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Survey of the possibilities to recycle products of synthetic textile blends in Sweden

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CHALMERS UNIVERSITY OF TECHNOLOGY
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Master's Thesis 2020

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Cover: Schematic picture showing the three product groups together with the symbol for recycling and a schematic picture of a return refinery.
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Abstract

The textile industry is an environmentally challenging industry with an almost linear value chain where resources are extracted and used in a wasteful manner. Recycling of textiles can save natural resources at a global scale and by that, contribute to the transformation towards a more circular industry. This master's thesis is investigating the situation related to recycling for products of synthetic textile blends, which are defined as footwear, outdoor clothing and sportswear by the researchers of this report. This master's thesis is performed at RISE Research Institutes of Sweden AB (RISE) at the division of Materials and Production. RISE is a Swedish research institute, active within a broad sector of research areas. RISE collaborates with universities, the industry and society for innovation development and sustainable growth. Three research questions are answered connected to the present state, stakeholder's view and external initiatives regarding recycling of synthetic textile blends. The master thesis consists of a literature study and an empirical study. The data in the empirical study was collected through questionnaires and interviews aimed at four stakeholder groups; retailers, municipalities, research institutes & authorities and recycling & collecting companies.

The findings showed that there are currently no large-scale system for handling of products of synthetic textile blends and that such a solution is still far away. Drivers and barriers have been identified from the four stakeholder groups. The drivers common by the majority of the stakeholder groups were change into circular business models and resource efficiency. The barriers were found to be more specific where the lack of a sustainable infrastructure was common for all stakeholder groups. External initiatives are found to be important, where an external producer responsibility will possibly have the largest impact regarding recycling of products of synthetic textile blends.

From today's situation for synthetic textile blends, two possible scenarios have been identified. The first scenario is to include the synthetic textile blends in a thermochemical recycling process where the outcome can be used as recycled raw materials to produce valuable chemicals and materials. The second scenario is to use the synthetic textile blends as fuel to other processes. Conclusions can be drawn that the industry need to be more transparent and that communication and cooperation between stakeholders need to be increased.

Keywords: recycling, circular economy, products of synthetic textile blends, footwear, outdoor clothing, sportswear, present state analysis

0.1 Acknowledgements

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0.2 Abbreviations

EPR - Extended producer responsibility
NIR - Near infrared
RFID - Radio-frequence identification
RISE - RISE Research Institutes of Sweden
RVP - Refunded Virgin Payment
SDG - Sustainable Development Goals developed by the United Nations
Swedish EPA - Swedish Environmental Protection Agency (In Swedish: Naturvårdsverket)

0.3 Glossary table

Table 1: Glossary table.

Term used in this master's thesis	**Definition**
Mechanical recycling process	A recycling process based on physical forces which may be used in fabric, fibre, polymer or monomer recycling.
Chemical recycling process	A recycling process using chemical dissolution or chemical reactions which is employed in polymer or monomer recycling.
Polymer recycling	A system for dissembling used fibres, extracting polymers and respinning them for use in new textile applications (Peters & Sandin, 2018).
Monomer recycling	A system for dissembling polymeric textile materials into their constituent monomers and rebuilding polymeric fibres for use in new textile applications (Peters & Sandin, 2018).
Thermal recycling process	A process that uses heat to dissemble waste textiles or plastics, typically employed in polymer recycling.
Thermomechanical recycling process	A combined process that uses both heat and physical force to dissemble waste textiles or plastics.
Thermochemical recycling process	A combined process that uses both heat and chemicals to dissemble waste textiles or plastics, such as pyrolysis or gasification.
Thermal recovery	A combustion process for extracting the fuel value of textile waste and deliver heat to another process (Peters & Sandin, 2018).
Post-consumer waste	Clothes and footwear that no longer meet the criteria of the consumer due to aesthetic, functional purpose, fashion reasons or worn out (Vadicherla, Saravanan, Muthu, & Suganya, 2016).
Closed loop recycling	A recycling strategy where the product can be recycled back into itself (e.g. fibre-to-fibre recycling).
Open loop recycling	A recycling strategy where the product can be recycled into other types of products (e.g. soda bottle into synthetic textile fibre).
Elastane	Fibres made of polyurethane.
Nylon	Fibres made of polyamide 6 and polyamide 6.6.
Polyester	Fibres made of polyethylene taftate (PET).

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1
Introduction

In this chapter, relevant background for the master's thesis is presented. Further the aim, the research questions and the delimitations of the project are presented.

1.1 Background

Each year, 53 million tonnes of fibres are produced globally for applications in clothes, in an almost linear value chain (Ellen MacArthur Foundation, 2017a). At present, raw materials such as oil and cellulose are extracted for the production of textile fibers, and when the finished product is worn out or discarded, the material leaves the value chain as it is incinerated or put into landfills. To create a new product, new raw material is extracted which generates large amounts of emissions and waste. Of the total fiber production for clothing, 73% of the waste is incinerated or put into landfills at the end of the product's life cycle. The textile value chain must be made circular, that is, the material must be circulated back into a previous step in the value chain again, after the end-of-life of the product in order to make use of the resources again. The recycling of the textile materials could contribute to the world's material needs, instead of relying on the use of virgin raw materials (Ellen MacArthur Foundation, 2017a).

It is not only the textile industry that has to become circular. The transformation in industries in general can be achieved by increasing the use rates of assets, such as buildings and vehicles, and prolong their use-phase, and recycle the used material to reduce the demand for virgin materials. In the food industry, using regenerative agriculture practices and designing out waste along the value chain will contribute to the circularity. The transformation needs a system-level change and action from multiple stakeholders from policymakers to academia (Ellen MacArthur Foundation, 2019).

1.1.1 Sustainable Development Goals

This master's thesis research contributes and is connected to mainly two of the Sustainable Development Goals and the 2030 Agenda for Sustainable Development. The goals have been discussed and put into context through work with RISE. The two goals are:

- 9. Sustainable industry, innovations and infrastructure.
- 12. Sustainable consumption and production.

More specifically, the master's thesis is focused around the sub goals connected to each goal. Regarding goal number 9, the sub goal is 9.1 Create sustainable, resistant and including infrastructures (The Global Goals for sustainable development, 2020b). For goal number 12, the outcomes of the master's thesis contributes to 12.2 Sustainable management and use of natural resources and 12.5 Substantially reduce waste generation (The Global Goals for sustainable development, 2020a).

1.1.2 Restrictions with regard to textiles

By 2025, Sweden will adapt Swedish law to new rules in an EU legislation regarding waste that will apply thereafter. Several proposals have been set up to implement the changes needed to meet most of the new EU requirements. Two of these EU requirements are primarily important for this master's thesis (Regeringskansliet, 2020a):

Separate collection of textiles:
The European Union has introduced new restrictions that affect the Swedish Waste Directive, as textile waste must be collected separately in each municipality by 2025 (European Commission, 2018).

The Swedish government has commissioned an inquiry in January 2020 to produce, among other things, a proposal for producer responsibility for textiles (Regeringskansliet, 2020a).

A future goal, proposed by the Swedish Environmental Protection Agency, is to reduce the textile waste in the residual waste by 60% in 2025, compared to 2015. Of this textile waste, 90% must be prepared for reuse or recycled (Naturvårdsverket, 2016).

Prohibition of incinerating separately collected waste:
EU member states shall ensure that waste collected separately for preparation for reuse and recycling does not directly go to incineration or landfill and it is proposed that such prohibitions should be imposed (Regeringskansliet, 2020a).

1.1.3 Synthetic textile blends

Synthetic textile blends is referring to products made of synthetic material mixes. Synthetic refers to that more than 50% of the fibres used in the product are made of synthetic material, that is, that are based on synthesised polymers. Textile products containing more than 50% of cellulose based fibres are not taken into consideration. Blend means that the product is not made from one single material. For example, not only made from polyester fibres, but contains elements of other synthetic fibers such as e.g nylon or elastane.

Products of synthetic textile blends are products designed with a mix of synthetic fibres and have a complex structure as it often include components such as zippers, buttons, elastic bands and the like, made of metals, plastics or similar material.

Three product groups have been identified that match the definition of products of synthetic textile blends. The product groups are footwear, outdoor clothing and sportswear. These products are defined as synthetic and complex, and consist of several different textile fibre materials. This makes the products complicated to recycle with the current recycling systems and processes. Therefore, these products are often put in the household waste when they reach their end-of-life. An overview of the chosen product groups are visualised in figure 1 below. The reason for choosing product groups is that the actors in the textile value chain have more precise data regarding product groups rather than specific textile fibres.

Figure 1: A schematic image of each product group included in products of synthetic textile blends.

1.2 Aim

The aim of this master's thesis is to investigate the current state for recycling of synthetic textile blends. The master's thesis primarily seeks to investigate the stakeholders' view on factors related to recycling of products of synthetic textile blends. Additionally, the master's thesis will examine challenges from a systems perspective by examining upcoming or researched external initiatives that might affect the chosen product groups.

This master's thesis is part of a larger project led by Johanneberg Science Park and RISE, which aim to developing plans for a plastic return refinery in Stenungsund, through Klimatledande processindustri and its priority area Returraffinaderi. Klimatledande processindustri is a national innovation project that strives for a fossil-independent industrial region that is a world leader in the production of chemicals, materials and fuels based on renewable and recycled raw materials (Johanneberg Science Park, 2020). The investment is financed by Vinnova and the Västra Götaland regionen and coordinated by RISE and Johanneberg Science Park through Västsvenska Kemi- och Materialklustret, which is a group of actors from business, academia and the public who collaborate with the ambition to contribute to a fossil-free region and growth in the Västra Götaland region. The priority area aims to close the plastic loop and the return refinery will include a thermochemical recycling process. By including textiles in the effort, and hence, products of synthetic textile blends, the input could possibly be expanded or supplemented by synergies with other material streams.

1.3 Research questions

The master's thesis aims to answer the three following research questions:

- What does the present state look like for synthetic textile blends?
- What is the impact of stakeholders on recycling of synthetic textile blends?
- How will external initiatives affect the situation for synthetic textile blends?

1.4 Delimitations

- The technical specifications regarding the thermochemical recycling process will not be included in this master's thesis. For further information regarding the chemical output of pyrolysis of polyester-cotton blends, the authors of this master's thesis suggest to read the neighbouring master's thesis "Thermochemical textile recycling" conducted by Julia Rittfors at Chalmers University of Technology.
- The master's thesis will not investigate material streams made of 100% of one fibre sort, material streams made of more than 50% of cotton or polyester-cotton blends.
- The master's thesis will only consider post-consumer waste.
- The master's thesis will investigate the situation in Sweden.
- The waste streams of synthetic textile blends are defined as streams that are currently incinerated, as the products are often put in the household waste when they reach their end-of-life.
- The master's thesis will not focus on specific chemicals used in products of synthetic textile blends, but generalise that chemicals are used in the product groups.

2
Frame of reference

In this chapter, the frame of reference for the master's thesis is specified. The following sections briefly explains concepts related to the recycling in the textile industry, and hence, recycling of synthetic textile blends.

