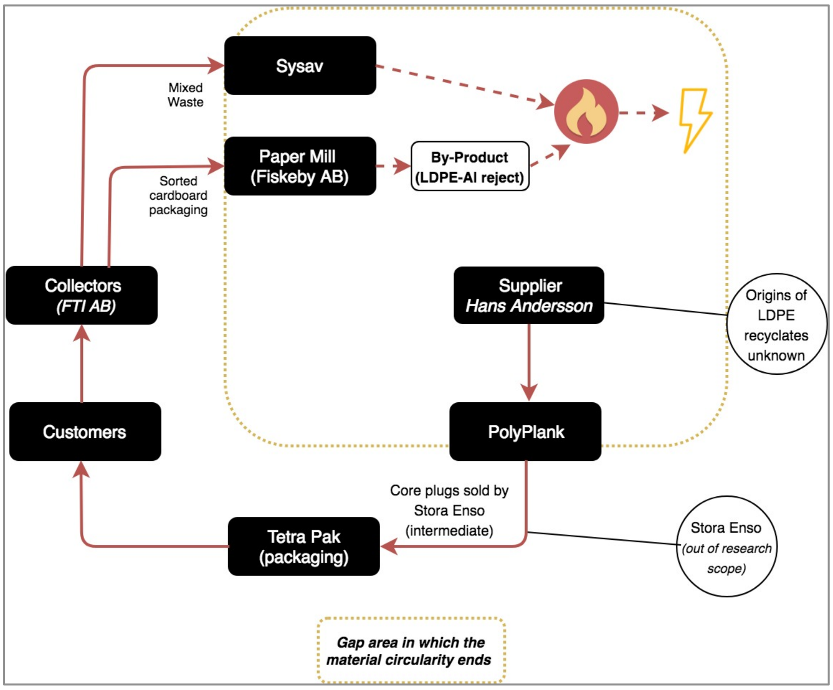

Figure 5-5 Tetra Pak and PolyPlank AB case study: Current situation of the LDPE flow
Source: Own illustration based on the author's analysis

As this illustration clearly shows, the main problem of this case study is the evident circularity gap occurring at the end-of-life of the cardboard packaging products from Tetra Pak. The gap area surrounded by the yellow dotted line shows the problem by itself caused by the burning of the LDPE material. As a result, the material loop cannot be closed, because the LDPE material derived from the post consumer packaging waste is not reused into PolyPlank's production of core plugs and composite planks. Scenarios with solutions for closing the loop will be presented in the ***sub-chapter 5.4***.

This illustration can answer the sub-research question 1: *"**Who are the relevant value chain actors around LDPE material flows stemming from Tetra Pak?**"*.

It clearly indicates that the most relevant actors of the LDPE value chain under the case study are obviously PolyPlank, Tetra Pak, Fiskeby AB, the collectors such as FTI AB and Sysav.

Customers are part of the stakeholders that can also influence the recycling rate by better sorting waste. Stora Enso being an intermediate for selling the paper rolls containing PolyPlank's core plugs to Tetra Pak is judged by the author to be out of the scope and irrelevant for this research.

Hans Andersson being the supplier of PolyPlank for recycled plastics may play an important role in this study, as they may be able to have the adequate technology to recycle the LDPE into granules. If it was the case, Hans Andersson could have received the rejected mixed plastics and aluminium from Fiskeby to be able to close the loop. However, the author is unable to confirm this assumption, as the company was unavailable for providing information to this research.

The next ***figure 5.6*** provides a more detailed understanding of all the players of the plastics waste streams containing LDPE material in Southern Sweden. The scope of the Tetra Pak & PolyPlank case study is delimited by a dotted line.

5.2 Plastic and LDPE Material Flow Analysis in the value chain under study

The author judged relevant to gather in parallel some quantitative data regarding the LDPE input and output among the actors to identify the possibilities of recycling and reusing LDPE from the material waste streams. However, the author had to extend the scope of the LDPE material to including as well the "mixed plastics" used for the PolyPlank core plugs. Some numeric data about LDPE flow and plastics were given for giving a rough representation. The needed figures for carrying out a more detailed and accurate MFA were either unknown by the interviewees or could not be disclosed. Therefore, the author presents more a mapping of material flows as an illustration of approximate volumes and directions of flows.

Visualizing LDPE and other type of plastic materials circulating in the value chain through this below chart flow helps identify potentiality of reusing certain type of plastics for future applications into PolyPlank's production. Also, this material flow analysis attempts to answer the sub-research question 3: ***"What is the current LDPE material flow within the system under study?"***.

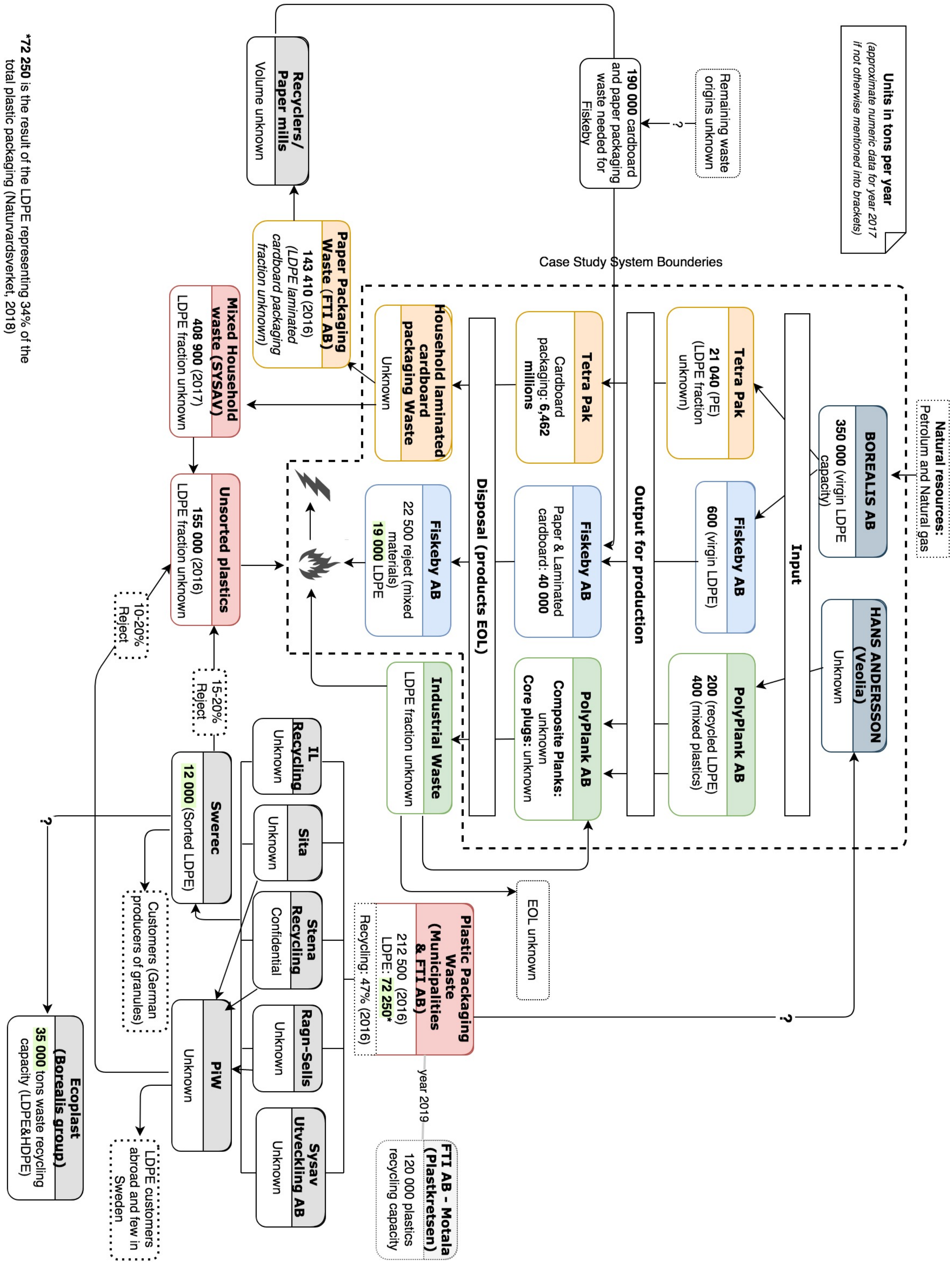

Figure 5-6 Simplified LDPE Material Flow Analysis in Sweden – Case study
Source: From primary and secondary data collected for this research and own calculations

5.2.1 Identification of possibilities to reuse LDPE and rejected mixed materials *(mixed plastics and aluminium)*

As we can see from the previous ***figure 5.6,*** the amount of LDPE rejected from the paper mill "Fiskeby AB" could possibly cover the need of PolyPlank's LDPE and mixed plastics volume for the planks and core plugs production. The total paper mill's reject is around **22 500 tons/year**, and contains approximately the same material composite types of the "mixed plastics" used for the core plugs production of PolyPlank with a purchasing volume of **600 tons/year**.

On the another hand, if we go further in the separation into pure material fractions, the LDPE reject could represent around **19 000 tons/yea**r (rough estimation from this Fiskeby's mixed reject) while PolyPlank purchases nearly **200 tons/year** of recycled LDPE. However, in order for Fiskeby to have a lucrative return on their recycling technology investment, more customers of recycled LDPE must be identified. Also, the aluminium being a valuable material could be an interesting material to re-sell on the market, and it could also solve the problem mentioned by one of the interviewee of Fiskeby stating that aluminium was not desired in their incineration plant (I2, personal communication, July 4th 2018).

