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Exploring the supply chain for textile waste recycling

A study of current and prospective supply chain facilitating textile waste from Swedish households to be recycled

Master's thesis in Quality and Operations Management & Industrial Ecology

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Abstract

In Sweden today, a significant amount of textiles are disposed by households in the household waste where they are directly send to incineration. This linear behaviour needs to change and Sweden and the rest of the EU state members are directed to collect post-consumed textiles separately by the 1st of January 2025. The aim for doing so is for textiles to become more circular and improve material efficiency. Collected post-consumed textiles of quality should be reused and second-hand markets exists in commercial scale today. This begs the question what can be done with the non-reusable, textile waste, fractions? A lot is happening within the field of textile recycling and at the same time, Sweden faces the challenge of re-looping its textile waste from households. Therefore, this study aims to increase knowledge about the supply chain that could facilitate textile waste caused by Swedish households to be re-looped via recycling.

To increase the knowledge on how to recycle textile waste from households, a abductive approach was conducted by combining a literature review and semi-structured interviews. The actors interviewed were automated sorters, recyclers, and experts within the recycling supply chain of textiles. An estimation of potential future volumes of textile waste from Swedish consumption was made, were the quantitative data identified in the literature was analyzed through a scenario analysis. In parallel, actors that could enable these volumes to be recycled were identified and interviewed. This resulted in increased knowledge about expected volumes of textile waste from households that could be collected in Sweden by 2025 and 2030, and the supply chain requirements of the identified automated sorters and recyclers that can manage these.

The results showed the complexity of textile waste from households that causes challenges to recycle this waste and exposed the enablers to improve the circularity of these textiles. Future volumes of textile waste from Swedish households are expected to be about 22100 - 24500 tonnes in 2025 and 22700 - 26800 in 2030. To manage these, the identified capacity for sorters and recyclers might not be enough. On this bases, the recycling supply chain capabilities should be further explored and developed by public and private incentives to increase the sustainability of the Swedish consumption of textiles.

Keywords: circular economy, textile waste management, textile recycling, textile supply-chain.

Acknowledgements

When we first entered this project we where two students with backgrounds from Industrial Ecology and Quality and Operations Management, little did we know about the textile industry nor textile recycling. However, through dedicated work and the knowledge gained from the actors and experts interviewed, we got an understanding on how the recycling supply chain works and what hinders textile waste to be recycled. We are grateful for participants in this study and we want you to know how thankful we are from the exiting and insightful conversations we have had. Additionally we cannot thank enough the guidance and council received from our supervisor at VTI, Linéa Kjellsdotter Ivert, that always resulted in new valuable leanings, and both personal and professional advice. Finally, we want to thank our supervisor at Chalmers, Patricia van Loon, that has provided insights in how to get from idea to result, and has pushed us to ensure the quality of this study.

We can conclude that it has been a major journey of exploration and learning throughout the semester. We have expanded our understanding for developments within the present and future textile industry and we could not have achieved this without the help of the ones mentioned.

Thank you!

Sofia Lindoth and Lars Stierna, Gothenburg, June 2021

Contents

Glossary

Word/Concept	Description
Closed-loop recycling	Recycling for the same application as the originating product.
Downcycling	Post-consumer textile recycling processes that result in a lower value or lower quality output than the originating product.
Fiber (or fibre)	A single piece of a given material made up of polymers (Rex et al., 2019).
Fiber mix	The distinguishable composition of the fibre and the proportion of fibre types found in a fabric.
Multi-layer textiles	Products build of multilayers like jackets that includes lining, padding and outer material.
NIR	Near-infrared (spectroscopic technology used to chemically identify fibre content from its unique, chemical, near-infrared spectrum).
Open-loop recycling	Recycling for other application than the originating product.
Separate Collection	'Separate collection' means the collection where a waste stream is kept separately by type and nature so as to facilitate a specific treatment (Dubois et al., 2020).
Textiles	Clothes and home textiles.
Textile waste	Refers to worn out textile products in the post-consumer volumes that cannot be used for reuse.
Upcycling	Post-consumer textile recycling process that result in a higher value or quality output than the originating product.
Used textiles/Post-consumer textiles	Textiles that are unwished by primary consumer.
VIS	Visible spectroscopy (spectroscopic technology that can identify different colours).
Volontary oragnisation	Nongovernmental organisation (NGO) that is driven by non-profitable purpose to support. Revenue is collected to support the organisations social work for domestic or ROW purposes (Statens Offentliga Utredingar, 2020).

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1
Introduction

The current textile industry is a globalized and linear industry. The system of production and consumption of textiles includes millions of producers and billions of consumers. This runs in an almost linear way, including raw material extraction, production, transportation, consumption, and after-use disposal that is mainly incineration or landfill (Koszewska, 2018; Manshoven et al., 2019). In 2019, fiber production for textiles was around 111 million metric tonnes. This production has been doubled over the last 20 years and the trend follows this path with an expectancy to increase another 30% in the next 10 years assuming business as usual (Opperskalski et al., 2020). Population growth and economic development are trends that have led to this increased consumption in mature economies (Sandin and Peters, 2018; Ellen MacArthur Foundation, 2017; Nørup et al., 2018), but the trend of fast fashion is also a contributing factor. Fast fashion can be characterized by quicker turnaround of new styles, and an increased number of collections offered per year that incentives textiles' quality and price to decrease (Statens Offentliga Utredingar, 2020). Fast fashion goes hand-in-hand with underutilization of textiles, where the average number of times a garment is worn before disposal has decreased historically (Ellen MacArthur Foundation, 2017).

Consequently, the current textile industry is an environmentally impactful industry. In the EU alone, household textiles and clothing are the forth most polluting products seen from a life-cycle perspective (Nørup et al., 2018). The production of textiles causes a large part of the environmental impact (Sandin et al., 2019). Of the global fibers produced, 63% are based on petrochemicals which are fossil-resources linked to high carbon dioxide emissions for production and further waste management. The second largest fiber is cotton (23% of global fibers produced) (Sandin and Peters, 2018; Opperskalski et al., 2020; Rex et al., 2019) whose production is associated with several environmental impacts such as, water depletion and toxic pollution from the use of pesticides. Furthermore, the production processes after raw material extraction may contribute to even larger environmental impacts. The wet treatment stage (dyeing, prints, etc.) uses chemicals that causes toxic emissions. The stage of spinning, weaving or knitting fabrics can also contribute to emissions of carbon dioxide and particulates when powered by fossil energy, which is commonly the case (Sandin and Peters, 2018; Manshoven et al., 2019). Further, land use for production of bio-based fibers will have to compete with food production in the future where arable land is more scarce (Svensson et al., 2020). The textile industry is hence a polluting industry that needs to become more sustainable.

Sweden is a clear example of a unsustainable linear use of textiles. In 2019, Swedish textile consumption was 13.7 kg per person, which means that around 141100 tonnes of clothing and home textiles were sold on the Swedish market (Statens Offentliga Utredingar, 2020; Naturvårdsverket, 2021). It is estimated that this Swedish textile consumption causes emissions of 4.2 million tonnes of greenhouse gases (Sandin, Roos, et al., 2019). Out of the consumed textiles, 7.6 kg per person are disposed annually to the household waste where it is directly sent to incineration. Additionally in Sweden, a high consumption of clothes and home textiles is continued at the same time as they are used for an increasingly shorter time (Statens Offentliga Utredingar, 2020).

Post-consumed textiles can originate from households and business (Statens Offentliga Utredingar, 2020; Hultén et al., 2016). Textiles consumed by households are more difficult to re-loop due to their unpredictability (Nørup et al., 2018), as textiles put on the market for consumption by households are designed to meet the infinite variety of needs of this consumer. The needs of the household reflects the different lifestyles and identities. This variability constitutes the core of the challenge to re-loop post-consumed textiles from households.

Today, Swedish post-consumed textiles from households are either donated to Non Governmental Organisations (NGOs), reused via Peer to Peer (P2P) markets or disposed in the mixed household waste (Statens Offentliga Utredingar, 2020). This is illustrated in Figure 1.1. Of the 7.6 kg of textiles disposed by business and household in the mixed household waste, households stands for disposing 5.1 kg (Statens Offentliga Utredingar, 2020; Hultén et al., 2016)

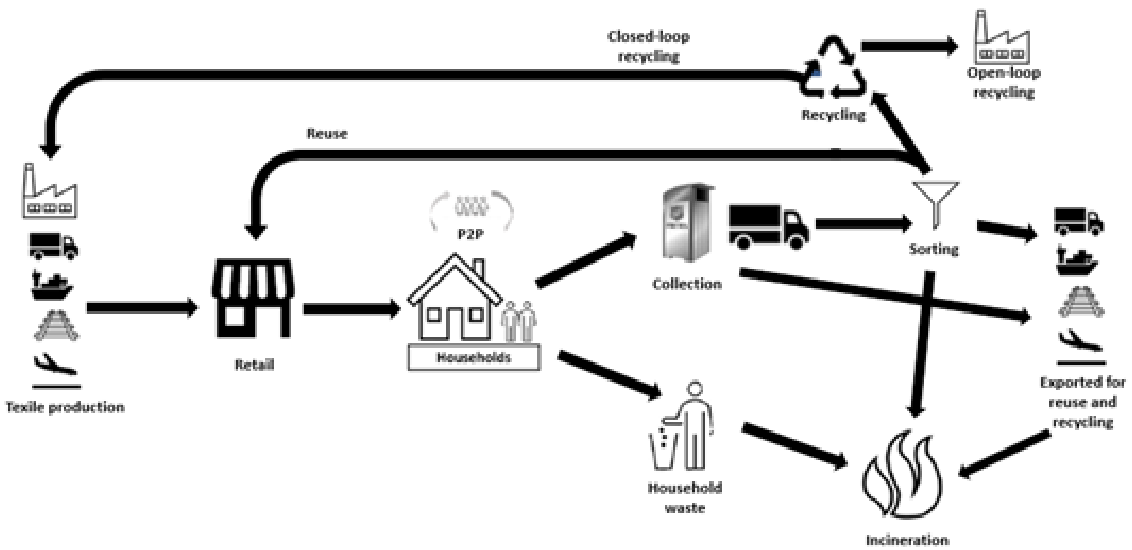

Figure 1.1: Today's Swedish supply chain of post-consumed textiles from households.

Due to the environmental impact of the textile industry, textiles should circulate to recover the embedded environmental- and economical values. The value can be recovered by either reusing textiles or recycling the materials. It has been concluded that the environmental impact of textiles can be reduced via reuse and recycling (Sandin, Roos, et al., 2019; Dahlbo et al., 2017).

The urgency to transition from a linear textile industry to a circular one has been recognized and on a European level there are several incentives addressing this. For example, the EU's Green Deal aims to implement eco-design measures to increase waste prevention, reuse and repair of textiles, focus on innovative solutions to increase collection, and sorting for closed and open loop applications. Moreover, it incentives the adoption of service-based business models through transparency and international cooperation (European Commission, 2020). As part of the EU's effort to become circular, in 2018, a revision of the Waste Framework Directive 2008/98/EG was presented (European Union, 2020; European Commission, 2021a). Included in this revision was an obligation of Member States to collect textiles separately by 1 January 2025. Collecting textiles at end-of life is a first important step to enable circularity.

1.1 Problem formulation

Once a separate collection of post-consumed textiles is in place, finding suitable outlets for increasing volumes will be important. As mentioned, textiles can mainly be re-looped via reuse or recycling. However, it has been identified that the global market for used clothing is becoming saturated (European Union, 2020; Ljungkvist et al., 2018). In the other hand, less than 1 percent of textile waste is recycled into new fibers for textile production (European Union, 2020; Ellen MacArthur Foundation, 2017). Therefore textile-to-textile recycling is an important solution to making textile consumption/production more sustainable. Consequently, technologies for processing textiles to recycled fibers are emerging (European Union, 2020; Ellen MacArthur Foundation, 2017).

Increasing recycling will not only require technology development, but also the development of a recycling supply chain that manages the textiles collected (Svensson et al., 2020). For example, there is currently neither a organized collection nor sufficient infrastructure, technologies and profitability for large-scale sorting and recycling of textile fibers into new ones. Furthermore, when enabling a resource efficient recycling system, textile characteristics like chemical content, fiber composition and quality of the textile waste must be managed. This will demand a range of solutions that can manage different textiles while being economically-, socially-, and environmentally justifiable (Svensson et al., 2020). Furthermore, closing the loop and building a supply chain managing post-consumed textiles that addresses the environmental and social aspects are clear, but the challenge lies in the economic aspect. For recycled materials to compete with virgin raw materials, the recycling needs to occur to a competitive price. This price must cover for additional cost of collection, sorting, and reprocessing, among other processes (Kjellsdotter Ivert et al., 2018). Therefore, a supply chain management (SCM) is needed to bridge future potential volumes of textile waste with potential actors and capabilities that can re-loop them. SCM defines how actors collaborate to develop a product or a service (Kalantari et al., 2019). In this context actors are to collaborate together to re-loop textiles via reuse or recycling to recover their value after the use phase. Examples of actors in this supply chain are collectors that deliver textiles for the sorting companies that find the portions that can be recycled. For this to be achieved, all companies must meet each others' needs and requirements to best recover the value of post-consumed textiles.

In conclusion, textiles are a material flow of interest when it comes to value recovery and applications of circular economy. The EU's Waste Framework Directive will ensure separate collection of textiles from household waste (European Union, 2020; European Commission, 2021a), but the steps after need to be explored. More specifically, there is an urgency to explore who can recycle textile waste.

1.2 Aim and Research Questions

This Master Thesis will contribute to exploring which existing actors could manage textile waste through recycling. This study therefore aims to increase knowledge about how the textile waste caused by Swedish households can be re-looped via recycling.

This is achieved by estimating future volumes of textile waste for recycling and mapping crucial actors that could be a part of the recycling supply chain for managing these volumes. Additionally, this thesis aims to identify the present and future supply chain requirements of automated sorting- and recycling actors that are key to enable recycled textiles. Finally, the study aims to present conclusions regarding recycling future volumes of textile waste from Swedish households by portraying the challenges and enablers for this system.

Estimating future volumes of textile waste from households is an important step to understand the magnitude of the capacity needed to recycle those textiles. In previous studies about post-consumed textiles in Sweden, there had been no clear distinction of the potential magnitude and content of textile waste from households (Hultén et al., 2016; Statens Offentliga Utredingar, 2020). Therefore, this study will try to estimate future volumes of textile waste from households by answering the following research question:

RQ1. What could be expected volumes of textile waste from Swedish households suitable for recycling in the years 2025 and 2030?

The next step is to understand the capabilities and supply chain requirements of the actors that have the potential to recycle household textile waste. Thus, this study will analyze the technology readiness, capacities available, strategies, customers requirements and the actors requirements to re-loop complex textile waste from households. To analyze this, the following research question was asked:

RQ2. What are the supply chain requirements and capacity linked to automated sorters and recyclers?

Lastly, the study will analyze the future challenges for recycling of textile waste from households that will be collected by the 1st of January 2025. To understand these challenges, the following research question was asked:

RQ3. What are the challenges that the textile recycling supply chain faces and what could enable textile waste from households to be recycled efficient?

1.3 Scope of study

As mentioned in the introduction, large fractions of post-consumed textiles from households are disposed in the mixed household waste today. This study has hence investigated what would happen if these volumes were separately collected instead. How the system could function with separate collection for textiles is illustrated in Figure 1.2. In this system, collection is mainly performed by both NGOs and separate collection. Green arrows indicates the main flows for the supply chain linked to recycling. This study only regards how large the volumes can be due to textiles consumed by and collected from Swedish households, and do not regard where these volumes occur. Lastly, textile volumes are investigated based on Swedish data, whereas actors for sorting and recycling are searched for on an European level.

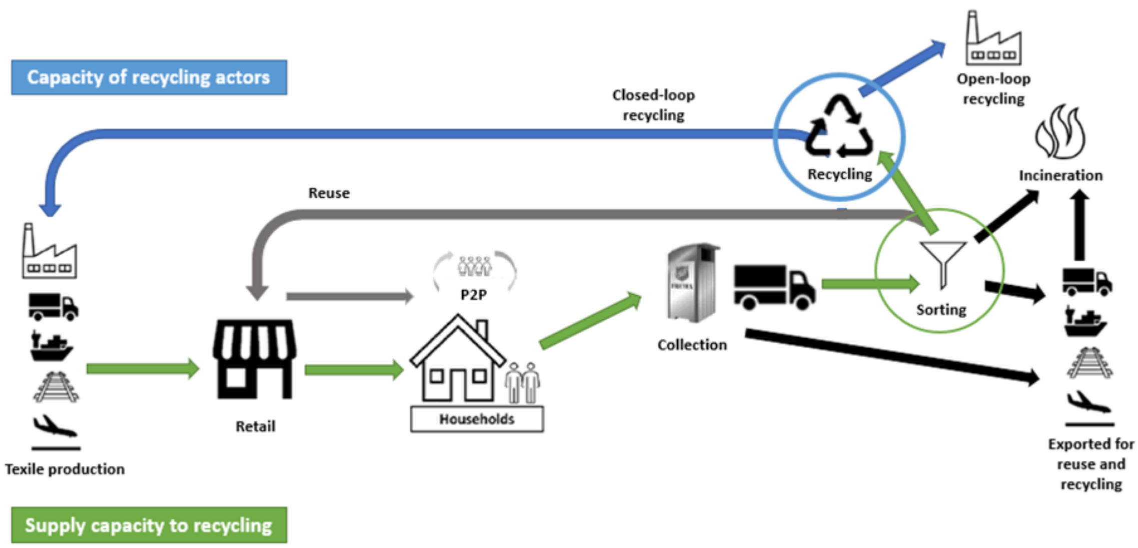

Figure 1.2: Supply chain of Swedish post-consumed textiles from households with separate collection.

The scope of the study is recycling of textile waste from households, shown in Figure 1.3 and highlighted in green. Thus, this study will cover only a part of the recycling supply chain of textiles. This thesis assumes that post-consumed textiles for households will be collected separately and treated according to the waste hierarchy. Thus, post-consumed textiles form households are first collected to be sorted manually for reuse. After the manual sorting process, the fractions of textile waste is obtained. This study investigates how those fractions can be sorted via automatic sorting and then recycled by the different existing technologies.

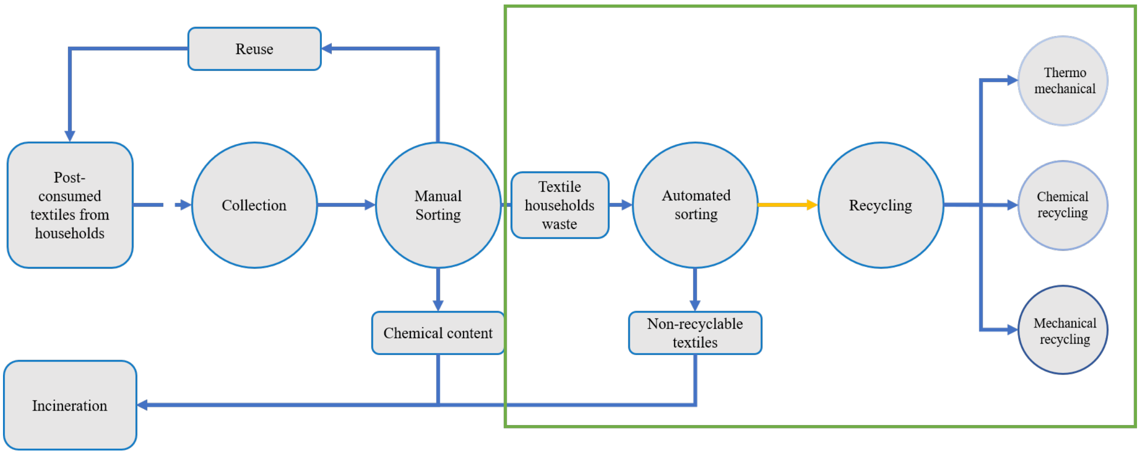

Figure 1.3: Scope of the study.

Even though the Swedish EPA states that the goal is for 60% of today's disposed volumes to be separately collected in 2025 (Statens Offentliga Utredingar, 2020), this report builds on the assumption that 100% will be collected. The reason for analysing 100% of the textile waste is to explore the full potential that can be reached by recycling.

The years 2025 and 2030 are the chosen years for estimating future volumes as a separate collection of textiles should be in place no later than 2025. The year 2030 was chosen to give an approximation of the near future volumes that need to be managed. Since the whole textile industry is under a transformation towards circularity, a relatively near future scenario was chosen.

This ongoing transformation for a more sustainable textile industry also requires finding up-to-date data. While some changes are occurring rapidly in the textile industry, others have been more stagnant. Finding statistics and relevant sources that provide the correct picture of today's situation has been within the scope of the study. Literature concerning the supply chain for textile recycling has been accepted from 2015 and onward with reasons further explained in the Methodology chapter.

1.3.1 Delimitations

The scope of the study is limited by the number of actors identified for interviewing. The supply chain requirements of the automated sorters and recyclers, or the challenges and enablers for circularity, are dependent on the type of actor interviewed and the limited picture they provide. Thus, this study does not analyze all the recycling technologies available in depth, nor all the supply chain requirements of all the existing European actors in the industry. Nevertheless, the objective is to gain a systematic understanding by extrapolating the findings from literature and interviews.

Furthermore, estimating flows of textile waste is a challenge due to the many actors affecting the industrial ecosystem where textile waste can be used as a resource. Since no clear picture of this system has been described in detail before, this thesis relies on estimates from a variety of sources. National statistics, interviews with actors within the recycling supply chain (mainly within sorting and recycling), and previous reports on the subject constitutes the premise for this thesis. The subject of this master thesis can be further explored to overcome uncertainties with the result.

1.4 Outline of thesis

The outline of the thesis is structured into seven chapters in the following way:

Chapter 1 - Introduction, gives the background and problem formulation to the investigated subject. In this chapter the aim of the study, along with research questions and scope is defined.

Chapter 2 - Theoretical framework, provides explanation for the necessary concepts managed in this report as well as the literature reviewed to answer the research questions.

Chapter 3 - Methodology, describes how the study was conducted. Hence, the methods for data collection by the literature reviewed and interviews, ethical considerations, and the quality of the study.

Chapter 4 - Results of scenario analysis, presents how the scenario analysis was conducted and the results from it.

Chapter 5 - Results of empirical study, presents the empirical findings from the interviews.

Chapter 6 - Analysis and discussion, combines the theoretical- and empirical findings in an analysis and discussion needed for answering the research question.

Chapter 7 - Conclusions, summarizes the insights gained to answer the aim of the study formulated in the introduction. This chapter will also mention future recommendations identified for gaining further knowledge about the subject.

2

Theoretical framework

The theoretical framework is structured into nine sections in the following way:

2.1 Circular Economy, gives the definition of what circular economy implies. This gives an intuition for the transition the textile industry stands before to become more circular.

2.2 Supply Chain Management, provides explanation to get a theoretical background how to analyze a supply chain.

2.3 Fibers used in textile production, this section will give an explanation of the global fiber production and some trends linked to it. It is important to get familiar with the fibers used in textile production, as these are the materials that eventually will end up as waste.

2.4 Textile consumption in Sweden, describes how textiles are currently consumed in Sweden and some trends that are associated with this consumption.

2.5 Collection of post-consumer textiles in Sweden, describes how textiles are managed by collection once becoming post-consumed in Sweden.

2.6 Sorting of post-consumer textiles from Sweden, describes some sorting technologies and how Swedish textiles are managed by sorting once becoming post-consumed.

2.7 Recycling of textile waste from Sweden, describes some recycling technologies and how Swedish textile waste are managed by recycling.

2.8 Textile volumes and trends, this section provides an aggregation of volumes and trends identified needed to estimate future volumes of textile waste from Swedish consumption.

2.9 Challenges and enablers for textile recycling, summarizes some identified challenges and enablers for the textile recycling supply chain found in the literature.

The Figure 2.1 illustrates the structure of the theoretical framework.

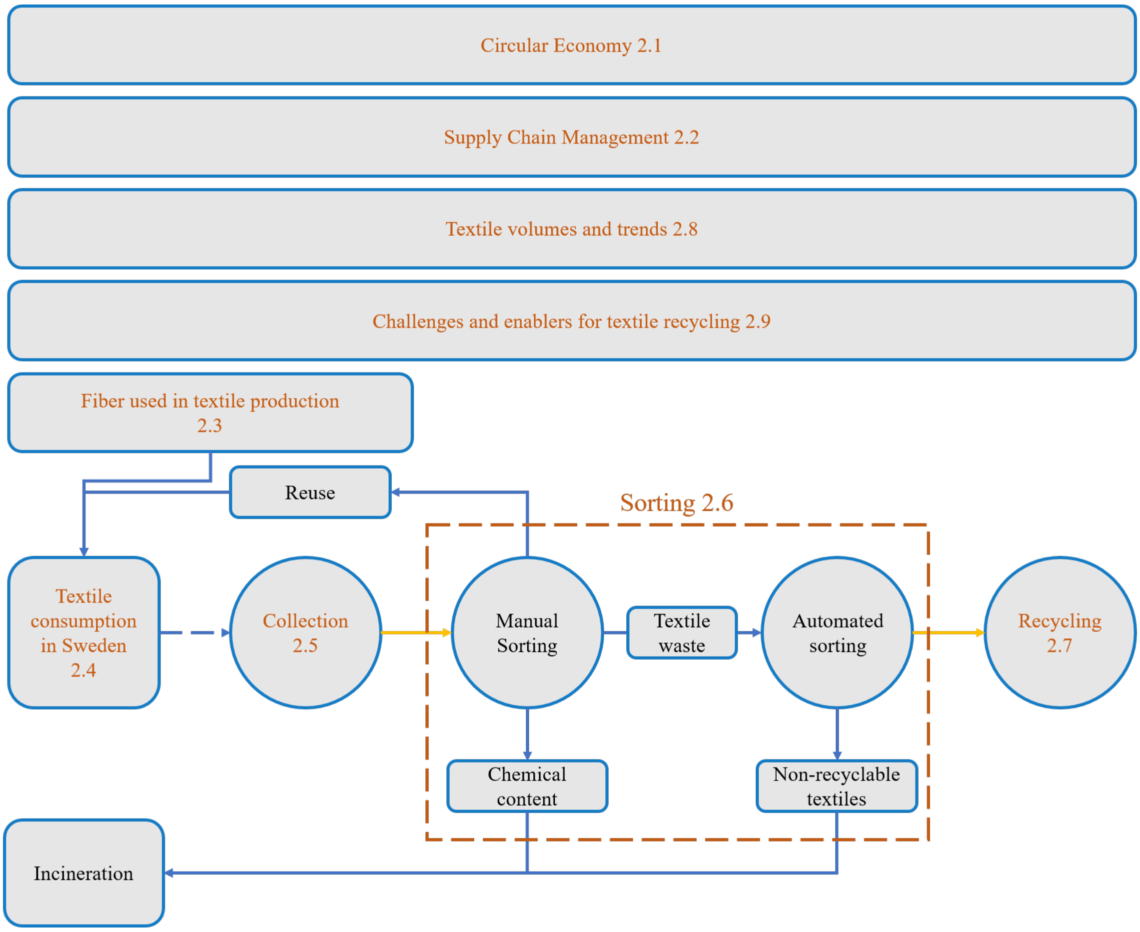

Figure 2.1: Structure of the theoretical framework.

2.1 Circular Economy

In contrast to linear economy that involves extraction of raw materials, manufacturing, use and disposal, circular economy aim for keeping materials and products in use for as long as possible. There are many definitions of circular economy, but the Ellen MacArthur Foundation's definition is one that is commonly used, and this definition states that "In contrast to the 'take-make-waste' linear model, a circular economy is regenerative by design and aims to gradually decouple growth from the consumption of finite resources" (Ellen MacArthur Foundation, 2021). The circular economy is based on three principles that are:

- Design out waste and pollution.
- Keep products and material in use.
- Regenerate natural systems.

By these principles a circular economy aims to identify and phase out negative externalities from economic activities that causes damage to human health and natural systems (Ellen MacArthur Foundation, 2021). For example, phase out emissions of greenhouse gases and hazardous substances. A circular economy also favours activities that preserves value in the form of energy, labour, and materials. In practice this can be achieved by design for durability, reuse, remanufacturing, and recycling. By doing so, the value of the products are preserved longer in the economy. Additionally, circular thinking favorites the use of renewable resources and aims to avoid non-renewable resources such as fossil based sources (Ellen MacArthur Foundation, 2021).