2.1 Circular economy

The Ellen MacArthur Foundation defines circular economy as; "A circular economy is an industrial system that is restorative or regenerative by intention and design" (Ellen MacArthur Foundation, 2013). Circular economy is centered around the concept of re-thinking that could be reality by creativity and innovation to build a restorative economy. The model of circular economy separate between technical and biological cycles. The technical cycle recover and restore products, components and material through reuse, repair, remanufacturing or recycling. Circularity in the biological cycle is where food and biologically-based materials such as cotton and wood are designed to return to the system by using processes such as composting and anaerobic digestion. To provide the economy with renewable resources, the biological cycle regenerate living systems such as soil (Ellen MacArthur Foundation, 2017b).

This approach leads to a better understanding of what impact human activities will have on the environment. Circular economy is based on four principles (Gardetti, 2019):

- Preservation of the natural capital.
- Optimisation of the available resources.
- Risk reduction related to running out of natural resources.
- Create and maintain a renewable flow of resources and products.

In order to transform today's industries towards a circular economy, a system-level change with commitment is needed. Further, it has to be flourished by collaborations and innovations between the stakeholders involved. The vision of circular economy is to improve economic, social and environmental outcomes (Gardetti, 2019).

2.1.1 Circular economy in the textile industry

Today's consumption and fast fashion mentality among apparel producers and customers lead to environmental and social challenges within the supply chain. This creates a very short use-phase of products that are manufactured under critical working conditions. Adopting circular economy in the textile industry correlates by other means to keep clothes, textiles and fibres at their highest value and make the products re-enter the economy, with the ambition that they never end up as waste (Ellen MacArthur Foundation, 2017a). The textile industry has a potential to adopt an overall circular economy approach as it currently have no standards for collection and recycling of textile waste. It might therefore be easier to create and shape standards that will foster circular economy from the beginning (Barla, Nikolakopoulos, & Kokossis, 2017).

Textile waste can be divided into three different profiles (Radhakrishnan, 2019), (Vadicherla et al., 2016):

- Pre-consumer textile waste; defined as the remains of every production process. In the textile industry, these consist of pieces of fabric, leather, and other raw materials discarded during the textile manufacturing processes.
- Post-consumer textile waste; Clothes that no longer meet the criteria of the consumer due to aesthetic, functional purpose, fashion reasons, or because they are torn or worn out.
- Post-industrial textile waste; defined as waste generated during the manufacturing processes and may be gases, liquids, or solids. Among them are dyes and chemicals dumped into water streams, the carbon footprint of every process and transport etcetera.

A new textile economy based on circular economy for clothing relies on four ambitions (Ellen MacArthur Foundation, 2017a):

1. Phase out substances of concern and micro fibre release.
2. Increase clothing utilisation
3. Radically improve recycling
4. Make effective use of resources and move towards renewable input.

To reach this, involvement from both public and private sector is necessary as well as collaborations across the value chain (Ellen MacArthur Foundation, 2017a). By utilising waste as a resource and converting the current linear production and disposal of textile waste, a closed loop variant can show positive effects. The European Commission has forecasted that by redesigning product life-cycles of textile products, it could increase the GDP up to 7% by 2035, indicating financial benefits for the textile industry (Barla et al., 2017).

2.2 Mistra Future Fashion

Mistra Future Fashion was a research programme for sustainable fashion that worked for a positive future fashion industry and was active from 2011 to 2019 (Mistra Future Fashion, 2019). The program was initiated and mainly founded by Mistra, the Swedish foundation for Strategic Environmental Research. From an unique systems perspective, multidisciplinary research was conducted within an association of over 60 partners. The research focused on circular economy, to transform today's linear industry into a sustainable circular industry. The research programme delivered significant amounts of research results in the form of reports, conference grants, academic publications and doctoral dissertations. Further, the programme developed new materials, tools and prototypes and implemented new concepts together with industrial partners. The most relevant conclusions of how to contribute to a systematic change in fashion are put together in 8 different recommendation cards. These recommendations are: design for circularity, textile fiber influence, production impact, user, alternative business models, policy instruments, end of life and joint effort (Mistra Future Fashion, 2019). The findings of the research programme have been used as an inspiration source to this master's thesis as some of the work performed by Mistra Future Fashion is connected to the research questions.

2.3 The waste hierarchy

Council Directive 2008/98/EC on waste describes the waste hierarchy which is a priority order developed by the European Commission for waste handling, see figure 2. It is a five-step hierarchy to ensure that the best overall environmental outcome is achieved. Council Directive 2008/98/EC states that textile waste should be prevented primarily, followed by reuse of textiles. If that is not possible, textiles must be material recycled, and then energy recovered through incineration. The last and least preferable solution, is that textile waste should be disposed into landfills. There are initiatives to increase reuse and fibre recycling of textiles, but system-wide challenges such as financial feasibility, market analysis and chemical management are causing commercial solutions to lag (de la Motte, Bour, Perzon, Sandin, & Spak, 2019).

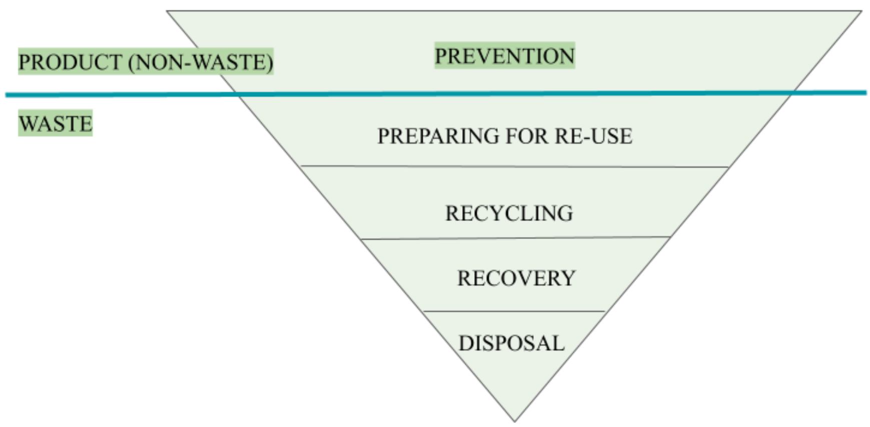

Figure 2: The waste hierarchy, revised from Council Directive 2008/98/EC.

2.4 External initiatives

In this section, several external initiatives regarding textiles will be presented. New initiatives are needed to meet the EU legislations, mentioned in section 1.1.2, and from this, four external initiatives are included in this master's thesis. The initiatives were evaluated through Mistra Future Fashion or by the Swedish Government and are chosen by the researchers of this master's thesis as they are predicted to have an impact on the recycling of products of synthetic textile blends.

2.4.1 Extended Producer Responsibility (EPR)

Extended Producer Responsibility is defined as an environmental protection strategy that makes the manufacturer of the product responsible for the entire life cycle of the product and especially for the take back, recycling and final disposal of the product (Lindhqvist, 2000). It is a policy instrument for achieving the environmental goals. The idea is to motivate producers to produce products that are more resource-efficient, easier to recycle and do not contain environmentally hazardous substances (Naturvårdsverket, 2020). Sweden has legislated producer responsibility for eight product groups today (Naturvårdsverket, 2020):

- Batteries
- Cars
- Tyres
- Electrical equipment (including light bulbs and certain lighting fixtures)
- Packaging
- Waste paper
- Medical drugs
- Radioactive products and stray radiation sources

Today, there is no extended producer responsibility for textile products in Sweden. However, this is under investigation by the Swedish Government together with a investigator from the University of Borås (Socialdemokraterna, 2019). By the end of 2020, a proposal of how the producer responsibility shall be structured will be announced (Regeringen, 2019).

In 2017, Mistra Future Fashion released a report that analysed the impact of a theoretical EPR-system for textiles in Sweden. The report described nine components of designing the EPR-system, and expected effects of implementing the specific system (Elander, Tojo, Tekie, & Hennlock, 2017). The nine components are translated into this research to investigate whether an identical system would have an impact on recycling of products of synthetic textile blends. The reason for choosing these nine components are that they are deemed appropriate by the authors because of their high relevancy for the textile industry. The EPR-scenarios are listed below and their relevance to the scope of this master's thesis will be analysed from the stakeholders' perspective in the study. The nine components are:

- Take-back requirements
- Financing mechanisms that reflect the actual cost of recycling specific fibers
- Financing mechanisms that contribute to the development of fibre-to-fibre recycling technologies
- Waste diversion targets
- Collection convenience and information requirements
- Preparation for reuse/recycling targets
- Consultation with existing actors

- Monitoring and control
- Mandatory nature

The original work focused on fibre-to-fibre recycling which differentiates from the outcome of this report, as this master's thesis will focus on fibres that cannot be fibre-to-fibre recycled with reasonable effort, but recycled thermochemically.

2.4.2 Refunded Virgin Payments (RVP)

A Refunded Virgin Payment system has been discussed through investigations by Mistra Future Fashion. It is a two-way measure, where the producer is charged for virgin fibre usage and refunded for recycled textile fibre usage. Companies using over average recycled content in their products become net receivers of refunds and companies using less than average recycled content in their products become net payers in the theoretical system. This economic instrument is expected to encourage textile producers to increase the amount of recycled textile fibres in their textile products as well as increase the demand for recycled textiles (Elander et al., 2017).

2.4.3 Incineration tax on waste 2020

On the 1st of April 2020, a tax on waste incineration will be introduced in Sweden, on behalf of the Swedish Government. The tax will be addressed to waste incineration or co-incineration plants. A tax on waste incineration will benefit recycling and benefit companies that invest in circular business models (Skatteverket, 2019). The tax will gradually increase, from 75 SEK per tonne of waste during 2020, 100 SEK per tonne of waste during 2021 and 125 SEK per tonne of waste during 2022. The gradual increase of the tax will give the stakeholders time to redirect and decrease eventual transition effects (Regeringskansliet, 2019).

The tax will not include (Skatteverket, 2019):

- Hazardous waste that is brought into the plant.
- Biofuel that is brought into the plant.
- Animal by-products brought into the holding.
- Waste that is brought into a co-incineration plant that mainly produces materials, and where waste incineration is included in the production of the material, provided that it contains part of the waste or its residual products.

The incineration tax on waste is included in this research as almost all textile waste is today currently incinerated by the end-of-life of the product.

2.4.4 Chemical tax for clothes and footwear 2020

The Swedish government has declared an inquiry regarding a tax on use of hazardous chemicals in clothing and footwear. The aim of the chemical tax is to reduce the occurrence or risk of exposure and spread of environmentally and health hazardous substances from clothing and shoes in a cost-effective way. The hazardous chemicals that can be found in clothing and footwear can cause three human health or environmental related issues (Regeringskansliet, 2020b);

1. Through long term exposure to the hazardous chemicals, the consumer might be exposed to health problems.
2. During washing of the products, harmful substances might be released into aquatic environment and damage organisms or enter the food chain.
3. Other substances, which are more durable and not released during washing, can cause environmental problems in other parts of the value chain, such as in the production or end-of-life phase.

The reason for including the chemical tax in this research is that the chosen product groups are generally treated with chemicals or additives to ensure that the products achieve desirable properties.

2.5 Textile fibres

Products of synthetic textile blends potentially consist of a blend of synthetic, natural and cellulosic regenerated fibres where synthetic fibres is the most dominant fibre type in the products. To gain a deeper understanding of the fibre types used in the products of synthetic textile blends, these fibre types are described below.