Therefore, this section helps identify areas 1) in which the rejected LDPE from the Fiskeby's paper mill can be recycled; and 2) where LDPE from the plastic packaging waste streams can be reused. Therefore, the main research question: *"What possibilities exist to closing the loop of LDPE material flow through reusing the post consumer LDPE derived from Tetra Pak's packaging into PolyPlank's production processes?"* is being addressed in this section.

In the material LDPE chart flow analysis (***figure 5.6)***, the green highlighted numbers point out the large potential to reuse LDPE reject, sorted waste or recycled plastic waste. The following areas of different streams are the ones identified by the author where possibilities exit to improve closing the loop of LDPE material flow within Southern Sweden.

5.2.1.1 From Tetra Pak's cardboard packaging stream

5.2.1.1.1 Area 1: Fiskeby AB

LDPE reject from the paper recycling process at Fiskeby AB will be the ideal recycling case for this research. It will not only cover the demand of recycled materials for PolyPlank's production of the composite planks (LDPE), and the core plugs (mixed plastics including small aluminium material content) but also it will create the strongest LDPE material circular flow system identified in this research. The plastic materials and aluminium coming from Tetra Pak's packaging will end up in the production of the core plugs parts of the paper rolls used by Tetra Pak.

For the case of the pure LDPE fraction used for the composite planks, it will also offer more circularity in the material flow coming from cardboard packaging households waste being one of the priority for PolyPlank in order to reduce environmental impacts but also to promote their efforts to their clients in reusing 100 % materials from household waste (I1, personal communication, June 20th 2018).

5.2.1.1.2 Area 2: Hans Andersson

Fiskeby's paper and cardboard packaging recycling reject could be sent to Hans Andersson for further drying, washing, grinding and granulation in the case the latter company has the technology for doing so. This should be confirmed in future research.

5.2.1.2 From plastic packaging waste stream

5.2.1.2.1 Area 3: Plastic packaging waste from household

Plastic packaging waste from household contains mostly LDPE, the rough estimation of 72 250 tons per year made by the author based on the most recent study in 2017 which found out that LDPE represented 34% of the total plastic packaging waste (Naturvardsverket, 2018). This 72 250 tons of LDPE present in the plastic packaging could be recycled and reused in several applications and may cover the demand of recycled LDPE in Sweden.

5.2.1.2.2 Area 4: Swerec

From this amount of plastic packaging household waste, Swerec sorts every year around 12 000 tons of LDPE which can be sent to other recyclers processing the sorted LDPE to get the right properties to be re-sold to converters. The recent Borealis group's recycling plant acquisition "Ecoplast" with a current recycling capacity of 35 000 tons (both LDPE & HDPE) may be one recycler that can be considered (even though it is outside of the Swedish frontiers).

5.2.1.2.3 Area 5: Future plastics recycling plant in Motala

Another possibility to reuse LDPE from plastic packaging exists in the on-going plastics sorting facility project in Motala, Sweden with a capacity to receive 120 000 households plastic packaging waste per year (I10, personal communication, 2018). However, it will reduce the plastic waste volume received by Swerec by 75% (I7&I8, personal communication, 2018). The new sorting facility plant will be able to sort out LDPE as a fraction. The FTI's new plant is designed to reach 95% purity in the recycled material (I10, personal communication, 2018). However, the author was not able to confirm if the LDPE will be cleaned, and granulised. If it is the case, PolyPlank could reuse the recycled LDPE in the form of granules, otherwise, another actor will be needed for further processing the sorted baled LDPE.

5.2.1.2.4 Area 6: Unidentified middle actors to wash and granulize

If the FTI new plant will not be able to wash and granulize LDPE, more actors in Sweden are and will be needed for further processing the material. In this way, it will prevent the sorted material to be sent outside of the country or into incinerators.

After identifying the areas where LDPE can be recycled, the next section will analyse and discuss the main barriers and drivers of the value chain actors for recycling LDPE.

5.3 Analysis of the Barriers and Drivers

In this sub-chapter, the author will compare, classify and discuss the barriers and drivers from the literature background and the actors' interviews.

First, findings from both literature review and the empirical data collection have been classified into the taxonomy of barriers and drivers used for the analytical framework of this study.

The taxonomy is categorized into three sections. The 'Confirmed' section reveals the findings from the interviewees confirming the ones found in the literature. The section 'Not Confirmed' lists the findings, which have been identified in the literature, but not confirmed in the interviews. Finally the 'Additionally Identified' shows the findings identified in the empirical data but not identified in the existing literature background.

In this section the sub-research question 2: "***What are the potential barriers and drivers for each actor to create a closed loop system of LDPE?***" is addressed.

The author highlighted in yellow the most significant barriers and drivers found both in the literature and in the empirical data that could respectively prevent or encourage actors to close the loop of the LDPE material derived from Tetra Pak's packaging waste stream.

5.3.1 Barriers from literature background and empirical data

The following ***table 5.1*** provides a comparison of the barriers found in the empirical data with the ones indicated in the literature review.

Table 5-1 Barriers comparison - existing literature background and the empirical data

Barriers	"Confirmed" (Literature & Empirical Data)	"Not confirmed" by empirical data	"Additional Identified" (information from empirical data but not in literature)
Political			-China import plastics waste ban
Economic	-Low market demand of recycled plastics -Virgin plastics cheaper -Lack of economic incentives for end-users to sort out the waste - Material value loss due to impurities and mixed content - High investment costs	-Oil prices volatility	-High cost of transportation -No reliable business case
Social (communication-wise)	- Lack of communication across value chains	-Disclosure of recycled materials in products may create a negative image regarding the quality -Lack of knowledge among actors	-Lack of material traceability among actors & business partners
Technological	-Complexity in separating mixed materials content and impurities from multi-layered packaging. -Quality requirements	-Lack of consideration of the end-of-life treatment in the product design	-Contaminations from impurities present in recycled plastics. -Current low plastics recycling capacity in Sweden -Technology able to completely disintegrate recycled plastics into molecules still not commercialized (pilot scale). -No washing technology at

			the sorting facilities. -Maximum of 3 to 4 times for the same LDPE material to be recycled and re-used into products. -Paper mill with no expertise in recycling plastics, not core business. -Finding a waste (fuel) substitute with similar high energy content (for waste-to-energy plants)
Environmental			-Indirect barrier caused by stored plastic waste on land: leakage and water bodies' contamination due to rainwater runoff.
Legislative	-Unclear criteria standardization of plastic waste -Diverse policies and implementations among municipalities and Nordic countries -Safety regulation for using recycled plastics in food packaging	-Lack of landfilling bans in some countries in Europe	-Banning and taxing plastics may not be the best solution to pushing forward the market demand on recycled plastics -Strict regulations on handling and storing waste in Sweden -"Waste" can not be use as raw material in some cases in Sweden - -End-of-waste definition interpretation difficulties

5.3.1.1 Discussion on barriers

Few barriers are contradicting each other, such as the political aspect of the China's import ban of plastic waste, which could be seen from two perspectives. It could either be a barrier in the past due to the lack of recycling facilities development in Europe since countries were dependent on China to receive their waste and didn't build plastics recycling facilities. China's import ban could be also perceived as an opportunity for the future to push forward countries to find solutions to handle the plastic waste by developing new plastics recycling plants and therefore, increase the recycling rate.

Also, contradictions appear in the diverse opinions (from actors and literature) on the recycled plastic demand situation. Most of the actors and the literature stated that the recycled plastics demand is low. However, Borealis group as well as other recyclers in Sweden mentioned that there is a growing demand of recycled LDPE in Europe. Borealis group even invested several millions of euros in the extension of two plastics recycling facilities in Germany (recycling LDPE to produce recycled LDPE in the form of granules and pellets) and in Austria. This high investment into recycling LDPE of a big group such as Borealis (being the main producer of polyethylene in Sweden) shows that the company is strongly convinced in the future growth of recycled LDPE demand in Europe.

Also, there are no clear barriers being mentioned in the empirical data regarding environmental issues with recycling techniques, however, among scientific literature, water and energy consumption were mentioned along with chemicals added in the chemical recycling method. Therefore, the author assumes that recycling LDPE may cause environmental impacts due to high-energy consumption as well as chemicals that could contaminate water bodies if not well handled. Nevertheless, recycling plastics environmental benefits are believed to outweigh those environmental impacts.

One interesting barrier that the author found out to be feasible to overcome is the lack of communication among partners. Even though it may be due to a confidentiality matter, business partners should be able to inform their recycled LDPE demand and supply volumes as well as informing market researchers in order to properly evaluate the recycled LDPE market in Sweden. The author believes that before finding solutions for closing the loop, not only improving the traceability of the LDPE flows within companies' activities is primordial but also sharing regularly the LDPE material volumes used, sold, disposed or needed within the production should be prioritized among the partners of the LDPE value chain of this study.

Finally, another reflection is about the challenge for recyclers to find a business case and remaining competitive in selling recycled plastics, as it is difficult to compete against the low prices of virgin plastics. It is assumed by the author to be due to the economies of scale obtained by large producer of polyethylene (Borealis AB in Sweden).

5.3.2 Drivers from literature background and empirical data

The drivers found in the interviews and in the literature are compared in this next ***table 5.2***.