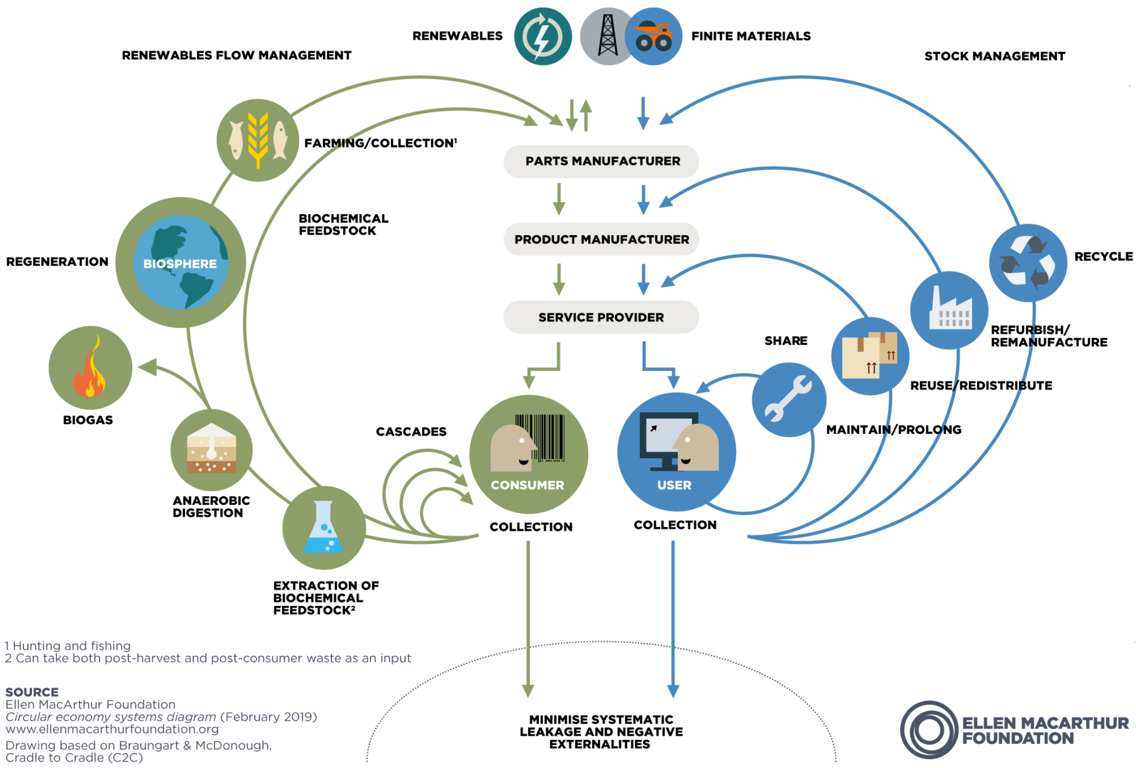

Figure 2.2: The 'butterfly diagram' from Ellen MacArthur Foundation (2019) (Ellen MacArthur Foundation, 2021).

A common diagram for explaining the essence of circular economy is the Ellen MacArthur Foundation 'butterfly diagram' shown in Figure 2.2. In this diagram, the flow of materials, nutrients, components, and products are captured while also adding an element of financial value (Ellen MacArthur Foundation, 2021). It is inspired by the book *Cradle to Cradle* introduced in 2002 by Braungart & McDonough, that called for change in the industry to switch from a cradle-to-grave pattern to a cradle-to-cradle pattern. The book puts forward a design framework that aims to eliminate the concept of waste. In the step of eliminating waste, they make the parable to the cycling of materials in nature. "In nature, the 'waste' of one system becomes food for another." This is why the 'butterfly diagram' illustrates that everything can be designed to be disassembled and safely returned to the soil as biological nutrients (green circles), or re-utilized as high quality materials for new products as technical nutrients (blue circles) without contamination (McDonough & Braungart, 2002).

Textiles are products that should follow the technical cycles in the 'butterfly diagram', Figure 2.2. In the technical cycles, the innermost loops show the strategy of maximizing the use of products and materials followed by prolonged lifespan through design for durability, maintenance, and repair (European Commission, 2021d). The outermost loops show the strategy of keeping the materials circulating in the system by remanufacturing and recycling. This logic correlates with the European strategy for waste prevention and management, that has the aim to improve resource efficiency by preventing products and materials from becoming waste for as long as possible and turning waste that cannot be avoided into a resource again (European Commission, 2021d). This is why a circular economy for textiles focuses on value creation in the technical cycle by increasing the rate of textile utilisation and lastly recycling (Ellen MacArthur Foundation, 2017).

Waste policies within the EU aims to contribute to the circular economy by collecting and re-looping high-quality resources from waste as much as possible. It sets objectives and targets to improve waste management, stimulate innovation in recycling, and limit landfilling. The EU's legal framework for treating and managing waste, the Waste Framework Directive (Directive 2008/98/EC), has introduced an order of preference for waste management called the 'waste hierarchy' (European Commission, 2021b). The five steps of the waste hierarchy is shown in Figure 2.3. These five steps are ranked according to their environmental impact. The priority is to prevent and reduce waste, and if waste cannot be avoided, the next priority should be recycling or recovering its energy content, and as a last resort, landfilling waste (European Commission, 2020).

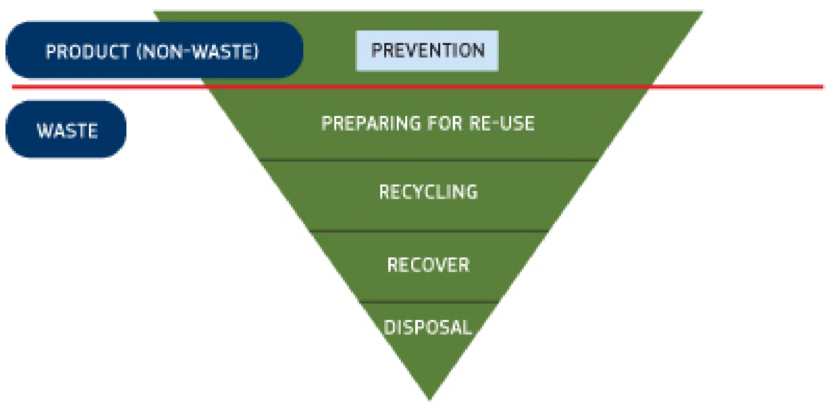

Figure 2.3: The waste hierarchy by the EU Waste Framework Directive (European Commission, 2021d)

Prevention

Measurements taken to prevent the generation of waste: the framework recommends using less material in design and production, extend the life usage of the products, and avoid the use of hazardous materials. Through waste prevention the value generated is maximized by preventing environmental and economical costs, and by maximizing the use of the product produced (European Commission, 2020).

Prepare for reuse
The process of assessing the product's end of life, and maintaining (clean), repair, or refurnish spare parts: the process entails sorting, logistical, repairing or re-manufacturing. The environmental and economical costs can be minimized by applying reuse (European Commission, 2020).

Recycling
The process of turning waste into raw materials or products by extending the usage of the materials: this process requires similar costs associated to reuse, and additional environmental and manufacturing costs when breaking down the product. The materials gained from recycling can be used for the production of new products in the same or other industries (European Commission, 2020).

Recover
The process of energy recovery in form of fuel heat and power, through incineration, anaerobic digestion, gasification, pyrolysis or backfilling: the energy recovery makes use of marginal value of the product at an environmental and economical cost (European Commission, 2020).

Disposal
The disposal of waste through incineration or landfill without energy recovery: the process where all the value of the product is lost at an environmental and economical cost (European Commission, 2020).

The Waste Framework Directive further defines when waste ceases to be waste and become a secondary raw material. Here it states that waste ceases to be waste based on the following (European Commission, 2021c):

- The substance or object that is commonly used for specific purposes.
- The substance or object that have an existing market or demand.
- The substance or object is used lawfully (substance or object fulfils the technical requirements for the specific purposes and meets the existing legislation and standards applicable to products).
- The use of the substance or object will not lead to overall adverse environmental or human health impacts.

The directive also introduces the 'Extended Producer Responsibility' (EPR) as a strategy to achieve better waste management. According to the European Commission "EPR puts an obligation on producers to take operational or financial responsibility for the end-of-life phase of their products", this requires to "set an obligation for collective schemes to modulate the financial contributions paid by producers for their individual products or groups of similar products, taking into account their durability, reparability, re-usability and recyclability and the presence of hazardous substances, thereby taking a life-cycle approach" (European Comission, 2019).

2.2 Supply Chain Management

The most quoted contemporary definition of the term Logistics might come from the interest group Council of supply chain Management Professionals (CSCMP). Logistics is "the process of planning, implementing, and controlling procedures for the efficient and effective transportation and storage of goods including services, and related information from the point of origin to the point of consumption for the purpose of conforming to customer requirements. This definition includes inbound, outbound, internal, and external movements" (CSCMP, 2013). This thesis treats the concept logistics and SCM as interchangeable (Kalantari et al., 2019).

The term Suppy Chain Management was coined in 1982 by Keith Oliver, who pointed out that many companies have a challenge in coordinating their ever longer and more complex supply chains (CSCMP, 2013). There was a need for a new term that emphasized the system view and the importance of relations between other actors in the supply chain. The main message in SCM means that companies that are in a supply chain must strive for low costs and good service to end customers, which is achieved through coordination with other players with a focus on "win-win" (CSCMP, 2013). The Figure 2.4 provides a picture of the different types of actors that can be present in a supply chain.

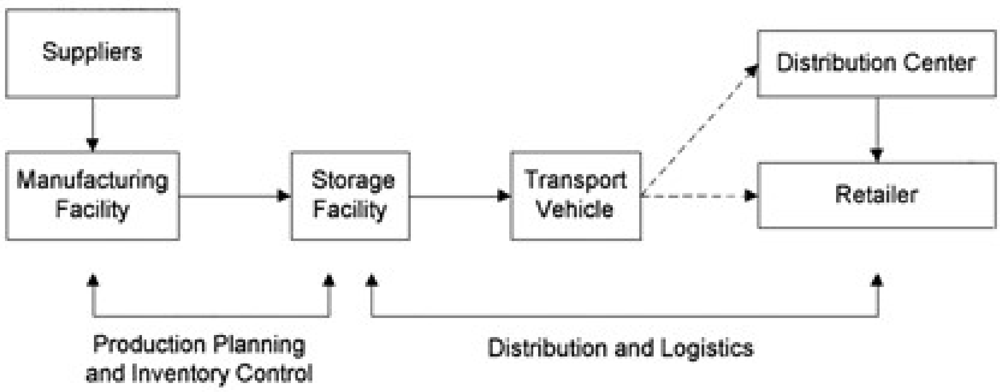

Figure 2.4: supply chain Management (SCM) process (Beamon, 1998).

Based on those definitions, SCM is the process in which the different stakeholders in a given supply chain collaborate based on their mutual interests to create a product or a service that provides value to the end customer. The stakeholders are interconnected in this chain of value. The materials are exchanged between the actors and transformed by each member of the supply chain. To be successful, each actor needs to meet their interests as well as the interests of the next actor in line of the supply chain (CSCMP, 2013; Heikkilä, 2002; Sandberg, 2021; Kalantari et al., 2019). Thus, analysing the supply chain implies understanding the role or importance of the actor, their strategy, their customer requirements and their requirements. These factors are based on the literature but has been aggregated by the authors in this thesis.

Importance
The first step to analyse an actor in a supply chain is to identify the role that the actor has in it (CSCMP, 2013). In other words, what role does an actor have and what is its relation to the other actors in the supply chain. By doing so we can understand the importance of relative value it provides in the supply chain and for the end customer (CSCMP, 2013).

Strategy
The second step is to analyze an actors strategy to provide the value they are set to provide. In order words, what are the capabilities and strategy that the actor has to transform the raw material or feedstock. Part of the process is to meet the needs of their customers while striving for low costs (CSCMP, 2013; Kalantari et al., 2019) .

Customer requirements
To best define the strategy, the next step that has to be analyzed is the customers' requirements. In other words, the needs of the next actor in line of the supply chain. The customers requirements can be defined in terms of quality, price and delivery of the product. The quality is the degree to which the product satisfies and/or exceeds the needs of the customers (Heikkilä, 2002). The price measurement evaluates the qualitative performance affecting the profitability of the product or service delivered (Beamon, 1998). The delivery is defined as activities aimed to deliver a product or a service to the correct customer, in the right condition, place and time (Sandberg, 2021).

Actor's Requirements
Inevitably, the challenges that an actor has to face to set their strategy and to meet their customer need can be described as the actor's requirement. Thus, the actor's requirements are the needs that the previous actor in the supply chain have to meet. This can be seen as the last piece of the puzzle to get the full picture of the supply chain requirements (Heikkilä, 2002).

In conclusion, a successful supply chain that manages materials transform them to create value to the end customer and society (CSCMP, 2013; Heikkilä, 2002). To determine the future of the supply chain, it must do so in a cost and resource efficient way. To analyse the efficiency and future of a supply chain, its actors and their requirements can be analyzed (Sandberg, 2021; Kalantari et al., 2019).

2.3 Fibers used in textile production

There are a wide range of different textiles that can be made from a number of different fibers. These fibers can be natural or synthetic, which are also different from each other (Statens Offentliga Utredingar, 2020). In 2019, 111 million metric tonnes of fibers was produced for textiles globally (Opperskalski et al., 2020). Of these, 52% was polyester, 23% cotton, 6.4% manmade cellulosics (MMCF), about 1% wool, less than 1% down, and the rest are other fibers (from hemp to elastane) (see Figure 2.5). Textile fabrics that consists of single fibers are rare on the market, most textiles are mixes of fibers to provide all the desired properties of comfort and quality (Rex et al., 2019).

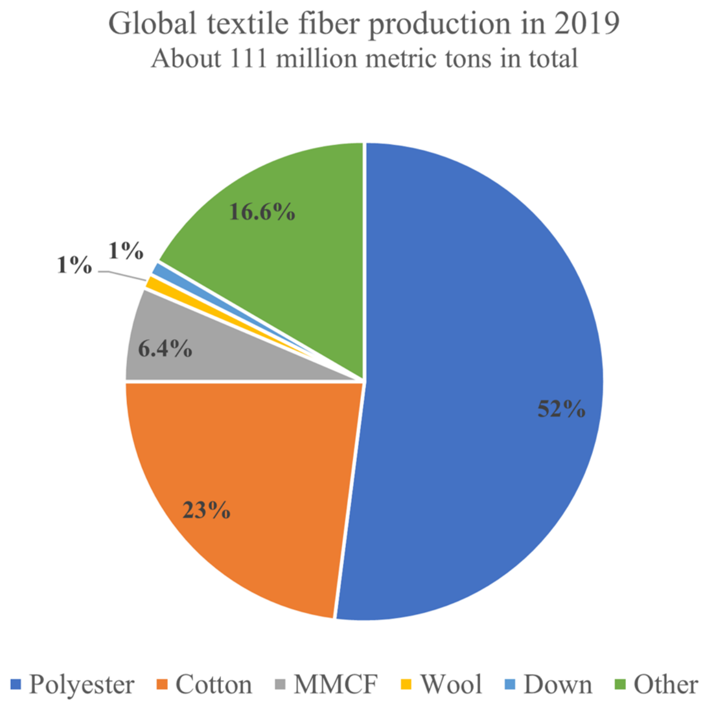

Figure 2.5: The global fiber production in 2019 (Opperskalski et al., 2020).

Synthetic fibers constitutes the largest share of global fiber production with approximately 63%. Polyester is the most common synthetic fiber and is produced from crude oil, but it is also estimated that 14% of polyester fibers derives from recycled plastics (mainly PET plastic bottles), and less than 1% of derives from bio-based materials (Opperskalski et al., 2020). Synthetic fibers are known for their strength, and this is why they often are mixed with other fibers to increase durability (Rex et al., 2019).

Cotton constitutes the second largest share of the global fiber production. Of the cotton produced, about 25% is preferred cotton which implies a more sustainable production (Opperskalski et al., 2020). It has been identified that conventional cotton fibers need to be replaced due to the impact of its cultivation that contributes to toxicity and water stress. This is something that has been identified for a long time, as the development of synthetic and regenerated fibers historically has been strongly influenced by the high price and uncertainties of the supply of cotton (Rex et al., 2019).

Textile-to-textile recycling is placed under the production of Man-made Cellulosic Fibers (MMCF) (also referred to regenerated cellulose fiber) (Rex et al., 2019). Although, less than 1% of the MMCF produced originates from textile waste. MMCF are currently mainly produced from wood that is a cellulosic fiber and since cotton also is a cellulosic fiber, the textile waste from cotton can be used to produce MMCF. This fiber is expected to become more important when supplying the demand of textile fibers in the future. The production volume for this fiber has already more than doubled in the past 30 years, and it is expected to further increase. MMCF can be used in the production of the textiles like viscose and lyocell. Viscose constitutes the largest application where 79% of all MMCF is used to produce this fabric (Opperskalski et al., 2020; Rex et al., 2019). Theoretically, MMCF or regenerated fibers could be made from any source of cellulose of sufficient concentration and quality (Rex et al., 2019). Regenerated MMCF are often claimed to be a more sustainable alternative to cotton. These fibers possess many similarities in properties to cotton since the chemical structure is similar (Rex et al., 2019). This is why recycling of cotton has been identified as one approach towards a more circular textile industry. As an example, if just 25% (5 million mt) of global pre- and post-consumer cotton textile waste along with 25% (1.6 million mt) of rayon waste (a type of MMCF) were to be used in the production of dissolving pulp for producing textiles of MMCF, it could replace all wood currently used in this production (Opperskalski et al., 2020).

There are no fibers on the market or in development in lab scale today that have the technical feasibility to match the comfort and technical properties of conventional cotton (Rex et al., 2019). If requirements can be lowered, there are several fibers that can substitute cotton. Here, wood-based regenerated fibers such as viscose and lyocell has been used to substitute cotton. When it comes to substituting conventional polyester or fossil-based synthetic fibers there are fibers that can match the comfort and technical properties. Synthetic fibers can be chemical recycled to gain equal performance to virgin fibers, and synthetic fibers can also be bio-based. The main challenge for more sustainable synthetic fibers is hence to develop production paths that preform good environmentally, economically and socially when substituting the fossil-based supply of synthetic fibers today (which is about 65 million tonnes annually) (Rex et al., 2019).

What can be concluded is that the sustainability performance of textiles can be decided by the fibers used in different types of textile products and their further possibility for reuse and recycling at end-of-life (Rex et al., 2019). It has been found that doubling the time a garment is used can decrease the climate impact by half. This implies that right quality for a specific product type is key for optimising the environmental performance of textiles through its life cycle. The fiber quality should hence be sufficiently dimensioned for the right application (Rex et al., 2019).

2.4 Textile consumption in Sweden

Statistics by the Swedish Environmental Protection Agency (Naturvårdsverket) show that in 2019 the netinflow of new textiles (textiles consumed) was 13,7 kg per person of which 9,9 kg where clothes and 3,8 kg home textiles. This means that a total of 141 100 tonnes textiles was consumed in Sweden in 2019. This consumption of textiles has increased with 30% compared to year 2000, were the consumption was 10,7 kg per person. The trend for consumption during these years can be observed in Figure 2.6. In this increase, home textiles makes up the largest share. The netinflow of home textiles in 2000 was 1,9 kg, which means it has doubled. The share of the total netinflow for home textiles has increased from 18% in 2000 to 28% in 2019 (Naturvårdsverket, 2021).

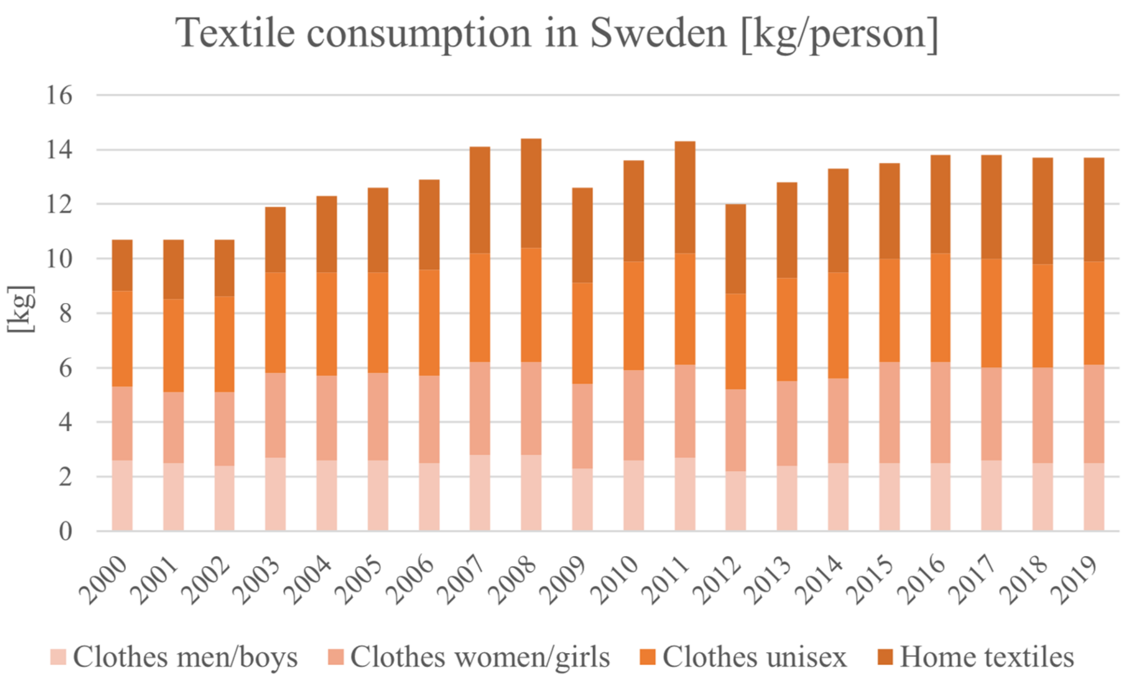

Figure 2.6: Annual netinflow of new textiles in Sweden from 2000 to 2019 (Naturvårdsverket, 2021).

The e-commerce consumption of textiles imported from outside the EU into Sweden are not included in the statistics of the netinflow of textiles (Statens Offentliga Utredingar, 2020). Paradoxically, the export in Sweden via e-commerce is included in the statistics of the national consumption on textiles. Due to the free movement of goods within EU, there is no national system to register the import of goods within EU. This is why statistics of the import of textiles by e-commerce in Sweden has not been investigated today and it is hard to estimate due to the lack of statistics. Although, other statistics can give an intuition of the extent of e-commerce, as this constituted 20% the total fashion trade in Sweden in 2019 (imports from EU around 62% and in the rest of the wold around 33%). It is also observed an increasing trend for Swedish textile retailers to establish e-commerce. Also, the Covid-19 pandemic who has given the e-commerce an increasing market share has probably lead to an increasing share of consumers that will continue to prefer e-commerce before shopping in physical shops (Statens Offentliga Utredingar, 2020).

When it comes to the consumption of secondhand textiles, there has been studies commissioned by the Swedish EPA on mapping online marketplace trade and trade by secondhand-actors. The latter refers to textiles collected and sold for reuse by NOGs in Sweden. The latest data for this is obtained by SMED in 2016, which shows that 7800 tonnes of textile in total and 0.8 kg/person was reused in Sweden. This was an increased by total amount from 2011, where total amount for reuse was 6500 tonnes, but this is not an increase per person since Swedish population increased the same degree between 2011-2016 (Belleza & Luukka, 2018). This indicates that the demand for reused clothes was stabilized for the mentioned years.

The increase of the Swedish population is an important factor to consider as this will have a affect on the total consumption in the future. In statistics from the governmental institution Statistics Sweden (SCB) about 'The future population of Sweden 2019-2070' (Statistiska Centralbyrån, 2019) the future population is prognosed. They concluded that in 2018 the Swedish population was 10.2 million, and by 2029 the 11 million inhabitants limit will be surpassed, 12 million by the 2050s and in year 2070 the population is estimated to be 12.8 millions. This increase is due to on an increase in childbirths (from 1.76 to 1.88 children per women), and increased average lifespan (about one year per decade), and an positive net migration. The statistics for the years 2025 and 2030 can hence be found on Statistics Sweden (SCB), where they are estimated to be 10,786 and 11,095 millions respectively (Statistiska Centralbyrån, 2021).

2.5 Collection of post-consumer textiles in Sweden

In Sweden, textiles are collected through municipal collectors, commercial collectors or NGOs (Statens Offentliga Utredingar, 2020). There is no national system for separate collection of textiles and there is no other large scale collection part from the ones mentioned. This implies that large fractions of unwanted textiles from households ends up in the mixed municipal waste, where it is sent directly to incineration for energy recovery (Statens Offentliga Utredingar, 2020).

The NGOs are dominating the collection and further the second-hand retail in Sweden today. These operates as voluntary organisations to raise revenues that can support non-profitable purposes as charity in Sweden but also abroad. As an example of the result of this work, in 2014 it was estimated that 12-15 NGOs part of the Ideal Secondhand Network (ISH) contributed to social benefit worthy of between

7,7-15 millions of Swedish crowns. It is estimated that there are around 15-20 voluntary organisations in Sweden, and the largest are Human Bridge, Myrorna and Röda Korset (Statens Offentliga Utredingar, 2020). It is estimated that swedes donate 3.8kg of used textiles per person annually to voluntary actors and this kind of collection is estimated to be 87% of the total collection of textiles in Sweden. The estimation is based on data from 2016, who also revealed an increase in volumes collected from NGOs with 27% from 2008 (increased volume collected per person) (Belleza and Luukka, 2018; Statens Offentliga Utredingar, 2020). The total collection of textiles by voluntary actors in 2016 was 38300 tonnes (3.8kg per person) and of this, around 68% was managed in Sweden. Of the collected fractions, about 20% were sold or distributed to charity purpose in Sweden. This is estimated to be 30-40% of total income for the voluntary organisations and are used run their business that promotes the social and environmental benefit. Further, 72% of collected fractions were exported to sorting facilities (Belleza and Luukka, 2018; Statens Offentliga Utredingar, 2020).

The commercial actors that provides textile collection are becoming a more common feature (Statens Offentliga Utredingar, 2020). The purpose of collection in this case is mainly reuse but some collect both reusable textiles and textile waste. Examples of commercial actors are retailers offering to take back used textiles in stores such as H&M. Accordant to a small investigation about the extent of this possibility, it was revealed that about 1000 stores in Sweden collects used textiles. It is further common that they collect in cooperation with further actors preforming collection like NGOs or larger international collecting actors. To incentive consumers to deliver their textiles, some commercial actors offer vouchers to be used for purchasing new products, others communicate the climate- and environmental benefit of this consumer behaviour. The fractions collected by retailers was estimated to be 1400 tonnes in 2019, which was increased with 320 tonnes from the year before. Other commercial actors are private collectors commissioned by municipalities or other actors, or private secondhand actors (Statens Offentliga Utredingar, 2020).

The municipalities are responsible for collection of household waste and it is estimated that 2-4% of this waste are textiles (Statens Offentliga Utredingar, 2020). These textiles are expected to be a mix of usable and worn-out textiles. Regardless of quality, these textiles ends up being treated as mixed household waste and goes to incineration for energy recovery. There are some municipalities in Sweden that has separate collection for textiles today. Furthermore, about 50 municipalities in Sweden state that they have separate textile collection at local recycling centres. This collection often occurs in cooperation with voluntary organisations, but there are municipalities that started social initiatives around post-consumed textiles. Which fractions of textiles that ends up in the waste that goes to incineration at the recycling centres are unknown, but it is estimated to be a significant amount after analysing this kind of treatment (Statens Offentliga Utredingar, 2020).

In a study by SMED (2016) commissioned by the Swedish EPA with the aim of mapping and analysing the textiles disposed in the household waste, it was revealed that households does not apply the waste hierarchy when disposing textiles (Statens Offentliga Utredingar, 2020; Hultén et al., 2016). The purpose with the study was to analyse what kind of textiles were disposed, and to make an estimation of the volumes that could be treated in this way and hence sent to incineration in Sweden. For this study they preformed 391 picking analyzes of municipal waste between the years 2012-2014 to estimate the share of textiles in this total waste volume. Further, they did 14 specific analyzes that looked into the different textiles, material composition and their quality. The result for the study confirmed that in Sweden, each person per year disposes 7,6 kg textiles. If fractions for business and shoes are subtracted, households stands for disposing 5,1 kg textiles per person annually. Of these 5,1 kg from households, 3,1 kg was clothes, 1,5 kg home textiles, and 0,5 kg was of special product groups (products who may contain hazardous substances). Further analyze of the content revealed that 59% of the content were in a shape for reuse, 58% of disposed products were pure cotton, and the rest was mostly mixed material compositions. It was also found that 10% of disposed textiles were classified as non-recyclable as they potentially could contain hazardous substances. The conclusion was hence that there was a potential to obtain fractions for reuse and further recycling if post-consumed textiles from households were to be collected and managed better (Hultén et al., 2016; Statens Offentliga Utredingar, 2020).

2.6 Sorting of post-consumer textiles from Sweden

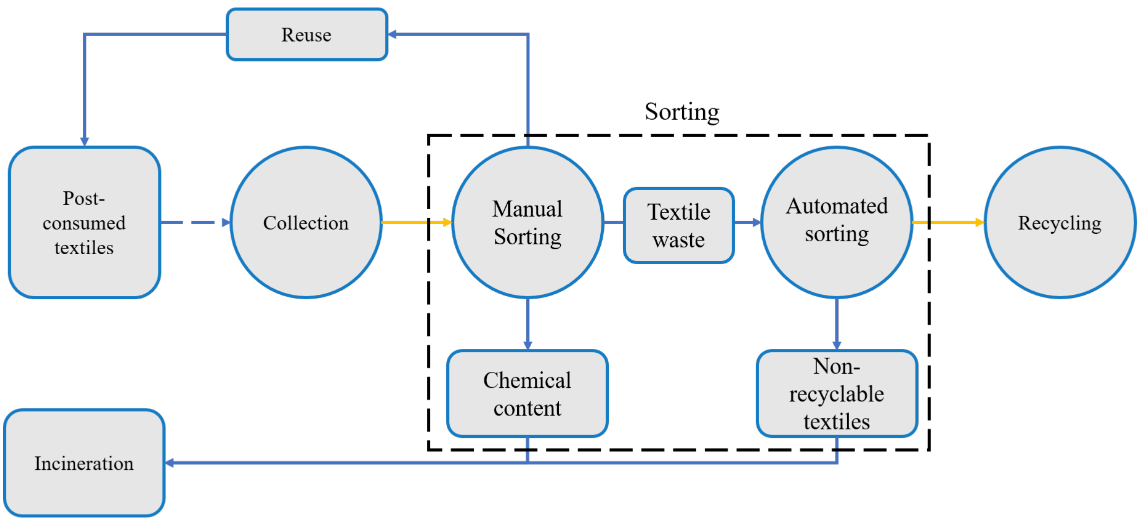

Figure 2.7: Sorting in the recycling supply chain of textiles.