2.5.1 Synthetic fibres

Synthetic fibres are made from synthesised polymers or polymers made from small simple molecules, manufactured by human. Polyester is one synthetic fibre that stand for 55% of global fibre production (de la Motte et al., 2019). Polyester production has grown more than 300% in 20 years and is expected to claim 72% of all man-made fibre production by 2020 (Fletcher & Tham, 2015). Synthetic fibres have a lot of advantages, as they have high tech versatility, easy care, durability, high fashion appeal and often a low price. Furthermore, these type of fibres have a large impact on the environment as they are mainly produced from fossil fuels. Elastane, nylon and acrylics are other synthetic fibres used in apparel (Kadolph & Langford, 2013).

2.5.2 Natural fibres

Natural fibres are both cellulosic and protein fibres that are produced by nature. Natural cellulosic fibres are made from plants and have been used since humanity first discovered how to work with textile fibres. Cotton is the most commercially used fibre and stands for 27% of the global fibre production (de la Motte et al., 2019). Protein fibres are from animal origin. Mostly the fibres comes from the hair and fur of the animal as for wool, mohair and cashmere. Silk however, is made from a thread extracted from the silkworm cocoon.

2.5.3 Cellulosic regenerated fibres

Regenerated fibres, such as lyocell and viscose, are produced from cellulose polymers, but need to be converted and processed into a textile fibre form (Kadolph & Langford, 2013). The production process of regenerated fibres contains a chemical process where the cellulose is dissolved. The output from the process is a pure cellulose solution from which textile fibres are spun. Depending on what dissolution and spinning process that is used, the regenerate fibre is named differently. For viscose, the cellulose is first treated with carbon disulfide to form sodium cellulose xanthate and then dissolved in aqueous sodiumhydroxide. For lyocell, the cellulose is directly dissolved in the solvent N-methylmorpholine N-oxide. These are the most common regenerated fibres used in apparel, interiors and technical products. Even though the regenerated fibres consist of the polymer cellulose, the physical appearance of the fibres are more similar to synthetic fibres than to cotton (Kadolph & Langford, 2013).

3
Methodology

This chapter describes the methodology used in this research. This chapter are divided into three different parts; research design, literature study and empirical study.

3.1 Research design

The research design of this master's thesis consists of two parts: a literature study and an empirical study followed by data analysis. The master's thesis began with an initial literature study, to get familiar with the scope and understand issues within the area of textile waste management and recycling of synthetic textile blends. In order to design the empirical study, the initial literature study was initiated first, thereafter the literature study and the empirical study were conducted in parallel. From previous research conducted within the area of textile recycling, similar projects could not found that investigates the recycling of synthetic textile blends in Sweden, which is the main reason for why the empirical research approach was used in this master's thesis.

The study was based on inductive reasoning, that is, when searching for a pattern or a trend at first, and after that, generalise the outcomes and build a hypothesis (Bryman & Bell, 2011). The approach was to administrate a survey for stakeholders within recycling of synthetic textile blends. Two qualitative data collection methods were used in this study, questionnaires and interviews.

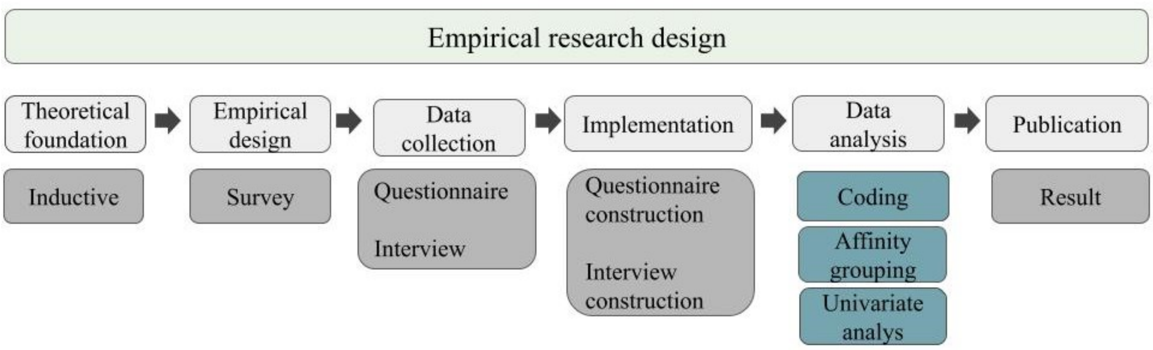

Figure 3: Overview of the empirical study design following the systematic approach.

3.2 Literature study

The initial phase in the literature study generated relevant topics and keywords and was done to engage critically with the ideas of other experts in the subject. Insights from conversations with researchers at RISE within the area of textile fibre development influenced the study.

The keywords from the initial literature study were used in different combinations in several databases to find relevant literature. The keywords used were *synthetic textile fibre, synthetic textile fibre AND blend, textile fibre AND recycling AND process, textile fibre AND synthetic AND mixed fibre, synthetic fibre AND recycling AND/OR process, synthetic fibre AND recycling* and *mixed fibre AND recycling.*

The scientific databases used were Google Scholar, ResearchGate and ScienceDirect. To find comprehensive information within the area, the search was divided into the research questions. RISE supported the literature study with several relevant articles regarding previous work done in the end-of-life management of textiles such as; waste stream analysis performed by Svenska MiljöEmmisions Data (SMED), the application for a specific government assignment regarding the planned return refinery, the research situation for circular textiles in Sweden, recommendations regarding sorting of textiles and a report concerning mapping of plastic waste flow in Sweden, as they work with research in textile recycling and have several projects involved in the subject. The literature study was an iterative process, where additional sources were gathered throughout the master's thesis.

3.3 Empirical study

The empirical study has followed the six stages in the systematic approach. A systematic approach could be used to conduct a empirical study (Flynn, Sakakibara, Schroeder, Bates, & Flynn, 1990). The systematic approach by Flynn et al contains of six stages; *Theoretical foundation*, *Empirical design*, *Data collection methods*, *Implementation*, *Data analysis* and *Publication*.

Theoretical foundation is the first step in the systematic approach. Regarding the *Empirical design*, there are several designs that can be used. A survey is the most frequently used by operations management researchers and relies on factual data and self-reports as well as opinions. A survey can be used to a group that has one characteristic in common, such as an industry or a common technology (Flynn et al., 1990). *Data collection method* is the third step where one or a combination of data collection methods are used that cooperate to the research design. The *Implementation* step includes the construction, that is, selecting a sample, designing and administrating the data collection methods. The next step is *Data analysis* where the data is processed and analysed. Lastly, the *Publication* step is where the result is presented (Flynn et al., 1990).

3.3.1 Selection of stakeholders

To ensure that the data was collected from appropriate stakeholders, existing knowledge about the textile industry was used along with information gathered from the literature study. From this, a value chain based on recycling was identified. The stakeholder groups within each step in the value chain were identified with respect to that they would probably be interested in recycling of synthetic textile blends. The stakeholders were considered most relevant for the research as they are treating synthetic textile blends and were deemed to have appropriate knowledge within the area of textile and recycling of synthetic textile blends. The chosen stakeholder groups for this research are: retailers, municipalities, research institutes & authorities and recycling & collecting companies. Common for all stakeholder groups are that they operate across Sweden. Both smaller independent companies as well as larger companies with global operations are included. A description of the stakeholder groups are shown in table 2 below.

Table 2: Description of the stakeholder groups.

	Description
Retailers	Retail companies whose supply largely consists of products of synthetic textile blends.
Municipalities	Municipal employees with professional titles such as environmental strategist, project manager of the environmental department. etcetera.
Research institutes & authorities	Researchers in the textile and environmental field, employees at environmental associations and relevant industry organisations.
Recycling & collecting companies	Municipal and privately owned recycling or collection companies, in which charities are included.

3.3.2 Questionnaire

A questionnaire is most commonly used in survey research, which is why the researchers decided to use it as a data collection method in this master's thesis (Flynn et al., 1990). Regarding the use of questionnaires in research, it should meet three criteria. The first criterion is that the questionnaire should be designed to collect data, rather than change peoples minds (Denscombe, 2014). As the main purpose of the questionnaires was to collect information to answer the three research questions, questionnaires were deemed appropriate for fulfilling the purpose. To gather information from the stakeholder groups for the possibility to recycle synthetic textile blends, four different questionnaires were created, one for each stakeholder group defined in section 3.3.1. In order to analyse the outcomes, multiple questions were identical among the stakeholder groups, with some modifications regarding their specific operations, which is the second criterion for questionnaires in research (Denscombe, 2014). The last criterion is that a questionnaire should gather information by directly asking questions regarding the respondents' opinions (Denscombe, 2014).

One of the main instrument for gathering data during a survey is to use a self-completion questionnaire, meaning that the respondent answers the questions by completing the questionnaire themselves (Bryman, 2015). Web-based questionnaires are often designed using a software tool that enables the questionnaire to be completed online (Denscombe, 2014). For this research, the web-based tool Microsoft forms was used as it provides a self-completion questionnaire design and offers a quick transfer of the collected data to Microsoft excel, which was a preferable feature. Additionally, Microsoft forms offers a large variety of question design and it is possible to choose the sufficient answer method, which was crucial for the research. The questionnaires were divided into the sections as follows; background information, present state analysis, impact of stakeholders, external regulations and comments and reflections.

The questions were based on the three research questions. Together with supervisors and researchers at RISE, relevant questions were created and decided through discussions and brainstorming to achieve the best possible outcome. A mix of qualitative and quantitative questions were used which means both open-end and closed-end questions (Denscombe, 2014). The full questionnaire design are presented in appendices A.1, A.2, A.3 and A.4.

Three different question types were used: open-ended text, single option closed-ended questions and matrix questions for rating and scaling. Open-ended text questions were used to ensure that the respondent could answer freely about the specific subject. As the research was conducted to collect the respondents thoughts and opinions, it was considered crucial that the responses to some questions would not be ticked into predetermined boxes. This was to ensure that interesting opinions and ideas were not missed out during the research (Denscombe, 2014). Single option questions were answered by radio buttons, as it is simple and straightforward for the respondent. Additionally, the use of radio buttons simplifies the data analysis, as only one answer can be given to each question (Denscombe, 2014). One of the answer alternative on each single option question was "N/A" (not applicable, not available or no answer) or "I have no opinion". The answer alternative was added as some of the questions could be sensitive to answer and this could lead to a more valid response, further to avoid incorrect data. The matrix structure was used on one question, to scale the answer between "No/Low impact" to "Large impact" on nine different components.

The questionnaires contained between 9-18 questions depending on the stakeholder group. The full questionnaire design including number of questions and question type is shown in table 3 below. The questionnaires were designed to take 20 minutes to answer.

Table 3: Question types and number of questions for each of the questionnaires.

Stakeholder groups	**Retailers**	**Municipalities**	**Research institutes & authorities**	**Recycling & collecting companies**
Qualitative questions	7	4	7	8
Quantitative questions	9	8	2	10
Total number of questions	**16**	**12**	**9**	**18**

The questionnaires were sent out to the members within Västsvenska kemi- and materialklustret where those who were interested in responding where contacted via email. Additional stakeholders within each group, that were not a part of the Västsvenska Kemi- and material klustret, were reached by email. An analysis of the response rate is presented in table 4 below.