Table 5-2 Drivers comparison - existing literature background and the empirical data

Drivers	"Confirmed" (Literature & Empirical Data)	"Not confirmed" by empirical data	"Additional information" from empirical data (but not in literature)
Political	-China plastic waste import ban encouraging European countries to improve development of new recycling facilities		
Economic	-Recycled plastics higher in the construction sector -Growth in demand of recycled plastics in diverse applications	-Avoided costs for negative externalities -Captured value of resources -Reduced risks of uncertainties regarding virgin plastics supply and oil price volatility	-Increasing need and demand for plastic recycling in Europe and in Sweden -Circular Economy as a business opportunity -Large extension of LDPE and plastics recycling facilities in Germany and Austria. -New and modern Motala recycling plant project will help Sweden to be self-sufficient. -Material circularity as a business's competitive edge
Social	*Unidentified*		
Technological	-Technology development increases level of purity	-Dissolution and reprecipitation methods	-Research and development investment into new recycling technologies

		could be attractive in the future	-Large possibilities of recycling, as well as many applications for low grades mixed plastics
Environmental	-Plastic leakage avoided and better impact on the environment	-Less pollution from incineration -Avoided greenhouse gas emissions -Large energy savings	
Legislative	-Risk avoidance of stringent targets and regulations		-Reaching increased recycling targets in Sweden

5.3.2.1 Discussion on drivers

Besides the benefits of reducing environmental impacts from plastic leakage or incineration, the actors mentioned drivers concerning the increasing demand of recycled materials in Europe and in Sweden (for the case of Borealis AB). Also, many actors believed in the large varieties of recycled material applications even with a low degree of purity. In fact, the construction sector is one identified area in which recycled LDPE or mixed plastics could be applied.

Buyers and sellers of recycled LDPE also believed that having material circularity in their core business provides a strong competitive advantage in the market. Furthermore, it allows actors to better anticipate future stringent regulations and targets. In fact, the recent EU single-use plastics rule to reduce marine litter demonstrates the stricter regulations trend on banning plastics (European Commission, 2018b). The recycling target for packaging waste of 75% by 2030 recently revised by the EU commission is another example that shows the direction of future legislations on regulating packaging (European Commission, 2018a).

Regarding the separation of LDPE from cardboard packaging into pure fraction, promising technologies exist. Despite some advanced technologies being on a pilot stage, existing technologies are available such as the one from the inventors from the University of Bologna (Alma mater studiorum universita di bologna) separating and recovering LDPE and aluminium derived from multi-layers food packaging (specifically the waste material from paper-recycling plants). This method based on switchable hydrophilic solvents (SHS) is entirely sustainable and can obtain high quantity recovery rate for both aluminium (99%) and LDPE (80%) as well as high quality (University of Bologna, 2016).

Finally, it is important to reflect upon the number of drivers compared to the barriers. In fact, in general there are more barriers than drivers that have been mentioned among both the literature and the interviews. Overall, the author can confirm that in the interviews, companies' representatives and experts mentioned more barriers for closing the loop, except Borealis group who invested into a new LDPE recycling plant in Austria, the buyer PolyPlank, and Tetra Pak, actors who mentioned several drivers.

After having highlighted the main barriers and drivers, the next section will explore different scenarios for closing the loop.

5.4 Scenarios for Closing the Loop

In this section the author proposes solutions to overcome the main barriers identified in the case study. First, the author suggests through an illustration some steps and options to close the loop of the LDPE material flow coming from Tetra Pak's packaging. Then, other solutions and changes needed at the institutional level and in market conditions will be summarized for each main barrier in *table 5.3*.

In the following sub-chapters, the author intends to answer the sub-research question 4: *"What are the possible solutions that can help companies close material flows of LDPE?".*

5.4.1 Strategies and options for a closed-loop system

Figure 5.7 presents a chart flow illustrating the strategies and options to increase the possibility to close the loop among the actors of the case study.

As shown in this illustration, the main area in need of improvement is located at the waste treatment plant of Sysav and at Fiskeby, where the post-consumer cardboard packaging waste could be re-sorted, recycled on site or sent to other recyclers to treat the waste before re-selling it to PolyPlank. Main barriers were considered in proposing strategies listed in the squared yellow boxes. Indeed, the yellow boxes highlight the strategies needed at each value chain actors level to optimize recycling. The box "option 1" gives solutions to Fiskeby AB (at the company level) to handle the by-product of LDPE and Aluminium rejected from the paper mill Fiskeby. The box "option 2" proposes collaborative solutions to Fiskeby AB and other actors (at the value chain level).

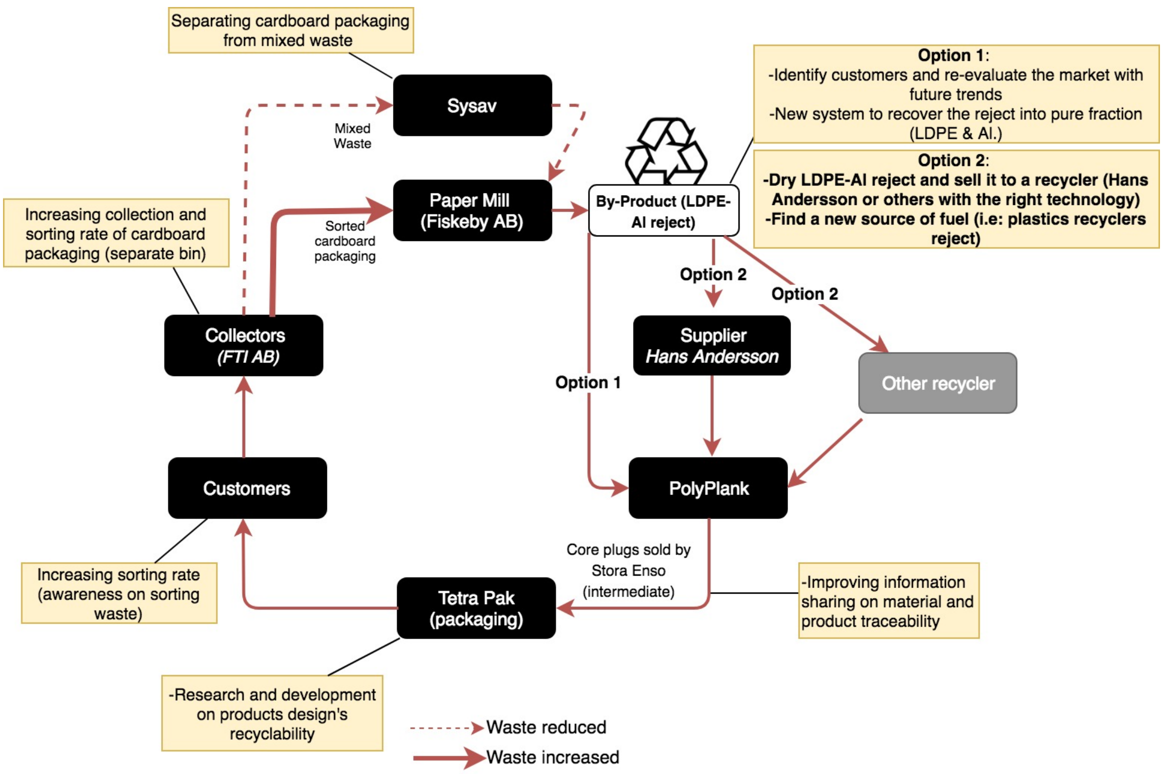

Figure 5-7 Steps and Options for a Closed-loop System– Own source

5.4.1.1 Strategies for optimizing recycling

In order to optimize LDPE material recycling within the value chain, the author suggests first to improve information sharing on material and product traceability among business partners (an example is given in the next section in *table 5.3*).

Another suggestion is to continue research and development on products design's recyclability (Tetra Pak's beverage carton packaging). At the customer level, it is important to educate households and improve their awareness on sorting waste in order to increase the sorting rate. In parallel, collectors of waste could increase the sorting rate by adding dedicated bins for special cardboard packaging containing mixed materials.

Finally, at the Sysav waste-to-energy plant, a future recommendation may be to invest into sorting technology to separate beverage carton packaging from mixed household waste, even though the author acknowledges current economic barriers that still persist.

5.4.1.2 Option 1: At the company level

To create a closed-loop system, the author suggests to recycle the Fiskeby paper mill's reject either on site or sending the by-product in another recycler facility able to separate into pure fraction LDPE and aluminium (for reusing the LDPE material into planks composite).

Another suggestion is to only wash and dry the reject from the paper mill to reuse the outcome into the PolyPlank's core plugs production. Fiskeby could undertake new market research to explore possible financial returns and reducing regulatory risks.

The author encourages the company to map all the recyclers and customers who may be interested in buying the paper mill's reject (particularly in Sweden and Northern Europe) and evaluate the future trends regarding regulations on plastics restrictions and the recycled plastic market in Europe.

5.4.1.3 Option 2: At the value chain level

If Fiskeby has concerns in finding new source of fuel for the energy supply of the paper mill, the author suggests to start selling half of the reject (as a pilot testing) and import new sources of waste from industrial waste, agricultural waste or even other paper mills who may not recover their reject.