Sorting of post-consumed textiles can be defined as the classification process of their function of usability (M. Dubois et al., 2020). The usability of post-consumed textiles depends on the economical value it can yield. The most profitable outcome of post-consumed textiles is reuse where they are sold second-hand (M. Dubois et al., 2020). When textiles are not reused, they are either recycled or send for incineration. Textiles can be sorted manually and automatically, were manual sorting is used to identify reusable textiles and automated sorting is used to sort textile waste for recycling processes as illustrated in Figure 2.7 (Statens Offentliga Utredingar, 2020; De La Motte et al., 2019).

Manual sorting

Manual sorting of collected textiles takes place in relatively small scale in Sweden, instead a large fraction of collected textiles in Sweden is exported and then sorted. This sorting is carried out primarily in the Baltic's countries and Central Europe at large-scale sorting plants (Watson, Kant Hvass, et al., 2020; Statens Offentliga Utredingar, 2020). Sorting textiles for reuse is today done manually and is labor-intensive because sorting by fashion, trend and demand requires professional knowledge and experience. Some non-profit organizations in Sweden sort all or parts of the collected material themselves (Belleza & Luukka, 2018). However, there are large variations between different organizations in how the sorting is carried out and where it takes place. Of the 38,300 tonnes of textiles and textile waste collected in 2016, 16,300 tonnes were sorted directly in Sweden, of which 7,800 tonnes were sold in the organizations' own second-hand shops and reused in Sweden. This implies that 27,700 tonnes of collected textiles were exported for further sorting, mainly to the Baltic's countries and Eastern Europe (Belleza and Luukka, 2018; Statens Offentliga Utredingar, 2020; Watson, Kant Hvass, et al., 2020).

Textile materials that are exported can be divided into the following three categories: pre-sorted, unsorted and aid (Statens Offentliga Utredingar, 2020; Belleza and Luukka, 2018). Unsorted textiles make up 79 % of the textiles exported. This proportion of exported textiles is the largest share partly because manual sorting is labor-intensive and that labor costs are high in Sweden, and partly because unsorted textiles are sold with a higher price since a higher percentage of reusable clothes are likely to be there (Statens Offentliga Utredingar, 2020). It is estimated that about 10 % of the textiles that non-profit organizations collect accounts for over 50 % of the value of what is being collected. This share is sold mainly in Sweden or in second-hand stores in Western Europe. Another 50–60 % of the material consists of clothing that is exported to other markets and they account for 40% of the value (Statens Offentliga Utredingar, 2020). Only 14 % of the exported material consists of pre-sorted textiles (Belleza & Luukka, 2018).

A rapport by the Nordic Council of Ministers addresses the role that the Baltic countries plays for the circular supply chain of Nordic textiles (Watson, Kant Hvass, et al., 2020). As explained, due to the low waging costs and market demand for reused clothes, 90.000 tones of textiles annually are imported by the Baltic countries to be sorted for reuse manually. Second-hand textiles make up a significant share of total household consumption of textiles: 29% in Latvia and Lithuania and 16% in Estonia and new actors are emerging to meet the needs of the market. However, is important to note that 42% of the collected textiles are send to landfills or incineration, because few of the sorted textiles are recycled. Thus, the rapport portraits one potential market and sorting actor in Europe, but also the importance to complement the textile supply chain for countries that have the capabilities to recycle discarded textiles.

After further sorting in the Baltic's countries or Eastern Europe, the textiles are sold on the global market. The best quality stays in Scandinavia or in Europe, since there is a great demand for used textiles in Eastern Europe, including Russia. Lower quality garments exported to Africa, the Middle East and Central Asia (Statens Offentliga Utredingar, 2020).

Automated sorting

As mentioned, textiles are not a homogeneous material but consist of a number of different fibers (Statens Offentliga Utredingar, 2020), and this is why specific sorting is key to provide recyclers with reliable feedstock. This means that sorting needs to be done at the molecular level, and this can not be done manually but requires automated sorting to achieve the required precision (Statens Offentliga Utredingar, 2020; De La Motte et al., 2019).

The automated sorting sorts textiles depending on material and color. This process can be done by the use of NIR and VIS technology (Watson, Trzepacz, et al., 2020; Nørup et al., 2018; WRAP, 2019). NIR stands for Near-infrared spectroscopy and is used to identify fiber content from its unique chemical near-infrared spectrum. VIS stands for Visible spectroscopy and this can identify different colours. With these technologies, textiles can be sorted to meet the specific requirements of the recycling companies (Statens Offentliga Utredingar, 2020).

In Sweden, several research and pilot projects are currently being scaled up to a larger-scale industry (Statens Offentliga Utredingar, 2020). In November 2020, the waste company Sysav started, in collaboration with Vinnova as funder, the research project Swedish Innovation Platform for Textile Sorting (SIPTex), the world's first large-scale automated sorting plant for textile waste in Malmö, Sweden. The plant will eventually have the capacity to sort 24,000 tonnes of textile waste per year.

2.7 Recycling of textile waste from Sweden

Recycling is the process of breaking down a product for it to be used in the production into new products (Ellen MacArthur Foundation, 2021). To achieve efficient recycling of textiles, three factors are to be considered: chemical content, fiber compositions and quality (De La Motte et al., 2019).

The main recycling routes for textiles are thermo-mechanical recycling, chemical recycling and mechanical recycling as shown in Figure 2.8. Each is able to recycle certain types of materials and outputs different product types. Different recycling techniques are suitable for different textile materials and this is why a broad spectrum of recycling techniques are needed to manage all types of textile fibers that has become waste (De La Motte et al., 2019).

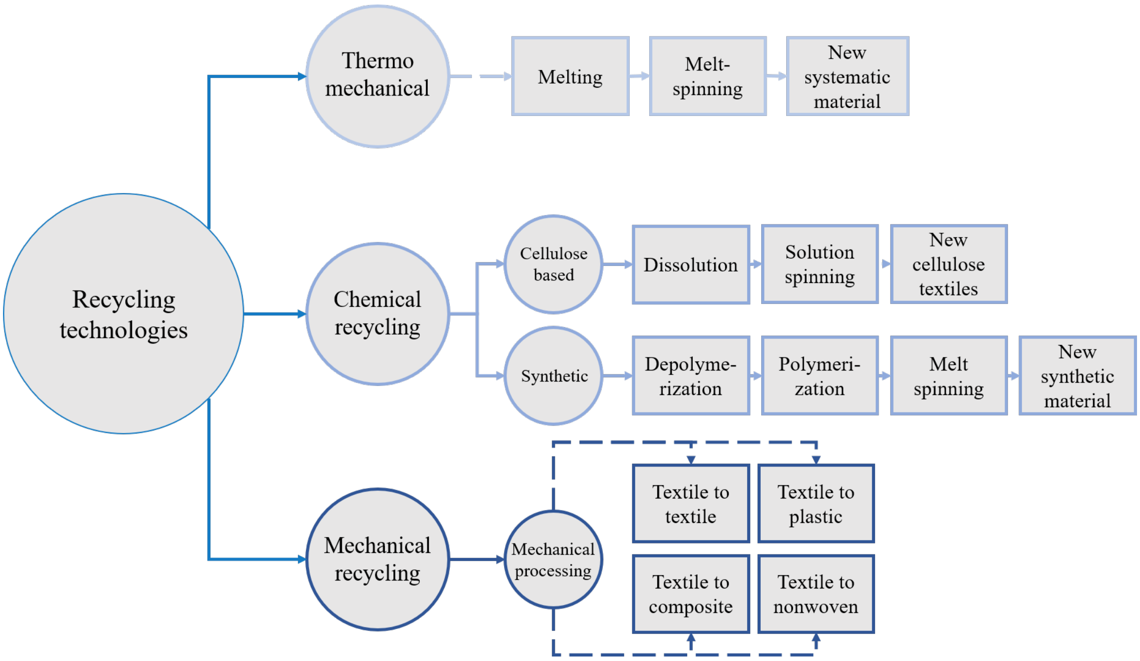

Figure 2.8: Recycling technologies (De La Motte et al., 2019).

Today, less than one percent of textile waste in Sweden is recycled (Statens Offentliga Utredingar, 2020). Swedish textile waste is mainly exported to be recycled. Of the exported Swedish textile waste, 20% reaches European recycling plants and becomes downcycled mechanically into rags, insulation materials for upholstery in cars, or used in various composite materials. In Europe, chemical recycling takes place mainly in pilot projects and on a smaller scale, but is developing at a rapid pace. Sweden is in the forefront of cellulose-based recycling (Statens Offentliga Utredingar, 2020).

Mechanical recycling
The most established way to recycle textiles today is through mechanical recycling. In this process, the majority of the textiles are typically downcycled into rags, isolation panels or mats (Palm et al., 2015; Schmidt et al., 2016; Lexén et al., 2016). The quality and durability of the material are deteriorated in the process since the textiles fibers are shorten, which makes them an inferior product to virgin textiles. However, the technology is simple, can handle a wide range of types of materials and consumes relative low energy (De La Motte et al., 2019; Lexén et al., 2016).

Mechanical upcycling solutions are in relative small scale compared to the downcycling solutions (Sandin & Peters, 2018). An upcycled solution can be new fiber production manufactured by spinning recycled yarn (Sandin, Peters, & Schwarz Bour, 2019). In Sweden, RISE and Borås School of Textiles are developing a test plant for mechanical recycling with the aim to develop upcycled materials from textiles (Statens Offentliga Utredingar, 2020).

Thermo-mechanical recycling
Synthetic fibers (for example, polyester that constitutes 52% of textile fibers globally (De La Motte et al., 2019)) can be melted to produce granules that are used to spin new fibers. Fiber and polymers such as elastane, and certain debris such as dust are dirt, are to be removed to enable this recycling process since they cannot be melted (Sandin, Peters, & Schwarz Bour, 2019).

Chemical recycling
A better alternative for recycling of textiles, but used in a smaller scale, is chemical recycling (Schmidt et al., 2016). Through chemical recycling, the value and properties of textile materials are better preserved. However, the process is more resource intensive and economically costly (Statens Offentliga Utredingar, 2020; Schmidt et al., 2016).

The method for chemical recycling aims to make use of the molecular constituents of textiles (De La Motte et al., 2019). By recycling into molecular level, new textile fibers as well as other materials can be produced from this. Different methods for chemical recycling of textiles has different feedstock requirements because this affects the chemical processes used and the quality of output products. This is why it is key to understand the textile content in feedstock for this recycling method. The most common feedstock for this process are blends of cotton and polyester as these fibers are commonly mixed since they complement each other (De La Motte et al., 2019).

Chemical recycling can be synthetic or cellulose based recycling (De La Motte et al., 2019):

- Synthetic fibers are recycled chemically by depolymerisation. The polymer chains are broken into monomers, and after being purified, additives removed (through distillation), and separated, they are turned into polymers once again (Sandin, Peters, & Schwarz Bour, 2019). The polyester polyethylene terephthalate (PET) and nylon are today chemically recycled at a commercial, yet limited, scale. The polyester input material is generally post-consumer PET from food packaging materials and (pre-consumer) industrial waste (Sandin, Peters, & Schwarz Bour, 2019). The nylon input is generally post consumer nylon from carpets, fish farm nets and industrial waste. Recycled fibres have in principle the same properties as virgin synthetic fibres (Statens Offentliga Utredingar, 2020). Almost all polymers can be depolymerised in theory, however, an efficient and practical process has not (yet) been developed for all polymers, for example for nylon.

- Cellulosic fibres (for example, cotton that constitutes 23% of textile fibers globally (De La Motte et al., 2019)) can be chemically recycled by a pulping process followed by solution spinning to produce other cellulosic fibre-based materials (De La Motte et al., 2019). These fibers are known as man-made cellulosic fibers (MMCF) and are mainly produced from forest-based cellulose today and used in the production of lyocell and viscose (De La Motte and Palme, 2018; Opperskalski et al., 2020). Chemical recycling of cotton produces MMCF that in principle have the same properties as other MMCF. The goal for further development is to decrease the environmental- and economical costs further (De La Motte et al., 2019).

Since 2017, the recycling company Renewcell operates one of the first chemical recycling facilities in Europe for textiles (Statens Offentliga Utredingar, 2020). The raw material consists of used cellulose textiles (mainly cotton) which are chemically dissolved into biomass and result in a cellulose granulate called Circulose. The granulate can be used as a raw material for fibers such as viscose and lyocell. Renewcell's current plant in Kristinehamn has a capacity of 7,000 tonnes per year. Another facility in Sundsvall with a capacity to process 70,000 tonnes of textile waste per year is under development. Establishment is expected to take place at the beginning of 2021 and production start is planned for 2022. The goal is to produce 60,000 tonnes of granules of viscose per year in the new plant. This spring, H&M launched the first garment out of textile waste - a dress - which consists of 50 % granules from Renewcell. Moreover, Renewcell has signed a five-year agreement with Chinese Tanghsan Sanyou, one of the world's largest producers of viscose fibers, where Renewcell will supply 175,000 tonnes of Cirqulose per year (Statens Offentliga Utredingar, 2020).

Another actor in Sweden doing chemical recycling of cellulose textiles (cotton) is Södra. Furthermore, they uses a technology that can separate cotton and polyester fibers from polycotton textiles (cotton and polyester). The cotton fractions can then be used to produce viscose (De La Motte & Palme, 2018). Södra Cell uses the separation technology, called OnceMore, on a large scale at Södra's mill in Mörrum. After separating the cotton and polyester fibers, recovered cotton fibers are added to Södra's regular production of cellulose pulp suitable for new textiles. Production has initially been at a low level of about 30 tonnes per year, but the goal is now to increase capacity and add 25,000 tonnes of used textile fiber to the company's pulp production as early as 2024. At the same time, Södra states that the amount of recycled textiles that are mixed in today amounts to 20 % of the total cellulose pulp, but the goal is for half of the pulp to be based on used textiles (Statens Offentliga Utredingar, 2020).

2.8 Textile volumes and trends

The volumes and trends needed to estimate future volumes of textile waste in the sections above has been aggregated. Volumes are presented in Table 2.1, and the trends affecting the supply chain for closing the loop of textile waste in Sweden identified are:

- The Swedish population is expected to increase accordant to the prognosis given by SCB (Statistiska Centralbyrån, 2019) (Statistiska Centralbyrån, 2021).

- The textile consumption has since 2000 to 2019 increased by 30%, although in an non-linear way (Statens Offentliga Utredingar, 2020) (Naturvårdsverket, 2021).

- Textiles collected per person by voluntary organisations (currently main collectors in Sweden) has increased with 27% from 2008 to 2016. However, data for reuse in Sweden of these fractions showed that of 0.8 kg/person was reused in both 2011 and 2016 (Belleza & Luukka, 2018).

Type of flow:	Year of data	Total volume [tonnes]	Per capita volume [kg/capita]
Netinflow of textiles	**2019**	**141000**	**13.7**
Reuse via online marketplaces	**2017**	**1300**	**0.1**
Collected textiles by NGOs	**2016**	**38300**	**3.8**
of which sorted in Sweden		16300	**1.6**
reused		*7800*	*0.8*
recycled		*100*	*0.0*
incinerated		*1800*	*0.2*
exported to charity (reuse)		*2100*	*0.2*
of which exported		27700	2.7
Exported pre-sorted		3800	0.4
reused		*3200*	*0.3*
recycled		*500*	*0.0*
incinerated		*100*	*0.0*
landfilled		*1*	*0.0*
Exported unsorted		21800	2.2
reused		*16000*	*1.6*
recycled		*4100*	*0.4*
incinerated		*1500*	*0.1*
landfilled		*100*	*0.0*
Disposed textiles in mixed waste	**2015**	**38200**	**5.1**
of which in reusable condition		22538	3.0
of which pure cotton		22156	3.0
of which non-recyclable		3820	0.5

Table 2.1: Consumed and post-consumed textiles in Sweden (Statens Offentliga Utredingar, 2020).

To summarize the main findings for textile volumes, Table 2.1 was done. In 2019 the netinflow of new textiles (textiles consumed) was 13,7 kg per person of which 9,9 kg where clothes and 3,8 kg home textiles (Naturvårdsverket, 2021). The NGOs are dominating the collection and further the second-hand retail in Sweden today. The total collection of textiles by NGOs in 2016 was 3.8kg per person (Belleza and Luukka, 2018; Statens Offentliga Utredingar, 2020). The volumes for what is being collected by NGOs is not necessarily the same volumes that are going out from NGOs during a year since stocks of textiles is expected to occur (Belleza & Luukka, 2018). In a report by SMED in 2016 commissioned by the Swedish EPA that mapped and analysed the textiles disposed in the household waste, revealed that each person per year disposes 7,6 kg textiles (Hultén et al., 2016; Statens Offentliga Utredingar, 2020). If fractions for business and shoes are subtracted, households stands for disposing 5,1kg textiles per person annually. Of these 5,1 kg from households, 3,1 kg was clothes, 1,5 kg home textiles, and 0,5 kg of special product groups (products who may contain hazardous substances). Further analyze of the content revealed that 59% of the clothes and home textiles were in a shape for reuse, 58% of disposed products were pure cotton, and the rest was mostly mixed material compositions. It was also found that 10% of disposed textiles were classified as non-recyclable as they potentially could contain hazardous substances.

2.9 Challenges and enablers for textile recycling

Ellen MacArthur Foundation published the report 'A new textiles economy: Redesigning fashions future' in 2017 where it was stated that for clothing only, 500 billion USD of value is estimated to be lost every year globally due to underutilisation and lack of recycling solutions. Another estimation is that less than 1% of global textiles that are used to produce clothing is recycled into new clothing in a so-called closed loop recycling, representing a loss of more than USD 100 billion in material value each year. The global open-loop recycling of clothes is estimated to be 12% annually (Ellen MacArthur Foundation, 2017). To improve this, better collection, sorting and waste management of textiles is key to reach higher levels of reuse and recycling (Manshoven et al., 2019). This chapter explores the different challenges and enablers that has appeared in the literature. These have been aggregated into themes by the authors in this thesis.

2.9.1 Challenges

Complexity of household waste
The complexity of household waste refers to the technical challenge of using textile waste from households as input materials for recycling processes. It is described that one challenge associated with textile recycling is that textile fabrics commonly consist of different types of fibers (Koszewska, 2018). This means that different fibers/materials first need to be separated, which in itself is complicated, and then different types of recycling processes are required for the different materials. In addition, there are quality aspects to take into account such as fibers being worn during use and washing as well as recycling, which results in fibers becoming weaker and shorter over time and the number of times a fiber can be recycled is limited (Petersson Mcintyre, 2020). Another prerequisite for large-scale textile recycling to be able to be developed is that textile waste can be sorted at fiber level. Textiles are not a homogeneous material but consist of a variety of fibers, mixtures and dyes, which means that the recycling processes need to be adapted to each specific fiber (Statens Offentliga Utredingar, 2020; De La Motte et al., 2019).

Cost of managing textile waste
One challenge is further the low price of virgin raw material, which has contributed

to the fact that the incentives to collect and develop new recycling techniques have long been insufficient. Likewise, the volumes of textile materials that can be recycled have been too small for it to be financially profitable to build up an infrastructure for textile handling (Koszewska, 2018; Statens Offentliga Utredingar, 2020).

Chemical content
One further important aspect to enable a circular economy for textiles is to ensure that textile waste when used as raw material for new products does not contain hazardous materials. Chemicals are added to textiles in production to achieve certain material properties, like colour or water-repellent. Some substances used have potential risk to human health due to carcinogenic, allergenic, and endocrine disrupting proeties for example (Schmidt et al., 2016). Some of these chemicals is degraded during the use of textiles but some remains. This is important information for a recycling process to obtain as the feedstock content may directly affect the content of the output material (De La Motte et al., 2019). It is therefore important to have a dialogue and further develop methods for transparency and traceability of textile content. Here one need to investigate how different recycling methods manage different textile contents, and how to address the insufficient information about textiles when applying recycling. This may give the premises for taking decisions about which textile waste are suitable or not for a certain recycling process and further product type (De La Motte et al., 2019).

Need for recycling technologies
The "EU guidance for collection" rapports that the downcycled market for textiles is close to saturated (M. Dubois et al., 2020). Thus, large scale recycling and new recycling technologies (fibre-to-fibre recycling technologies) are needed to create higher valued textiles out of textile waste for the economical viability of collection and sorting; specially if reusable fractions decrease and non-reusable textiles increase as has been the trend with fast fashion (Koszewska, 2018; Schmidt et al., 2016; M. Dubois et al., 2020).

Moreover, fiberblends are as mentioned very common currently, but posses a challenge to recycling (De La Motte et al., 2019; Schmidt et al., 2016; Koszewska, 2018). As there is a wide range of textile fibers, a wide range of recycling technologies needs to be developed. For example, chemical recycling might be needed to processes and separate fibers into pure fractions of one fiber type. The development of further recycling technologies has to be viable from an economical and environmental perspective.

2.9.2 Enabers

Policies and EPR
The most evident regulating policy in this context is the EU's new waste directive that demands all Member States to collect textiles separately from other waste by the 1st January 2025. This means that large volumes of textiles that will be col-

lected needs management, which creates new opportunities for the textile industry to develop circular solutions.

Furthermore, Extended Producer Responsibility (EPR) has been discussed to be a policy for ensuring a separate collection of textiles in Sweden (Statens Offentliga Utredingar, 2020). As mentioned in Chapter 2.1, EPR aims to give producers (including importers) a significant degree of responsibility for the environmental impacts their products are accountable for through out its whole life-cycle (Elander et al., 2017). This addresses specifically the responsibility of the end-of-life phase of products. Research funds or investments via EPR could incentive the development of a recycling supply chain. In the case of a EPR for textiles, this could enable financing for collection, communication to consumers, research, development, demonstration and scaling up recycling technologies. Furthermore, an EPR could incentive producers to adapt eco-designed products (M. Dubois et al., 2020). Better design can increase resource efficiency by making products more durable, easy to repair and enable recovery of valuable materials at end-of-life (Bauer et al., 2018).

Another economic policy instrument could be the introduction of tax and value added tax (VAT) for retailers (M. Dubois et al., 2020). Some taxes that already exists within EU, such as in France, and incentives retailers to donate or sell unsold textiles for reuse or recycling is incineration tax and landfill tax. For taxes like this to incentive preferred waste management accordant to the waste hierarchy, sending textiles to reuse or recycling must be a cheaper option than sending then to incineration for example (M. Dubois et al., 2020).

In a report from Mistra Future Fashion (Elander et al., 2017) investigating policies for fiber-to-fiber recycling they state that further policies of importance can be for example eco-labeling, labeling requirements of recycling content and public procurement for minimum recycled content. Eco-labelling and recycled content labelling can provide the consumed with information about the for example environmental performance of a product.

Digitalization and traceability

Traceability and transparency is crucial to make it possible to create sustainable, resource-efficient and non-toxic cycles where textiles are recycled and treated as an attractive raw material (Statens Offentliga Utredingar, 2020). Producers who want to produce new products from recycled raw materials must be able to ensure that the recycled fiber is non-toxic and safe to use. The same applies to players who manufacture products from used textile material, so-called remake products. The lack of large-scale transfer of information between the various stages of the textile value chain from production and consumption is a challenge that if solved, would greatly improve sorting- and recycling process (De La Motte et al., 2019). Technical labeling solutions (RFID) to transfer information between the various links of the value chain are already available on the market today but not necessary applied on textiles. If this technology were to be integrated in textiles, traceability and transparency through the whole supply chain could be shared. This would provide the information needed to enable more efficient decisions about how to manage the textiles at end-of-life (De La Motte et al., 2019). What this suggest is that right recycling method is applied for different textile waste and before that, sorting can become more focused for this process. The RFID tags could also be beneficial by providing information on the use-phase of the textile, for instance the amount of times the garment have been washed since the quality and material composition is affected in the process (Statens Offentliga Utredingar, 2020; De La Motte et al., 2019). Initiatives around this kind of information system for textiles is ongoing research by RISE in Sweden (De La Motte et al., 2019).

3
Methodology

The research design applied for this study is explained in Figure 3.1. Information was collected through a combination of a literature review and interviews, this will be described in following sections of this chapter. Once collected, the data was analysed both quantitatively and qualitatively. Quantitative data is defined as the value of data that takes form in numerical value (Bell et al., 2018). It is further explained that this data is quantifiable information that is used for statistical analysis. The quantifiable information that this study provides is the estimation of textile waste volumes suitable for recycling explored in RQ1. The qualitative process focuses on describing phenomena in context, interprets processes or meanings, and uses theoretically based concepts to seek understanding (Silverman, 2011). This is useful when the research questions are formulated in a varying degree of explicitness (Silverman, 2011; Bell et al., 2018). This approach provided the information needed to answer mainly RQ2 and RQ3. However, to fully provide the answer for RQ3, insights from both approaches (quantitatively and qualitatively) had to be combined. How the analysis for each approach has been done will also be described in following sections of this chapter.

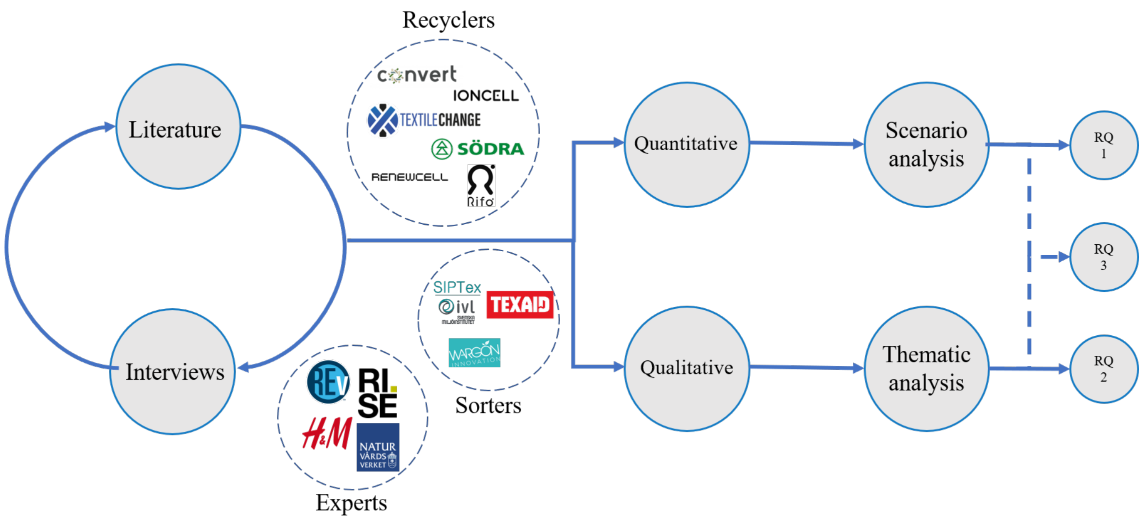

Figure 3.1: Research design framework.

This study has used an abductive approach referred to as systematic combining. The systematic combining approach builds on the continuous movement and reorganization between the theoretical framework and the empirical result (A. Dubois and

Gadde, 2002; Mason, 2002). Thus, the theoretical framework and empirical data should be developed in parallel to each other. This is useful since theory cannot be understood without the context of the empirical world and vice versa (A. Dubois & Gadde, 2002). An abductive approach is further explained to be useful for seeing things that otherwise might be overlooked and to provide expanded explanations to the scope (Shank, 2002). Thus, it was an appropriate approach for the aim of this study. For example, an abundance of theory and previous research was processed to gain insights of the demand-side of post-consumed textiles, which was needed to find an appropriate problem formulation for the study. Formulating the aim and research questions was then iterative process driven by inputs from theory and supervisors at VTI (see Section 3.5 for more information). Systematic combining thus allowed for new perspectives and for the study to be continuously developed. This created a deeper understanding of the subject.

3.1 Data collection

The data was collected using multiple sources of information, including both primarily and secondary ones. The method applied for inquiring the primary (empirical) data was through semi-structured interviews. The secondary data (theory) was obtained by an literature review, but also by reviewing institutional reports, and reviewing reports with similar scope.

3.1.1 Literature review

As explained, the literature review was conducted in a iterative approach throughout the study, and resulted in the theoretical framework presented in Chapter 2. Hence, this chapter provides existing knowledge relevant for answering the research questions under study.

The literature review was performed by searching literature using keywords relevant to the subject of the study such as, circular economy, supply chain management, textile recycling, and automated sorting for textiles. The search was preformed using the University database and Google Scholar with critical evaluation of the sources. Since the scope of the study deals with textiles specifically and the textile waste arisen in Sweden, information had to be collected from gray data from relevant rapports of research institutes and research papers on the study's topic. Due to this scope, literature published in Swedish and English has been used. In a previous literature review on the subject by Ki et al. (2020), it was pointed out that time period of relevance for literature on the subject should be in regard to the Circular Economy Action Plan that was established in 2015 in Europe. Further in the context of the fashion industry, 'Make Fashion Circular' initiative was launched by Ellen MacArthur Foundation in 2017 (Ellen MacArthur Foundation, 2017). Thus, literature regarding circular economy and how to apply it on the fashion industry was estimated to be of relevance for the time period 2015-2021.

The literature used in the theoretical framework served as bases to build the scenario analysis. The data was gathered through a combination of grey data by rapports from SOU, the Swedish EPA, and SMED. SOU is short for Swedish Government Official Reports (Statens Offentliga Utredningar), and is an official series of reports of committees appointed and convened by the Government of Sweden for the analysis of issues in anticipation of a proposed legislation before the Swedish Riksdag or the issuance of ordinances. The Swedish EPA (Naturvårdsverket) is a governmental agency in Sweden responsible for proposing and implementing environmental policies and reports to the Swedish Ministry of the Environment. SMED is short for Swedish Environmental Emissions Data, which is a collaboration between IVL Swedish Environmental Research Institute, SCB Statistics Sweden, SLU Swedish University of Agricultural Sciences, and SMHI Swedish Meteorological and Hydrological Institute. SCB's (Statistiska Centralbyrån) database was further used to obtain statistics on the Swedish population used for estimating future consumption of textiles. Since there has been comprehensive work done before on the subject of collecting data on textile waste by primarily SMED, this thesis has aggregated secondary data relevant for this study.