Table 4: Total number sent out questionnaires, number of responses and the corresponding response rate within each stakeholder group.

Stakeholder groups	**Retailers**	**Municipalities**	**Research institutes & authorities**	**Recycling & collecting companies**
Number of sent out questionnaires	32	14	20	17
Number of responses	9	4	14	5
Response rate	**28%**	**25%**	**70%**	**33%**

3.3.3 Interviews

Interview is a well-known data collection method used in qualitative research and is appropriate to use to explore the opinions and experiences of the interviewees (Bryman & Bell, 2011). Further, it is a particular useful method for understanding complex issues or when the research is in need of privileged information (Denscombe, 2014).

There are different types of interviews and it is conventional to classify them as being structured, semi-structured or unstructured (Denscombe, 2014). For this research, the chosen interview style was semi-structured interview, as it is a suitable tool for gathering information and creates the possibility to ask further questions (Denscombe, 2014). Four interviews were conducted, with one actor within each stakeholder group. The interviewees were chosen based on their initial interest in participating in the research as well as how relevant their business is in order to give the research more information. The chosen interviewees and their role at the company are shown in the table 5 below.

Table 5: The chosen interviewees and their role at their company.

	Role of interviewees
Retail	Sustainability manager, quality manager.
Municipalities	Production and recycling manager, textile handling manager.
Research institutes & authorities	A textile and environmental expert.
Recycling & collecting companies	A representative from a municipal-owned recycling company.

There were two main purposes with the interviews. Firstly, to discuss the outcomes from the questionnaires and secondly, to gain deeper knowledge regarding a common barrier: lack of sustainable infrastructure. This was done by using a common interview guide, see appendix A.5, which was divided into the following parts; Description of the master's thesis, introduction phase, general information about the interviewee, discussion of the result from the questionnaire's and follow-up question regarding the common barrier.

The introduction phase was performed to inform about the research, its purpose and that their responses will be treated with confidentiality, as there are crucial factors to succeed with an interview (Denscombe, 2014). Further questions were asked to understand the interviewees role and business, which according to Bryman and Bell (2011) is important for the success as well. The question in the last part was the key questions based on the result from the questionnaires. This was done to gain feedback on the result and to further discuss the findings. A follow-up question regarding the findings were asked to gain deeper understanding of the issue. The question was based on a common barrier among all stakeholder groups to further examine the issue.

The interviewees were initially contacted via email and the interviews were conducted online via Microsoft teams or Skype. Two of the interviews were held as group interviews where two persons from the specific stakeholder group were interviewed which had the advantage of getting responses and thoughts by several people at the same time which gave a broader spectrum (Denscombe, 2014). The other two interviews were conducted with one person from the stakeholder group. Each interview was conducted during 30 minutes.

3.3.4 Data analysis process

In this section, the process and outcomes of the data analysis for each data collecting methods are described, see figure 4 below. Data analysis was made for both questionnaires and interviews where the same sub methods, coding and affinity grouping were used. The results from the data analysis process are presented in chapter 4 Results.

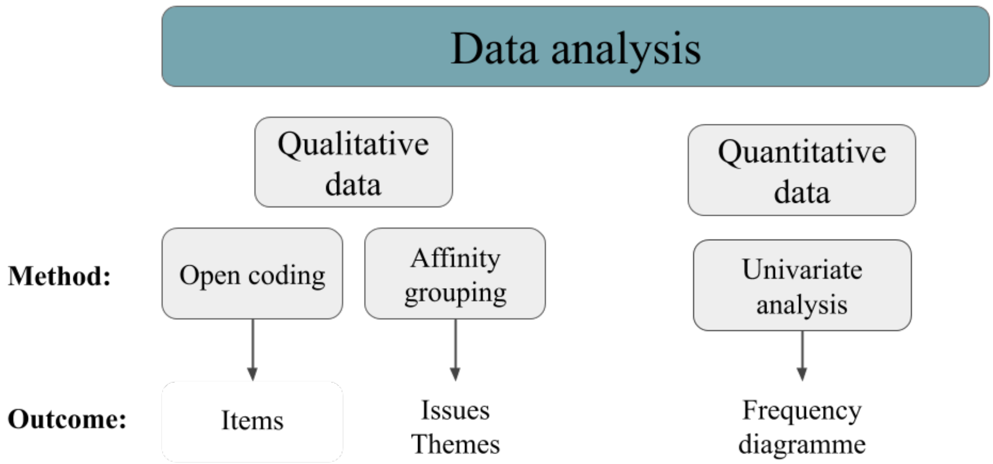

Figure 4: Data analysis overview with methods and outcomes shown.

3.3.4.1 Qualitative data analysis

The collected data from the questionnaires were transferred into an Excel sheet to organise the data and facilitate the coding process. The coding session started by reading through all the data from one questionnaire to get an overview and observe interesting opinions. Open coding was used as it allows the researcher to gather data as items such as as a word, a comment or an sentence that are important or interesting for the study (Bryman & Bell, 2011). In this research, the data from each qualitative question were open coded to identify the items. To organise the qualitative data, the methodology of affinity diagram was used. The affinity diagram is one of the seven quality management tools from Japan and has since then become widely used in qualitative research (Beyer & Holtzblatt, 2016). Affinity diagram has two main areas of use: to compile an overall picture of large amount of verbal data and to communicate the result in an effective way (Karlsson, 2007a). The outcome of the affinity diagram illustrates relationship between the collected data that for example could be issues or specifications (Karlsson, 2007a). The affinity diagram follows a methodology based on seven steps (Karlsson, 2007b):

- Step 1: Write the items on sticky notes and ensure that only one statement is written on each note.
- Step 2: Place all the notes in the upper left corner of a large piece of paper.
- Step 3: Select a note and place it at the center of the paper.
- Step 4: Select the next note and place it on the paper. If the note is related to a previously placed note, these two pieces should be placed near each other.
- Step 5: Continue until all notes are placed on the paper.
- Step 6: Group all the labels into thematic groups.
- Step 7: Put headings on the groups.

Building an affinity diagram is an inductive reasoning as it is built on peoples perspectives (Beyer & Holtzblatt, 2016). As Microsoft forms provides preferable features, the researchers of this master's thesis chose to keep the affinity diagram session digital and hence, no sticky notes were used. The affinity diagram started with reading the items and group related items together by searching for similar words. This process continued until all items were grouped together generating in a number of issues. Thereafter, the issues were grouped together to form themes. The themes are the identified drivers and barriers. The same procedure was used to code the data from the interviews. The coding session for the drivers is found in appendix A.6 and the coding session for the barriers is found in appendix A.7.

3.3.4.2 Quantitative data analysis

When analysing quantitative data, there are 4 types of variables which depend on the question asked and the way the respondent can answer it (Bryman & Bell, 2011). Univariate analysis refers to the analysis of one variable at a time and is commonly known as descriptive statistics (Djurfeldt, Larsson, & Stjärnhagen, 2006). The analysis studies the variation and other properties of a variable. When performing an univariate analysis, the aim is to find information regarding the distribution, the central tendency and the measure of dispersion of the variables.

The variables can be quantitative or qualitative, even if the question asked is closed end and therefore considered a quantitative question (Bryman & Bell, 2011). Mean value, mode and the median are examples of different ways to measure and indicate the central tendency of qualitative variables (Djurfeldt et al., 2006). The first step in the quantitative data analysis was to identify the variable for each quantitative question. In this research, only qualitative variables were identified and the two different variables, nominal and ordinal, are shortly described in table 6 below.

Table 6: Type, scales, characteristics and example of variables.

Variable type	**Scale**	**Variable values**	**Characteristics**	**Example**
Qualitative	Ordinal	Discrete	Distance between the categories is not equal across the range Can be rank ordered Classified	Grades, attitudes
	Nominal	Discrete	Order between the categories is arbitrary Classified	Type of accommodation or employment type

After the quantitative questions had been identified, they were given a specific variable according to how the questions could be answered. A summary of the amount of identified variable types are shown in table 7 below.

Table 7: Number of identified variables related to each question.

	Retailers	**Municipalities**	**Research institutes & authorities**	**Recycling & collecting companies**
Nominal	6	7	1	9
Ordinal	3	1	1	1

Lastly, the most appropriate data analysis method was chosen. Depending on the type of variable, different approaches for data analysis are generally used (Djurfeldt et al., 2006). The approaches are mentioned below (Djurfeldt et al., 2006):

- Qualitative variable: Frequency table, histogram, median, mode, chi$\hat{2}$-test.
- Quantitative variable: Histogram, mean value, standard deviation, t-test.

The mode is the value that occurs most frequently in a distribution (Bryman & Bell, 2011). This is often presented and analysed in frequency tables. The median is the mid-point in a distribution of values (Bryman & Bell, 2011). The median is most commonly used for ordinal variables (Djurfeldt et al., 2006).

4

Results

In this chapter, the results from the literature study and the empirical study are presented. The chapter is divided into three parts corresponding to each research question; present state analysis, stakeholder impact and external initiatives.

4.1 Present state analysis

This section answers to research question number one *What does the present state look like for synthetic textile blends?*.

4.1.1 Analysis of the literature

There is currently no available recycling route for textiles in general, and therefore assumed that the same scenario applies for products of synthetic textile blends. The literature study mainly includes a status analysis of the current value chain of recycling of textiles where three main steps were identified and within each step, different collecting, sorting and recycling methods were found, see table 8.

From the literature, it has been clear that there is no recycling process that can handle products of synthetic textile blends alone. Recycling consists of several different recycling processes, thus the main focuses in this section are mechanical, chemical and thermal recycling processes.

Table 8: Overview of the literature analysis with the steps in the recycling value chain.

Steps in the recycling value chain	Main point	Reference
Textile collecting systems	Types of collecting methods	(IVA Kungliga Ingenjörsvetenskapsakademien, 2020), (Naturvårdsverket, 2016), (Belleza & Luukka, 2018), (Åsa Östlund et al., 2015), (Hultén, Johansson, Dunsö, & Jensen, 2016)
Sorting	Techniques and platforms for sorting of textiles	(IVA Kungliga Ingenjörsvetenskapsakademien, 2020) (IVL Svenska Miljöinstitutet, 2017) (Englund, Wedin, Ribul, de la Motte, & Åsa Östlund, 2018) (IVA Kungliga Ingenjörsvetenskapsakademien, 2020) (de la Motte et al., 2019)
Recycling processes	Mechanical, chemical and thermal recycling	(Peters & Sandin, 2018), (de la Motte et al., 2019), (Naturvårdsverket, 2016), (Nordin et al., 2019) (Åsa Östlund et al., 2015), (Åsa Östlund, Syrén, Jönsson, Ribitsch, & Syrén, 2017)

4.1.2 Today's textile value chain

Today, the textile value chain is based on a linear system where 73% of the global material for clothing ends up in landfill or is incinerated. Of the input to production, 97% is made of virgin feed stock which in turn consists of 63% plastic, 26% cotton and 11% other fibre types (Ellen MacArthur Foundation, 2017a). These numbers show that products of synthetic textile blends could be represented in a large part of the global textile composition, that is, theoretically 74% of the total global fibre production. More than 50% of the global waste textile is blend-fibres that are inseparable by mechanical means which is one of the biggest barriers regarding textile recycling (Barla et al., 2017). This master's thesis assumes that the numbers from the global market reflect how the situation looks like in Sweden as well, although differences might occur on national levels.