Another option that may be feasible is to use, as a fuel substitute, the undesired plastics waste reject from recyclers in Sweden (Swerec and PiW having 10-20% rejected plastics from recycling and sorting processes). For this option, the simplified Material Flow Analysis (***figure 5.6***) shows that 155 000 tons of unsorted plastics (for the year 2016) are sent to energy recovery.

In the case of involving Hans Andersson as a possible recycler to receive the dried by-product from the paper mill, the author recommends beforehand to 1) make sure Hans Andersson has the technology to further process LDPE-Al reject, 2) from where their LDPE waste streams come from 3) and lastly, to evaluate their degree of willingness to collaborate in closing the loop of the cardboard packaging waste.

On the ***figure 5.7***, the option 2 has been bolded by the author to show that this option may be the most feasible at the moment. Nevertheless, the option 1 is judged by the author to be the best option in the future due to current barriers.

5.4.2 Proposed solutions to overcome the main barriers

The goal of this paper is to find ways to recycle the LDPE contained in food and beverage cardboard packaging from Tetra Pak and reusing this plastic into PolyPlank's products. The author came up with solutions in the following ***table 5.3*** that may overcome the four main barriers mentioned by the interviewees along this research. This table summarizes what are the changes needed in an institutional context and in market conditions to overcome the principal barriers identified in this research. Some solutions are additional from the previous proposed steps and options discussed in the previous section.

Table 5-3 Proposed solutions for each main barriers – Own source

Main barriers identified	Proposed Solutions
1) Low market demand of recycled plastics	-Re-evaluate the future market trends in Sweden and Europe – finding new strategies to increase the demand. -Politicians and policy makers could provide economic incentives to companies using recycled materials in their production. -Higher recycling targets. -Clearer standards and harmonization of instructions and policies implementation among municipalities and European countries for collecting, sorting and recovering waste.
2) Lack of communication and material traceability	-Value chain coordination: Create an online platform to share the input and output flows of LDPE materials among business partners and organizations. Rejected materials could be also indicated in order to identify possible solutions. Stronger network of the actors of the value chain may increase the recycling rate of LDPE and finding new ways of overcoming challenges. -Creating confidentiality agreements among partners.
3) High cost of the technology to separate rejected LDPE-Al from packaging	-Find a middle actor with technology providing high recovery quantity and quality rate that could recycle the reject from paper mills in Sweden. (Example of the technology from the University of Bologna mentioned in *section 5.3.2.1*). -Eco-design incentives for improving the recyclability of packaging products.
4) Fuel substitute if no more burning reject (Fiskeby barriers)	-Using landfilled waste (i.e. industrial waste), agriculture waste or rejected plastic waste from recyclers in Sweden (currently going to Sysav's incinerator).

5.4.3 Incentives to increase recycled plastics market demand

Regulations have a major role in modifying the current LDPE flows in Sweden. Direct regulations (commonly referred as command and control policy) may perhaps increase the recycling rate, but not systematically lead to an increased demand of recycled LDPE in the country. As Tetra Pak's representative (I4) stated, instead of imposing strict bans on landfilling and incineration, more incentives should be created in order to drive the market towards more using recycled plastics.

The author believes that economic incentives could encourage companies in reusing recycled materials in their products. For instance, it could be a tax reduction depending on the percentage of the volume of the recycled materials use, or in terms of materials type.

Another way to increase the recycled plastics demands on the market is indirectly through a green public procurement policy requiring a certain percentage of recycled plastics material content into some product categories. Consequently, a strong business case for investing into recycling LDPE could be possible to attain.

Also, creating a certification of high quality and purity for recycled plastic materials (for LDPE for instance) could help converters to get assured that the LDPE material is safe to use in their production processes. This certification should be created among the Swedish industries or European industries. In this way, more producers could be interested in buying recycled plastics material leading to create a growing market demand for recycled LDPE. *(NCM, 2018)*

5.4.4 Discussion on the solutions

Previous mentioned solutions in the ***sub-chapter 5.4*** are specifically proposed for the case study of Tetra Pak and PolyPlank to close the loop of the LDPE material flow. However, as the author extended the exploration of other LDPE waste streams, diverse possibilities appeared outside of the case study scope.

In fact, PolyPlank could reuse LDPE from other plastics packaging waste stream from the two main recyclers Swerec and PiW, however a middle actor is needed for washing, grinding and granulize the material. A possibility exists by potentially having the new Motala recycling plant able to do so or to send the baled LDPE to the Austrian recycling plant "Ecoplast". However, this option will not be considered as properly closing the loop as the LDPE waste stream differ from the cardboard packaging waste, and it will be send outside of Sweden for further processing.

The author mentioned some policies and regulations improvements to overcome the main barriers identified in this research. Policy makers are not in the research scope of the stakeholders analysed in this study. Nevertheless, the author judged relevant to include that policy actions are needed in order to help closing the loop of plastic material flow and may be one of the main solutions to overcome the barriers identified among the main actors. Indeed, regulatory and economic incentives could act as catalysts to increase the recycled plastics demand.

5.5 Method Discussion

In this section the author is analyzing and discussing the study's methodological and analytical choices while providing some reflections to the readers about the limitations regarding the data collection and analysis.

5.5.1 Research Questions and Objectives

In this study, the author chose many objectives in order to cover a case study with many areas to explore. The unclear situation of the LDPE material flow in Sweden was judged important to investigate in order to come up with solutions. Therefore, one main question was presented and 4 sub-questions were given to help answering this principal question. It could be argued that the numerous questions and objectives could be somehow too ambitious, principally regarding the Material Flow Analysis, which requires a lot of time and persistence to obtain data, but the author believes that those research questions were legitimate in order to bridge the existing knowledge gap and better understanding the relationships and roles of the actors in the value chain of this case study. They were deemed useful in order to frame the research in a logical way and attain the research objectives.

5.5.2 Research Methods and Analytical Framework

The chosen methods and analytical framework (using the PESTEL factors) oriented the study to analyze different opinions of the actors involved in the LDPE value chain in Southern Sweden. The use of the barriers and drivers ensured to identify the possibilities to close the loop of the case study. It helped to undertake an in-depth analysis of the situation. It would be highly recommended to use a similar framework in future relevant studies.

However, it could be argued that the PESTEL framework could limit the number of factors that interviewees could have mentioned which didn't fit into it.

The author found also relevant to use both qualitative and quantitative data collection method for this specific study in order to find correlations between the barriers and drivers and the quantitative data. This method was important to use in order to find the adequate solutions by taking into account companies' challenges and opportunities.

The units of analysis of this study were the drivers and barriers of the actors categorized into suppliers, converters (Tetra Pak), recyclers and collectors, and buyers (PolyPlank). Even though PolyPlank is a manufacturer that could be considered as converter, these categories of value chain were deemed to be the most suitable for illustrating the LDPE material flow. Further research regarding this topic, could classify some actors differently, such as differentiating recyclers (with the technology to wash and granulize LDPE) from sorters being also collectors. Therefore, there are many ways to look at the categorization of the players of the LDPE value chain.

5.5.3 Research Limitations and Geographical scope

Regarding the Material Flow Analysis, some numerical data were difficult to obtain through investigation and remained even unknown by the interviewees. Consequently, the Material Flow Analysis has been simplified and shows additional waste streams in order to explore other possibilities to close the loop. It was impossible to trace one individual material flow, therefore, the author chose to include other types of materials due to the lack of information regarding LDPE material share.

Nevertheless, the simplified MFA was deemed important to perform (even with missing information) to propose a chart showing how the LDPE material flow looks like in Sweden as well as the plastic recycling system. This chart *(figure 5.6)* helped the author finding areas to propose solutions to improve LDPE material circularity.

As this is a case study of Tetra Pak and PolyPlank located in Southern Sweden, the author found it relevant to scope the study to the Southern part of Sweden where most of the relevant stakeholders of those companies are located. However, it could be interesting in further research to extend the scope to Nordic countries, and found other similar manufacturing companies as PolyPlank interested in buying recycled LDPE.

5.5.4 Stakeholders and Interviewees

Stakeholders were chosen according to the initial value chain system given to the author at the beginning of the study. Along the research, the author thought about including more stakeholders such as customers, policy makers and other buyers/secondary converters (with similar interest in buying recycled LDPE materials as PolyPlank). However, due to the time constraint of conducting a master thesis as well as uncertainties given at the beginning of the research concerning the LDPE material flow situation in Sweden, the author believed that it would have been difficult to get into an in-depth analysis of a large amount of stakeholders. Therefore, it is highly recommended to include those previous mentioned stakeholders in future researches.

Interviewees were selected according to the author's assumptions. At the beginning of the study, the author had three main known value chain actors: PolyPlank, Tetra Pak and Sysav. It is only through interviews with the representants of those latter actors that the author acknowledged other companies and organizations names that could be part of the LDPE value chain in Southern Sweden. As uncertainties persisted, the author had to ask recyclers (both mentioned in interviews and found through desk research) if they dealt with aseptic cardboard, LDPE, or mixed plastics. This investigation was an important part of the study in order to understand who are the main players in the value chain and where possibilities could exist.

6 Conclusion

This chapter answers the research questions by summarizing the main findings of this paper. It draws conclusions on the roles of the LDPE value chain actors, their barriers and drivers in achieving to close the loop of the post-consumer LDPE material flow as well as the different possibilities that exist to close the loop.