3.1.2 Semi-structured interviews

Interviews are the most common method for obtaining primary data in qualitative studies (Bell et al., 2018). There are two kinds of interviews: semi-structured and unstructured. Due to the scope of this study, semi-structured interviews has been used. According to Bell et al. (2018), this style of interview follows a guideline of open-ended structures questions with room for unstructured answers to follow (Bell et al., 2018). This allows for in-depth information and encourages for a two-way communication with the interviewee.

The aim of the interviews was to collect information from actors within the supply chain for recycling of textile waste to gain better understanding of the requirements of those actors. The actors of interest in this supply chain was identified to be those who did automated sorting and recycling of textiles. Further, experts within the field was contacted with the aim to provide different knowledge of the system for textile recycling. This could provide additional insights about the overall challenges and enablers for the textile recycling supply chain to operate efficient. In total, 28 actors was contacted of which 14 responded. The Tables 3.1, 3.2, and 3.3 presents the actors interviewed and their relevance for the study. The length of the interviews was about 1 to 1.5 hour each. The interviews were lead by one person responsible for the dialogue and one person responsible for taking short notes for a summary. The interviews were recorded with permission for the purpose of having a free dialogue and follow-up questions and further complement the summary. After a conducted interview, the summary was sent to the interviewee to read and complete with additional comments if needed. Due to the ongoing pandemic of the Covid-19 virus, the interviews had to be conducted over Microsoft Teams.

Sorting actors	Importance to the study
SIPTex	Obtaining requirements for SIPTex automated sorting process and gaining knowledge about challenges and enablers for textile sorting and the textile recycling supply chain in general.
Wargön Innovation	Obtaining requirements for WI automated sorting process and gaining knowledge about challenges and enablers for textile sorting and the textile recycling supply chain in general.
Taxaid	Gaining knowledge about manual sorting of textiles and challenges and enablers for the textile recycling supply chain in general.

Table 3.1: Actors for sorting interviewed.

Recycling actors	Importance to the study
Convert	Obtaining requirements for Convert's recycling process and gaining knowledge about challenges and enablers for textile recycling and this recycling supply chain in general.
Södra	Obtaining requirements for Södra's recycling process and gaining knowledge about challenges and enablers for the textile recycling supply chain in general. (Purchasing manager)
Södra	Gaining knowledge about challenges and enablers for textile recycling and this recycling supply chain in general. (Expert in the recycling technology)
IONCELL	Gaining knowledge about challenges and enablers for textile recycling and this recycling supply chain in general.
Textile Change	Obtaining requirements for Textile Change's recycling process and gaining knowledge about challenges and enablers for the textile recycling supply chain in general.
Renewcell	Obtaining requirements for Renewcell's recycling process and gaining knowledge about challenges and enablers for the textile recycling supply chain in general.
Rifo	Obtaining requirements for Rifo's recycling process and gaining knowledge about challenges and enablers for the textile recycling supply chain in general.

Table 3.2: Actors for recycling interviewed.

Experts	Importance to the study
Revolvewaste	Gaining knowledge about challenges and enablers for textile recycling and this recycling supply chain in general.
RISE	Gaining knowledge about challenges and enablers for textile recycling and this recycling supply chain in general.
H&M	Gaining knowledge about the demand and strategies for using recycled textiles.
Naturvårdsverket	Gaining knowledge about the work done at the department for resource efficiency at the Swedish EPA for implementing policies that will improve the circularity around textiles. Gaining knowledge about current volumes of collected post-consumed textiles.

Table 3.3: Interviewed experts within the subject of the study.

Due to the different characteristics of sorting, recycling and expert actors, different interview forms where designed and used to guide the different interviews. The interview guides can be found in Appendix A.1.

3.1.2.1 Sampling

The sampling of which actors to interview followed an combination of a snowball and generic purposive approach. A snowball sampling refers to when an interviewee recommends another, until the sample is large enough (Bell et al., 2018). The interviewed actors recommended and encouraged to interview other knowledgeable actors within their network. This benefited the quality of the research and facilitated the contacting process. However, such a sampling technique have the risk of interviewing people with the same professional background and thus increasing the risk for a bias perception of the industry (Bell et al., 2018). To combat this risk purposive sampling was also used, targeting experts that could give new perspectives of the industry. The purpose of each interview is explained in the Tables 3.1, 3.1, and 3.3 under importance to the study.

3.2 Data analysis

This section will explain how the collected data was analysed to answer the research questions.

3.2.1 Scenario analysis

To mainly answer RQ1, but also RQ3, and estimate future volumes of textile waste from households suitable for recycling, this thesis used an scenario analysis based on trend extrapolation. The trend extrapolation builds on an exploitative and quantitative approach. Exploitative scenarios explores possible future developments with the present as a point of departure (Kosow & Gaßner, 2008). It is further explained that a typical procedure for quantitative scenarios is collection and processing of data, identification of logical process of development, and statistical projection of these into the future. This is hence a method for predicting the possible future assuming that a phenomenon or trend will continue in the future (Kosow & Gaßner, 2008). Scenarios are not intended to represent a full description of the future, but rather to highlight central elements of a possible future and to draw attention to key factors that will drive future development. Thus, scenarios are hypothetical constructs (Kosow & Gaßner, 2008). This is why this kind of analysis was seen as a useful tool for answering RQ1. Data was collected and processed, and by this a projection of future volumes could be made.

3.2.2 Thematic analysis

Again to answer RQ2 and RQ3, information was gained through literature and interviews. This information was then thematically analysed. Thematic analysis is a method that can be used to analyze any type of qualitative data (Damayanthi, 2019), as it helps to elevate the important information that can be found in the qualitative data by enabling the researcher to identify commonly recognized patterns and relationships to meaningfully answer the research questions of the study. The thematic analysis consists of four different steps that are: data generation, codification process, generation of themes, and analysis (Damayanthi, 2019). This was seen as a appropriate approach to identifying supply chain requirements and further challenges and enablers for textile recycling. This provided the premisses for structuring Chapter 4 - Results of empirical study, and further to answer RQ2 and RQ3. How this was done accordingly to the steps of thematic analysis is expressed in the list below:

- *Data generation* was preformed via semi-structured interviews. Generally in a thematic analysis the interviews were transcribed (Damayanthi, 2019), however in this study, the interviews where summarized in a structured manner to increase the amount of valuable information gathered from the interview.

- *Codification process* consists on summarize families of thoughts found in the interview data (Damayanthi, 2019). This was explained to be the first step to identify different patterns expressed by the interviewees. The patterns were coded and the codes can be semantic or latent (Damayanthi, 2019). Semantic codes are ones that were found in the data, where as latent codes are part of a pre-designed framework to guide the codification process. Latent codes are generally based on the literature and other pre-existing knowledge on the topic (Damayanthi, 2019). According to Demayanthi (2019) the codes identified should be revised and renamed to ensure that it best reflects the data analyzed. Finally the codes were given a frequency and a level of importance to give a sense of direction for the analysis (Damayanthi, 2019). In this study, the codes analyzed were only semantic since the analysis only were only based on the knowledge gained by the empirical data.

- *Generation of the themes* implies that after codes are generated, they are categorised into themes (Damayanthi, 2019). According to Braun and Clarke (2006), a theme "captures something important about the data in relation to the research question, and represents some level of patterned responses or meaning within the data set" (p. 82). It is the final process of finding the patterns in the qualitative data (Damayanthi, 2019). In this study four themes were found (sorting requirements, recycling requirements, drivers/enablers and challenges). The result of this is presented in Chapter 4 - Results of empirical study.

- *Analysis* is the final stage where the data gained is analyzed and discussed (Damayanthi, 2019). In this study, the result of this step is presented in Chapters 5.2 and 5.3. It is in these chapters the analysis and discussion for RQ2 and RQ3 is presented.

To enable answering RQ2 in a structured way the result of the thematic analysis around actor's requirements was aggregated accordingly to a similar structuring of analysis by Ki et al. (2020). Thus, actors interviewed can be grouped depending on their role and be described in general terms. Figure 3.2 illustrates how the result of this grouping can look like.

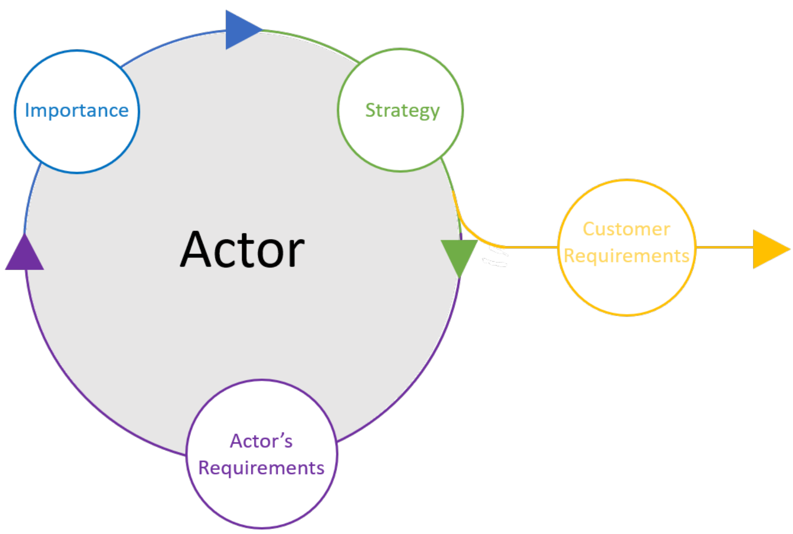

Figure 3.2: Framework of the analysis in RQ2, inspired by Ki et al., 2020

Actors were analyzed according to their importance, strategy, customer requirements, and actor's requirements. The meaning of these terms have been described in Chapter 2.2 of the Theoretical Framework.

3.3 Quality of the study

The following section identifies weaknesses of the study and develops a mitigation strategy to limit the effects of the weaknesses of the study.

One of the limiting factors of any study is the data. The amount and quality of the data collected affects directly the quality of the study. The aim of the study is to increase the knowledge on how the Swedish textile waste can be re-loop via recycling. By exploring and analysing the volumes of textile waste in Sweden, as well as who could be the actors in the textile recycling supply chain and what are their requirements. To do so, the study needs to get a holistic understanding of the supply chain requirements of the different actors in the industry and to find updated data on the volumes of textiles consumed in Sweden. Ideally, to have a complete data set, a significant portion of the actors in the industry should be interviewed (Bell et al., 2018), in this case, actors from all the different parts of the recycling supply chain (sorters, recyclers, and experts). However, when it comes to the empirical data, due to time constraints and lack of resources only a fraction of the actors has been identified and interviewed. Consequently, The length of the interviews. To mitigate this limitation, the insights gathered in the inductive part of the research was backed by the theoretical information gained in the literature. Also, after concluding the interviews, a summary of the understanding and insights gathered by the researchers was send to the participants to ensure that they agreed with the conclusions, thus, minimizing the risks of misinterpretations from the interviewers and allowing the interviewee to reformulate thoughts if they felt it was necessary.

Moreover, the interviewees may have a bias or angled understating of the supply chain requirements of this industry (Bell et al., 2018). Therefore, an extensive literature analysis was carried out prior and after each interview. The objective of this iterative process was to find any discrepancies by contrasting the empirical result with the general understanding of the industry found in the literature.

The scenario analysis preformed to estimate future volumes of textile waste for recycling was preformed based on some ongoing trends (Kosow & Gaßner, 2008). To account for some uncertainty with estimated trends, various scenarios where made. This tested the sensitivity in the result by examine how changes in input variables affected the result. The input variables that were based on trends were hence changed and this could give an hint on how the assumptions made in the scenario analysis affected the result.

3.4 Ethical considerations

According to Richardson & Godfrey (2003) there are three ethical considerations that were considered and respected when performing interviews as in this study. These are relationships with research participants, possibilities of 'harm' and regard of 'well being' (Richardson & Godfrey, 2003). Before the interview, the interviewers considered if there is any potential harm to the participants. During the interview, the interviewers ensured that the physical and mental well being of the interviewees were respected and accounted for (Richardson & Godfrey, 2003). The interviewers ensured that the interview can be stop if the interviewees feel any discomfort of any type. Additionally they ensure that the interviewees consented 'ownership' of the study (Richardson & Godfrey, 2003). The researcher informed the participant what is the research is about, explained the boundaries of anonymity and confidentiality, the possible uses of the data, and how it could be shared in the future. The described procedures were applied when conducting the interviews in this study. Lastly privacy was considered (Richardson & Godfrey, 2003). It was explained that privacy comes hand-to-hand with anonymity and confidentiality. The identities of the participants have been kept private. Lastly, the qualitative data was used respecting copyright and confidentiality guidelines.

3.5 Research process

The background to the study were derived from the SATIN-project. Nordic Innovation investment fund has financed the two-year (2020-2022) project SATIN. SATIN - Towards a sustainable textile circular system in the Nordic region (Norway, Denmark, Sweden, and Finland) - aims to develop and test cost-effective circular solutions of the Nordic textile industry by adopting a Supply Chain Management (SCM) perspective. More specifically, the project aims to develop cost-efficient collection solutions that stimulates consumers to hand in their used textiles for an increased collection rate. The solutions are implemented by SATIN's partners. This Master Thesis is supported by The Swedish National Road and Transport Research Institute (Statens väg- och transportforskningsinstitut, VTI) and is part of the project's first stage Work Package 1 (WP1). WP1 aims to map the current circular system of textiles. One big question that needed exploring in this WP1 was: who will constitute the demand of collected textiles from households? Thus, our study was developed to increase knowledge about how textile waste can be re-looped via recycling and to explore potential actors in a supply chain facilitating textile waste to be recycled.

The topic and general expectations of the project were presented in November 2020. Throughout December and January our supervisor from VTI Linéa Kjellsdotter Ivert introduced us to circular textiles in the Nordic countries and the first introductory rapport was created. In this first rapport the problem formulation and aim was drafted, and the research questions were set. At the first stages of the study the aim was to study the supply chain requirements for circular textiles. After closer consideration and assessment from supervisors, the scoped was narrowed and the objective changed to focus on specifically the recycling supply chain of textiles.

From February to May the empirical data and theoretical data were simultaneously developed though an iterative process based on the abductive approach set for this study. A continuous understanding of the supply chain requirements of the actors interviewed and what caused textile waste in Sweden gave the bases to answer the research questions of the study. A midway rapport was finished in the middle of April to obtain feedback from supervisors on the quality of the findings so far. The rapport included the first three chapters.

In may, the data was analysed and contrasted to the theoretical framework developed. Two concluding workshops were conduced on the 17th and 18th of May. The workshops had the aim to present the result of the study for interested actors and to have a discussion to reach a consensus in the result. The fist workshop invited sorters, recyclers and experts interviewed, hence this aimed to hear their view on the subject once again. The second workshop invited actors within the SATIN-project, here the discussion was about how to move forward with the project. During May and early June, the last parts of the thesis were generated and completed. Here, the conclusions and further recommendation of research were developed, as well as several iterations of adjustments. In June, the thesis was presented and opposed. The critique was reviewed and adjustments were made where necessary prior to the final hand-in in the middle of June.

4
Results of scenario analysis

The scenario analysis will provide the potential volumes of textile waste in 2025 and 2030. The analysis will hence describe the potential supply of feedstock material for sorting- and recycling processes. This has been done mainly by aggregating the data and system description obtained in the literature describing how current supply chain for managing Swedish textile waste operates (Statens Offentliga Utredingar, 2020; Naturvårdsverket, 2021; Statistiska Centralbyrån, 2021; Belleza and Luukka, 2018; Hultén et al., 2016), along with coupling this information with trends in population growth and textile consumption. Following sections are divided into describing the expected textile waste volumes in the current system, how these will shift in a system where separate collection is applied, and lastly what may be the fiber content of the textile waste.

4.1 Current textile waste volumes

The volumes found in the literature explains how consumed textiles from households are treated without separate collection of textiles currently (Statens Offentliga Utredingar, 2020; Naturvårdsverket, 2021; Hultén et al., 2016; Belleza and Luukka, 2018). NGOs are the main collectors in Sweden today (87% of total collection) and data on the quality of collected textiles was provided (Belleza & Luukka, 2018). Even though other collection might occur in Sweden, there was no identified data for this. This is why only collection by NGOs is included in analysing the current system for collection.

The quality of the textiles collected by NGOs and textiles that are to be additionally collected (currently disposed) was found in the literature (Belleza and Luukka, 2018; Hultén et al., 2016). Of consumed textiles by households, about 28% is estimated by be donated to NGOs. These textiles are manually sorted and in this sorting the waste hierarchy is expected to apply since this is how post-consumed textiles should be treated within EU. This is why current fractions for reuse, recycling and incineration in the data can give an intuition of the expected quality of collected textiles by NGOs. Furthermore, it was revealed that of consumed textiles by households, about 37% is estimated to be disposed in the mixed household waste. These are the volumes that should be additionally collected. The quality of the disposed textiles was determined by a picking analysis that revealed that of disposed textiles, 59% were reusable, 58% were pure cotton, and 10% was estimated non-recyclable due to expected hazardous chemical content (Hultén et al., 2016).

Type of flow:	Year of data	Total volume [tonnes]	Per capita volume [kg/capita]
Netinflow of textiles	**2019**	**141000**	**13.7**
Reuse via online marketplaces	**2017**	**1300**	**0.1**
Collected textiles by NGOs	**2016**	**38300**	**3.8**
of which sorted in Sweden		16300	**1.6**
reused		*7800*	*0.8*
recycled		*100*	*0.0*
incinerated		*1800*	*0.2*
exported to charity (reuse)		*2100*	*0.2*
of which exported		27700	2.7
Exported pre-sorted		3800	0.4
reused		*3200*	*0.3*
recycled		*500*	*0.0*
incinerated		*100*	*0.0*
landfilled		*1*	*0.0*
Exported unsorted		21800	2.2
reused		*16000*	*1.6*
recycled		*4100*	*0.4*
incinerated		*1500*	*0.1*
landfilled		*100*	*0.0*
Disposed textiles in mixed waste	**2015**	**38200**	**5.1**
of which in reusable condition		22538	3.0
of which pure cotton		22156	3.0
of which non-recyclable		3820	0.5

Table 4.1: Consumed and post-consumed textiles in Sweden (Statens Offentliga Utredingar, 2020).

The baseline data presented in Chapter 2.8, and again in Table 4.1 provided the information of volumes in the current supply chain. The volumes on what is being collected by NGOs was provided by SMED (2018), which explains that what is being collected is not necessarily the same volumes that are going out from NGOs during a year since stocks of textiles is expected to occur.

With the information in Table 4.1, the connection of flows could be estimated. In other terms, how much of incoming volumes to households that were donated and disposed and this was calculated in percentages. In the same way, percentages could be calculated for how textiles donated to NGOs were managed either by reuse, recycling or incineration. For examlpe, of donated volumes to NGOs, 43% were sorted in Sweden and of these sorted fractions 48% was reused, 1% recycled (open-loop recycled), 13% was exported to charity (reused), 10% was exported for other secondhand markets, and 11% was sent to incineration (Statens Offentliga Utredingar, 2020; Belleza and Luukka, 2018). The percentages or rates was hence obtained from division between the per capita data in Table 4.1. The per capita data was used as these volumes were normalized to the population for each year. As an example, the rate for how much of incoming textiles to households (Naturvårdsverket, 2021) that were disposed in household waste (Hultén et al., 2016) was calculated by:

$$Disposal\ rate\ of\ what\ has\ been\ consumed$$
$$= \frac{Disposed\ textiles\ in\ mixed\ waste}{Netinflow\ of\ textiles} = \frac{5.1\ kg\ per\ capita}{13.7\ kg\ per\ capita} = 37\%$$

Calculating rates and flows of textiles in the baseline system		
Based on 2019 Swedish population:	10.292 millions	
	Kg per capita	Volumes [tonnes]
Netinflow of textiles	13.7	141000
	Rate	Volumes [tonnes]
of which is going from retails to households	100%	141000
of which is disposed in household waste	37%	**52489**
and further incinerated	100%	52489
of which is donated to NGOs	28%	**39110**
and further sorted in Sweden	43%	16645
reuse	48%	*7965*
recycling	1%	*102*
incineration	11%	*1838*
charity export reuse	13%	*2144*
and further exported pre-sorted	10%	3880
reuse	84%	*3268*
recycling	13%	*511*
incineration	3%	*102*
landfilled	0%	*1*
and further exported unsorted	57%	22261
reuse	73%	*16338*
recycling	19%	*4187*
incineration	7%	*1532*
landfilled	0%	*102*
of which is reused via online marketplaces	1%	1338
Total volumes for reuse		**29715**
of which reused in Sweden		*7965*
of which exported and reused		*21750*
Total volumes for recycling		**4799**
of which recycled in Sweden		*102*
of which exported and recycled		*4697*
Total volumes to incineration		**55961**
of which incinerated in Sweden		*54327*
of which exported and incinerated		*1634*
Total exported volumes to landfill		**103**

Table 4.2: Volumes of interest for the scenario analysis in Sweden normalized to the year 2019.

This reasoning resulted in the Table 4.2 which shows the retrieved rates and volumes estimated to occur in the current supply chain. Again, when percentages do not add up, stocks of textiles are expected. For example, of volumes collected by NGOs, there is a 110% output due to already existing stocks (Belleza & Luukka, 2018). Hence, Table 4.2 builds on the Swedish population in 2019 (Statistiska Centralbyrån, 2021) and the expected volumes to reuse, recycling, incineration, and landfill due to the textile consumption (netinflow of textiles) that year (Naturvårdsverket, 2021). As an example, since 37% of what was consumed by households were disposed in the household waste (Hultén et al., 2016), the volume of disposed textiles were calculated by following equation:

$$Volume\ disposed\ in\ household\ waste$$

$$= Volumes\ to\ households\ *\ Disposal\ rate$$

$$= 141000\ tonnes\ *\ 37\% = 52489\ tonnes$$

How the current system for textiles consumed by households operates can hence be described by looking at the inflow to households and what is happening to the outflow volumes. This is described by the retrieved percentages and volumes in Figures 4.1 and 4.2.

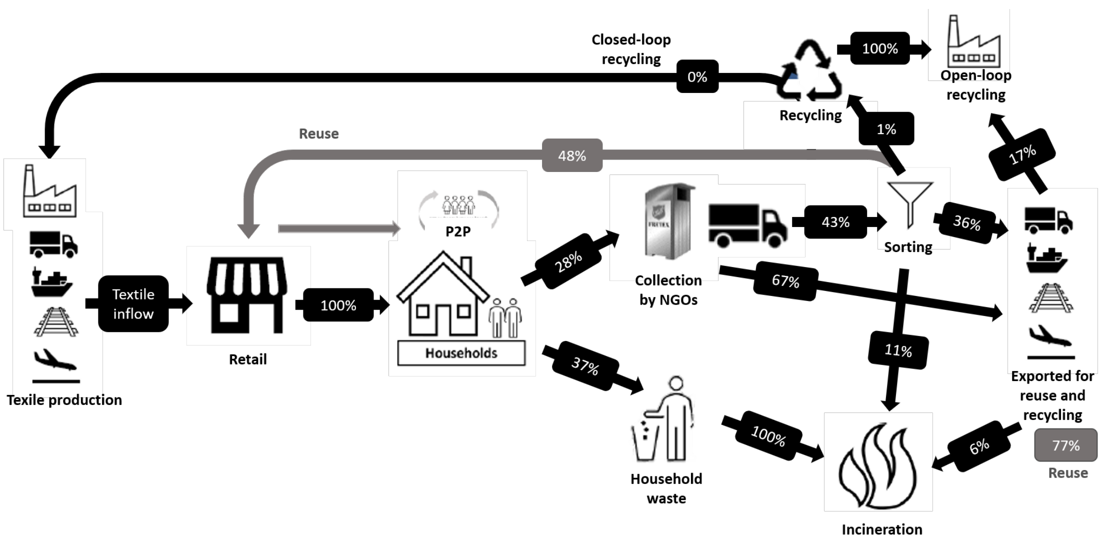

Figure 4.1: How inflows of textiles to households are estimated to be managed in percentages once they become post-consumed currently.

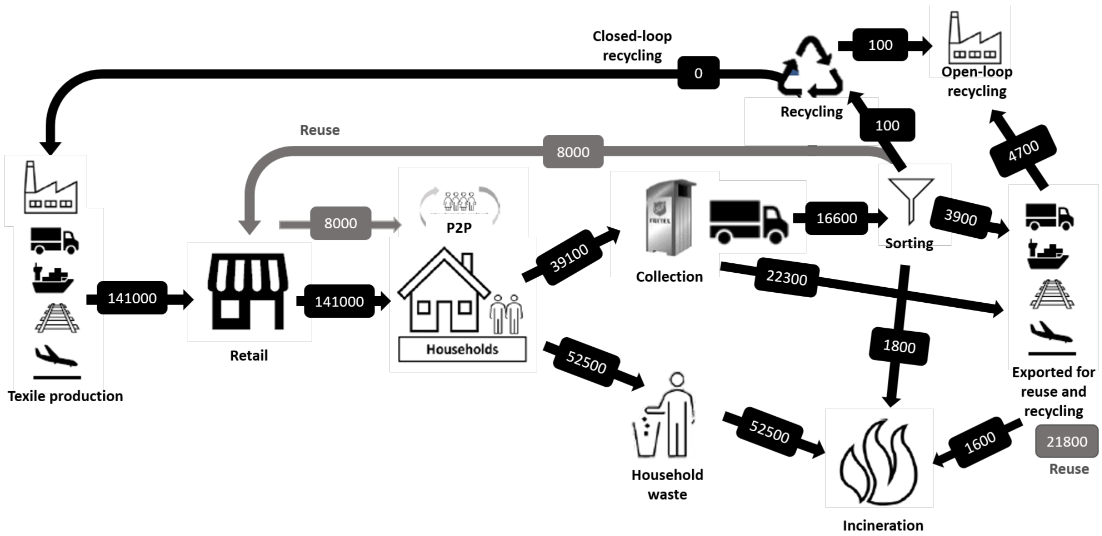

Figure 4.2: How inflows of textiles to households are estimated to be managed in volumes once they become post-consumed currently.

The volumes for recycling in the current system are as mentioned mainly supplied via collection and sorting by NGOs (Statens Offentliga Utredingar, 2020; Belleza and Luukka, 2018). The volumes derived from Swedish textile consumption that are recycled, are currently about 4800 tonnes. Of these, about 100 tonnes is estimated to be recycled in Sweden and the rest after being exported. Ellen MacArthur foundation (2017) presented that less than 1% of clothes are closed-loop recycled globally. Instead textile recycling mainly consist of cascading to other industries for use in lower-value applications (downcycled) (Ellen MacArthur Foundation, 2017). Commonly textiles are used for applications such as insulation material and wiping cloths, which are final use for these textiles. This is estimated to be the fate for current volumes going to recycling. No closed-loop recycling where the textile waste are upcycled into new textiles for example is expected to occur from the information given by the literature (Statens Offentliga Utredingar, 2020, Belleza and Luukka, 2018).

4.2 Scenarios on future volumes of textile waste

When aggregating the information needed to understand what could be future volumes of textile waste, the flows of interest were the netinflow of textiles that is consumed by households and further how these were managed by households by disposal in household waste or donation to NGOs. What households dispose should in 2025 instead be separately collected, donation to NGOs will still occur with separate collection. This is why these two collections mainly will constitute the start of the supply chain managing textile waste as described in Figure 4.3. Textiles that before was disposed in the household waste by households should then be collected and managed accordant to to waste hierarchy (M. Dubois et al., 2020; European Commission, 2021d; European Union, 2020). These volumes will hence be collected and sorted with the aim to be reused when possible, if not they will be recycled, and if textiles cannot possibly be recycled due to hazardous substances or contamination they are currently sent to incineration for energy recovery.

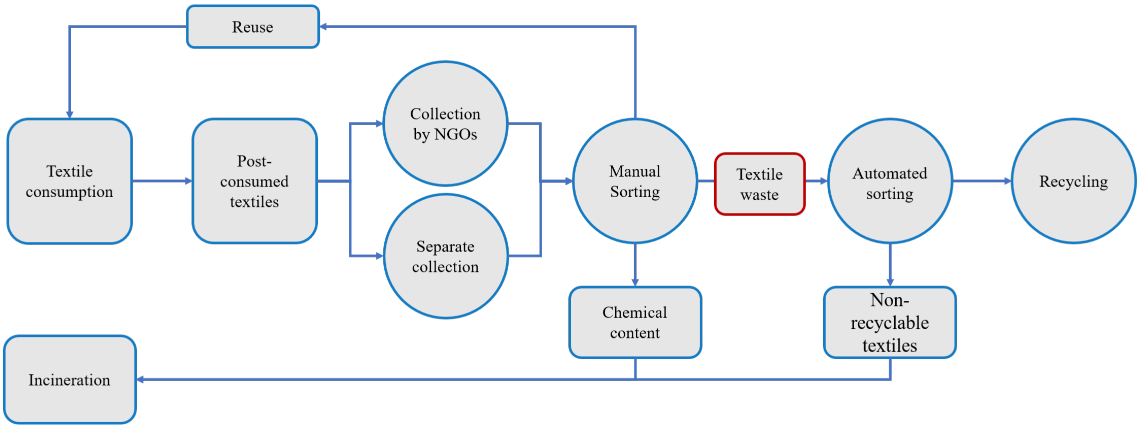

Figure 4.3: Supply chain of post-consumed textiles with separate collection and collection by NGOs.