4.1.3 Textile collecting systems

Currently, there is no structured common collecting system for textiles in Sweden. However, there are a lot of individual initiatives from both private and public sector trying to close the textile material loop. According to IVA, 38 000 tonnes of textiles are collected in Sweden each year (IVA Kungliga Ingenjörsvetenskapsakademien, 2020). In order to reach the Swedish Environmental Protection Agency recommendation on a collection volume of 85 000 ton per year in 2025, a large-scale collection system is needed (IVA Kungliga Ingenjörsvetenskapsakademien, 2020). A summary of textile collecting systems in Sweden is presented in table 9 below.

Table 9: A summary of textile collecting systems.

	Retailers	**Municipalities**	**Recycling & collecting companies**
Collected from	Individuals	Households Industries	Individuals Municipalities Retail companies Housing companies
Collecting methods	Containers in store	Containers located near residential areas Recycling centrals Recycling stations	Containers located near residential areas Submission to store

4.1.3.1 Retailers

The retailers that collect post-consumer textiles often have collecting programmes where individuals can hand in used textiles, clothes and shoes regardless of brand in the shops. One organisation that collect and takes care of the textiles is, among others, I:Collect (I:Collect, 2020). This company is part of a German recycling industry group called Soex, that mainly recycles through a mechanical process (Soex, 2020). Some retailers have their own second-hand shops in their regular stores, where they collect used garments of their brand and sell them to a lower price.

4.1.3.2 Recycling & collecting companies

Swedish recycling industries do not focus on textiles as a separate fraction in their collecting system today, nor do they separate textiles from other fractions in their sorting. The textiles that they handle are mostly from the automotive industry, as a by-product from end-of-life vehicles. This means car carpets, upholstery in car seats and other textile applications in the automotive product. However, charities, such as Röda korset, Myrorna or Stadsmissionen, collect textiles through various collecting systems. The most well-known is that individuals hand them in directly at the store.

Another system is that retail companies put up the charities' containers in their store. Some municipalities collect textiles at their recycling stations and centrals which are handed to the charities. Additionally, the charity organisation can place containers located near residential areas (Naturvårdsverket, 2016). In 2016, 38 300 tonnes of textiles were collected by charity organisations in Sweden. 7 800 tonnes of this was reused in Sweden. 27 700 tonnes were exported to other countries of which 21 300 tonnes were reused abroad. The main stream of these textiles were unsorted textiles. Of the collected quantities, only 0,2% is material recycled and 5% is incinerated with energy recovery in Sweden (Belleza & Luukka, 2018). About 43% of the collected textiles in Sweden are sorted domestically. This is summarized in table 10 below.

Table 10: Summary of collected textiles year 2016 in Sweden, modified from Belleza & Luukka (2018).

Total amount per year collected by charities	**Tonnes**	**%**
Collected quantities in Sweden	38 300	100 %
Of which		
Unknown quantities		~ 2,8%
Reused in Sweden	7 800	20%
Material recycled in Sweden	100	0,2%
Incinerated/energy recovered in Sweden	1 800	5%
Exported	27 700	72%

As a reference, 18,9% of the textiles collected by Myrorna were sold in their shops and 70% was exported in 2018 (Myrorna, 2018).

4.1.3.3 Municipalities

Many municipalities have specific collection containers for textiles at their recycling stations and centrals, or located near residential areas. 98% of the municipalities in Sweden have some of the above collecting method. The collecting methods varies between the municipalities but in general, two out of three gives place for collection at their centrals. Further, 20% of the municipalities have formal collaboration with collecting actors (Åsa Östlund et al., 2015).

The total amount of textiles from households in Sweden was from a waste stream analysis measured to be 48000 ton. Of the collected textiles, 5100 ton was named as "specific product groups", that is, sportswear, work wear, outdoor clothing and textiles with plastic prints. The collected amount of footwear from households were measured to be 9800 ton (Hultén et al., 2016). Table 11 below visualises the quantities of textiles in household waste, and products of synthetic textile blends are color coded.

Table 11: Quantities of textiles in household waste year 2014 in Sweden, modified from Hultén et al. (2016).

Categories	**Total tonnes/year (rounded values)**
Textiles and footwear	57 800
Of which	
Clothes	29 200
Home textiles	13 700
Specific product groups	**5 100**
Footwear	**9 800**

4.1.3.4 Waste handling in Sweden

Each municipality in Sweden are responsible for the household waste and should make sure that the waste in each municipality are handle according to the waste hierarchy, see figure 2. The handling of waste that best protects human health and the environment as a whole should be considered most appropriate, if the chosen treatment is not unreasonable. Household waste refers to waste that comes from households and thus comparable waste from other operations. The waste handling could not be carried out by anyone other than the municipality or the one employed by the municipality. The one who, in a professional activity, gives rise to waste other than household waste, must submit it to someone who has the permit or has made the notification required for handling the waste (Sveriges Riksdag, 2020).

4.1.4 Sorting

The collected textiles are today mainly sorted manually. The reason is that there is no automatic large-scale plant in Sweden that can match the collected textile volume as well as lack of transparency and traceability techniques that can distinguish between the different materials (IVA Kungliga Ingenjörsvetenskapsakademien, 2020). However, there are ongoing initiatives in Sweden that are testing automatic sorting techniques.

4.1.4.1 Sorting techniques

Near infrared spectroscopy (NIR) is a technique where infrared light is illuminated on garments. Different textile materials absorb different wavelengths from the light. The reflected light is detected in sensors and forms a spectrum and depending on the spectrum, the machine can decide the fibre material composition of the garment (IVL Svenska Miljöinstitutet, 2017). Additionally, NIR is a very fast method which have some superior characteristics when it comes to identification from a longer distance (Englund et al., 2018).

To facilitate and speed up the sorting, digital labeling might be required. Today there are for example QR-codes, RFID-tags integrated in the products and DNA that can be woven into the material as a digital content list (IVA Kungliga Ingenjörsvetenskapsakademien, 2020). By scanning the RFID-tag, it can give access to a large amount of data. Compared to the QR code, the RFID tag do not have to be visible for the reader and can be scanned at a longer distance, approximately 5 meters, compared to QR codes that requires a shorter reading distance. The RFID-system could be useful if sorting on specific parameters for example a certain amount of chemicals or colour. To be able to ensure efficient sorting of different fibre composition the technology has to be further developed (de la Motte et al., 2019).

4.1.4.2 Sorting platforms

SIPTex is a Swedish innovation platform for textile sorting. It is a pilot-scale research collaboration project between 21 actors in Sweden, focusing on automatic sorting of textile materials. The machine sorts by fibre type and color which will be more efficient than manual sorting and generate large volumes of high quality textile fractions. The machine uses NIR to ensure accurate and efficient sorting. The plan is that the SIPTex plant will be able to sort large volumes of textiles in the plant, which will scale up to full scale production in August 2020.

Wargön Innovation is another innovative platform that sorts textile in pilot scale. The machine used is a FIBERSORT with NIR technique that sort by fibre and color. The FIBERSORT is able to sort out by 15 different variables, that is, the 15 most common materials and colours. Wargön Innovation sorts out clothing and footwear for reuse and uses the machine to sort on a specific category i.e lady top. After the textile has been sorted out by category, the textile is packaged and sent to charities for reuse. In the pre-sorting stations in the plant, some products of synthetic textile blends i.e footwear are sorted separately. The primary reason for that is because the sorting system can not guarantee that those products end up in the same container as they have no value if separated (personal communication, 23th of April 2020).

The difference between SIPTex and Wargön innovation is that Wargön Innovation is supposed to continue to act as an innovation centre, whereas SIPTex will be a full-scale production plant in the future.

4.1.5 Recycling processes in the textile industry

Recycling processes are often classified as mechanical, chemical or thermal processes, depending on the driver of the process. Thus, this is a simplification of the reality as one recycling process often consist of a combination of mechanical, chemical or thermal processes (Peters & Sandin, 2018).

Today's heterogeneous fibre compositions in textiles makes it impossible for just one recycling process to meet the recycling demand. It has to be combined of several processes, as well as resource synergies with other industries (de la Motte et al., 2019). The potential application for the textile will vary a lot depending on origin of the material, the fibre type and fibre composition. An overview of identified recycling processes are shown in figure 5 below.

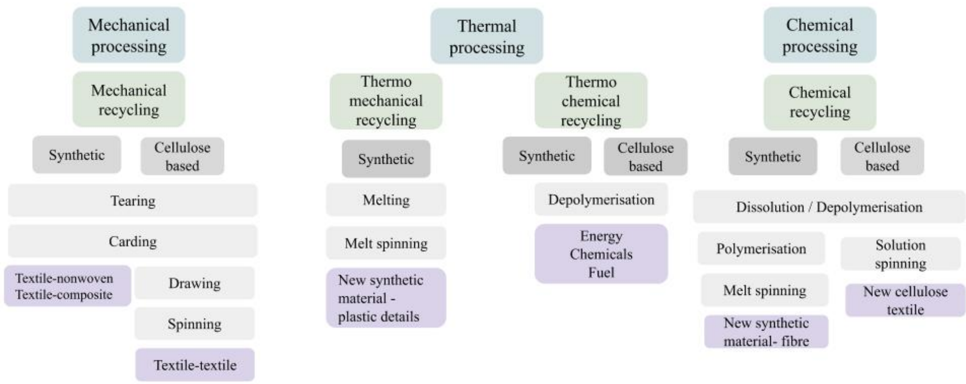

Figure 5: Overview of different types of recycling methods.

4.1.5.1 Mechanical recycling

Mechanical recycling of textiles is when the fibres are separated by tearing or carding. There are two alternative processes for mechanical recycling. The most common is open loop recycling which is when the recycled material is of lower quality or value than the original product. The material is used for non-woven products such as upholstery, padding, insulation and car mats (Naturvårdsverket, 2016). The quality and the construction of the input material determines if the material should be down-cycled or spun into threads.

The second alternative is closed loop recycling where new thread is spun of previously used fibre. Further, to increase the quality of the recycled thread virgin fibres has to be added. This means that a pair of jeans consist of approximately 20% of used fibres and the rest are virgin fibres (Åsa Östlund et al., 2015). This process lead to a higher value end-product as the fibres can be circulated many times before ending up as energy recovery.

Several challenges of mechanical recycling exist. The challenge with synthetic textiles is that the synthetic fibre is often a lot stronger than the natural fibre which requires more energy to tear apart the material. One disadvantage of mechanical recycling of textiles is that the quality of the textile fibres are often lower, since every process shortens the fibres. Additionally, the material that entries the recycling process is of lower quality that cannot be recreated (Nordin et al., 2019). The possibilities for the recycled material and its quality depends on the original fibre. A lot of differences exist between natural fibres, synthetic fibres and blends of mixed fibres (Åsa Östlund et al., 2015).

4.1.5.2 Chemical recycling

Chemical recycling include regeneration processes which means that the various fibres are chemically affected on a molecular level. The fibres can be dissolved to molecular level, down to polymers or monomers, to ensure that the fibres can be recycled to the highest possible quality (Åsa Östlund et al., 2015). A worn out cotton fibre cannot be regenerated to its original fibre structure, but is used to create regenerated fibres as lyocell, viscose and acetate (de la Motte et al., 2019).