In order to address this problem, this research first aimed at providing an overview of the barriers and drivers to the LDPE recycling in the specific case study of the two companies, Tetra Pak and PolyPlank, in Sweden and to identify possibilities to bring more material circularity. The study includes perspectives from both Tetra Pak cardboard packaging stream (being the main focus of the case study), and the plastics packaging waste stream to further investigate potentiality to recycle LDPE.

Due to a limited peer reviewed knowledge and literature on the recycling LDPE layers from polylaminated food and beverage cartons, the author attempted to fill this research gap by developing the research with the aim of: 1) identifying the key actors of the value chain under the case study of Tetra Pak and PolyPlank, 2) analysing their drivers and barriers in bridging the gap, and 3) performing a simplified LDPE Material Flow Analysis for exploring the possibilities of reusing recycled LDPE and "mixed plastics" into PolyPlank production processes.

The type of plastic "LDPE", having the particularity to be flexible, is the main focus of this study. The author chose to explore possibilities to reuse the reject of the paper recycling process, at the Fiskeby AB's paper mill, into the PolyPlank's core plugs production.

As this imperceptible material is hidden in the cardboard packaging, representing nevertheless a significant content percentage of 21% (Kaiser et al., 2017), this could explain why LDPE didn't get much attention in the last years by the public and researchers. However, with more than 188 billion of Tetra Pak's packages sold worldwide in 2017 (Tetra Laval, 2018), LDPE material layers recovery from those packages must be further studied in academia. Furthermore, household customers should be better informed about the material content in the packaging they consume to raise awareness on the importance of sorting their waste properly.

In Southern Sweden, all the aseptic cardboard packaging that is not sorted at the consumer stage (mixed with household waste) is incinerated to generate energy (i.e. at Sysav's waste treatment plant). In addition, rejected materials containing LDPE from the recycling process of the sorted cardboard packaging are also recovered into energy (i.e. at Fiskeby's paper mill). Resource recovery from waste-to-energy is the second least preferred option in the waste management pyramid *(appendix 8)* before landfilling disposal. In contrast, after waste prevention, the reuse of the material and the recycling are the most preferred options being the core subject of this paper by proposing LDPE recycling solutions for the companies under the case study.

6.1 Research Questions and Achievements

Below is the main research question along with the four sub-questions in an attempt to achieve the research objectives earlier mentioned:

Main research question: ***What possibilities exist to closing the loop of LDPE material flow through reusing the post-consumer LDPE derived from Tetra Pak's packaging into PolyPlank's production processes?***

Sub-research questions:

1. *Who are the relevant value chain actors around LDPE material flows stemming from Tetra Pak?*
2. *What are the potential barriers and drivers for each actor to create a closed loop system of LDPE?*
3. *What is the current LDPE material flow within the system under study?*
4. *What are the possible solutions that can help companies close material flows of LDPE?*

The study aimed in contributing to the existing body of academic literature to generate new knowledge and in responding to the research questions by:

-Identifying and mapping the main actors in the LDPE value chain under the case study *(a response to SRQ1 can be found in the figure 5.1 and more precisely in the figure 5.5 illustrating the current situation of the case study*) but also understanding in a larger context the LDPE value chain from the plastics packaging stream (*shown also in figure 5.1*).

-Providing an in-depth analysis of the main actors' drivers and barriers to close the loop of the LDPE material flow, drawing on the analytical framework (incorporating the PESTEL factors) *(a response to SRQ2 can be found in tables 4.1 and 4.2).*

-Carrying out a simplified LDPE material flow analysis in Southern Sweden *(the figure 5.6 answers the SRQ3)* in order to identify the areas in which possibilities exist to close the loop *(Section 5.2.1 partially answers SRQ4 and the main research question).*

-Proposing solutions based on the findings analysis and literature background to increase the chance of bridging the gap by future collaborations among the actors *(the figure 5.7 and the table 5.3 answer the SRQ4).*

All those previous listed outcomes help to answer the main research question. *Sub-chapter 5.4* presents the solutions for closing the loop of the specific case study of Tetra Pak and PolyPlank.

6.2 Results and Analysis Overview

In this section, the author presents an overview of the main results of this research.

6.2.1 LDPE value chain actors of the case study

After several attempts to understand the plastics recycling system in Sweden, the author finally identified the key actors of the LDPE value derived from Tetra Pak packaging to be reused in PolyPlank's materials composites. Obviously, *Tetra Pak* is the main actor by producing polylaminated food and beverage packages. The *consumers* (out of the study scope), consuming and disposing the packaging product at its end-of-life, could be argued to be important players to be studied in further research. Then, other key actors include the collector *FTI AB* responsible for collecting the household packaging in Sweden, *Sysav* receiving mixed household waste which may contain unsorted cardboard packages recovered into energy (this household waste is collected and sent to Sysav by a contractor hired by the municipality), *Fiskeby AB* recycling paper and rejecting the unwanted mixed materials (LDPE, aluminium and other small fractions of paper and other types of plastics) and *PolyPlank* interested in reusing the LDPE fraction from this reject (or the mixed plastics from the reject). *Hans Andersson* is also an important actor as it is the supplier of recycled LDPE and may have the technology to recycle the reject from Fiskeby AB's recycling processes. This latter actor could not be analysed in depth in this research due to the unavailability of the company to provide information. Therefore, this research could be continued by looking at the feasibility of closing the loop with the contribution of Hans Andersson (acquired by Veolia).

6.2.2 Barriers and Drivers

From the main actors of the LDPE value chain, the overarching barriers under the case study are principally the "*low market demand of recycled LDPE*" in Sweden and in Europe (economic factor), the "*high cost of investment in the technology and the system installation for separating the LDPE into pure fraction*" (economic factor), and *"finding a fuel substitute for the current incineration plant*"(technological factor). Even though only one main actor mentioned it, the author judged that "*the lack of communication and material traceability*" could be the core barrier for advancing into a more circular economy in which a strong collaboration and networking of partners are needed. Solutions to those four barriers are given in the *table 5.3*.

Regarding the drivers, even though the actors shared different opinions on what could encourage them to increase LDPE recycling, the author confirms that there are four main drivers: the "*Circular economy as a business opportunity and competitive edge*" (economic factor), *"Risk avoidance for future stringent regulations and targets*"(legislative factor), "*Technology development increasing the level of purity*"(technological factor) and "*Growth in demand of recycled plastics (even with low grades) in various applications*"(economic factor).

This latter driver contradicts with the barrier of "*low market demand*". However, it is important to differ the recycled plastics into different types of plastics and quality. In this way, a more precise business case for the LDPE on one part, and the mixed plastics materials rejected from paper mills (with low grade) on the other part can be attained.

Also, from interviewees, experts and desk research, the author believes that the recycled LDPE market will grow in the future due to the increasing policies towards creating a more circular economy and due to more stringent regulations on plastics use. Also, the China's ban on plastics waste import will oblige European countries to find new ways to handle the waste such as by improving the design for products' recyclability and creating more circularity of the materials at their end-of-life.

6.2.3 Suggested solutions for closing the LDPE material loop

The main targeted audiences of this paper are the actors who are involved in the LDPE value chain of Tetra Pak's packaging as well as PolyPlank being the buyer of the recycled LDPE wishing to reuse the reject from the paper mill of Fiskeby AB.

Fiskeby AB is identified as the key player in contributing to the success of bridging the current gap of the LDPE flow in the system under study. After a clearer vision on the LDPE material flow and throughout an in-depth analysis of the barriers, the author proposed two main options to close the loop:

> 1) Fiskeby could invest into a recycling technology using dissolution and reprecipitation method or the sustainable technology from the University of Bologna specifically designed for recovering the waste materials from paper-recycling plants such as LDPE and aluminium. In order to convince the management board to invest

in such technology, an in-depth market research must be carried out by taking into account future regulations and market trends as well as evaluating the feasibility to re-sell the recycled materials.

2) Otherwise, the author suggests Fiskeby to undergo a pilot testing by sending half of the reject (beforehand dried) to a recycler able to further process the materials (separation into pure LDPE and Aluminium fractions) from which LDPE could be reused into the PolyPlank's composite planks. In the case of the "mixed plastics" used in the PolyPlank AB's core plugs, the reject could be washed, dried and grinding at a recycling facility (i.e. Hans Andersson as an assumption) hence the mixed materials recovered (largely containing LDPE) could be reused into PolyPlank's production of core plugs.

Other types of audience are targeted in this paper. Indeed, through this research, academia, market researchers and policymakers could get an overview of the LDPE material streams and flows in Southern Sweden and get some insights of the challenges and opportunities to modify the flow into a more circular way.

Also, the study is of direct relevance to other manufacturers using recycled LDPE to gain a better understanding of the state-of-the-art of recycling LDPE from polylaminated cardboard packaging in improving the circularity of the LDPE material flow.

6.3 Recommendations for Future Research

At the beginning of this research project, the author started with two main actors of this case study: Tetra Pak and PolyPlank AB. Along the research more actors appeared in the LDPE value chain through data collection. It appears that plastics recycling in Sweden particularly for the LDPE plastic material could be challenging to comprehend and still remains a complex system.

At the end of this study, the author still believes that some areas remained unexplored. This is due to the time restraint of the master thesis and the difficulties to gather information from actors. Other stakeholders may also have an influence to help increasing LDPE recycling in Sweden or contributing to close the LDPE material loop. For instance, a stakeholder analysis including consumers, public authorities, policy makers and NGOs could be further conducted in similar research topic.