The Figure 4.4 show how a more circular system could look like. In this system textiles that before were disposed to household waste should instead be separately collected and further sorted for reuse and recycling. Collection is performed by NGOs and by a additional collection system. The green arrows represent the main material flows in the supply chain for recycling processes.

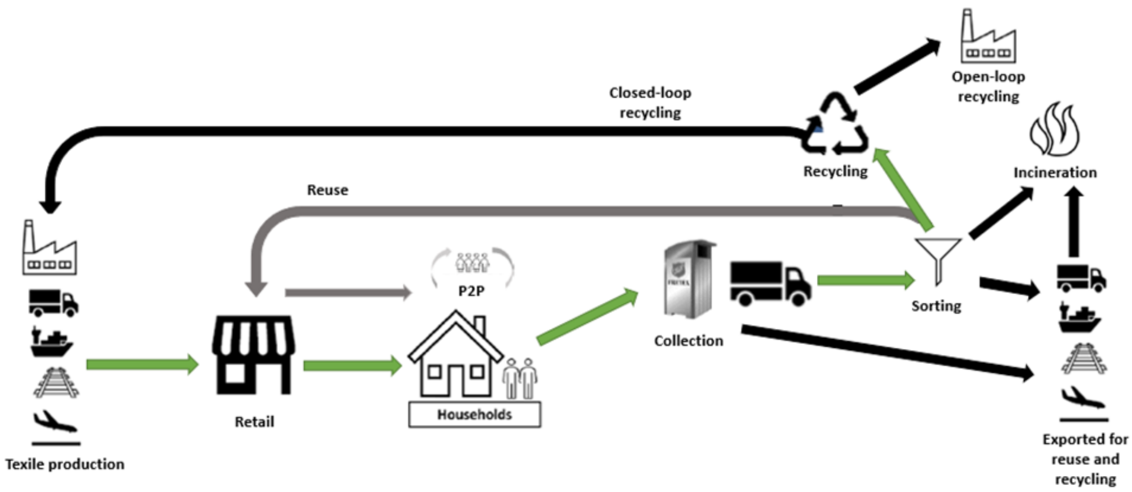

Figure 4.4: System without disposal of textiles in household waste.

The estimation of volumes of textile waste to recycling is hence performed for the flows illustrated in green in Figure 4.4. How these flows interact are dependent on the connections given in the baseline system and shown in Figure 4.5. The different fractions for reuse, recycling and incineration of the volumes collected by NGOs could be retrieved from Table 4.2 which tells that of donated textiles, 76% is reusable, 12%

recyclable, and 9% are non-recyclable (treated by incineration) (Belleza & Luukka, 2018). It was revealed that of disposed textiles in the mixed household waste, 59% was reusable, 58% were pure cotton, and 10% was estimated non-recyclable due to expected hazardous chemical content (Hultén et al., 2016). Note that this only regards how large the volumes for reuse, recycling, and incineration can be due to textiles consumed by and collected from Swedish households. This study do not regard where these volumes occur (for example if they are exported before becoming recycled).

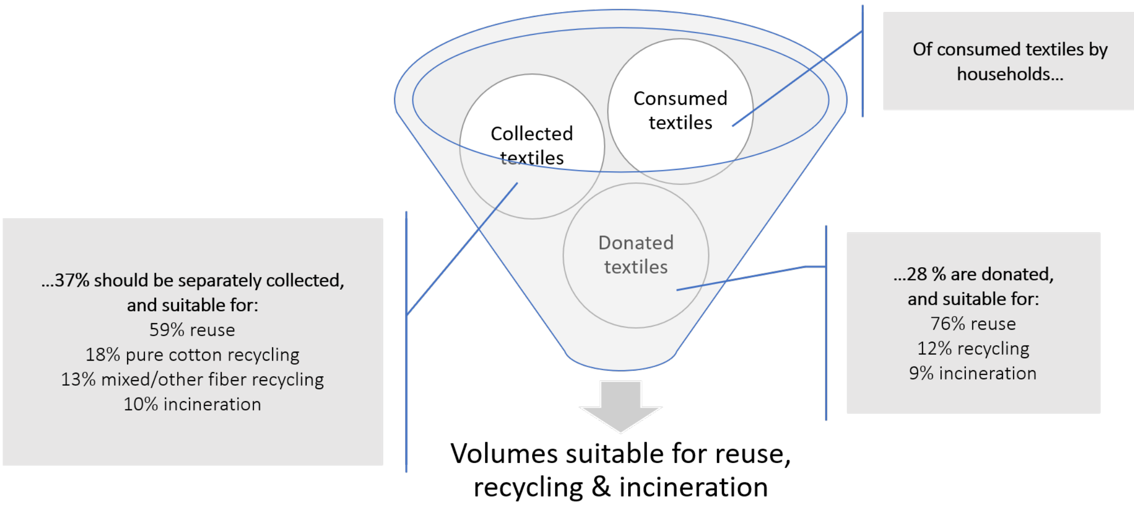

Figure 4.5: Connections of flows.

Trends that could affect how much is being consumed and collected in the future were explored. One obvious trend that affects the consumption in Sweden is the expected population increase (Statistiska Centralbyrån, 2021). Furthermore, it was identified that there had been an increased consumption of textiles since year 2000 (Naturvårdsverket, 2021). The existing literature revealed a increase in donation to NGOs (Belleza & Luukka, 2018), at the same time the demand for buying second-hand appeared to be saturated (Belleza and Luukka, 2018; European Union, 2020; Ljungkvist et al., 2018). This could be one explanation to why stocks exists at NGOs. This is why the trends for increased population, consumption, and donation to NGOs were used to build future scenarios. It was identified that consumption has not had an linearly increase for the last years and the data on donation to NGOs was from 2016. Therefore, to take into account for some uncertainty about these trends, 6 scenarios were performed. Three respectively for the years 2025 and 2030 were increased consumption of textiles and/or increased donation to NGOs were included or not. By this, the result from the different scenarios could then give a lower potential limit and a upper potential limit of expected future volumes. The scenarios with both trends (increased consumption and donation) included was modelled based on following assumptions:

- Swedish population growth will follow the prognosis given by Swedish Statistics (SCB) (Statistiska Centralbyrån, 2021).

- The Swedish EPA states that textile consumption has increased 30% from the years 2000 to 2019 (Naturvårdsverket, 2021), an continued increase was estimated. This increase is estimated to be linear and continue so for the years investigated. By this, textile consumption increases by about 0.16 kg annually.

- Donating post-consumed textiles to NGOs has increased with 27% during the years 2008-2016. If this increase is estimated to be linear, this implies an increase with 0.1kg/person annually. Collection by NGOs was 3.8kg/person in Sweden 2016.

- Volumes are disposed in mixed household waste are estimated to be separately collected in the future.

- The share of pure cotton fractions in the collected textiles are estimated to follow the picking analysis made by SMED (2016) that revealed a 58% share of pure cotton (Hultén et al., 2016).

As an example for how the calculations were made, the prognosis for the Swedish population in the year 2025 is 10,786 millions. This data, along with the netinflow per capita of textiles that was expected to increase linearly, provided the total volumes going from retails to households. This was hence calculated by following equation:

$$Textiles\ consumed\ by\ households\ in\ 2025$$

$$=\ Population\ 2025\ *\ (Netinflow\ year\ 2019\ +\ Netinflow\ increase)$$

$$= 10,786\ millions\ *\ (13.7kg/capita\ +\ 0.16kg * (2025 - 2019)) = 157987\ tonnes$$

The netinflow of textiles to households in 2025 that accounted for an increase in consumption was then estimated to be 14.6 kg per person. Furthermore, the new rate for how much of incoming textiles to households that was donated to NGOs and that accounted for an increase was calculated by:

$$Donation\ rate\ of\ what\ has\ been\ consumed$$

$$=\ \frac{Donated\ textiles\ + donation\ increase}{Netinflow\ of\ textiles}$$

$$=\ \frac{3.8\ +\ 0.1 * (2025 - 2016)\ kg\ per\ capita}{14.6\ kg\ per\ capita} = 32\%$$

With the new rate representing an donation increase, the new amount for what is being donated to NGOs could be calculated:

$$Textiles\ donated\ by\ households\ in\ 2025$$

$$=\ Volumes\ to\ households\ *\ Donation\ rate$$

$$=\ 157987\ tonnes\ *\ 32\% = 50694\ tonnes$$

The scenarios for the years 2025 and 2030 where increased population, consumption, and donation to NGOs are included are presented in the Tables 4.3 and 4.6. The calculations reveals that maximum estimated volumes for recycling in 2025 could be about 24500 tonnes, of which 14200 tonnes could potentially be pure cotton. Again, to account for some uncertainties about the trends, further scenarios were made where these trends were excluded or not. In Tables 4.4 and 4.7 the result for an increased population and donation to NGOs are presented. The Tables 4.5 and 4.8 present the result with only a population increase and can hence be seen as the minimum expected volumes.

Estimated future volumes year 2025 with separate collection		
Increased population, consumption & donation		
Calculating rates for flows in a system with separate collection		
Based on 2025 Swedish population:	10.786 millions	
	Kg per capita	Volumes [tonnes]
Netinflow of textiles	14.6	157987
	Rate	Volumes [tonnes]
of which going from retails to households	100%	157987
of which separately collected	37%	58812
and suitable for:		
reuse	59%	34699
pure cotton recycling	18%	10574
mixed/other fiber recycling	13%	7657
incineration	10%	5881
of which donated to NGOs	32%	50694
and suitable for:		
reuse	76%	38517
recycling	12%	6221
incineration	9%	4500
Total volumes suitable for reuse		**73216**
Total volumes suitable for recycling		**24453**
of which pure cotton recycling		*14183*
Total volumes to incineration		**10382**

Table 4.3: Estimated future volumes in 2025 with an increased population, consumption, and donation to NGOs of textiles by households.

Estimated future volumes year 2025 with separate collection Increased population & donation		
Calculating rates for flows in a system with separate collection		
Based on 2025 Swedish population:	10.786 millions	
	Kg per capita	Volumes [tonnes]
Netinflow of textiles	13.7	147768
	Rate	Volumes [tonnes]
of which going from retails to households	100%	147768
of which separately collected	37%	55009
and suitable for:		
reuse	59%	32455
pure cotton recycling	18%	9891
mixed/other fiber recycling	13%	7162
incineration	10%	5501
of which donated to NGOs	34%	50694
and suitable for:		
reuse	76%	38517
recycling	12%	6221
incineration	9%	4500
Total volumes suitable for reuse		**70972**
Total volumes suitable for recycling		**23274**
of which pure cotton recycling		*13499*
Total volumes to incineration		**10001**

Table 4.4: Estimated future volumes in 2025 with an increased population and donation to NGOs of textiles by households.

Estimated future volumes year 2025 with separate collection
Increased population

Calculating rates for flows in a system with separate collection		
Based on 2025 Swedish population:	10.786 millions	
	Kg per capita	Volumes [tonnes]
Netinflow of textiles	13.7	147768
	Rate	Volumes [tonnes]
of which going from retails to households	100%	147768
of which separately collected	37%	55009
and suitable for:		
reuse	59%	32455
pure cotton recycling	18%	9891
mixed/other fiber recycling	13%	7162
incineration	10%	5501
of which donated to NGOs	28%	40987
and suitable for:		
reuse	76%	31141
recycling	12%	5030
incineration	9%	3639
Total volumes suitable for reuse		**63596**
Total volumes suitable for recycling		**22082**
of which pure cotton recycling		*12808*
Total volumes to incineration		**9139**

Table 4.5: Estimated future volumes in 2025 with an increased population.

Estimated future volumes year 2030 with separate collection		
Increased population, consumption & donation		
Calculating rates for flows in a system with separate collection		
Based on 2030 Swedish population:	11.095 millions	
	Kg per capita	Volumes [tonnes]
Netinflow of textiles	15.4	171272
	Rate	Volumes [tonnes]
of which going from retails to households	100%	171272
of which separately collected	37%	63758
and suitable for:		
reuse	59%	37617
pure cotton recycling	18%	11464
mixed/other fiber recycling	13%	8301
incineration	10%	6376
of which donated to NGOs	34%	57694
and suitable for:		
reuse	76%	43835
recycling	12%	7080
incineration	9%	5122
Total volumes suitable for reuse		**81453**
Total volumes suitable for recycling		**26845**
of which pure cotton recycling		*15570*
Total volumes to incineration		**11497**

Table 4.6: Estimated future volumes in 2030 with an increased population, consumption, and donation to NGOs of textiles by households.

Estimated future volumes year 2030 with separate collection		
Increased population & donation		
Calculating rates for flows in a system with separate collection		
Based on 2030 Swedish population:	11.095 millions	
	Kg per capita	Volumes [tonnes]
Netinflow of textiles	13.7	152002
	Rate	Volumes [tonnes]
of which going from retails to households	100%	152002
of which separately collected	37%	56585
and suitable for:		
reuse	59%	33385
pure cotton recycling	18%	10174
mixed/other fiber recycling	13%	7367
incineration	10%	5658
of which donated to NGOs	38%	57694
and suitable for:		
reuse	76%	43835
recycling	12%	7080
incineration	9%	5122
Total volumes suitable for reuse		**77220**
Total volumes suitable for recycling		**24621**
of which pure cotton recycling		*14280*
Total volumes to incineration		**10780**

Table 4.7: Estimated future volumes in 2030 with an increased population and donation to NGOs of textiles by households.

Estimated future volumes year 2030 with separate collection		
Increased population		
Calculating rates for flows in a system with separate collection		
Based on 2030 Swedish population:	11.095 millions	
	Kg per capita	Volumes [tonnes]
Netinflow of textiles	13.7	152002
	Rate	Volumes [tonnes]
of which going from retails to households	100%	152002
of which separately collected	37%	56585
and suitable for:		
reuse	59%	33385
pure cotton recycling	18%	10174
mixed/other fiber recycling	13%	7367
incineration	10%	5658
of which donated to NGOs	28%	42161
and suitable for:		
reuse	76%	32034
recycling	12%	5174
incineration	9%	3743
Total volumes suitable for reuse		**65418**
Total volumes suitable for recycling		**22715**
of which pure cotton recycling		*13175*
Total volumes to incineration		**9401**

Table 4.8: Estimated future volumes in 2030 with an increased population.

To summarise what could be the magnitude of future volumes of textile waste from Swedish households, the scenarios are presented in Figure 4.6. The trend for consumption has not been linearly increasing, although for simplicity, this is the estimation. The trend for donation to NGOs has its latest data from 2016 and can have changed. Due to the uncertainty with these trends, three expected volumes for each year were calculated and the differences in the staples build on if there will be an increase in consumption and/or donation.

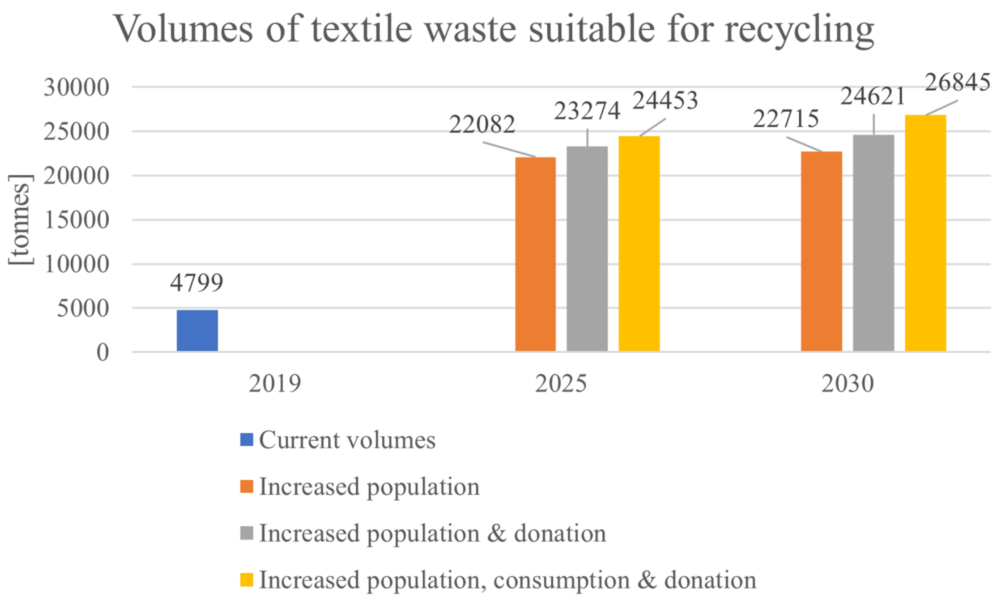

Figure 4.6: Recycled volumes in 2019 (Belleza & Luukka, 2018) and expected volumes in 2025 and 2030 (based on assessment in this thesis).

Furthermore, Figure 4.7 illustrates how post-consumed textiles from Swedish households are estimated to be managed currently compared to the identified volumes suitable for reuse, recycling, and incineration. What can be concluded is that what is currently sent to incineration will with a separate collection be distributed for reuse and recycling instead.

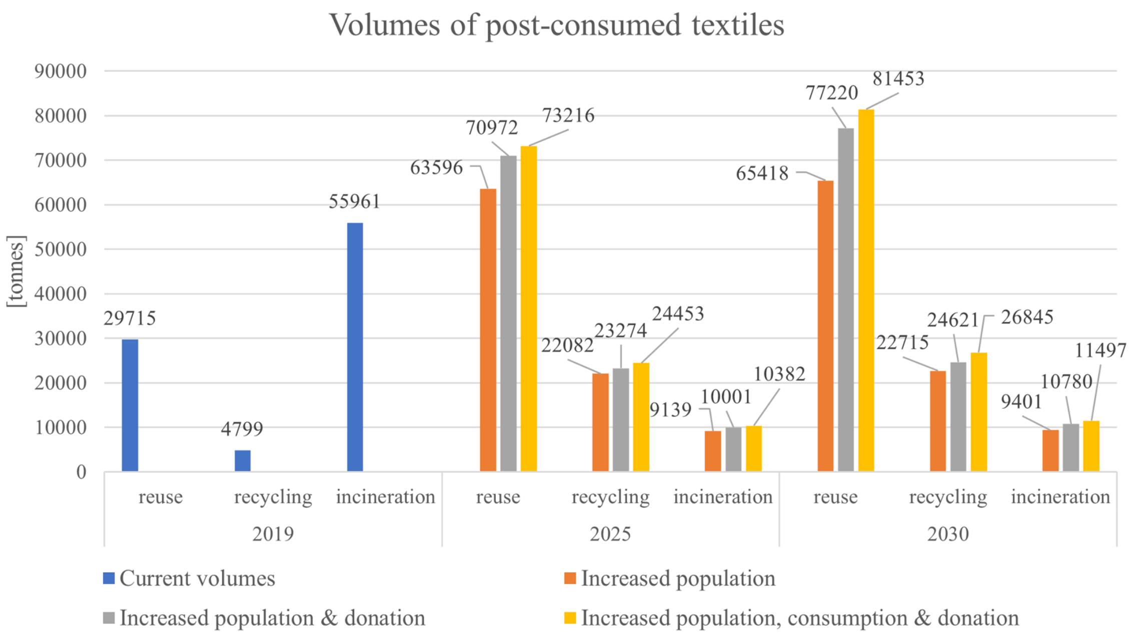

Figure 4.7: How post-consumed textiles were treated in 2019 (Belleza & Luukka, 2018) and suitable volumes for reuse, recycling, and incineration in 2025 and 2030 (based on assessment in this thesis).

It was identified in the literature (Belleza and Luukka, 2018; European Union, 2020; Ljungkvist et al., 2018) that the global market for reuse is becoming saturated, this begs the question if it is reasonable that the volumes for reuse are to more than double. Textiles that can be reused should be reused, but if there is no market for reuse, there will perhaps be more volumes going to recycling. The further assessment although builds on the volumes for recycling shown in the Figures 4.6 and 4.7.

In this analysis, rates are fixed and based on secondary data that varies in time and content. The real world system is a more dynamic system that probably works in a different way then presented here. The aim of the analysis of the expected volumes in this study is not to obtain new data (as this would be a major study in itself), but to give an estimation of the magnitude of volumes a supply chain for recycling must manage based on the information provided today. To make more accurate estimations of future volumes, more accurate and up to date data would be needed.

4.3 Fiber content in the textile waste

For the year 2025 for example, it is presented in Tables 4.5 and 4.3 that estimated volumes for recycling are about 22100 to 24500 tonnes, of which about 12800 to 14200 tonnes could potentially be pure cotton if based on a share of 58% cotton in previously disposed textile found by SMED (2016). As some recycling techniques that are becoming commercial in Sweden are relying on cotton- or cellulose based textiles as feedstock, this volume is specifically interesting to look at (Statens Offentliga Utredingar, 2020). Based on the picking analysis by SMED (2016), the retrieved volumes of textile waste could potentially consist cotton volumes presented in Figure 4.8.

Although, this high share of cotton becomes contradictory when looking at the global textile fiber production. Today's production of fibers was given by Textile Exchange (2020) and has the allocation 52% polyester, 23% cotton, 6.4% manmade cellulosics (MMCF), about 1% wool, less than 1% down and the rest are other fibers. If the fibers that are currently produced becomes waste in the future, the identified volumes of textile waste could have the content as Figure 4.9 indicates. Compared to this, there is probably a great uncertainty to the indicated 58% share of cotton.

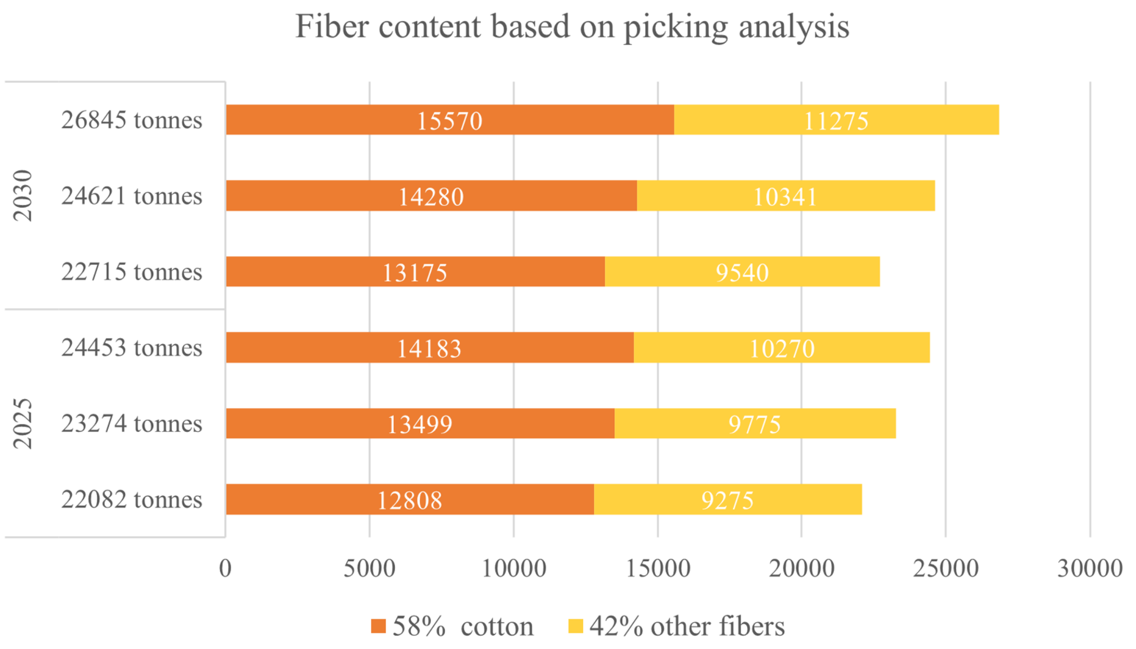

Figure 4.8: Expected volumes of textiles in the years 2025 and 2030 from households suitable for recycling by potential fiber content.

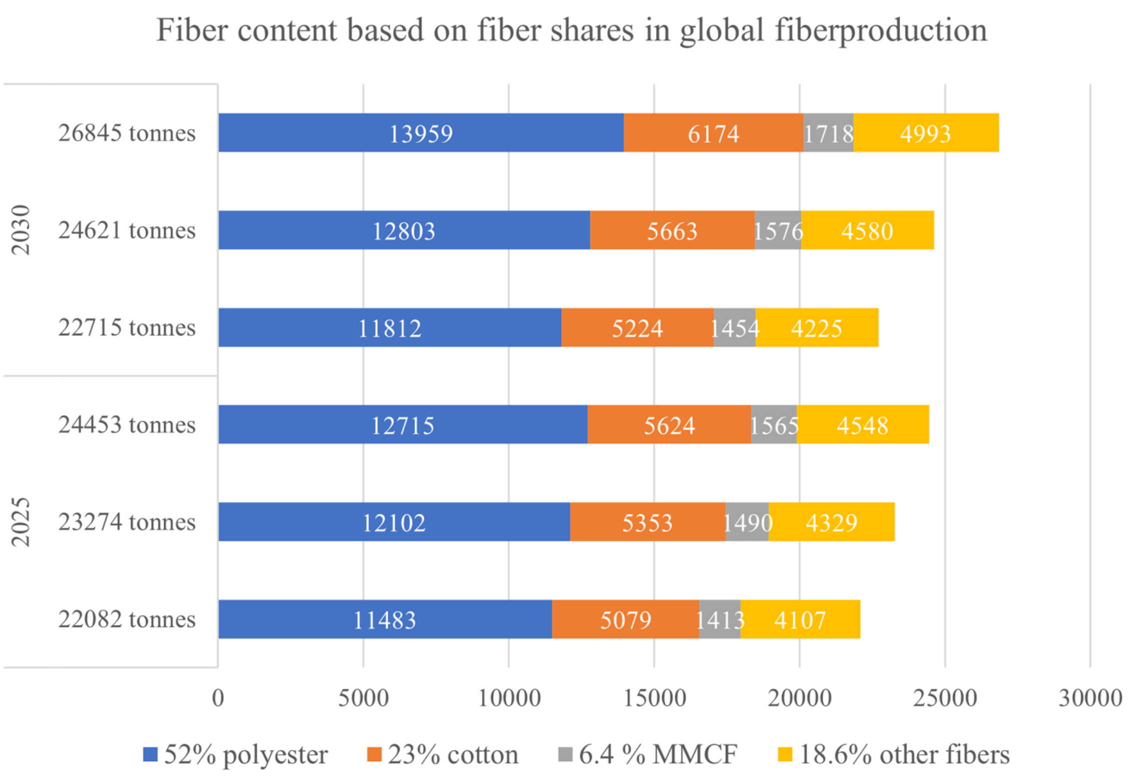

Figure 4.9: Expected volumes of textiles in the years 2025 and 2030 from households suitable for recycling by potential fiber content.

If Figure 4.9 provides a more representative description of the fiber content of the textile waste in the future, the volume of cotton fibers in 2025 suitable for recycling would be about 5100 to 5600 tonnes. The fiber that would make up the largest share of the textile waste would hence be polyester, which in 2025 would have volumes suitable for recycling of about 11500 to 12700 tonnes. Same reasoning can be observed in Figure 4.9 for the year 2030. Note that these different fiber shares present the fibers produced. Fibers are then used in textile production where it is commonly the case that fibers are blended to create textiles of different properties (Rex et al., 2019).

What can be concluded is that there is a need to more properly investigate what textile waste from households consist of as the literature lacks in information about this. This includes investigating which fiber mixes are commonly used and what could be future fibers on a more sustainable market. For example, the manmade cellulosics (MMCF) should increase if recycling of cellulosic textile waste becomes more commercial.

5

Results of empirical study

This chapter aims to present the results of the semi-structured interviews. As explained in the methodology, the data from the interviews have been analyzed making use of a thematic analysis. The codes generated out the analysis are presented in Table 5.1. As it can be observed, the codes are grouped into four themes that set the structure for this chapter. The frequency for the number of times each code was refereed to is presented in Table 5.1. The color on the different frequencies in Table 5.1 depends on which type of actor referred to the code. The three types of actors interviewed (sorters, recyclers and experts) are represented with one color each seen in Figure 5.1. As it can be deduced, if the color of the frequency is black, it means that all three actor groups referred to the code.

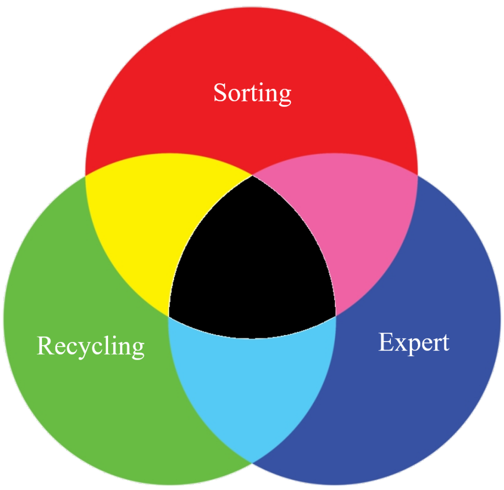

Figure 5.1: Color categorization of actors to portrait who mentioned the codes.

Codes	Frequency	Theme
Value of sorting.	9	Sorting of textiles waste
Cost-effective collection and sorting.	5	
NIR and VIS technology.	2	
Customer specific sorting.	7	
Hardware removal.	6	
Clean textile waste.	4	
The higher the requirement level the higher the cost and value.	1	
Value of recycling.	3	Recycling of textiles waste
Recycling technologies.	5	
Chemical content management.	7	
Reliable feedstock.	6	
Low requirement level.	3	
High requirement level.	11	
Complexity of household waste.	8	
Value of textile waste.	9	Challenges for Circulairty
Waste collection directive.	4	
Cost for managing textile waste.	6	
Need for increased amount of textile recycling technologies.	8	
The transition challenge.	2	
The cellulose gap.	3	
Unstructured collection.	5	
Need for scale.	12	
Policies.	4	Enablers for Circualrity
EPR.	7	
Standardization.	4	
Market forces.	2	
Industry interests.	5	
Collaboration.	6	
Digitalization for traceability.	10	
Design focus.	6	

Table 5.1: Result of the thematic analysis performed on the conducted interviews.