Re:Newcell is a Swedish company that through a chemical process dissolves used cotton and viscose (at least 95% cellulosic) into biodegradable raw material. A circulose pulp is created that can be turned into cellulose fibres such as viscose or lyocell. This process is up and running in there first plant in Kristinehamn where they produce 7000 tonnes of biodegradable circulose pulp per year (Re:newcell, 2019). The company plans to build a plant in Sweden that will start operating in 2020 and have a capacity of 3000 ton per year (Åsa Östlund et al., 2015).

OnceMore® is a project at Södra that collect blends of polyester-cotton and dissolves polyester from the blend. The remaining cotton fibres are blended into the dissolving mass that are further sold to their customers that produces viscose and lyocell. Thus, this material can be used in the production of new textile products. The production will maintain 30 tonnes the current year and with the goal of 25 000 ton per year (Södra, 2019).

Chemical recycling of plastics is often done by depolymerisation, which means that the fibres are broken down into polymers and further down to monomers by breaking the chemical bonds between the polymer chains. Depending on the material composition, different additives and chemicals must be used (Nordin et al., 2019).

There are several companies focusing on chemical recycling of polyester. The company Teijin in Japan are producing recycled polyester textiles under the trade name Eco Circle™ fibres. The recycling system and the product has the same level of quality as virgin polyester fibre, as well as equivalent functionality and feel. Teijin has developed their technology to separate and eliminate additives and colorants from polyester products, and the process includes step of materials purification. The first step in the process is to process recovered fibre products which are granulated. Through chemical purification, polyester rawmaterial is produced which is polymerised to polyester polymers. Of this material, yarns are produced and can be used to produce textile fibre products (Teijin Frontier Group, 2020).

Ioniqa is a company located in the Netherlands and they focus on upcycling both transparent and coloured polyester. By depolymerisation, the plastics is dissolved and from the raw material that is extracted, new clear PET bottles are produced (Ioniqa, 2020).

There are two types of nylon; PA 6 and PA 6,6. PA 6 is mostly occuring in carpets and fishing nets, whereas PA 6,6 is used mainly in sportswear and hoisery (de la

Motte et al., 2019). Currently, the process of recycling of PA 6 is the only one commercialised. ECONYL® is a trademark of Aquafil, an Italian company recycling PA 6 on a commercialised scale. The company are collecting waste, such as fishing nets and fabric scraps. The waste is sorted followed by a cleaning process to recover as much of the collected nylon as possible. Thereafter, the waste is regenerated and purified which brings the nylon back to its original quality. The nylon is then processed into yarns for fashion or industrial interior and the yarn can be found in high-performance sportswear, swimwear and outdoor garment (Econyl®, 2020). Further, there is a process for recycling of PA 6 in South Korea and the actor Hyosung, as they are producing a recyclable nylon yarn, MIPAN regen, which is made by recycling of pre-consumer waste (Hyosung TNC, 2020). Both the processes takes in textile waste and makes new fibres out of it (Åsa Östlund et al., 2015).

4.1.5.3 Thermal recycling

Thermal recycling of textile fibres are processes where heat is the driver component of the reaction and includes a number of processes. The following sections describes a thermal recycling process, combined with either mechanical or chemical processing.

4.1.5.3.1 Thermomechanical recycling Thermomechanical recycling is mainly made on synthetic fibres which are melted and further processed. This means that the fibre quality remains and there is no limit of how many times the material can be circulated (Naturvårdsverket, 2016).

Re:mix is a project that was conducted in Mistra Future Fashion, the project investigated which technical methods that are required to separate nylon and elastane from other fibre types, in order to recycle these textile blends. During the project, two separation methods were identified that could either work separately or in combination. The first method is a melting process of the synthetic fibres, so called thermomechanical separation; and the second method is a design of new specific enzymes that will act as biocatalysts for degradation of a specific polymer which will further facilitate the re-synthetisation of the polymers (Åsa Östlund et al., 2017).

4.1.5.3.2 Thermochemical recycling Gasification and pyrolysis are two thermochemical recycling processes that involves recycling of the constituents of textile fibres, in the form of small molecules, instead of whole textile fibres, polymers or even monomers. The small molecules can be used as recycled raw materials to produce valuable chemicals and materials, both textiles and others, which are otherwise manufactured from virgin fossil raw materials (Vela, Maric, & Seemann, 2019). Gasification is especially interesting as the input can consist of several different materials simultaneously, both synthetic and biomass, which could make it suitable for complicated textiles that today cannot be recycled (Lopez et al., 2017).

A test on a lab scale at Chalmers University of Technology has shown that textile waste stream can be converted into high-value chemicals and replacing fossil fuels as feedstock. The fibre compounds used in these tests were 100% cotton, 100% polyester and clothing containing 50% polyester and 50% cotton. The result and outcome from this test is that cotton is more suitable for syngas production while polyester and the blends could produce both syngas and aromatic compundus (BTXS) (Vela et al., 2019). The report brought up that there are two large challenges for textile recycling today; firstly, the textiles consists of a variety of polymers which complicate sorting and secondly, a lot of textiles produced today are produced by many different fibres (Vela et al., 2019).

There is a proposal where textiles, together with other materials such as biomass waste, PET and carbon fibres, can be used as fuel to drive the thermochemical recycling process. The report describes a transformation from a existing petrochemical cluster into a thermochemical recycling plant (Thunman et al., 2019).

4.1.6 Identified value chain for the plastic return refinery

The following section describes an identification of the value chain for recycling of products of synthetic textile blends, with respect to a possible return refinery in Stenungsund. Figure 6 describes a circular value chain for waste treatment of synthetic textile blends which potentially could create synergies with other value chains. The blue part is the core concept of the identified value chain based on the steps that are required to implement a well-functioning strategy for recycling of synthetic textile blends. The green part illustrates the possibilities for how the material can be kept in the core value chain for as long as possible.

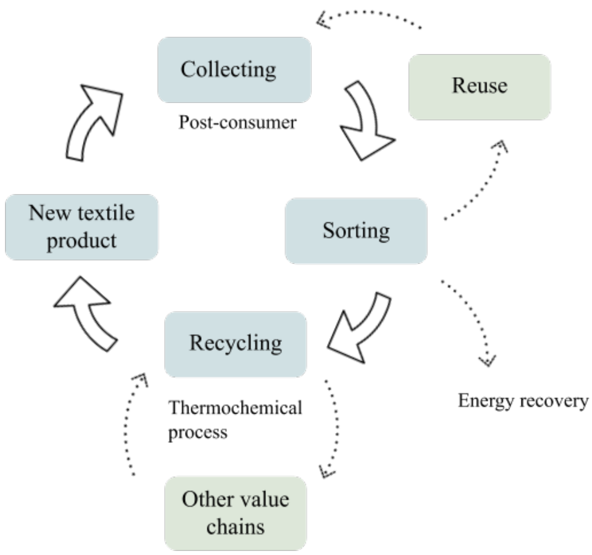

Figure 6: Possible value chain for recycling of products of synthetic textile blends.

The collected synthetic textile blends from post-consumer waste is transferred to a sorting system. Depending on the quality of the textile waste, three options are available. If the textile is of good quality, it follows the waste hierarchy and goes to reuse. If the textiles for some reason, e.g contamination, cannot be recycled, it goes to incineration with energy recovery. The textile product that is worn out or broken, or by other reasons can not follow the first two options, it will go to the next step which is thermochemical recycling process in a plastic return refinery. The output from the thermochemical recycling process can possibly be used as material in other value chains and back to thermochemical recycling again or potentially be used as raw material for a new textile product. When the new textile product reach its end-of-life, it is collected and the circular system is closed.

4.1.7 Money and waste flow

This section describes the findings from the questionnaires conducted in the survey. There were four different questionnaires sent out, depending on the stakeholder groups, see appendices A.1, A.2, A.3 and A.4.

The first section in the questionnaire is directly linked to the first research question: "What does the present state look like for synthetic textile blends?". In order to answer the research question, a map of the current state is presented based on the outcomes from the questionnaires, visualised in figure 7 below. The map is limited to only consider post-consumer waste, that is, products of synthetic textile blends that no longer meet the criteria of the consumer due to aesthetic, functional purpose, fashion reasons, or because they are torn or worn out.

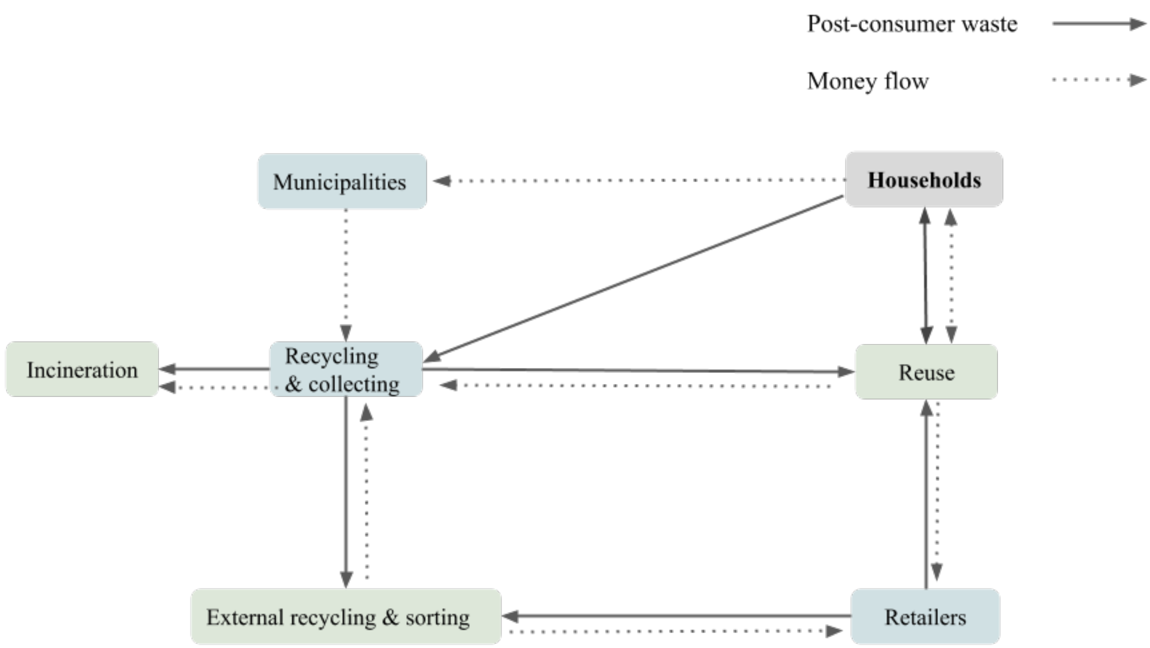

Figure 7: Flow of post-consumer waste of synthetic textile blends and related finances.