To conduct a market study, it requires an evaluation of the market prices fluctuation for primary LDPE material and LDPE recycled material in Europe and in Sweden. The latest report of the Swedish Environmental Protection Agency (SEPA) (Naturvardsverket, 2018) provides some ranges of LDPE prices in the European market for raw and recycled material. As the sources of the data were from the Plastic Recyclers price index of the year 2015, the author recommends gathering more recent data to have a more accurate market analysis. This new report of the [NATURVÅRDSVERKET}, the Swedish Environmental Protection Agency, was released in September 2018 and provides some updated data regarding the use of the LDPE in Sweden (Naturvardsverket, 2018). The author could not fully analyse this report due its late release. Therefore, the author suggests referring to this report for further investigations.

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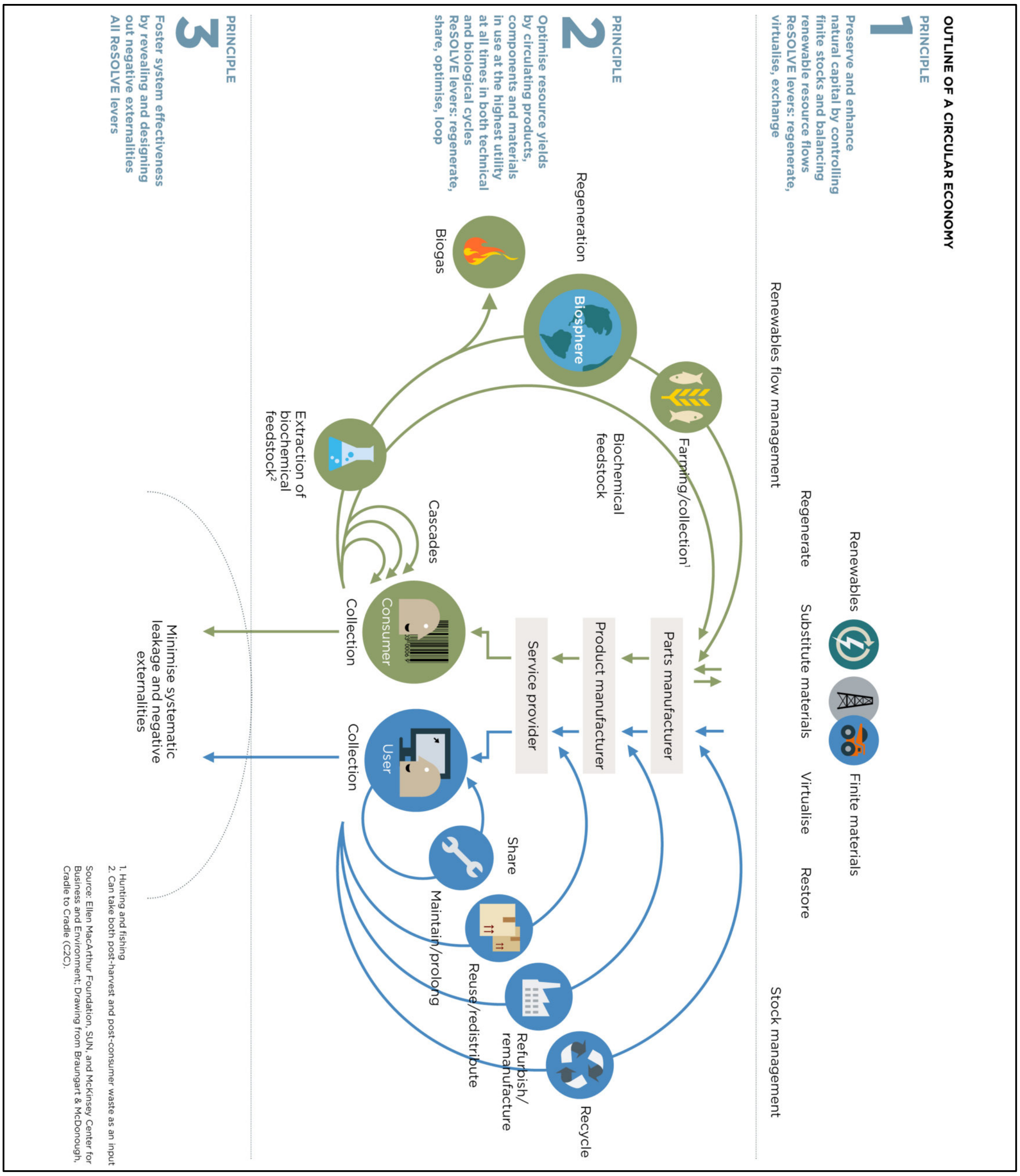
Appendix

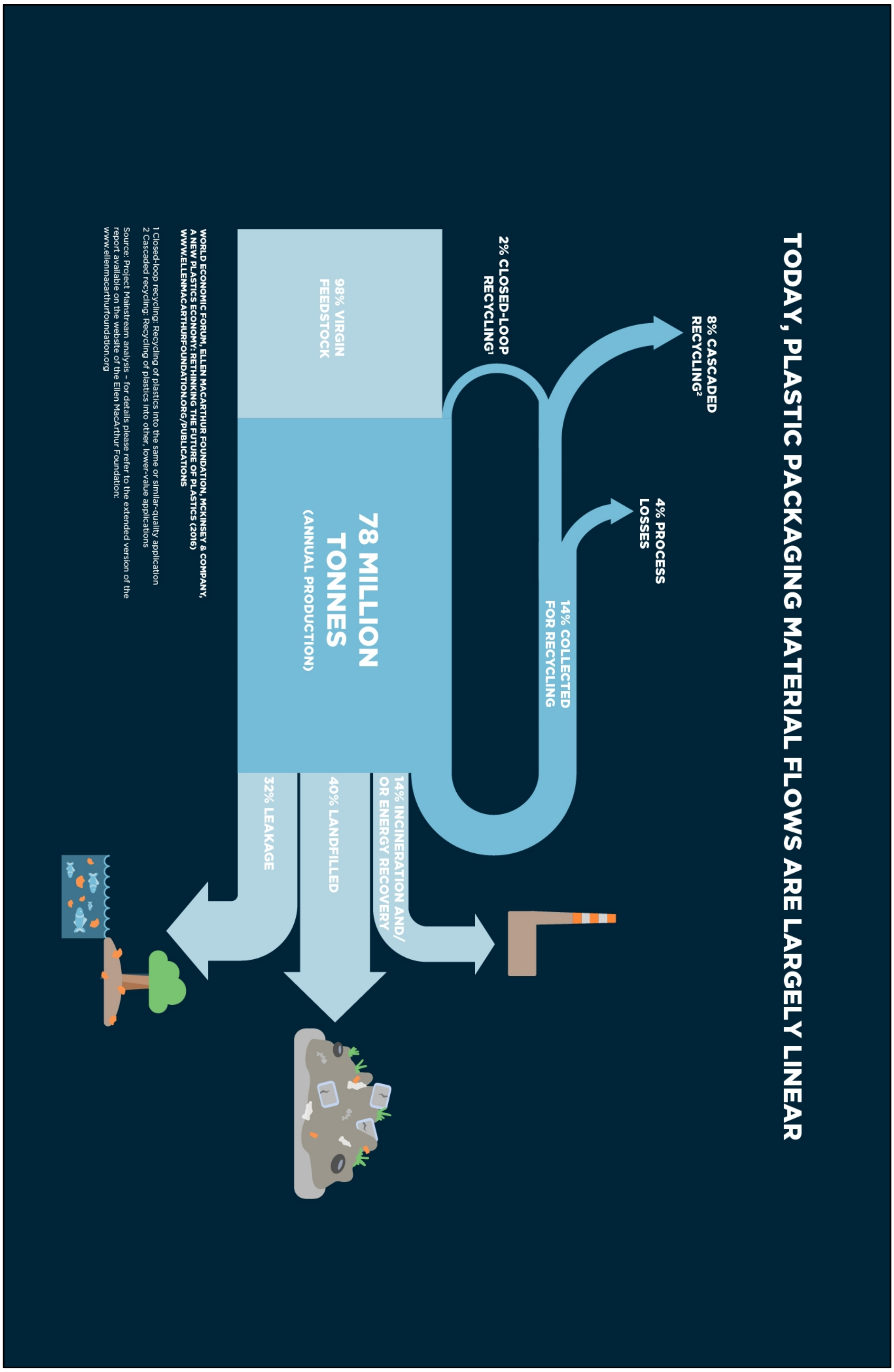
Appendix 1. Diagram of the Circular Economy System

Source: Ellen MacArthur Foundation, SUN, and McKinsey Centre for Business and Environment; Drawing from Braungart & McDonough, Cradle to Cradle (C2C). (Ellen MacArthur Foundation, 2017).