5.1 Sorting of textile waste

Value of sorting

One of the key puzzle pieces for textile waste to be re-looped is the sorting process. One of the sorting actors explained that post-consumed textiles is sorted manually for reuse, a process that demands the human touch which is why it can be labour-intensive and costly. The non reusable fractions, the textile waste, should be sorted accordant to specific requirement for recycling processes. As there is low value in managing waste, this sorting cannot be to costly. This is why automated sorting preformed by machines should be applied on textile waste. The sorting actors presented their views on the value of sorting in the circular supply chain of textiles. Despite the value that manual sorting provides for textiles to get re-looped, the focus of the interviews was around automated sorting for recycling.

The automated sorting facility SIPTex was developed out of a need for gaining reliable feedstock to the recycling processes. This was seen as missing link for recycling technologies to scale up. If feedstock could not be ensured, there was no incentive to further invest in these recycling technologies. By the development of automated sorting, textiles can be sorted exact and efficiently, allowing a cheap sorting process. The value of automated sorting is hence to sort textiles in a rapid and cost-effective manner. The sorting actors explain that the textiles get sorted according to the customer requirements. The customer is hence the recyclers who get the textiles that meet their needs. For the recycling companies getting the right sorting and fiber mix is the most important to ensure quality. However, there are some limitations and to maximize the value and cost-effectiveness of the recycling supply chain, the sensors for automatic sorting need to be improved to be more accurate and faster. Recycling actors defend that sorting processes will need to ensure the separation of valuable materials such as cotton, wool, other natural fibers, and pure polyester fibers; and downcycle the rest. Nevertheless, as explained by some of the recycling actors, there is a need for reliable feedstock, and recycling companies are in search for sorting partners to ensure their supply needs.

Cost-effective collection and sorting
Additionally, the SIPtex facility increases the average speed and scale needed of the industry. Scale is one the barriers for the development of the recycling industry of textiles. Consequently, the sorting actors emphasize the need for a cost-effective collection and sorting system to decrease the costs associated to those processes. Experts explain that there is still not a good enough business case to sort through recycling feedstock, since only a small fraction of the collected textile waste can be send for recycling, and to sort out that fraction, the only technology available is the NIR and VIS technology. If complemented with technologies such as digitized solutions, the efficiency of the sorting process could increase, and thus the costs could be reduced. If a cost-effective sorting is reached, less innovating companies and projects are going to start sorting and recycling at scale, since reliable feedstock could be found at an affordable price.

To achieve cost-effective waste management of textile waste derived from households is of extra importance. This volume of textile waste was called "wild volumes" by a sorting actor which reflected on the heterogeneous content of materials and textile products. The more "wild" collected volumes, the more pre-treatment and sorting it will require to sort out valuable fractions.

NIR and VIS technology
The technologies used for automated sorting are Near-Infrared Spectroscopy (NIR) to sort textiles based on material type and VIS sensors to sort textiles based on their colors. The sorting actors explain that this technology is improving the recycling supply chain since one of its base requirements are to identify the materials circulating. Textile waste is fed onto a band manually or automatically, of which they pass through a detector and according to it are placed in fractions to pre-programmed requirements. For example, Wargön Innovation, their sorting process can sort 16 fractions at a time. However, the sorting actors and the experts explain that the technology cannot sort through all the materials. Since this technology builds on detecting what can be seen, materials that are not visible at the surface cannot be

detected. This is why materials of multi-layers such as jackets or elastane are not identifiable correctly by the sensors. This begs the need for an increase traceability of textiles.

Customer specific sorting
As introduced by the sorters, the sorting facilities sort based on the needs of their customers (the recycling companies). Consequently, all textiles processed are not suitable for recycling. The textiles that do not meet the recycling requirements depend on the variety of customers that the plant can send different textiles to and the requirement level that the customers have. As an example, experts explain the materials can be separated for chemical cellulose-based recycling, chemical fossil-based recycling, and mechanical recycling.

Hardware removal
One of the supply requirements for textiles to be recycled are the removal of hardware. Preventively, sorters explain that automating sorting only process textiles that have their hardware removed. The hardware are buttons, zippers, and similar details commonly used in textile products. Moreover, multi-layer textiles such as jackets with outer material, padding and lining needs to be disassembled to be accepted in the automated sorting process. According to one of the recycling actors, part of the reason that the recycling supply chain has not been cost-optimized, are the lack of efficient collection, sorting, pre-treatment of textiles. Since that infrastructure and standardized procedures are lacking, some of the sorting companies remove the hardware themselves at their own expense.

Clean textile waste
Similarly, another of the supply requirement for textiles to be recycled are that they need to be clean. This was identified to be of importance for all recycling actors. The reason for this is that the input in a recycling process equals the output of the same in terms of the end product's quality. Consequently, experts said that the collection system aims to respect that need and improve those processes for textiles to be distributed cleaned.

The higher the requirement level the higher the cost and value
The need of customer specific sorting, hardware removal and cleaned textiles becomes added to the requirement level of the feedstock the recycling companies need. One of the sorting actors noted that the higher the requirement level, the higher costs associated for sorting. This is due to the need to process the textile waste several times to sort out the textiles that do not meet the requirements of their customers. But the result of this sorting is also a higher value of the materials delivered from the sorting process.

5.2 Recycling of textile waste

Value of Recycling
Recycling technologies allow textile waste to be recycled. For the past century companies have found new ways to make use of used textiles. Textiles are going to be increasingly abundant and viewing them as disposable product instead of durable is not sustainable. Consequently, treating post-consumed textiles according to the waste hierarchy is needed. As explained by one of the recycling actors, the waste that would be incinerated should be recycled. Both sorters and recyclers agree that with time the recycling supply chain will be improved, and textile waste will be seen as raw material. The actors base their prediction by comparing to other industries where recycling is more incorporated in the products life cycle, such as the aluminum-, plastic-, and paper industry. However, recycling of textiles comes with its challenges. The technology needs to be able to handle the complexity of textile waste, and the supply chain need to meet the requirements of the recycling companies.

Recycling technologies
The recycling actors interviewed either recycle mechanically or chemically. Mechanical recycling by the actors interviewed (Convert, and Rifo) consists of shredding the textile waste into smaller fibers. The applications of mechanical recycled materials by the actors varied from isolation panels, furniture, cleaning rags, or new yarn for textile production. Mechanical recycling has been developed the most due to the simplicity of its technology.

Chemical recycling by the actors (INONCELL, Södra, and Renewcell) consists of creating viscose fibers out of cellulose-based textile waste. Viscose is today mainly based on wood, another material built from cellulose. Sweden has benefited from its history around paper- or cellulosic-based recycling. With this history, Sweden posses knowledge and infrastructure needed to recycle this kind of fiber. Sweden is hence proficient in chemically recycling of textile waste. Out of this chemical recycling process companies produce a “dissolving pulp” that is then used to manufacture new textiles. Chemically recycling solutions are more resent and are gaining interests by the industry since the MMCF have similar or improved properties than virgin materials but are more sustainable and attractive in their essence. For example, the Finish research about IONCELL has enabled recycling of cotton into a MMFC of doubled strength.

Synthetic fibers can also be chemically recycled. In Denmark the focus for textile recycling has evolved more around the recyclability of polyester. This, explained by the Danish recycling company Textile Change, has to do with trends for cotton production not being sustainable which has lead to an increasingly market share of polyester. It is therefore expected that polyester will play a bigger role in the future where it needs to be recycled. New chemical recycling around synthetic- and mixed fibers is being developed by innovative companies such as Textile Change that uses their chemical process to separate and recycle the materials of complex textile waste. Moreover, innovative research is being developed by universities such as Chalmers for the gasification of textiles to recycle them in a molecular level. This process is more established on plastic products at present, but research is ongoing on how textiles work in these reactions. The purpose of the research is to find synergies between different industries to find the most efficient routes for material flows. This can mean, for example, a cascade recycling where plastic can be converted into textiles that are converted into gas that can be converted into plastic.

Chemical content management
The recycling process of some of the recycling companies involve bleaching the textiles to take of the unwanted dyes. Undoubtably, this process and others create wastewater that contain chemicals that need to be managed. One of the experts explain that this are one of the environmental concerns of the recycling industry of textiles and it has not been decided yet who will be responsible for this waste. The chemicals are introduced into the textiles in their production phase, and thus transparency and accountability are essential. The chemical content within the garments consumed will affect the content of the output material from the recycling processes. Additionally, the chemical content is also altered in the use phase of a garment. One of the recycling actors explain that the uncertainty in the type of detergents used by consumers or other consumers behaviors create enough unpredictability that some recycling companies refuse to take in post-consumed textiles due to health and security concerns.

Reliable feedstock
One of the bigger concerns described by the recycling actors are to find reliable feedstock. The recycling companies use textile waste as their raw material and as such, the waste has to be reliable. What is used as feedstock materials directly affects the output material from recycling processes. This is why the quality of the waste affects the quality of the materials derived from recycling. There is a lack of transparency around the content of textile products, something that is a challenge for estimating the quality of the textile waste. Experts explicate that this difficulty is then dependent on the tolerance level for feedstock material to recycling technologies, in other words their requirement level. From another view, the difficulty can then be dependent on the collection and sorting infrastructure that should meet the need of recyclers better.

Low and high requirement level
As introduced, depending on the recycling technology, companies found it harder or easier to source the feedstock material needed. The requirement level also depends on the end-product and its application. Lower valued recycled (downcycled) textile products such as cleaning rags are less demanding on the specifically of the textile waste, meaning that they can take in large mixes of textiles. However, to produce new yarn, quality isolation panels, furniture, or MMCF, that have higher market value (upcycling), requires more specific textile waste. Recycling actors described a high demand for homogeneous textiles such as cashmere, wool, and cotton. Due to the challenging dyeing process, white cotton is the highest demanded textile based

on the information gathered from the interviewed actors. Nevertheless, innovative technologies such the one developed by Textile Change is decreasing the requirement level form textile waste while promising valuable recycled textiles.

Complexity of household waste
Household textile waste or “wild textiles” (as referred to by one of the recycling actors) are complex due to the material mixes that can be found in clothes and home textiles. The requirement level of the recycling processes makes it difficult to recycle complex household waste. Experts explain that recycling textile waste from households needs to prove profitability economically, ecologically, and socially if innovative technologies around it are to be developed. Some textile waste require polymerization processes for the management of residuals such as paints, chemicals, various fibers etc. Some textile waste has no solution that can manage its content today. Thus, if the textile waste from households is recycled as it currently is, there is always going to be fractions that cannot be recycled and are to be incinerated.

5.3 Challenges for circularity

Value of textile waste
The economic value that the textile waste provides drives or hinders the development of circular textiles. One of the experts explain that out textile waste collected from post-consumed textiles, 10% of the garments referred as the “cream fractions” provide 98% of the total economic value that can be profit from the textile waste. Those fractions have such profitability since they are sold on secondhand markets. This is one of the main reasons for the secondhand industry to be as developed as it is compared to the recycling industry. Of the collected textiles, 50% are considered to be used for recycling and they only count to one percentage of the economic value. One of the sorting actors explain that difference of value gain from post-consumed textiles encourages reuse, which is positive to respect the waste hierarchy but it poses a challenge for the economic viability of the recycling textile industry. The low economic return from the recycling industry is caused by the downcycling of textile waste through mechanical recycling that is commonly applied today. Mechanical recycled materials such as cleaning rags have low economic return and are one of the main recycling applications that can be found at scale in Europe. How circular this kind of recycling is can be questioned due to the fact that after the rags has been used they are disposed where they probably go to incineration.

Waste collection directive
The biggest challenge all actors agree upon down the line, is the waste framework directive that will force post-consumed textiles to be collected separately. All actors reflect on the challenges that the industry will face when making use of the textile waste. The gap lies on the technological readiness of recycling technologies at scale, where investment is needed to implement them at scale. Moreover, they describe the lack of infrastructure for both collecting and sorting the post-consumed textiles.

Cost of managing textile waste
The recyclers and experts explain that there is both an economical and environmental costs associated with textile waste management. It has been explained that an incineration tax often is required for waste that is sent to incineration. Therefore, recycling companies have explained that the laundry industry for instance, must pay to get rid of their textile waste if it is sent to incineration. Recycling companies are therefore arranging win-win situation where they are offering laundries to pay them instead to manage the textile waste by recycling. Despite it, the experts explain that there is a need for scale to compensate the economic costs of recycling textiles.

Need for increased amounts of recycling technologies
As it has been reasoned by all the actors, there is a need for innovative technologies to deal with complex textile waste. As mentioned, companies like Textile Change or innovations at universities are being developed. Experts explain that this should be highly incentivized for the future of the recycling industry. There is a gap between what is collected and what can be taken care of.

The transition challenge
A recycling actor reason that there is no clear solution on how to recycle complex mixtures of materials used in textiles. This might lead to a change for which fibers and fiber-mixes are used in future textile production. This creates a paradox and challenge for recycling companies since there is a need to manage the complex textile waste in the near future, but also another type of textile waste that is expected to change with companies and business models becoming more circular. The investments for future recycling technologies must have this in mind. Thus, there must be a balance to support the problem in the present and to develop the solutions that are also useful in the future.

This was also mentioned by a recycling company who said "the textile industry will become more circular, but how is the question? Either the industry will use more bio-materials, like grass fibers, hemp fibers [...] Another scenario is using waste as a resource more. Textile waste will be significant in the short term, but in the long term its more uncertain." Both taught reflects on the uncertainty for which path the textile industry will take when transitioning to circularity. Will the solution be to develop technologies that can manage the textile waste today? Or, will the solution be to change the characteristics of textile waste by changing how textiles are designed? These where points brought up by actors.

The cellulose gap
Experts and one recycler interviewed believe that the fashion brands are interested in polyester and to recycle it because they think that this material will have a larger market share in the future since arable land is scarce and needed for food production. The world population will continue growing and with it the need for food production. Consequently, cellulose fibers such as cotton will reach a limit and will no longer be prioritized. This is referred as the cellulose gap that is expected to be reached by 2030. Due to the cellulose gap, it is expected that polyester will

play a bigger role in textile production, and there will be a higher need for recycled polyester textiles. H&M has historically been the largest consumer of cotton in the world and therefore wants this raw material to be from sustainable produced cotton or replace cotton with other sources of material and use recycled cotton. Sustainability produced cotton reduces water consumption, and its environmental impact is kept below certain limits.

Unstructured collection
Due to the scale of the recycling industry, sorting and recycling actors explain that they do not have a standardized way of sourcing their feedstock. They accept their supply to be transported in pallets, plastic bags, or other forms. The same goes for their frequency where their frequency of delivery vary. The collection system is not given a priority and will possible cause future problems and unoptimized costs.

Need for scale
As it has been evident in the empirical results, the recycling industry needs scale. Scale is needed to research the economic viability to recycle textiles, for new technologies to be research, to streamline the collection - sorting - recycling supply chain, and consequently, to make the textile industry more circular.

Capacity The Table 5.2 shows a summary of the capacities of the actors interviewed.

Acror	SIPtex	Wargön Innovation	Taxaid
Capacity for sorting (tons/year)	24 000	500 -1 000	90 000

Acror	Convert	Södra	IONCELL	Textile Change	Renewcell	Rifo
Capacity for Recycling (tons/year)	1 920 - 5 760	25 000 - 30 000	Lab level	10 - 15 000	70 000	3.6

Table 5.2: Capacity based on the empirical results.

5.4 Enablers for circularity

Policies and EPR
When asking the actors for next steps to improve the recycling industry, experts, recyclers and experts referred to the needed guidance governance to streamline the supply chain, scale up or help to develop the needed technologies to recycle complex household waste. One of the ways to increase the needed guidance is through a Extended Producers Responsibility (EPR) for textiles. The first advantage of such policy is to help define who should be responsible for collection and sorting to create an effective system.

Moreover, EPR directives will be crucial and an important strategy for the textile industry in Europe and can change the cost structure of the industry, since part of the costs of recycling can be assumed by the producers of textiles. One sorting actor exemplified that France have already implemented a extended producer responsibility for textiles called Refashion. The French fashion industry hence finances the collection, sorting, recycling, and R&D for recycling technologies. The recycling actors have explain that currently is more expensive to be circular than linear. One of the recycling actors gave the example of the content declaration process at the end of the production line. All companies have to declare the content of the materials at the end of a production line. For linear companies, the content of the batches produced are always the same since the quantities of the material content are controlled and predictable. However, circular companies (in this case recycling companies of textiles) have to measure and declare new content of each of the batches produced since the material proportions vary for each feedstock batch used. There was hence an expressed need for policies that balance the cost for being linear verses circular. One recycling actor was hopeful and said that "in future the prizing of the different systems will probably be changed, more taxes on the linear system for example."

Lastly, policies can also enforce goals for such as 10% recycled material content to create a pull incentive. Policies aiming for spreading information to consumers was also mentioned, like labels. Experts and recyclers agree on that standardized labels that can assure a sustainable performance of textiles could provide the information needed for consumers not to only choose after price.

Standardization
"When understanding what kind of products are collected (if they are standardized) it will become easier to collaborate." This was expressed by an recycling actor that highlighted the need for standardization when it comes to textiles. This was brought up by other recycling actors as well that stressed that not only do they want standards for what products contains (materials, chemicals, etc.), but also for how to collect and sort.

One of the recycling actors explained that when it comes to standardization, one can look at how the paper industry created a global standard that defines how paper should be sorted based on the quality of paper. Their standards also guide the prices and value on the global market. Similarly, a standardization process is needed in the textile industry to facilitate the sorting process and allocate roles. However, textile is a more complex material, and this process of standardization will take time to implement. One possible scenario is that different textile wastes will cost according to usability and how much sorting/processing they require to become a feedstock. If this will be the case, sorted textile waste from households will not be such a valuable raw material, thus the price should correlate the cost they require to be recycled. There is a ongoing development of ISO standards for the textile industry.

Sorters, recyclers and experts explain that ther standards could be applied to guide how garments should be produced and designed for circularity. Experts recommend to design textiles for durability and recyclability.

Design for recyclability needs to be explored since the standards should facilitate the recycling processes of all the recycling companies. The experts arrive in a consensus when defending that reducing the complexity of the garments (by using more homogeneous the textile blends) yields increased recyclability. Reducing labels and hardware also facilitates the recycling process.

In the other hand, experts defend that durability should be promoted and standards should support that principle too. The material blends could be justified if it increases the durability of the garments. Durability as a principle follows better the logic of the the waste hierarchy, since durability extends the life usage of the garment. Durability also combats destructive nature that fast fashion has in the textile industry. If garments were more durable and less "trend" dependant, garments and the industry will be by definition more sustainable.

Recyclability and durability standards can be categorized as sustainability standards for textiles. Expert suggest that this parameters can be translated in a kind of standardized grading system such as the ones that is found in for appliances such as fridges, washing mashing and others. This grading system can guide consumers and increase the accountability of their purchases.

Industry interests and market forces
Innovative recycling companies interviewed perceive a high interest form the industry to make use of their technology to produce recycled textiles. The industry is attracted to recycled textiles because the occidental market where customers are demanded sustainable textiles. However, it is important to notice that according to some experts the need of sustainable textiles are not perceived in all markets. (But it can be assumed that the market within EU follows this trend.) Nevertheless, the industry and market inters are indisputably two of the strongest drivers for the transition of a circular industry.

Collaboration
To minimize the risk associated to large-scale implementations, companies should work together based on the same interests and share the costs needed for scaling up. These collaborations should be facilitated and stimulated as there are business models that are proven viable, but companies need to share the risk and costs for them to work. All actors agree that the circular economy is in its essence a collaborative ecosystem of companies that maximizes the value usage of products consumed by the market. All the actors aims to find ways to best collaborate and develop the recycling supply chain. For example, a large player in the textile industry H&M is developing its ecosystem to gradually change their business models. An other good example is Renewcell that collaborates directly with the retail companies to share the knowledge and capabilities needed to produce new garments out of recycled materials. The retail companies help Renewcell to transform their recycled textiles into new garments by making use of their infrastructure (transportation, production, and more) to create a product out of the recycled textiles.

As a key part of the supply chain, recycling actors highlight that collaboration between collectors and sorters is needed. Furthermore, to ensure same quality from different suppliers of textile waste. It is stressed a will for different collectors and sorters to follow standard procedures for achieving this. "What do we do after collection is key! How should textiles be treated when collected? It should be a standard how to sort etc, to ensure that same quality is obtained from different suppliers."

Digitalization for traceability
Another essential piece for the future of the textile industry is to develop the digital passport of textiles produced. Experts explain that to increase circularity in all regards, there must be a better visibility of what are the materials in use. To do so, manufactures are to be more transparent on their chemical usage, material composition, the quality of the feedstock, energy mixed used, and more. A digital passport can also provide information on the use phase and the brand of textiles. For example this could provide information on how many times a textile has been washed since it could affect the material composition. One actor explained that for every wash of textiles containing cotton, one percentage of cotton is lost. Moreover, technologies to increase traceability such as RFID can help with the limitations of automated sorting. Sicne NIR and VIS technologies only can read the surface of textiles, complementing these technologies with RFID technology can allow detecting materials and substances that are not visible on the surface. Further, it could enable a even more efficient automated sorting process since it would allow scanning volumes before. If the content of incoming volumes for automated sorting was know, the sorting could be programmed accordingly and become more efficient. Projects such as Tex.ID by RISE are being developed to test the future of RFID. With more information provided on textiles, the sorting for reuse could also benefit since it would allow for so-called 'cream products' to be easier identified.

Design focus
Design for circularity or new business models for circularity have been described by the experts as drivers to for the recycling supply chain. Design for circularity is a relative new concept as described by the experts. Thus, the knowledge need of circular thinking for the designers is not currently widely available. Recycling companies such as Renewcell are collaborating with the industry to teach the principles to design for recyclability. Thus, the design process should prioritize to design for durability and reuse. Consequently, business models that allows durable textiles to be reused and used resource efficient through renting and leasing is expected to occur more frequent.

Experts defend, that material mixes should be allowed depending on the motivation behind the decision. If the reason to mix textiles such as cashmere with cheaper materials is to decrease the costs, it should be questioned because it lowers the economic value of the cashmere and affects the recyclability. On the other hand, mixes such as cotton and polyester that complement each other should be allowed since cotton provides a comfortable softness and polyester durability.

6 Analysis and discussion

6.1 RQ1: What could be expected volumes of textile waste from Swedish households suitable for recycling in the years 2025 and 2030?

In this section, the potential future volumes of textile waste from Swedish households suitable for recycling will be discussed. Before doing this, it is important to stress that managing post-consumed textiles should occur accordingly to the waste hierarchy. This is stated in legislation like the EU Waste Framework Directive (European Commission, 2021b) and by actors interviewed. Post-consumed textiles of reusable quality should be reused, and non-reusable fractions constitutes the textile waste. This reasoning is due to the embedded labour, resources and energy used to produce textile products which makes it clear that reusing textile products for as long as possible leads to the most resource efficient material use and lowers the impacts of textile consumption the most. But when textile products becomes worn out or broken, they become textile waste. The textile waste needs to undergo some waste management and in the context of circular economy and resource efficiency, recycling processes is preferred to other waste management options commonly used today like incineration or landfill (European Commission, 2021b). It is also important to stress that reuse and recycling of textiles must substitute the need for new production of textile products and raw materials to lower environmental impacts and make the industry more sustainable.

Interviewed actors recognize that there is a big flow of textile waste volumes that needs to be managed to be able to close the loop for textiles. Recycling actors see the business potential as well as the opportunity to contribute to a more sustainable waste management, and developed recycling processes and technologies to make use of the textile waste. The literature reveals that there are significant fractions of textile waste occurring from just the consumption in Sweden (Statens Offentliga Utredingar, 2020; Hultén et al., 2016; Belleza and Luukka, 2018).

The current supply chain described in the literature illustrates how consumed textiles from households are treated without separate collection of textiles (Statens Offentliga Utredingar, 2020; Naturvårdsverket, 2021; Hultén et al., 2016). It is clear that household waste does not follow the waste hierarchy. It has been estimated that of consumed textiles by households, 37% are disposed in the mixed household waste. These fractions are then estimated to consist of 59% reusable textiles, 58% pure cotton, and 10% are estimated non-recyclable due to expected hazardous chemical content. Of consumed textiles by households, 28% are estimated to be donated to NGOs that mainly uses collected textiles for charity purposes (Belleza & Luukka, 2018).

Volumes for recycling in the current system are mainly supplied via collection and sorting by NGOs (Statens Offentliga Utredingar, 2020; Belleza and Luukka, 2018). The volumes derived from Swedish textile consumption that are managed by textile recycling are currently about 4800 tonnes. Of these, about 100 tonnes is estimated to be recycled in Sweden and the rest after being exported. Ellen MacArthur Foundation (2017) presented that less than 1% of clothes are closed-loop recycled globally (Ellen MacArthur Foundation, 2017). Instead textile recycling mainly consists of cascading to other industries for use in lower-value applications (downcycled). The majority of the textile waste is used for open-loop applications such as insulation material and wiping cloths, which are final use for these textiles. The literature that tells how collected textiles from households are managed does not describe how textile waste is used for close-loop recycling (Statens Offentliga Utredingar, 2020, Belleza and Luukka, 2018).

This information contrasts to the insights found in the empirical study of the closed-loop recycling actors. Some actors can make use of textile waste from households already and some want to do so in a future where more textiles are collected. Although, these actors mention that textile waste from households is a difficult volume to recycle due to a wild mix of fibers, colours, and chemicals found in textile products for households. Some actors that are doing closed-loop recycling are today mainly gaining their supply from more homogeneous textile waste fractions, like waste from the hotel- and service industry or post-industrial waste. For example, sheets and towels used in hotels are commonly made out of textiles based on cotton and polyester fibers. For actors demand cotton as feedstock to their chemical recycling process, supplying their demand from this source would be more reliable and cheap than sourcing from the household waste.

6.1.1 Potential magnitude of future volumes of textile waste

The scenario analysis presented in Chapter 4 is used to answer the RQ1. The magnitude of expected volumes in 2025 and 2030 are presented in Figure 6.1. The scenario analysis builds on identified quality (suitable for reuse, recycling, and incineration) of Swedish post-consumed textiles in Figure 6.2, and identified trends for an increased Swedish population and consumption of textiles. Textiles that before were disposed by households are in the scenario analysis expected to be separately collected instead. This implies that collection by NGOs and a separate collection will be the start of the recycling supply chain.

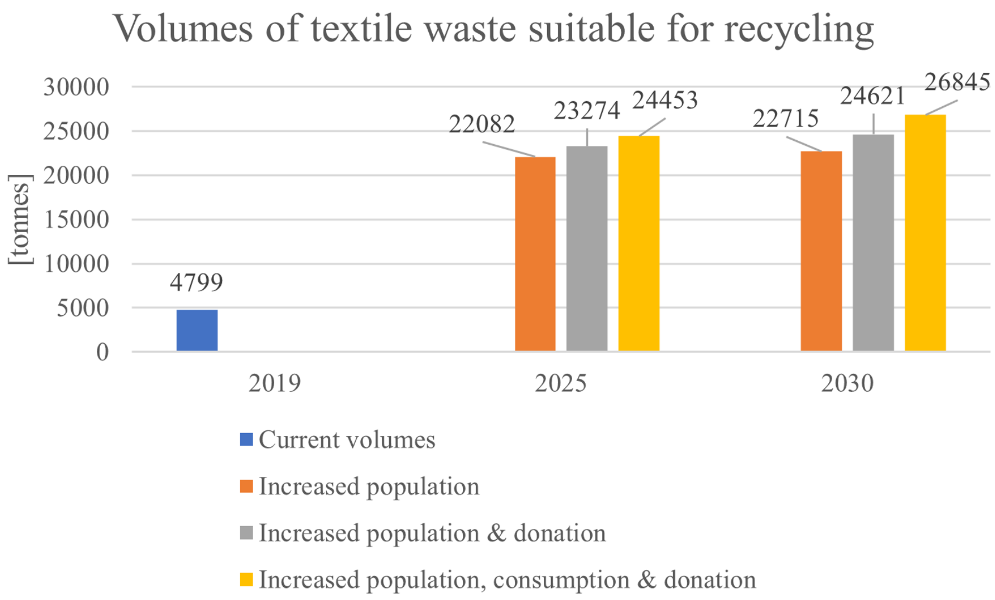

Figure 6.1: Recycled volumes in 2019 (Belleza & Luukka, 2018) and expected volumes in 2025 and 2030 (based on assessment in this thesis).

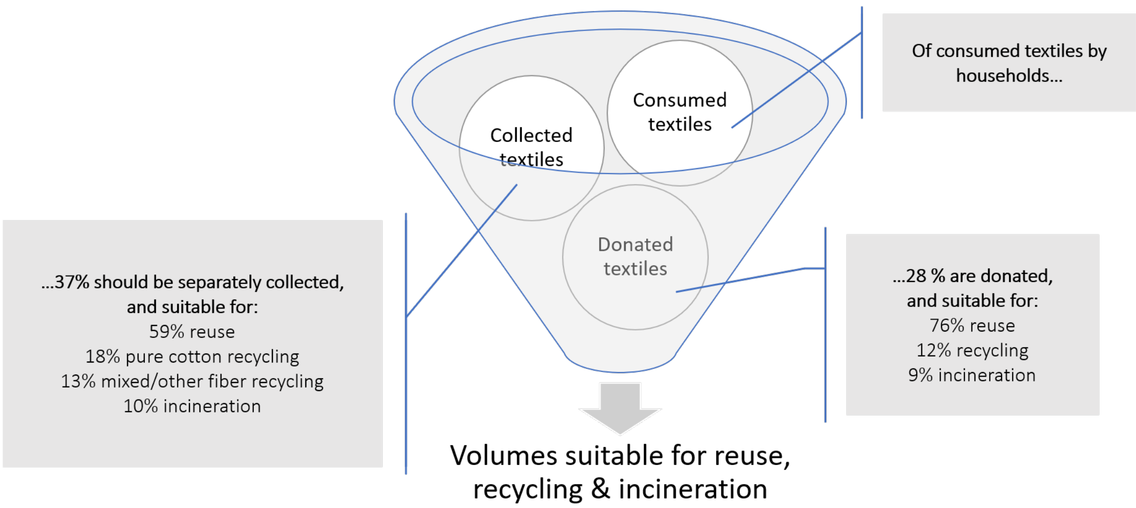

Figure 6.2: Connections of flows.