Figure 7 shows the present state of post-consumer waste, visualised by the solid arrows, and money flow, visualised by the dotted arrows, for products of synthetic textile blends. The stakeholder groups are marked in light blue. Due to the fact that the stakeholder group research institutes & authorities are not included in the core value chain for products of synthetic textile blends, previously identified in section 4.1.6, the stakeholder group is not represented in figure 7. The light green boxes indicate the route for products of synthetic textile blends and is based on the answers collected by the questionnaires. By reuse, it means that the products of synthetic textile blends are of enough high quality and can be used again. External recycling and sorting companies refers to companies whose main business is sorting textiles to reuse or to mechanical recycling, depending on the quality of the garment. Today there are no companies operating like this in Sweden, which is why the route has been named external.

Retailers
From figure 7, the products of synthetic textile blends goes from retailers to reuse or external recycling and sorting. Reuse are defined as products that are not sold according to the retailers' core business. Reuse and external recycling and sorting services generate an income for retailers.

Municipalities
The municipalities gets an income from the households for waste handling services. The waste handling service is however, mostly assigned to a recycling & collecting company. The material goes to the recycling & collecting company where the municipalities only handle the administration and therefore, the municipalities does not handle the material per se, which is why the solid arrow from households is directly connected to recycling & collecting companies.

Recycling & collecting companies
The recycling & collecting company, assigned the municipality waste treatment, can either have internal sorting where the sorted products that are in enough good quality goes to external recycling and sorting companies which generate an income for the recycling and collection company. If the products cannot be reused, they will be incinerated which is an expense for the recycling & collecting company.

Additionally, recycling & collecting companies collects material from industries, and the products goes to incineration or to reuse, depending on the quality of the product. Regarding the money flow, recycling and collecting companies get an income from the material that they send to reuse and pay for the incineration part.

4.2 Stakeholder impact

This section answers to research question number two: *What is the impact of stakeholders on recycling of synthetic textile blends?*. Drivers and barriers have been identified. Table 12 describes the abbreviation for the stakeholder groups used in this section.

Table 12: Abbreviation for the stakeholder groups.

Stakeholder groups	**Abbreviation**
Retailers	R
Municipalities	M
Research institutes & authorities	A
Recycling & collecting companies	C

4.2.1 Drivers

In the following section, six drivers have been identified for all stakeholder groups. The drivers are mentioned in table 13 below.

Table 13: Drivers related to the various stakeholder groups.

Drivers	**R**	**M**	**A**	**C**
Change into circular business models	x	x	x	x
Resource efficiency	x	x	x	
Change in consumer behaviour			x	
Collaboration between stakeholders			x	
External initiatives			x	
Economic aspects				x

4.2.1.1 Change into circular business models

A common driver for all four stakeholder group was to change into more circular business models. This includes to follow the waste hierarchy, where reduce waste and reuse of products of synthetic textile blends should be prioritised over recycling. However, recycling should be considered for those products that cannot be reused. For this to happen, some retailer agreed that there is a need for them to take a larger responsibility for the products after they are sold. As the customer mostly have the ownership of the product, one stakeholder within the retailers stated that there is a need to ensure that the customers send the product to the appropriate place when the product is totally worn out.

One aim for adopting a circular business model among retailers is to produce products that consist of material that later can be recycled into high-value products or material which will generate an income from their sustainable produced products.

The challenge to switch to a circular business model includes many complex parameters. One retailer brings up two of those parameters. The first is that it is unfortunately too expensive to succeed in circular business models compared to virgin products at the moment. The second is that there is a gap between consumer expectations and consumer behavior when it comes to circularity, as a large majority of consumers prefer virgin products if they get the choice.

In order to change into more circular business models, several of the retailers agree that some kind of regulations or policies needs to be developed. One retailer pointed out the importance of developing solutions for recycling before implementing a policy such as a producer responsibility on textiles. Further, circular incentives from the EU Commission and the EU member states will be crucial. Circular business model needs to promote the circular economy as well as to take the organisational step to implement it and by that, reduce the environmental impact that is connected to the recycling of synthetic textile blends. Further, a recycling facility in Sweden was considered to be crucial, as a national recycling facility saves transport, which generates fewer emissions and is less time-consuming than sending the products of synthetic textile blends abroad for recycling.

4.2.1.2 Resource efficiency

A common driver among retailers, municipalities and research institutes & authorities is resource efficiency. That include to take an environmental responsibility and more specific reduce landfills, reduce waste and increase recycled content in the products of synthetic textile blends. Among the retailers, two trends associated with resource efficiency were identified. First, the material must be reused by recycling to avoid that the product groups end up in landfill. Second, product development and material selection where the search for recycled, natural and renewable materials are important factors to facilitate for recycling. One retailer mentioned that there is a concept shoe where the complete shoe is made in one material in different shapes. According to the retailer, the shoe is possible to melt down and create new material from. The three stakeholder groups underlined the importance for closed material loops and protect nature capital when it comes to resource efficiency which correlates to decrease the use of virgin materials.

One actor within research institutes & authorities stated that as the production and consumption of fossil-based plastics as a primary raw material need to decrease, there is a need for finding new raw material resources so that the global fibre demand will be covered.

Products of synthetic textile blends could potentially be a secondary raw material, as several of the stakeholders agreed that raw material must be extracted from today's waste streams to lower the dependence on primary fossil-based raw materials. One researcher pointed out that the waste streams will be of higher value in the future than today, as the industry will seek raw material in these streams.

Another view stated by research institutes & authorities is that a circular system for textiles must be put into place to ensure that the resources are properly taken care of in each step of the value chain. It is shown that the stakeholder groups are well aware that more have to be done within this area when it comes to recycling of complex products such as products of synthetic textile blends. There is a desire within the stakeholder groups to recycle their waste to help society lessen its environmental impact.

4.2.1.3 Change in consumer behaviour

According to research institutes & authorities, there is a need for change in consumer behaviour as the current view on consumption is not sustainable. The concept of fast-fashion and capitalism has led to the overconsumption of textiles, and products of synthetic textile blends, that get discarded before their expected lifetime. Demand from customers through large retailers can help increasing the interest for recycling of products of synthetic textile blends.

4.2.1.4 Collaboration between stakeholders

It was pointed out that collaboration between stakeholders is an important driver for several of the stakeholder groups. It includes the need to work cross-industries as well as across the value chain. One actor within research institutes & authorities mention that a recycled fraction of synthetic textile blends can possibly become a resource for another industry. It is stated as an important factor, to be able to use the materials for energy, fuel, chemical raw materials or as processable material fractions. There are both chemical and textile clusters in Sweden that hopefully can cooperate in a positive way, such as Chemsec and Textile & Fashion 2030, that several of the stakeholders mentioned that they are interested in participating in.

One municipality stated that focus must be put on the customer demand and take the manufacturing companies opinions and strategies into consideration. An aspect brought up by among the retailers was that there is a need for a common recycling system. In order to not put all pressure and responsibility to each individual company a large scale and common system is needed. One retailer took the soda industry as an example and stated that they have a common recycling system for their bottles but still have different products. It needs to be a scalable process that could be used for every retailer, no matter the size of the company. As a small company it is difficult to make an impact, therefore it is important for the larger established retailers to lead the way. To make the recycling route work properly, methods for collecting, sorting, recycling needs to be developed in a big scale in perfect timing in order to take advantages of each other.

4.2.1.5 External initiatives

According to research institutes & authorities, external regulations is an important driver to recycle products of synthetic textile blends. The upcoming Extended producer responsibility for textiles and a ban against incineration on textile waste are important to focus more work on recycling the product groups.

4.2.1.6 Economic factors

The economic aspect is an important driver to ensure income and enhance the circular economy. As some of the actors within recycling & collecting companies does not collect products of synthetic textile blends, there are other economic factors that are of importance to them, such as recycling of valuable metals, as the products of synthetic textile blends currently comes in with metal rich products.

4.2.2 Barriers

In the following section, seven barriers have been identified. The barriers are mentioned in table 14 below.

Table 14: Barriers related to the various stakeholder groups.

Barriers	**R**	**M**	**A**	**C**
Lack of sustainable infrastructure	x	x	x	x
Lack of technology	x		x	
Complex products	x		x	
No economic feasibility		x		x
Low volumes of synthetic textile blends			x	x
Knowledge gap			x	x
Low market value for post-consumer textiles		x		

4.2.2.1 Lack of a sustainable infrastructure

One barrier was common for all stakeholder groups, the lack of a sustainable infrastructure related to all steps in the recycling value chain for products of synthetic textile blends. This include both to create more collaboration and trust between stakeholders as well as a functioning logistics system. There is currently no common collection system that can take in products of synthetic textile blends and no logistics solution to transfer the collected products of synthetic textile blends to a recycling plant that can handle them. Moveover, there is no receiver of the synthetic textile blends waste that is able to recycle them and the logistics regarding the route products of synthetic textile blends are not in place, which truly complicates the recycling of the products. In general, there is no waste stream or outlet for the stakeholders to send the specific waste to recycling.

According to the stakeholder groups, it should be easy to hand in the products of synthetic textile blends and to make sure that the product groups does not get contaminated. In order to not put all the responsibility on the stakeholders in charge of waste collecting, regulations and policies needs to involve all the steps in the value chain. One stakeholder particularly mentions that the earlier in the value chain the control is inserted, the sooner it has a greater effect. If products are regulated even before they are released on the market, no restrictions are needed or instruments for the consumer. Two retailers wished for a local recycling possibility that would gain them in terms of reduced transport, as a large part of there textile waste are in Sweden. A trend among the retailers was that collaboration will have a important role in order to succeed with a sustainable infrastructure, as the transition need to be a large movement were the stakeholders need to work together. To increase the collaboration among the stakeholders, it was clear that platforms are needed where Textile & Fashion 2030 and Chemsec once again were mentioned as examples.

4.2.2.2 Lack of technology

Lack of technology is a common barrier for retailers, research & authorities and recycling & collecting companies. According to the stakeholder groups, the technology development within this area is still lagging as the full-scale solutions are not available in Sweden yet. There is currently lack of sorting techniques that can separate synthetic textile blends in pure fractions. The recycling technology development is delaying as well, as effective and value-preserving recycling methods that are more resource efficient than incineration must be used which is currently not the case.

To be able to recycle products of synthetic textile blends, an effective sorting and separation method of the fibres needs to be developed as the full production process are not available in Sweden yet. Regarding recycling of synthetic textile blends today, it is not enough with one recycling process to meet the demand, instead it has to be a combination of several methods. As the quality of the recycled material is often too low to be used in products again, the recycling techniques must be refined to preserve value of the original material and to create high-quality secondary raw material. One of the stakeholders within research institutes & authorities pointed out the fact that the issue is not only related to the fibres in the products, but that there is a lack of chemical recycling facilities as well.

4.2.2.3 Complex products

Another common barrier is that the products of synthetic textile blends are complex in terms of a large mix of materials. Footwear is a particularly challenging product group to recycle as it consist of many different materials. One retailer explain that some of the components in footwear, that is, mid sole, out sole, upper textile, mud guards and studs, are tightly bonded together which make it hard to separate. Further, it was explained that the mid sole was the most tricky part to handle since the physical characteristics are difficult to achieve without different types of foams with highly cross linked polymers. Closed loop recycling of other parts of the shoe could be made but a separation from the sole has to be done prior to the process. According to research institutes & authorities, it is currently difficult for users to identify the polymer or plastic type used in the garments. This barrier might complicate the value chain for recycling of synthetic textile blends, as collection, sorting and recycling might be affected if the worn out product end up in an incorrect container in the first step.