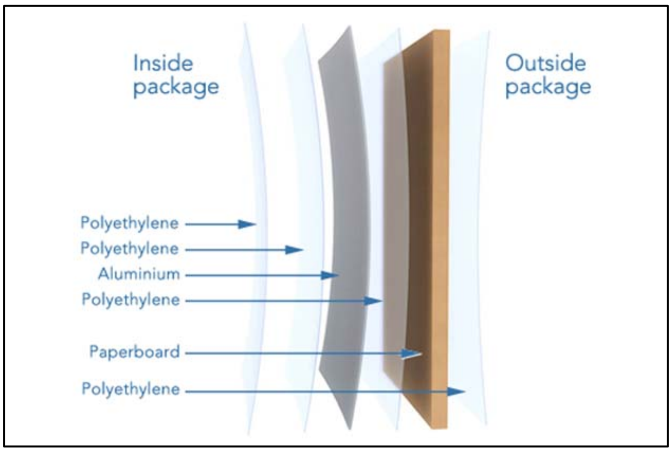
Appendix 2. Plastics packaging system (mostly linear) in 2013

Source: Ellen MacArthur Foundation and McKinsey & Company, The New Plastics Economy — Rethinking the future of plastics (2016)



Appendix 3. Layers of the Tetra Pak Carton Packaging

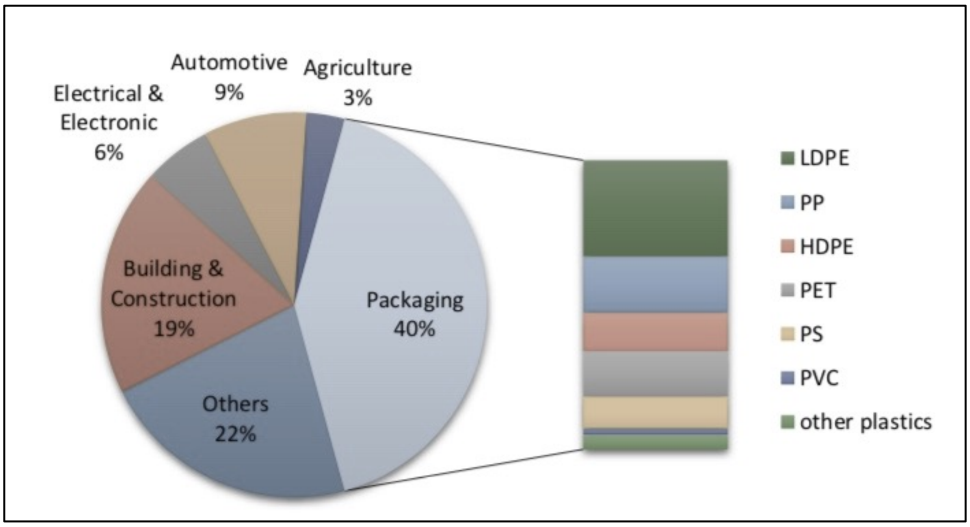
(Polyethylene is referred to LDPE) - **Source**: Tetra Pak Website



Appendix 4. Sectors of plastic materials applications & polymer types used in packaging in Europe

Source: from Kaiser et al. (2017) - graphic illustration inspired from the polymeric composition of the plastics packaging in Europe (PlasticsEurope, 2016).

Abbreviations used: LDPE (low-density polyethylene), PP (polypropylene), HDPE (high-density polyethylene), PET (polyethylene terephthalate), PVC (polyvinyl chloride), PS (polystyrene), PA (polyamide).



Appendix 5. Flows of plastics waste in Sweden 2010 and recovery methods in Sweden and abroad

Source: Adapted from SMED (2012) and Angel (2018).

Sector/Use area	Waste flow	Amount of plastic (tons)	Material recycling (tons) in Sweden/ Abroad	Energy recovery (tons) in Sweden/ Abroad	Incineration w/o energy recovery (tons) in Sweden/ Abroad	Fuel (cement industry) (tons) in Sweden/ Abroad	Landfilling (tons) in Sweden/Ab road
Household	Sorted plastics packaging	46 000	23 000/ 23 000				
	Packaging in residual waste (mixed)	151 000		151 000/ 0			
	Other plastics in the residual waste	42 000		42 000/0			
	Plastic packaging in the sorted food waste	1 000		1 000/0			
	Sorted deposit bottles	19 000	19 000/0				
	Bulky waste	39 000	3 000/0	36 000/0			
	Total households waste	**298 000**	**45 000/ 23 000**	**230 000 /0**			
Construction & demolition	Sorted plastics	<1 000	<1 000/?				
	Bulky combustible and mixed waste	43 000		43 000/0			
	Total construction & demolition waste	**43 000**	**<1000/?**	**43000/0**			
Electronics	Sorted & collected electronic waste (households)	24 000	<1 000/ 10 000	8 000/ <1 000	1 5000/ <1 000		<1 000/ 3 000
	Sorted & collected electronic waste (industry)	9 000	<1 000/ 4 000	3 000/ <1 000	<1 000/0		<1 000/ 1 500
	Electronics in combustible waste	1 000		1 000/0			
	Total electronics waste	**34 000**	**1 000/14 000**	**12 000/ <1 000**	**2000/ <1 000**		**<1 000/ 5 000**
Vehicles	Collected vehicles	**18 000**		**12 000/ 0**			**6000/0**
Production industry	Sorted plastic waste	**134 000**	**45 000/ ?**	**9000/?**		79 000/?	<1 000/?
Medical applications	Risk waste	**13 000**		**13 000 /0**			
Agriculture	Silage plastics	**18 000**	**0/16 000**	**2 000/0**			
Total		**558 000**	**91 000/ 53 000**	**321 000/ <1 000**	**2 000/ <1 000**	**79 000/?**	**7 000/ 5 000**
Import		**300 000**					
Export		**91 000**					

Appendix 6. Categories of plastics used in Sweden

Source: Data from SMED (2012)

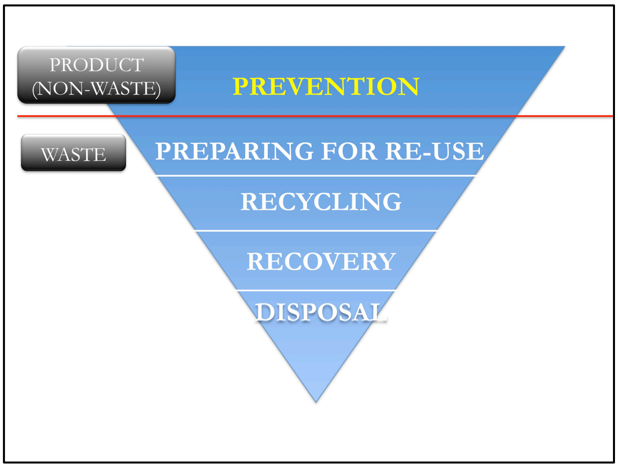
Type of plastic	Fraction (%)	Amount (tons)
Polypropylene (PP)	19	167 000
Polyethylene, low density (LDPE, LLDPE)	17	150 000
Polyethylene, high density (HDPE)	12	106 000
Polyvinyl chloride (PVC)	12	106 000
Polystyrene (PS)	8	70 000
Polyethylene terephthalate (PET)	6	53 000
Polyurethane (PUR)	7	62 000
Other plastics	19	167 000
Total	**100**	**880 000**

Appendix 7. Interviewees list

Interview	Company/Industry	Interviewee	Job Position	Medium	Interview Date	Buyer
I1	PolyPlank AB	Annika Fernlund	Chairman of PolyPlank Board	In person	June 20th, 2018	Buyer
I2	Fiskeby AB	Erika Fröjd	Technical Manager	Phone call	July 4h, 2018	Recycler
I3	Sysav Utveckling AB	Ellen Lindblad	Project Leader	In person	July 6th, 2018	Recycler/ Collector
I4	Tetra Pak	Erik Lindroth	Nordic Environmental Director	Phone call	July 11th, 2018	Converter
I5	PolyPlank AB	Anton Aldentun	Production & Marketing Coordinator	Email response	June 18th, 2018	Buyer
I6	Stena Recycling AB	Martin Leander	Head of paper & plastics	Email response	N/A	Recycler
I7	Swerec	Leif Karlsson	Managing Director	Email response	N/A	Recycler
I8	Swerec	Roger Eliasson	Technical Supervisor	Email response	N/A	Recycler
I9	Fiskeby AB	Magnus Johansson	Quality Management Manager	Email response	N/A	Recycler
I10	FTI AB	Håkan Ström	Communications Manager	Email response	N/A	Recycler
I11	Borealis	Patrick Laureys	Senior External Communications Manager	Email response	N/A	Supplier

Appendix 8. Waste management hierarchy

Source: Adapted from the European Waste Framework Directive 2008/98/EC (European Commission, 2012)



Appendix 9. Interview Guides

Appendix 9.1 Interview Guide: Suppliers

Introduction: I arrive at the end of my master program in Environmental Management and Policy at the IIIEE (Institute of Industrial Environmental Economics) in Lund University. I'm currently doing my thesis on plastic recycling and reusing in a Swedish context, specifically I'm looking at the possibility to close the loop of plastic material waste from packaging in reusing this plastic into other companies production processes.

Through this interview, I aim to understand *name of the company*'s main barriers and drivers of recycling plastic material such as LDPE. *Name of the company* could be an important actor in improving recycling plastic and closing the loop of plastic waste in Sweden, consequently, I will need some information from you in order to better understand the current situation and evaluate the potentiality of reusing plastic into other companies manufacturing processes.

Questions

Background questions to get to know the interviewee and the company's business activities:

1. Can you briefly explain your role in your company?
2. What kind of plastics does your company sell?
3. Do you sell recycle LDPE? Or other type of plastics?
4. If yes, from which origins it comes from?
5. Who are your main clients?
6. If you recycle LDPE, what is the recycling method for recycling the LDPE in your facility?

LDPE material flow related questions:

7. What is your company's volume of sales of LDPE each year in Sweden? What about recycled LDPE?
8. If you recycle LDPE, do you receive packaging waste and separate paper from plastic materials? If yes, how much packaging do you receive each year? And how much LDPE and mixed plastic do you separate per year?
9. If you recycle LDPE, what is your total recycling capacity of LDPE?