Note that the data for consumption is retrieved from 2019 (Naturvårdsverket, 2021), data on collection by NGOs is from 2016 (Belleza & Luukka, 2018), and data on what is currently disposed is from 2015 (Hultén et al., 2016). This portraits a lack of updated data for an accurate analysis. Due to the lack of available data, the analysis in this study has assumed a steady state and this is probably not the real world case. To make a better assessment, data on how textiles are consumed, for how long they are used, where they end up once becoming post-consumed, and the quality of post-consumed textiles needs to be explored. With this information, a better estimation of the connection between consumed and post-consumed textiles can be made.

This study builds on the assumption that 100% of post-consumed currently disposed in the household waste will be separately collected from 2025. The reason for this is to explore the full potential that can be achieved. What has to be kept in mind is that the Swedish EPA has stated a goal that at least 60% of post-consumed textiles should be collected by 2025 out of the 7,6 kg per person (households stand for 5.1 kg of these) disposed in the household waste in 2015 Statens Offentliga Utredingar, 2020. Further, the goal for the collected textiles is that 90% should go to reuse or recycling. This implies that the actual collected volumes in 2025 is allowed to be lower than the full potential that can be achieved. If there will only be a effort in collecting 60% of currently disposed textiles, expected future volumes of textile waste for recycling in 2025 could be lower than presented here. At the same time, textile waste from households will not be the only textile waste as the 7.6 kg per person currently disposed indicates (Hultén et al., 2016). This implies that the total textile waste from Sweden is higher than presented in this analysis. It is although estimated to be of importance to distinguish between post-consumed textile waste from households and post-industrial waste for example, as the waste from these different sources is expected to have different characteristics. Textiles consumed by households are complex garments and home textiles. These textile products consists of mixes in colours, materials, designs, and quality. The complexity of the textile waste from households makes this volume unique compared to textile waste derived from other sources that are more easy to predict due to its homogeneity.

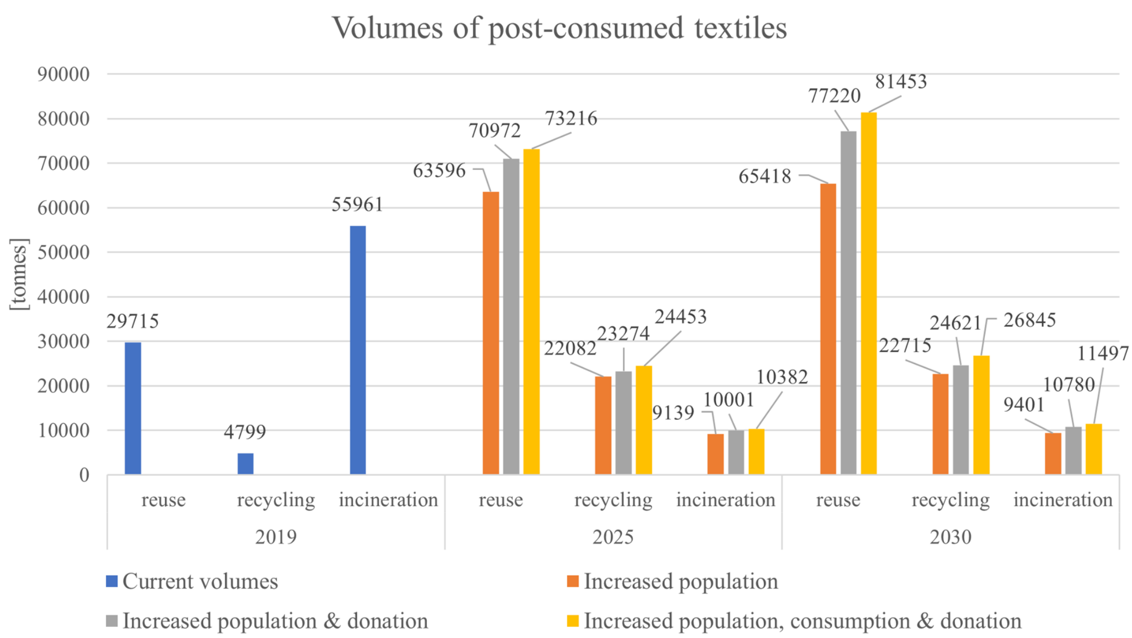

Figure 6.3: How post-consumed textiles were treated in 2019 (Belleza & Luukka, 2018) and suitable volumes for reuse, recycling, and incineration in 2025 and 2030 (based on assessment in this thesis).

Also, unless there are efforts in increasing the demand for buying second-hand (reuse collected textiles), there might be more post-consumed textiles going to recycling.

As explained in Section 4.2 and again in Figure 6.3, the volumes for reuse is currently about 29700 tonnes and these could potentially more than double when a separate collection is in place. At the same time, markets for reuse is becoming saturated not only in Sweden (Belleza & Luukka, 2018), but also globally (European Union, 2020; Ljungkvist et al., 2018). This highlights a great challenge to be addressed by a future supply chain managing post-consumed textiles and this calls for change. Again, note that this study regards how large the volumes for reuse, recycling, and incineration can be due to textiles consumed by and collected from Swedish households. This study do not regard where these volumes occur (for example if they are exported before becoming reused). It has been explained by literature (Statens Offentliga Utredingar, 2020; Belleza and Luukka, 2018; Watson, Kant Hvass, et al., 2020) and interviewed actors that a significant amount of textiles from countries like Sweden are being exported as the second-hand market might be larger abroad.

Furthermore, how textiles are consumed and treated when becoming unwanted by households in Sweden today is not reasonable in terms of circularity. It is clear in Figure 6.3 that textiles are currently not treated accordant to the waste hierarchy but they should to become more sustainable and circular (European Commission, 2020). The estimated future volumes in 2025 and 2030 (Figure 6.3) has volumes distributed more accordingly to the waste hierarchy as reuse is the highest staple, followed by recycling, and incineration has an significant reduction to current treatment. Although, recycling should preferably treat textile waste and not reusable fractions. If reusable fractions of textiles might go to recycling due to a saturated demand for buying second-hand, the waste-prevention step in the waste hierarchy might need exploring. This step aims to maximize the use of products (European Commission, 2020) and this begs the question if it is reasonable that there are high volumes of consumption and further unwanted textiles from households today? Therefore, how textile waste can be prevented and consequently how consumption of textiles can become more sustainable is a future area to be explored. Even though this study has investigated a supply chain with a future development dependent on if there will be a reliable supply of textile waste to recycling or not, the majority of the actors interviewed agree that the most sustainable way forward for the industry is to decrease consumption of new textiles and to maximise the use of textiles.

6.1.2 Potential content of future volumes of textile waste

Lastly, some information that can give an intuition of what textile waste might consist of was found by SMEDs picking analysis (2016) and by looking at the global fiber production given by Textile Exchange (2020). The result of this analysis can be found in Figures 6.4 and 6.5.

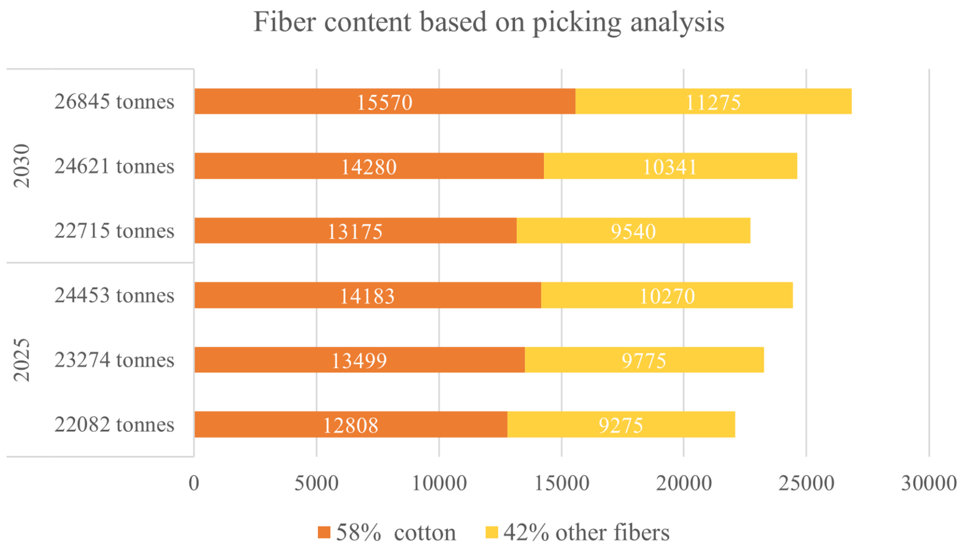

Figure 6.4: Expected volumes of textiles in the years 2025 and 2030 from households suitable for recycling by potential fiber content.

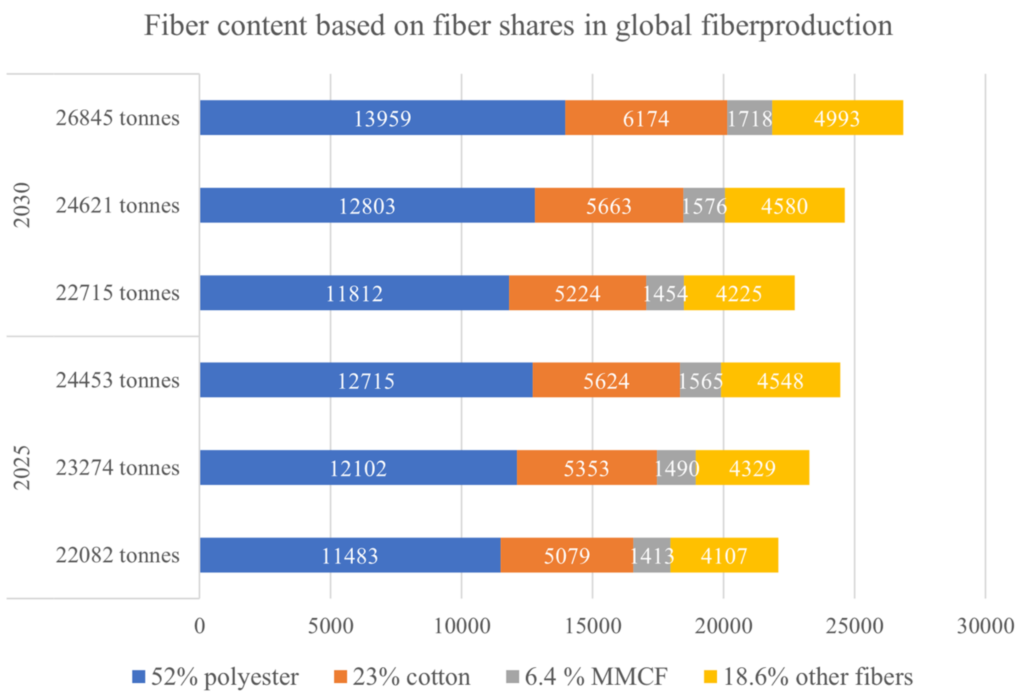

Figure 6.5: Expected volumes of textiles in the years 2025 and 2030 from households suitable for recycling by potential fiber content.

The attempt to explore what the expected future volumes of textile waste could consist of turned out to be a challenge. The information provided for doing so was the picking analysis of disposed textiles that revealed a 58% cotton content (Hultén et al., 2016). Although, this share of cotton becomes contradictory to the global fiber production that has an 24% share of cotton and a 52% share polyester (Opperskalski et al., 2020). Again, what can be concluded is that there is a need to more properly investigate what textile waste from households consist of. This includes investigating which fiber mixes are commonly used and what could be future fibers on a more sustainable market.

To conclude RQ1, the volumes of textile waste expected to occur from textiles consumed by households in Sweden is estimated to be around 22100 to 24500 tonnes in 2025 and around 22700 to 26800 tonnes in 2030. This has been estimated based on current trends who reveals that how consumers from households consume, use and dispose textiles in a quite linear way today. This behavior can be questioned if countries like Sweden are to become more resource efficient and circular. What can be drawn from this is that in the long-term future, how we consume, use and dispose textiles has hopefully changed within the principles for resource efficiency and circular economy. Another aspect that has hopefully changed in the same way is how producers source their raw materials and design products. The textile waste that will arise in the near future is hence expected to be different in terms of volumes and content than the textile waste in the longer term. Hopefully there will be less textile waste in the future, and hopefully the textile waste that is inevitable will go to recycling were it is re-looped not once, but many times. This is important to consider when further estimating future feedstock volumes to recycling processes.

6.2 RQ2: What are the supply chain requirements and capacity linked to automated sorters and recyclers?

To answer RQ2, understanding the context of the recycling industry today, the challenges of managing textile waste from households, and the requirements of the actors analysed in this study (sorters and recyclers) has been explored. The actors interviewed are aware of the waste framework directive and the challenges that come with it. Post-consumed textiles are going to be collected separately by 2025 and actors perceive that the industry is not ready for it. The nature of the challenge lies from the complexity of textile waste from households and the lack of capabilities to deal with such volumes. The challenges presented here will further be explored in in RQ3 along with potential enablers to solve them.

As explained by the actors, the textile waste from households is complex, and its complexity set the first challenge for its recyclability. By complex they refer to the amount of materials that exist in the different textiles that are used by households. This challenge set the premise for the actors in the supply chain. To further develop the textile recycling industry and make it an industry of scale, collaboration and a more streamlined supply chain is needed. The actors referred to enablers like standardization to ease the future collaboration. Standardization could be applied on the way garments are designed (design for recylability) or/and for a clear definition of roles in the recycling supply chain.

6.2.1 Sorting Requirements

As mentioned in the literature (De La Motte et al., 2019, Watson, Trzepacz, et al., 2020; WRAP, 2019), the technologies currently used for sorting are manual and automated. To be able to meet the specific requirements on feedstock to recycling processes, automated sorting is crucial. The identified technology for automated sorting enables textile waste to be sorted into fractions of fibers, fiber-mixes and colour. This has been described by literature (Statens Offentliga Utredingar, 2020; De La Motte et al., 2019) and interviewed actors as a large piece of a puzzle that needs to be in place to enable recycling technologies to scale up and become commercial. Manually sorting is the technology applied for separation fractions for reuse with the fractions of textile waste today. As reuse of textiles is out of the scope for this study, manually sorting has not been in focus. It is although important to highlight that manual sorting is the step in the supply chain before automated sorting. Today it is commonly that the actors that collect also organises manually sorting, how this will occur with a system for separate collection of post-consumed textiles has been out of scope in this analysis but is is an important subject to further investigate.

The complexity of the textile waste from households and the possibility of the existing recycling technologies with high requirement levels on their feedstock limits the sorting actors. The sorting actors sort according to specifications of their customers (the recycling companies). The interviewed recyclers are mainly chemical- or mechanical recycling companies. The literature provides an description of mechanical recycling companies that has low level of requirements (De La Motte et al., 2019; Lexén et al., 2016). They downcycle textiles into products such as rags, isolation or mats that can be produced out of complex textile waste, which means that they can take in a large variety of materials. The interviewed actors that do mechanical recycling although upcycle textiles. The mechanical recycles Covert and Rifo have a high requirement level, but those types of companies are in relative small scale compared to the rest of the downcycling mechanical recyclers. The chemical recyclers interviewed that preforms textile-to-textile recycling generally has high requirements on their feedstock material. Companies such as Södra and Renewcell only take in textiles that are made of a high percentage of cotton. By understanding the different levels of requirements for different recycling technologies, it becomes clear that sorting for a certain recycling process has to meet their specific needs. This affects the economic value of the textile waste and the costs associated with sorting. The more specific requirements, the more the sorting process will cost. Further, if the sorting companies must sort to meet the requirements of the recycling companies, there may arise textile volumes from the sorting process that becomes waste or are mechanically downcycled. Since downcycled mechanically recycled textiles commonly are sold for a lower price, the profit margin for sorting companies is reduced. More on how to mitigate costs associated with sorting is explained on the business gap of the RQ3.

An additional challenge the sorting actors' faces is the importance of the textile waste to be clean and out of hardware (zippers, buttons etc.). This speaks to the missing collection infrastructure to provide clean textile waste and the missing link of a hardware removal facility. These challenges and their solutions are explored further in RQ3.

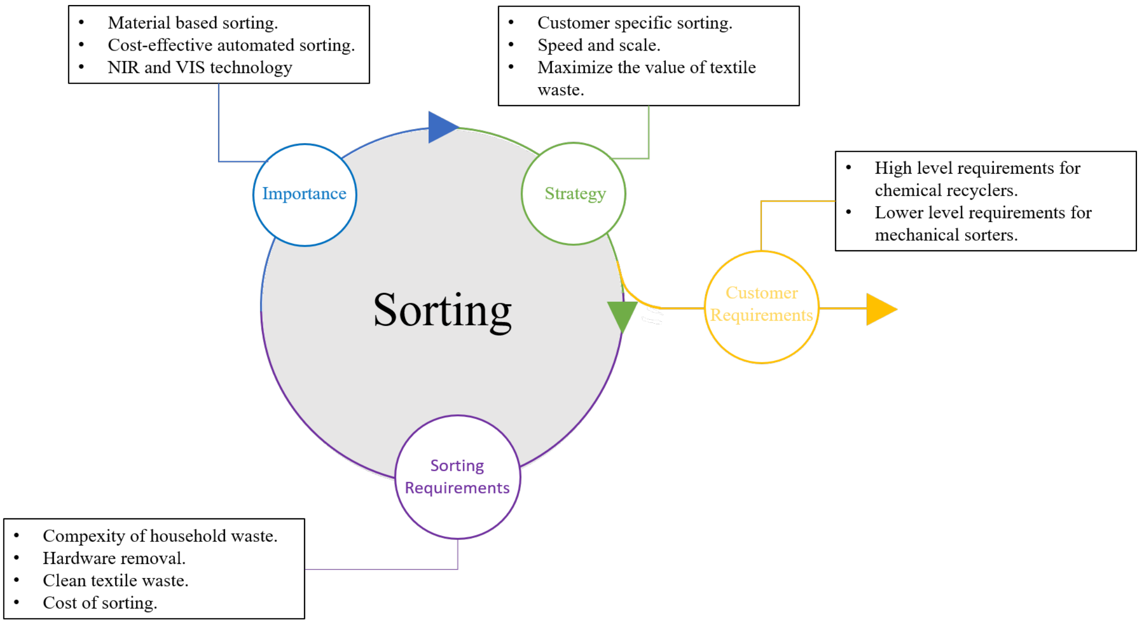

Figure 6.6: Sorting Requirements.

Many of the concepts and findings discussed in this section are also found in the literature. The value and logic used in sorting is mirrored in the literature too (Statens Offentliga Utredingar, 2020). The sorting companies aim to meet the requirements of their customers and sell their raw material according to the economic value it provides. Additionally, the SIPTex center have also been introduced in the literature, as well as challenges such as hardware removal (De La Motte et al., 2019). However, what hasn't been accentuated in the literature is the scale of the challenge that sorting companies face to meet the high requirements of the recycling companies. Also, the implications that those recycling requirements have on the economy of the supply chain.

6.2.2 Recycling Requirements

The value that the recycling actors provide have also been perceived by the stakeholders of the supply chain. For the past century companies have found new ways to make use of used textiles. Mechanical recycling has been developed the most due to the simplicity of this technology. Chemically recycling solution are more resent and are gaining interests by the industry. Its attractiveness comes from the quality or upcycling it can provide from the textile waste. For example, MMCF can be produced by chemically recycle cellulosic textile waste and this fiber can be used to produce high quality textiles. As explained by Södra, the technology has grown out of the existing knowledge of creating cellulose pulp out of wood. The process and technology are similar since they both treat cellulosic material to create the "dissolving pulp" used in for example viscose production.

Despite the differences between mechanical and chemical recycling, similar supply chain requirements have been perceived by both actors. The actors interviewed are limited by the high requirements on their feedstock material. Södra requires mixes of white cotton and polyester, Convert requires certain homogeneous textiles limited by their colours and preferably made of cotton, IONCELL (lab-scale) will require a minimum of 80% or more cotton content for their recycling technology to work, and Renewcell between 90% - 98% of cotton content. One of the challenges this poses is the difficulty of finding reliable feedstock if it is to be sourced from textile waste from households. Due to their high-level requirements, they are sourcing their feedstock from sources like laundry industry that work with industries such as the hostelry industry. The textile waste they provide is expected to be more homogeneous in fiber content and occur with an more predicable frequency. This is why they are seen as more reliable and can be expected to meet their requirements.

Evidently and explained by the experts, cotton is currently a highly demanded resource for chemical recycling. The recycling companies analysed have a high requirement level for their feedstock, and thus, if it is the only upcycling technology used in scale, the value that can be obtained out of textile waste is limited. This limitation hinders the recycling potential of the recycling industry since they currently are not able to handle the complexity of textile waste from households. As a result, and as explained by Wargö Innovation, most of the value (98%) of the value of textile waste is obtained by 10% of the textiles that are sold for reuse. This results in the challenge of a costly recycling process that yield to a limited economical value. However, if recycling technologies were to be implemented in scale, its attractive product can increase the economical value of the totality of the textile waste. The fashion industry has high demands for recycled materials since it opens an attractive market share in the occidental world, and they know it is going to be demanded by directives such as the eco-design directive of the EU. To meet that demand, recycling companies should improve their technology to increase the tolerance level for feedstock used in their processes. A company that has done this to tackle the source of the problem is Textile Change. Their technology is designed to separate the fibers existing in complex textiles in household waste. They are in small scale but their technology and others (such as gasification presented by RISE), promise breakthroughs that the industry needs to manage all kinds of textile waste.

An additional challenge that all the actors perceive is the difficulty of dealing with the chemical content of the textile waste. The recycling companies require textiles to be free of toxic chemical content to be allowed to recycle such materials. The management of the chemical waste generated in the chemical recycling process is a costly operation, and thus it decreases the profit margins of the recycling companies. Experts haven't figure out the solution, but they agree that it is a challenge and deciding who will be responsible for the chemical content in textile waste is the first step. Thus, directives such as EPR are to give a sense of direction for this challenge, and traceability and digitalization can once again help to mitigate the problem.

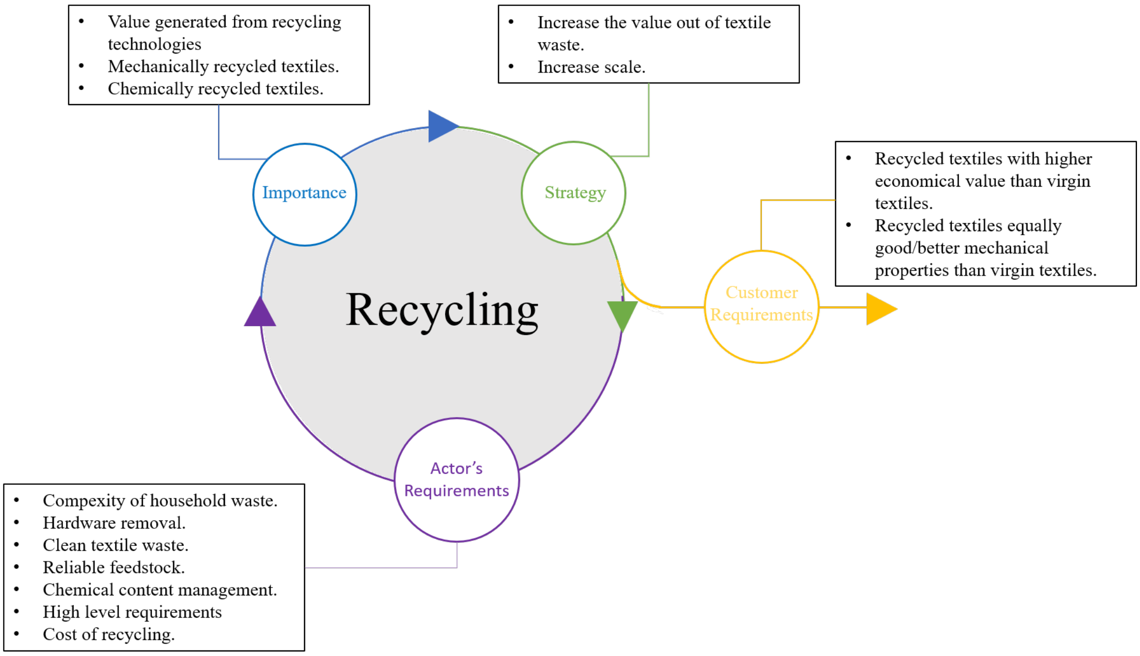

Figure 6.7: Recycling Requirements.

Similar to the sorting requirements, findings on the recycling requirements can also be found in the literature. The value of textile waste, requirements of chemical recycling, and research for new recycling technologies have all been touched upon in the literature (Ellen MacArthur Foundation, 2021; De La Motte et al., 2019; Sandin and Peters, 2018; De La Motte and Palme, 2018). However, it was interesting to get some new insights on the increasing demand of recycled- and more sustainable materials. Also, the importance of finding reliable feedstock to recyclers that has led them to source their textile waste form more homogeneous waste streams from industry and business.

In conclusion, the supply chain requirements of the automated sorters and recyclers in the textile industry are governed by the current possibilities of recycling technologies. Different technologies can manage different textile fibers, and this is why managing post-consumed textiles from households comes with its challenges. Digitalization and traceability coupled with an increase of recycling technologies and scale, are needed to improve the recyclability of all textile waste. Standardization and policies such as EPR can guide the transition. How to tackle the challenges are explained in Section 6.3 "RQ3".

6.2.3 Capacity

The capacity requirements of the actors interviewed is presented in Table 6.1. The reason for this analysis is to get an estimated idea of the scale and capacity of the actors identified. The Table 6.1 sets the bases for the analysis in RQ3. Moreover, it portraits the supply requirements associated with each recycling technology.

Actor	Type of actor	Location	Technology	Capacity (tons/year)	Supply requirements
SIPTex	Sorting	Sweden	Automated sorting	24 000	Hardware removed Clean textiles No multilayerd materials No longer than 2m
Wargön Innovation	Sorting	Sweden	Manual sorting Automated sorting	500 -1 000	Clean textiles
Taxaid	Sorting	Germany Switzerland Bulgaria Hungary	Manual sorting	90 000	Clean textiles
Convert	Recycling	Denmark	Mechanical recycling	1 920 - 5 760	Blue jeans White cotton Clean textiles
Södra	Recycling	Sweden	Chemical recycling	25 000 - 30 000	50% - 100% white cotton mixed with polyester Hardware removed Clean textiles
IONCELL	Recycling	Findland	Chemical recycling	Lab level	80% - 100% cotton fibers Hardware removed Clean textiles
Textile Change	Recycling	Denmark	Chemical recycling	10 - 15 000	Household waste Clean textiles
Renewcell	Recycling	Sweden	Chemical recycling	70 000	90%-98% cotton textiles Clean textiles Hardware removed
Rifo	Recycling	Italy	Mechanical recycling	3.6	Pure cashmire (2,5 tons per year), cotton (1,1 tons per year) and wool

Table 6.1: Capacity Requirements.

6.3 RQ3: What are the challenges that the textile recycling supply chain faces and what could enable textile waste from households to be recycled efficient?

The challenges for the supply chain managing textile waste by recycling can by one way be understood by comparing the needed capacity for managing the textile waste that will arise when a separate system for collection of textiles from household waste will be in place. Therefore the steps after collection has been explored, and has resulted in more knowledge about the requirements and capacity of automated sorters and recyclers that could be a part of the investigated supply chain. To estimate how well they can close the loop for textile waste, their capacity has been compared to the expected volumes of textile waste. When further requirements was explored, two other gaps were identified. These were the technology gap and the business case gap. The technology gap became evident when analysing the actors capabilities to handle the complex characteristics of textile waste from households. The business case gap is a result of the barriers the actors face to increase their capacity to manage such volumes.

6.3.1 The capacity gap

The estimation of future volumes of textile waste from households in the scenario analysis reveals that these volumes could be about 22100 to 24500 tonnes in 2025 and around 22700 to 26800 tonnes in 2030. For a comparison, if the textile waste would have similar content as the global fiber production today, the maximum expected volumes of textile waste in 2025 would have the content like Figure 6.8 illustrates.