Barriers related questions:

10. Do you have some challenges in supplying LDPE, or recycled LDPE to your clients?
11. Do you see any disadvantages in recycling LDPE?

12. In your opinion, why plastics are largely incinerated in Sweden?

Drivers related questions:

13. What were your main motivations for selling recycled plastic materials?
14. What are the advantages of recycling LDPE?
15. In your opinions, is there a growing market in Sweden regarding the demand of recycled plastic material?

End of the interview:
We arrive at the end of the interview. Thank you again very much "*name of the interviewee*" for all the information you provided me, I have few more questions to ask you:

- Do you have any questions regarding this research?
- Is it ok to follow-up via email with any further questions or clarifications?
- Would you agree to have your name listed in my appendix section in my thesis?

Appendix 9.2 Interview Guide: Converter (Tetra Pak)

Introduction: I arrive at the end of my master program in Environmental Management and Policy at the IIIEE (Institute of Industrial Environmental Economics) in Lund University. Related to the Mistra REES project, I'm currently doing my thesis on plastic recycling and reusing in a Swedish context, specifically I'm looking at the possibility to close the loop of plastic material waste from your packaging in reusing it into PolyPlank and other companies' production processes.

Through this interview, I aim to understand *name of the company*'s main barriers and drivers of recycling plastic material such as LDPE. *Name of the company* is an important actor in improving recycling plastic and closing the loop of plastic waste in Sweden, consequently, I will need some information from you in order to better understand the current situation and evaluate the potentiality of reusing plastic into other companies manufacturing processes.

Questions

Background questions to get to know the interviewee and the company's business activities:

1. Can you briefly explain your role in your company?
2. Do you use recycled LDPE in your product? Do you use other type of recycled plastics?
3. Who are your main suppliers?
4. Who are your main clients?
5. What are the main recycling methods for recycling the LDPE from your packaging today?

LDPE material flow related questions:

6. What is the total amount of LDPE used each year in your production?
7. Do you know what is the recycling rate of your packaging at the consumer stage?
8. What is the total volume of the cardboard packaging production containing LDPE plastic each year?

Barriers related questions:

9. What are your company's main barriers for advancing the plastic recycling in Sweden?
10. Would you in the future consider requiring recycled LDPE plastic film in your cardboard? If not why?
11. In your opinion, why plastics are largely incinerated in Sweden?

Drivers related questions:

12. In which way, your company may be able to contribute in increasing recycling and reusing of plastic waste from your packaging?
13. Why are you part of the MISTRA REES project?

End of the interview:
We arrive at the end of the interview. Thank you again very much "*name of the interviewee*" for all the information you provided me, I have few more questions to ask you:

- Do you have any questions regarding this research?
- Is it ok to follow-up via email with any further questions or clarifications?
- Would you agree to have your name listed in my appendix section in my thesis?

Appendix 9.3 Interview Guide: Recyclers

Introduction: I arrive at the end of my master program in Environmental Management and Policy at the IIIEE (Institute of Industrial Environmental Economics) in Lund University. I'm currently doing my thesis on plastic recycling and reusing in a Swedish context, specifically I'm looking at the possibility to close the loop of the Low-Density Polyethylene (LDPE) plastic material waste from packaging in reusing this plastic into other companies production processes.

Through this interview, I aim to understand *name of the company*'s main barriers and drivers of recycling plastic material such as LDPE. *Name of the company* could be an important actor in improving recycling plastic and closing the loop of plastic waste in Sweden, consequently, I will need some information from you in order to better understand the current situation and evaluate the potentiality of reusing plastic into other companies manufacturing processes.

Questions

Background questions to get to know the interviewee and the company's business activities:

1. Can you briefly explain your role in your company?
2. Do you recycle LDPE in your facilities or are you planning to recycle LDPE in the future?
    a. If no, could you explain me what are the reasons?
    b. If yes, from which origins it comes from?
3. Who are your main clients for recycled LDPE?
4. If you recycle LDPE, what is the recycling method for recycling the LDPE in your facility?

LDPE material flow related questions:

5. What is the amount of packaging containing plastic you receive each month or year?
6. What is the amount of LDPE recycled each month approximately?
7. What is the volume of your sales for recycled LDPE in Sweden?

Barriers related questions:

8. What are the main challenges with recycling LDPE from packaging compared to other type of plastic?
9. Do you have some challenges in supplying recycled plastic to your clients?
10. Do you see any disadvantages in recycling LDPE?
11. In your opinion, why plastics are largely incinerated in Sweden?

Drivers related questions:

12. If you sell recycled plastics in Sweden, what were your main motivations for selling recycled plastic materials?
13. What are the advantages of recycling LDPE?
14. In your opinions, is there a growing market in Sweden regarding recycled plastic material?

End of the interview:
We arrive at the end of the interview. Thank you again very much "*name of the interviewee*" for all the information you provided me, I have few more questions to ask you:

- Do you have any questions regarding this research?
- Is it ok to follow-up via email with any further questions or clarifications?
- Would you agree to have your name listed in my appendix section in my thesis?

Appendix 9.4 Interview Guide: Buyer (PolyPlank AB)

Introduction: I arrive at the end of my master program in Environmental Management and Policy at the IIIEE (Institute of Industrial Environmental Economics) in Lund University. Related to the Mistra REES project, I'm currently doing my thesis on plastic recycling and reusing in a Swedish context, specifically I'm looking at the possibility to close the loop of plastic material waste from Tetra Pak packaging in reusing this plastic into your production processes.

Through this interview, I aim to understand *name of the company*'s main barriers and drivers of recycling plastic material such as LDPE. *Name of the company* is an important actor in improving recycling plastic and closing the loop of plastic waste in Sweden, consequently, I will need some information from you in order to better understand the current situation and evaluate the potentiality of reusing plastic into other companies manufacturing processes.

<u>Questions</u>

Background questions to get to know the interviewee and the company's business activities:

1. Can you briefly explain your role in your company?
2. Do you use recycled LDPE in your product? Do you use other type of recycled plastics?
3. Who are your main suppliers?
4. Who are your main clients?

LDPE material flow related questions:

5. What is the percentage of recycled LDPE (or other types of plastics) used each year in your products?
6. What is the amount of recycled LDPE purchased from suppliers each year?

Barriers related questions:

7. What are your company's main barriers for advancing the plastics recycling in Sweden?
8. What is the maximum amount of times that LDPE can be recycled in order to be reused in your products?
9. In your opinion, why sorted LDPE is largely incinerated in Sweden?
10. What are the specific requirements for your plastic suppliers?
11. What would be the important conditions to reused LDPE into your products?

Drivers related questions:

12. What are your main arguments for reusing recycled LDPE?
13. Why are you part of the MISTRA REES project?
14. What are your hopes with the MISTRA REES project?

End of the interview:
We arrive at the end of the interview. Thank you again very much "*name of the interviewee*" for all the information you provided me, I have few more questions to ask you:

- Do you have any questions regarding this research?
- Is it ok to follow-up via email with any further questions or clarifications?
- Would you agree to have your name listed in my appendix section in my thesis?

Glossary

Waste Management terms

The Waste Framework Directive (WFD), 2008/98/EC defines some of the most significant terms in waste management such as definitions regarding waste, recycling, and recovery. The below table lists the definitions given in the WFD:

Terms	Definitions	Articles
Waste	"Any substance or object which the holder discards or intends or is required to discard"	Article 3(1)
Waste prevention	"Measures taken before a substance, material or product has become waste that reduce: •the quantity of waste, including through the re-use of products or the extension of the life span of products; •the adverse impacts of the generated waste on the environment and human health; or • the content of harmful substances in materials and products"	Article 3(12)
Recycling	"Any recovery operation by which waste materials are reprocessed into products, materials or substances whether for the original or other purposes. It includes the reprocessing of organic material but does not include energy recovery and the reprocessing into materials that are to be used as fuels or for backfilling operations."	Article 3 (17)
Recovery	The principal result of a recovery operation is the "waste serving a useful purpose by replacing other materials which would otherwise have been used to fulfil a particular function, or waste being prepared to fulfil that function, in the plant or in the wider economy" Recovery is divided into three sub-categories: preparation for re-use, recycling, and other recovery (European Commission, 2012). *Opposite term: Disposal*	Article 3(15)
Re-Use	"Any operation by which products or components that are not waste are used again for the same purpose for which they were conceived"	Article 3(13)
End-of-waste	"Becomes a product or a secondary raw material when the waste ceases to be waste through a recovery operation including recycling"	Article 6(1) and (2)
Disposal	'Any operation, which is not recovery even where the operation has as a secondary consequence the reclamation of substances or energy.'	Article 3(19)
Incineration	Classified as "other recovery" which fails to meet the requirement for re-use and recycling. The Guidelines on the interpretation of key provisions of Directive 2008/98/EC on waste defines incineration or co-incineration when "the principal use of the waste is as a fuel or other means to generate energy. It is a waste management operation with energy recovery, classified as R1 in Annex II to the WFD. This contrasts with the incineration of waste without energy recovery, classified as a disposal operation D10 in Annex I to the WFD"	Article 4(1)

Source: European Commission, 2012. Guidelines on the interpretation of key provisions of Directive 2008/98/EC on waste.