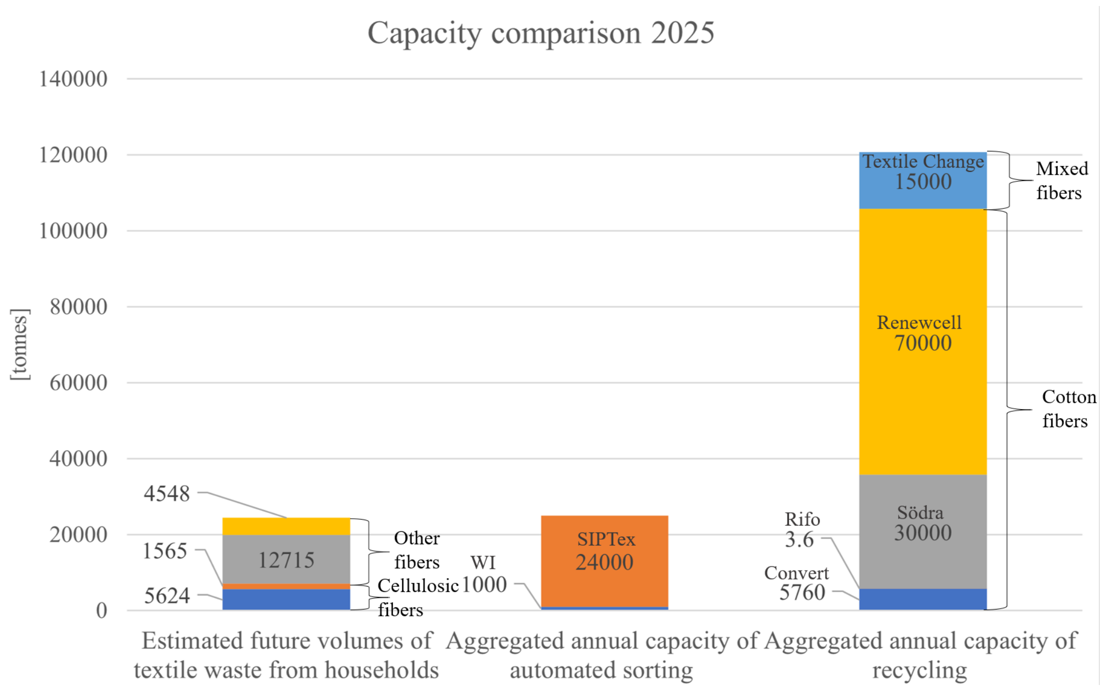

Figure 6.8: Comparison of volumes of textile waste in 2025 to identified capacity for sorting and recycling.

As can be seen, the identified capacity for automated sorting allows the expected volumes of textile waste from households to be sorted in this way. When further comparing the volume with the recycling capacity it looks like there is significantly more capacity than needed. Although, when taking into account that different recycling techniques demands different textile waste it is not so clear that there is enough capacity. It can be concluded that there will be capacity to manage cellulosic textile waste of pure cotton or with a high share of cotton. At the same time, 23% of fibers produced are cotton and 6.4% are MMCF (both are cellulosic fibers).

The rest could consist of mainly polyester, and due to the characteristics of textile waste from households, the textile waste will probably consist of mixed fibers. The identified capacity for managing mixed fibers is 15 000 tons, by the Danish recycling company Textile Change.

When looking at the same comparison with expected volumes of textile waste in 2030 in Figure 6.9 the result has not significantly changed.

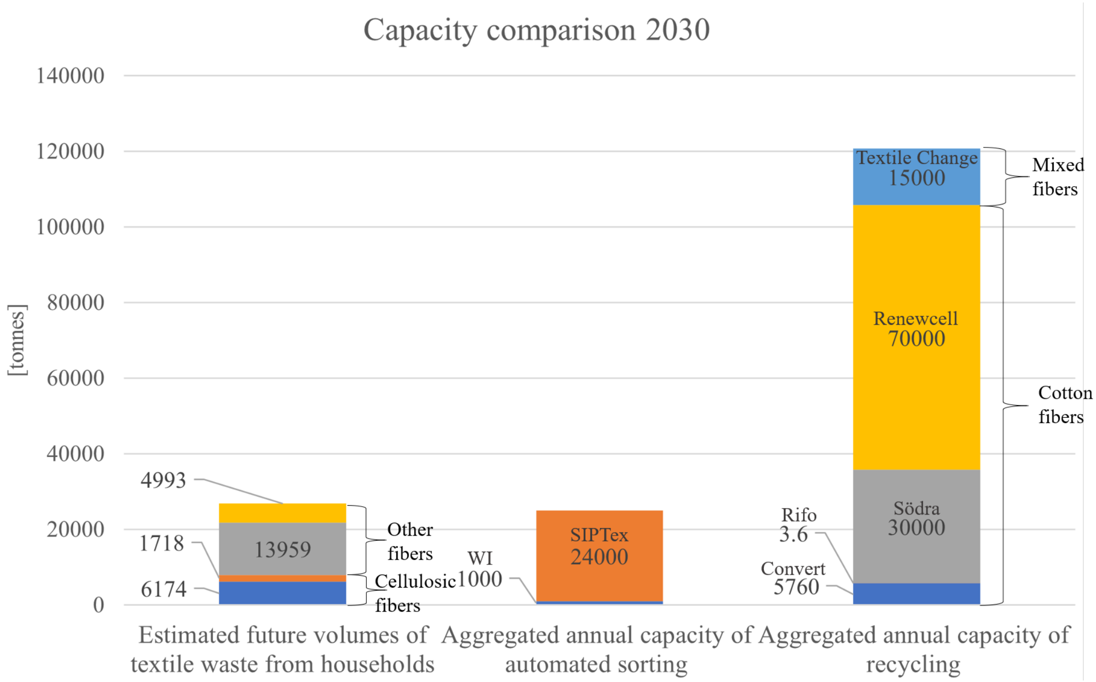

Figure 6.9: Comparison of volumes of textile waste in 2030 to identified capacity for sorting and recycling.

What can be concluded for both years is that the investigated volume will not be the only volume of textile waste generated in the coming years. For example there will be textile waste from business and industry as well, and from the whole EU. Consequently, textile waste from Swedish households will have to compete with other textile waste streams for supplying sorting and recycling processes. In this regard, the capacity for automated sorting is not enough, and this can also be concluded by comparing the two staples for sorting and recycling in Figures 6.8 and 6.9. As automated sorting is key to gain reliable feedstock for recycling, more capacity within sorting is needed. Also, due to the heterogeneous characteristic of textiles consumed by households, they will demand allot of sorting, which would make this volume expensive to use as feedstock in recycling processes that has high requirement of pure materials. The given solution by actors to this challenge described that it can be tackled on two fronts. Either a higher capacity of recycling techniques that can mange a range of fibers is needed. Or, a range of recycling technologies to manage different fibers is needed. It is hard to tell which will be the case and probably there will be a mix of solutions to enable closing the loop for textile waste.

When it comes to fiber blends several interviewed actors stresses that materials that are put on the market needs to be motivated and price should not be the only motivator. For example, blends of cotton and polyester into polycotton is commonly used as these two fibers has qualities that complement each other. Cotton provides a nice feeling and absorbs moisture, and by mixing it with polyester the strength and ability to dry increases. This fiber blend is hence optimal to be applied for textile products like sheets and towels, something that can motivate this fiberblend to exist. Actors has lifted that in the future it is further important to analyse which blends should be motivated and to match quality of materials to intended use. By this, durable products should be made of durable materials. That right quality should be dimensioned for the right application of a product was something that was identified in the literature too (Rex et al., 2019). The motivation for this is that reusability of textile products can decrease the environmental impact significantly, it is therefore key to match quality with the right product type.

What can be concluded from this is that to enable closing the capacity gap, the waste arisen from textile consumption needs to be understood. When understanding the waste and what it really consist of, more accurate decisions about how to structure and further develop the supply chain for circularity can be done. Again to pick up were RQ1 ended, the balance between available feedstock to recycling processes in terms of textile waste and feedstock requirements from recycling processes is a important task to solve to enable really closing the loop for textile waste. To be able to do so in the long term, how textile waste volumes and content might sift needs to be considered. An expert expressed this wisely by telling there is a paradox between managing the challenges today and the challenges of tomorrow as they may appear differently. There is a need to manage the textile waste arisen today, but along with business and business models becoming more circular, the recycling technologies that are develop and invested in today might not be fruitful tomorrow. Solving the challenges of today is important, but this needs to occur in parallel with planing for the circular future.

6.3.2 The technology gap

The textile industry is a globalized and linear industry, and its environmental impact has been acknowledged by numerous stakeholders that are aiming to make it more circular.

As part of this effort, there is allot going on in the technological field of textile recycling, and technologies for automated sorting is a result of this. The sorting actors have taken advantage of NIR and VIS technologies to visualize the contents of post-consumed textile waste (De La Motte et al., 2019). The world's first automated sorting facility at scale have been developed recently in the SIPTex project. These technologies are the first step to guarantee a reliable feedstock for the recycling actors. Reliability in of the feedstock is one of the key puzzle pieces for a streamlined supply chain. Recycling technologies have also improved (De La Motte & Palme, 2018). Until recently, mechanical recycling has been the main recycling method found to recycle textiles. Consequently, mechanical recycling can be found in scale. Mechanical recycling offers for the most part, downcycled products form textile waste such as rags, blankets and isolation. However, new recycling technologies such as chemical recycling have been developed that offers an alternative to mechanical recycling. Chemical recycling has gained popularity and companies such as Renewcell have invested in new manufacturing to increase scale. Cellulose-based recycling offers an attractive alternative to cotton that is a fiber with an production causing high environmental impact. However, despite the technological advancements that the recycling industry have experienced, there still exist a gap to manage textile waste from households efficient. As described in the in the capacity gap, household textile waste can vary in material mix, colors or quality. This increases the difficulty for textiles to be recycled.

The sorting facilities should be able to sort textiles according to the specific requirements of the recycling technologies. Unfortunately, as described in the literature and by the experts, the technology is not efficient enough to meet speed and accuracy that the recycling companies demand (De La Motte et al., 2019). An increased efficiency and accuracy would make the sorting companies a more reliable player in the supply chain for recycling. Something that could enable this is a higher transparency of what textiles consists of. As explained by the experts and in the literature, technologies like RFID-tags along with digitalization could provide the missing information about textiles at end-of-life. By this, textiles could be accompanied by their digital passport (De La Motte et al., 2019; Statens Offentliga Utredingar, 2020). More information on the material content of the textiles will not only improve the recycling supply chain but could also help to sort for reuse, which would allow textiles to climb in the waste hierarchy. One key information that should be traced for recyclability is the chemical content of the textiles. The literature explain how textiles are produced (and chemicals used) directly affect the recycling companies (Schmidt et al., 2016). Additionally, the recycling actors also explain that it is a risk to use household textile waste as feedstock due to the lack of information and uncertainty of the content in the textile waste from households. Therefore, traceability and transparency increases the likelihood that textile waste from household can be used as a reliable feedstock to recyclers.

As discussed in the capacity gap, the empirical data collected and literature show that cellulose-based textiles are upcyclable (De La Motte and Palme, 2018; Sandin and Peters, 2018), but only if there are pure or largely cellulose based. However, this is not the case of the textile waste from households. This begs the question, to whom will the sorters send textile waste to that is not cellulose based? The lack of alternatives may explain why downcycling is commonly applied on for textile waste today. Consequently, new recycling technologies are needed to make use of the value of the textile waste and hence, reduce the volume of waste that is send to incineration. This leads to the next gap, which is the business gap, that is caused by the lack of economic value that can be profited out of textile waste from households.

In conclusion, the technology gap demonstrates the need of investing in projects to increase the information about textiles at end-of-life, and new recycling technologies such as the one of Textile Change that is designed to deal with complex textile waste.

6.3.3 The business case gap

When assessing the future for recycling of textiles, profitability can be a driver or a barrier. Ensuring a business case creates a pull effect that incites innovation, and new actors willing to recycle textile waste.

The literature and the empirical results defend that producing recycled textiles is today cheaper than to recycle them into new fibers ((Koszewska, 2018; Statens Offentliga Utredingar, 2020)). In the same way, it is less resource demanding and cheaper to downycle textiles into rags and isolation for example, but the end-product is also of low value. For upcycled textile waste to compete with virgin materials, recycling needs to occur to a competitive price and this is a challenge to achieve in the current textile recycling supply chain. One example given by a recycler is the complexity and costs associated to declaring the content for recycled products from household textile waste. Since low information is provided, each bunch of feedstock used needs to be analysed and as can be understood, this is not efficient.

The solutions discussed to increase profitability for textile recycling were policy instruments, collaboration, and to make use of existing knowledge and infrastructure if possible. Policies discussed were for example EPR, incineration tax, standardisation, labeling, and recycling targets. What these have in common is that they provide governance for a more structured and oriented supply chain. These policies could also be found in the literature reviewed (Statens Offentliga Utredingar, 2020; Elander et al., 2017; M. Dubois et al., 2020). Additionally the literature mentions further taxes that would benefit being circular over linear, and eco-design for more durable-, repairable-, and recyclable products (Bauer et al., 2018; M. Dubois et al., 2020). Experts have defended the need of scale and building the recycling infrastructure to reduce costs. Scale reduces costs since the unit costs value of a product is ultimately reduced. It was suggested by actors interviewed that for the recycling supply chain to achieve scale, companies should collaborate to reduce the risk that comes with large investments needed for scale. Today there is little infrastructure to produce textiles in Europe as companies has relocated their manufacturing to locations where labour is more cheap. Building the infrastructure once more, takes time, requires a systematic change and also, involves risks. The risks are caused by the uncertainty that the future holds. As introduced in the capacity gap, there is a risk that infrastructure investments in managing the textile waste today, may not be profitable in the future. To mitigate the risks and costs, a lot can be learned the the journey of Södra. Södra makes use of its existing infrastructure to produce MMCF from wood to produce fibers from textile waste. Experts have hinted to other synergies to between with the plastic industries or others. Similarly, experts pointed that other industries such as the paper or plastic industry have gone through the process of standardization and infrastructure development, and thus the same knowledge can be translated into the textile industry.

Moreover, as exposed in the empirical results and discussed in the capacity gap, the high requirement level that recyclers have affects the costs and business viability of recycling textile waste (Koszewska, 2018). Sorting companies have to sort though large volumes of textile waste before finding the small portions that fit the needs of the recycling companies. This makes the sorting inefficient and costly. It is costly because the sorting machine have to scan though the same textile waste several times to identify the different materials. These costs cripple the sorting companies which in turn affects the rest of the supply chain. Thus, their costs can be lowered if sorting companies find customers for all type of waste fractions, or if sorting can become more efficient by utilizing the new digital solutions. Consequently, finding new value out of textile waste favorites the actors that already exits. If sorting companies can find more applications for the textile waste they collect, feedstock costs to recyclers can be lowered. Which in turn will open the opportunity for recycling companies to try to take on more textiles and expand their capacity.

On the other hand, an increase profitability can be obtained if textiles are recycled into fibers that meet the needs of the market. Recycled fibers such as MMCF are demanded by textile producers because they are comparable to virgin fibers in terms of quality but have the advantaged to be sourced out of textile waste, which in the occidental market, is gaining popularity. In other words, sourcing from recycled sources represents a competitive advantage for the textile retail industry. However, there are currently no technologies that take advantage of this opportunity to recycle textiles into textiles at scale, except cellulose based recycling. Nevertheless, a business case can be made for the companies that uses technologies that recycle other textiles. The only company identified that is taking full advantage of this opportunity is Textile Change. Textile Change have developed a technology to separate the different materials in textiles despite its complexity. However, it is important to note that the rest of the recycling supply chain needs to be developed to take advantage of the separated textiles and recycle them. Likewise, a business case can also be made if new applications for textile waste can be found in other industries that have also a high profitability. Thus, new industry symbioses should also be explored.

The policies mentioned could also have an influence on the market. Informative labels or other policies could enables a pull-effect from the market (Statens Offentliga Utredingar, 2020). As learned from he empirical results, experts believe that a labeling system that facilitate responsible consumption can create a pull effect for the rest of the industry to change. Labels that guide the consumer into choosing recycled and durable textiles before than cheaper but unsustainable options, will increase the interests from the industry to invest in sustainable sourcing and production of textiles. This in turn will also encourage the industry to invest in recycled textiles. H&M is already thinking in front of the curve in this sense, and is investing is several initiatives to get closer to the production of sustainable clothing. Similarly, policies that direct retailers to produce with a certain percentage of recycled textiles, also create a pull effect that motivates the investment in recycled textiles.

Furthermore, to ensure profitability a lot can be learned from the strategy of Renewcell. Renewcell collaborates directly with the end-customer (retail companies) to ensure the production of recycled cotton. Renewcell collaborate directly with the end of the supply chain (the retail companies) to ensure profitability and share the knowledge needed to produced garments out of recycled textiles.

As closing remarks, is important to note that development of new technologies for the recycling supply chain should always follow sustainable principles and not only focus on the business interests. Companies should have sustainable values at their core that are responsible also environmentally and socially.

7
Conclusions

Is it reasonable to consume 13,7 kg of newly produced textiles per person per year? Is it reasonable that a garment is used only a few times before becoming post-consumed? Is it reasonable to dispose 5.1 kg of textiles to the household waste where it goes directly to incineration, even though a large share is in perfect condition for reuse? No, this is not reasonable. However, it is how households in Sweden make use of textiles today.

This needs to change, and the EU has recognized the magnitude of the problem and acted accordingly. The EU's Waste Framework Directive states that post-consumed textiles should be separately collected and treated accordant to the waste hierarchy no later than 1st of January 2025. Projects like SATIN are investigating how collection solutions may appear, but who will make use of collected textiles? This is why this study has contributed to increase the knowledge about how the textile waste caused by Swedish households can be re-looped via recycling.

Throughout this study it has been stressed that it is important to understand the material content of the textiles that result in textile waste. The material content affect the recyclability of the textiles since it limits the applicability of the recycling technologies that exist. Complex fiber-mixes makes textile waste less recyclable. The main findings related to the aim and the research questions of the study are:

Findings by analyzing volumes of textile waste:
This study has made an estimation of the magnitude and content of textile waste from Swedish households as these has the potential to be managed by a recycling supply chain in 2025 and 2030. The result of the scenario analysis revealed that textile waste volumes can be about 22100 - 24500 tonnes in 2025, and 22700 - 26800 tonnes in 2030. The uncertainty in the consumption of textiles by households and donation to NGOs is what makes the result vary. Estimating what these volumes potentially could consist of turned out to be more difficult. This is due to the complex characteristics of textiles consumed by households since they are designed to meet the infinite variety of consumer demands. Although, the market share of the different fibers in the global textile production can give an intuition that polyester (52%), cotton (23%), and man-made cellulosic fibers (6.4%) will play a key role in the future where materials are to be circulated.

Findings by analyzing sorters and recyclers:
The automated sorting facilities and recyclers are the start of the value chain of

recycled textiles. To recover the economical value of textile waste from households, the automated sorting companies must sort the textile waste based on the potential value that can be recovered. The largest recycling companies identified in Sweden are Renewcell and Södra. The first automated sorting facility in scale in the world (SIPTex) aim to supply reliable feedstock for such recycling companies. However, the high requirement level of the recycling companies, and the complexity of household waste difficult the ambition of the sorting companies. The recycling companies identified have high requirement levels on their feedstock material, for example high cotton content and clean textiles. As a result, the sorting companies require efficient sorting processes to make textile household waste a reliable feedstock.

Findings by analyzing challenges and enablers:
When comparing textile waste volumes from households with the capacity for sorters and recyclers, the capacity gap was identified. The core of this gap lies in understanding that even though textile waste volumes from households might be significant in volume, they might not be the preferred choice to supply identified recycling actors. Since it was identified that a majority of the recyclers had high feedstock requirements, finding these specific fractions in the textile waste from households will be a challenge. These volumes will need allot of pre-processing (cleaning, hardware removal, sorting) before reaching recyclers. A solution to this challenge was discussed to be a supply chain (collection and sorting) with clear role divisions and following standard procedures. This could provide reliable feedstock to recyclers and make the supply chain more efficient.

Recycling textile waste is today challenged due to the technologies available. By analysing the capabilities of automated sorters and recyclers, challenges for both actor groups could be found. The aim of automated sorting is, as explained, to provide reliable feedstock to recyclers. However, to do so complex textile waste they would need to sort more efficiently and accurately than is being done currently. One technology that could enable this are RFID tags, which could be use to develop digital passports of textile content and use. Moreover, as we have observed in the capacity gap, the recycling technologies that can manage all types of textile waste are limited. The objective of the recycling companies is to best make use of the value that can be recovered from textile waste. However, currently the recycling companies that best recover the value of the textiles have really high requirements, and thus, only some materials can be recycled, and only a part of the household textile waste. Thus, for this to be improved they need to increase their tolerance, have technologies that separate and recycle multiple material textiles (such as the one of Textile Change), and by doing so truly increase the current value that can be recovered from textile waste.

An expert explained "a clear business case will create a pull effect for the rest of the industry to re-loop textile waste via recycling", however, currently it is difficult to make a business case to recycle household textile waste. The fact that circular supply chains in the textile industry is not jet optimised constitutes one challenge for making a business case of textile recycling. Today, it is commonly more profitable to be linear that being circular. If countries like Sweden are to transition towards circularity for material flows, the cost for being linear versus circular need to be balanced in the favour for circularity. Policy instruments that can enable this cold therefore be a solution, but actors in the recycling supply chain can also improve reducing costs and increase profitability. Costs can be reduce by utilizing existing infrastructure (like Södra) and profitability can be assured by collaborating directly with big retail companies that have the resources and interest to make use of recycled textiles (like Renewcell). Lastly, consumer awareness is key to enable, not only recycling, but also circularity of textiles, because without the consumer there is no business case.

During the process of answering the aim it could be concluded that for textiles to become circular, the whole life cycle of textiles needs to be explored. When acquiring a systematic understanding, right decisions about how to develop further technologies, business cases and policies for the circularity of textiles can be made.

7.1 Recommendations for future studies

Based on the challenges and knowledge gaps identified, some future research recommended has been identified. To further increase the knowledge about a future supply chain managing textile waste by recycling, following is recommended:

- Get to know the the waste - in terms of volume, content and where it arises. To better make judgement of what is the textile waste that can supply recycling technologies, better investigations about the textile waste needs to occur. Data on how textiles are consumed, for how long they are used, where they end up once becoming post-consumed, and the quality of post-consumed textiles needs to be explored. With this information, a better estimation of the connection between consumed and post-consumed textiles can be made. It was also found in the literature that a significant amount of textiles are being exported as the second-hand market might be larger abroad (Statens Offentliga Utredingar, 2020; Belleza and Luukka, 2018; Watson, Kant Hvass, et al., 2020). This implies that a textile product can be consumed in Sweden but it will become textile waste in a completely different geographical location. The aspect that should be considered for textile waste is hence: how much, what, and where? These are important questions to answer when estimating the supply for recycling technologies and further designing the supply chains for textile recycling.

- On the same theme, what could potential textile waste volumes from other sources be? As it was identified that there are higher capacity for recycles than textile waste from households can supply, it can be interesting to investigate other sources of textile waste. This study has investigating textile waste from a specific source as a point of departure for investigating upstream supply chain. Another way of doing it could be to investigate the recyclers capacity and go downwards in the supply chain, investigating if there is enough sorting capacity, and further supply of textile waste that meets the existing requirements of recyclers.

- It was discussed that the development of supply chains for textile recycling is still in an early phase. There is much optimisation to be done and one way to make this process faster is to learn from other industries that is already applying recycling. The plastic-, paper- and metal industry were mentioned to be industries that already have collaboration and supply chains managing their material flows. Investigating the transition they made and gaining knowledge from this could help the textile industry to shift to circularity faster.

- As it was identified that reusable textiles will increase significantly with separate collection of post-consumed textiles, this study wants to stress that it is further important to explore how these volumes will be utilised. If markets for reuse are becoming saturated, textiles of reusable quality might be sent to recycling or incineration. Solving this challenge is needed to further enable the textile industry to become more circular.

In conclusion, the recycling supply chain and the textile industry should be further developed to recover the value of textile waste from households. Textiles will be separately collected by the 1st of January 2025 in Europe. The inherent complexity of textile waste from households sets the challenges for these to be recycled. After being collected, post-consumed textiles are sorted for reuse, and the fractions left are the textile waste that should be sorted automatically to meet the recyclers demand. The automated sorting is hence key for enabling reliable feedstock to recycling. But it comes with its limitations as aspects like chemical content and non-visible materials cant be detected by the current technology NIR and VIS. Thus, increasing the traceability and transparency on how textiles are produced and used, will increase the likelihood textile waste from household will be trusted as a feedstock. Traceability and transparency can be achieved through digitized solutions and EPR policies. The technologies that the identified recycling actors have also limits the recyclability of complex textile waste. Only one recycler can manage heterogeneous textiles whereas the rest needs a 50-100% share of cotton. However, there are more recycling technologies emerging to better recover all kinds of textile waste. The complexity of textile waste from household also increases the costs on the recycling supply chain of textiles. Thus, collaboration, scale, and economical incentives are needed to allow this supply chain to develop. Finally, the textile industry must become more circular. Textiles have to be designed with circularity and durability in mind, and their business models must evolve accordingly for fast fashion to diminish. Policies focused on standardization must guide and encourage this change.

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A
Appendix

A.1 Interview guides

Presented here are the different interview guides used to guide the interviews with the actors for sorting, recycling, and expert knowledge.

All interviews began with an introduction of the researchers and the purpose of the study. Further, if recording was allowed were asked for along with an explanation for how the empirical data were to be used in the study. The procedural for writing the summary of the interview and sending it for approval by the interviewee was further explained before starting interview.

A.1.1 Sorting

Introduction. The present role in the Recycling Supply Chain of Textiles

1. Interviewee name, position, experience in Circular Economy.
2. The name of the organization, role in the Recycling Supply Chain of Textiles.

Product and Process Limitations
The product(s)
1. Main use of the textiles sorted.
2. Quality requirements of the textiles sorted(s). Sorting criteria.
3. Volumes of textiles sorted.
4. Price of textiles sorted (if possible).

The recycling processes
1. Steps (operations) of the sorting process.
2. Technology used.
3. Total capacity.
4. The desired output of the process.

Supply Requirements
1. Name of Suppliers and origin (country).
2. Volumes imported, frequency and packaging.
3. Price of supply (if possible).

4. Requirements form suppliers.
5. What practices are in place to deal with poor quality.

Customer Requirements
1. Customer's Industry.
2. Name of main customers.
3. Delivery channels and frequency of delivery, to ensure right place, right time, and right customer.

Concluding. The future role of the actor in the Recycling Supply Chain of Textiles
1. Future volumes (capacity): What are the expected volumes of used textiles the organization will be dealing with in 2-5 years.
2. Strategy of the company.
3. What are the main challenges and potential realizing a circular system of textiles?
4. What role will recycling have when closing the loop for the textile industry – now and in the future?
5. How should the European actors in the Recycling Supply Chain of Textiles co-operate?
6. What are the possible drivers or enablers that mitigate the challenges?
7. Are there digital tools that can be used to improve sorting?

A.1.2 Recycling

Introduction. The present role in the Recycling Supply Chain of Textiles
1. Interviewee name, position, experience in Circular Economy.
2. The name of the organization, role in the Recycling Supply Chain of Textiles.

Product and Process Limitations
The product(s)
1. Main use of the textiles recycled.
2. Quality requirements of the textiles recycled.
3. Volumes of textiles processed.
4. Price of textiles recycled (if possible).

The recycling processes
1. Steps (operations) of the recycling process.
2. Technology used.
3. Total capacity.
4. The desired output of the process.

Supply Requirements
1. Name of Suppliers and origin (country).
2. Volumes imported, frequency and packaging.
3. Price of supply (if possible).

4. Requirements form suppliers.
5. What practices are in place to deal with poor quality.

Customer Requirements
1. Customer's Industry.
2. Name of main customers.
3. Delivery channels and frequency of delivery, to ensure right place, right time, and right customer.

Concluding. The future role of the actor in the Recycling Supply Chain of Textiles
1. Future volumes (capacity): What are the expected volumes of used textiles the organization will be dealing with in 2-5 years.
2. Strategy of the company.
3. What are the main challenges and potential realizing a circular system of textiles?
4. What role will recycling have when closing the loop for the textile industry – now and in the future?
5. How should the European actors in the Recycling Supply Chain of Textiles co-operate?
6. What are the possible drivers or enablers that mitigate the challenges?
7. Are there digital tools that can be used to improve recycling?

A.1.3 Experts

Introduction. The present role in the Recycling Supply Chain of Textiles
1. Interviewee name, position, experience in Circular Economy.
2. The name of the organization, role in the Recycling Supply Chain of Textiles.

Product and Process Limitations
Recycling process
1. Which countries or actors that recycle the most (what capacity and volumes) in Europe and where do they import their textiles from?
2. Overview of the existing recycling technologies (mechanical, thermal, and chemical).
3.Quality requirements set upon the sorting process to ensure quality in recycling process.
4. Barriers of recycling companies.

Production of new products
1. Applications of recycled textiles (example of upcycling and downcycling) and recycling technologies needed.
2. Barriers to upcycle textiles.

Sorting process
1. Estimated volumes (%) of sorted textiles that are used for recycling.

2. Technologies currently used for sorting.
3. How does the sorting processes meet the needs of recycling companies?
4. Barriers and opportunities for sorting companies.

Supply Requirements and limitations (collectors)
1. Why are textiles collected, and who are the actors that collect textiles?
2. Whom are the existing actors that collect textiles with the objective of recycling them?
3. What textiles are being mostly collected and why?
4. What are the challenges or advantages of recycling textiles collected from one origin or another?

Transport requirements
1. Are logistical costs a limiting factor to ensure cost-effectiveness in the recycling chain of textiles?
2. If yes, why, and how can it be improved?
3. Is there any standard for transporting textiles?

Concluding. The future role of the actor in the Recycling Supply Chain of Textiles
1. Future volumes (capacity): Can we expect an increase of recycled materials in Europe in the next 2-5 years?
2. How do you think collected textiles from households will be re-looped after a collection system is in place latest 2025?
3. What are the main enablers needed for a circular system of textiles to exist?
4. What role will recycling (in general) have when closing the loop for the textile industry – now and in the future?
5. And how should the European actors in the Recycling Supply Chain of Textiles cooperate?
6. Are there digital tools that can be used to increase circularity?

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