4.2.2.4 No economic feasibility

This barrier is referring to the fact that according to the stakeholder groups, there is no economic feasibility for recycling of products of synthetic textile blends today. One municipality explains that if a household-based collecting and sorting system should become a reality, the cost is a critical factor. There must be a provision for the products on the market, meaning that there must be purchasers of the textile fraction as corresponds to the collection rate. Actors within research institutes & authorities stated that too low volumes of similar fractions could make it difficult to shape a business case, meaning that low volumes do not lead to low processing costs. High process costs together with low cost of raw material, and that the process of both separation and recycling is not economic feasible at the moment. Today, it is too expensive to sort out the products of synthetic textile blends and some of the stakeholders mention the difficulties of ensuring appropriate pricing.

4.2.2.5 Low volumes of synthetic textile blends

According to research & authorities and recycling & collection companies, the available quantities of products of synthetic textile blends that are ready to be recycled are too low at the moment. There is a lack of continuity of waste streams of products of synthetic textile blends. Actors within research institutes & authorities urged the development of a proper collection system to ensure that the material streams are large enough and continuous.

4.2.2.6 Knowledge gap

Two of the stakeholder groups, research & authorities and recycling & collecting companies, urged that there is a wide knowledge gap related to mainly two areas. Regarding the chemicals used in the products of synthetic textile blends, there is a lack of knowledge regarding how these chemicals might behave in a recycling process and how to prevent the possible side reactions that the chemicals might cause. The other aspect is that there is a knowledge gap related to sorting, where the recycling & collecting companies believed that how to sort different items and how to handle the products correctly are crucial aspects.

4.2.2.7 Low market value for post-consumer textiles

Two of the municipalities stated that there is a lack of market for post-consumer textiles which is a barrier for recycling of products of synthetic textile blends. Today, municipalities collect textile fractions separately in different collecting systems and some of the stakeholders are eager to expand their separate collection of textiles, but if there is no market for the post-consumer waste or a place to send the material to, it will not be possible. By expanding separated textile waste the total volume of the household waste will decrease, which will affect the situation for products of synthetic textile blends, as they are mainly incinerated today.

4.2.3 Stakeholder's view on barriers

During three of the interviews, the results of questionnaires and mainly the barriers were discussed. This is to analyse and compare the data from two different data collection methods.

Overall, the three stakeholder groups agreed on the barriers found in the questionnaires. During the interview with the stakeholder in retailer, it was stated that there is currently no functioning infrastructure around recycling of their specific product group, but believed that the technology is in place in some areas, especially regarding mechanical recycling. This means, that some of the technologies are present if the company is willing to take the cost of separating the materials but that it is not financially profitable at the moment. Additionally, the interviewee strongly agreed that one large barrier is complex products, because their product group consists of a very complex set of materials. Further, they mean that the increasing use of mono material is an important issue in the industry.

The interviewee within research institutes and authorities added that in order to handle all the different type of materials, several specific return refineries must be developed. That leads to a need for expertise within different materials and for extensive research that has to be conducted in parallel. According to the interviewee, the chemical content and the mix of different materials in textile products will have a considerable role when it comes to the thermochemical recycling process.

One barrier that was further discussed with two of the stakeholder groups, research institutes & and authorities and recycling & collecting companies was that there is a knowledge gap related to chemicals. Both stakeholder groups raised concern relating to how the chemicals used in the thermochemical process will affect both the environment but also the human health.

During the interview with the stakeholder group recycling & collecting companies, some question marks regarding the financing of a return refinery initiative were discussed. It was discussed that is fundamental that a legislation is required regarding the collection of products of synthetic textile blends since the market need help in order to solve the issue.

4.2.3.1 Stakeholder's view on common barrier: Lack of sustainable infrastructure

Overall, most of the interviewees agreed that the volumes of synthetic textile blends was an important factor to achieve a sustainable infrastructure. According to the interviewee within research institutes & authorities, the most important factor is to have sufficiently large and continuous streams of material to recycle synthetic textile blends. Further, all factors needed for a sustainable infrastructure can not occur at the same time. Step one is to collect the material and then sort the products of synthetic textile blends, where the sorting has to be done according to the waste hierarchy. It is not certain that the outcome from the recycling process can be put back to the textile value chain, instead another value chains like the biochemical and chemical industry will be a possible alternative.

The current situation regarding Covid-19 has affected the waste management industry. A lot of actors in waste management have stopped emptying textile collection containers. In the operating area of the interviewee within recycling & collecting companies, there is only one actor that still empties textile collection bins, as the rest of the actors have restricted that business. From a long-term perspective, it is not sustainable to have a system where the actors can decide not to collect textiles, and therefore products of synthetic textile blends, anymore. The lack of material directly affects the industries that are based on getting this material. According to the interviewee, this industry requires security of supply and large volumes as this is extremely economically sensitive value chains. Additionally, it is important to select actors with sufficient capacity to handle the issue. Most actors who collect textiles often have another purpose, such as charity. Often the equality sign is set between charity and textile which might put the issue in the wrong context, according to the interviewee within municipalities. The interviewee further explains that they have no possibility to sort out synthetic textile blends from the textile stream that are collected today, as the collected textiles are sent to a sorting company and thus, the control of the products are lost.

There was several views on where to start the transformation towards a sustainable infrastructure for recycling of synthetic textile blends. One important factor, according to the interviewee in retail, is to have a common system where all steps in the value chain works well. As mentioned from the findings from the questionnaire, once again, a return system for products of synthetic textile blends was brought up as an example. However, in order to develop a common system there has to be many different initiatives to evaluate the concepts and extensive collaboration to find the most suitable system, which is the situation for the retail industry in Sweden at the moment, according to the interviewee. One interesting view that was stated by the interviewee was that the first step would be to have develop a pilot case, where a product are designed for recycling, and it is clearly stated how much of the product that can be recycled.

In all recycling contexts, the stakeholder groups agreed that the last part of the value chain must be taken into account, i.e the stakeholders that want to produce a new product. It is important to identify what the actors need: what material, in what form and in what volumes. One interviewee explained further that the value chain of products of synthetic textile blends must be followed backwards and screening of the market must be done. This to determine if there is any actor that can achieve something desirable for an interesting price for the textile manufacturer. One example that was brought up, is that the companies that work with collection of products of synthetic textile blends will get problems if there is no provision for the material or the products.

From the interviews, it has become clear that it is of high importance to consider whether recycling is the best method to use both from a environmental and an economic perspective. The recycling system needs to be beneficial for the environment, and this has to be shown for the stakeholders involved. This could be done by performing a life cycle analysis of the environmental benefits, to calculate the environmental footprint throughout the product's life cycle. The actor within retail explained that when they are designing a product, it is a balance between life-span, quality and the ability to recycle. One interviewee states that it is not entirely certain that it is desirable that every product is recyclable, as there is not enough knowledge in if it is entirely possible and it might be more desirable to only use materials from renewable raw materials. To increase the collection rate and raise awareness among the consumers, a verification is central, to ensure that the products of synthetic textile blends end up in the accurate place once it is outworn.

Regarding whether it is worth recycling products of synthetic textile blends with a thermochemical recycling process in Stenungsund, some scepticism was raised, concerning the economic feasibility and the issue regarding enough purified output. Two of the interviewees stated that it may prove that the output of it becomes too toxic. The output could possibly be purified infinitely, but then also becomes infinitely expensive. However, one interviewee stated that their company can deliver waste to such a return refinery if someone else owns and operates it, if the operating company can offer an environmentally friendly solution at a good price.

4.3 Impact of external initiatives

This section answers to research question number three *How will external regulations affect the situation for synthetic textile blends?*

4.3.1 Extended Producer Responsibility

In this section, the various stakeholder groups had to judge which of the nine components from Mistra Future Fashion regarding a producer responsibility (see section 2.4.1) that will have the largest impact.

Retailers:
From the frequency diagram shown in figure 8 below, Retailers considered that component 6. Preparation for reuse/recycling would have the largest impact of the nine components. Component 7. Consultation with existing actors was considered to have no or low impact.

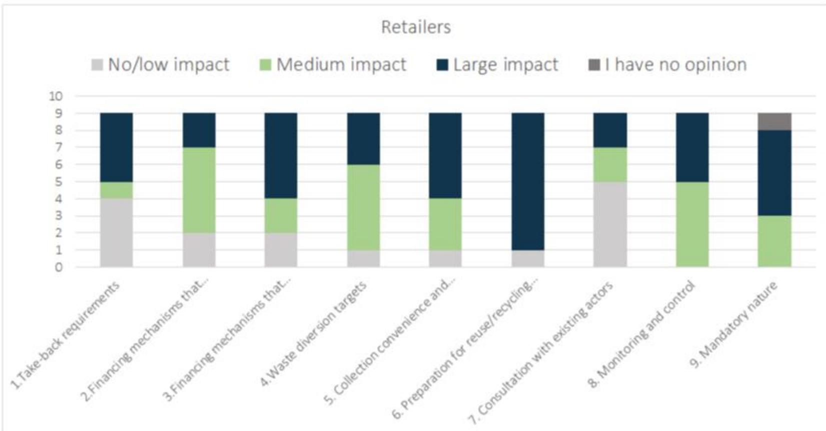

Figure 8: Frequency diagram related to what component of the EPR-system that will have the largest impact for Retailers.

Municipalities:
From the frequency diagram shown in figure 9 below, Municipalities considered that component 4. Waste diversion targets and component 5. Collection convenience and information requirements regarding collection would have the largest impact of the nine components. Component 2. Financing mechanisms that reflect the actual cost of recycling specific fibers, 3. Financing mechanisms that contribute to the R&D of recycling technologies for your specific products, 6. Preparation for reuse/recycling targets and 7. Consultation with existing actors were considered to have no or low impact.

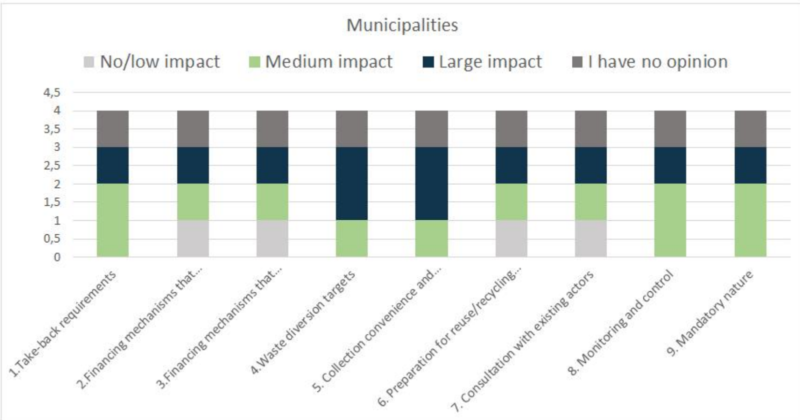

Figure 9: Frequency diagram related to what component of the EPR-system that will have the largest impact for Municipalities.

Research institutes & authorities:
From the frequency diagram shown in figure 10 below, research institutes & authorities considered that component 1. Take-back requirements would have the largest impact of the nine components. Component 4. Waste Diversion targets was considered to have the lowest impact, together with component 8. Monitoring and control. The stakeholder group consider component 4 and 8 to be less relevant.

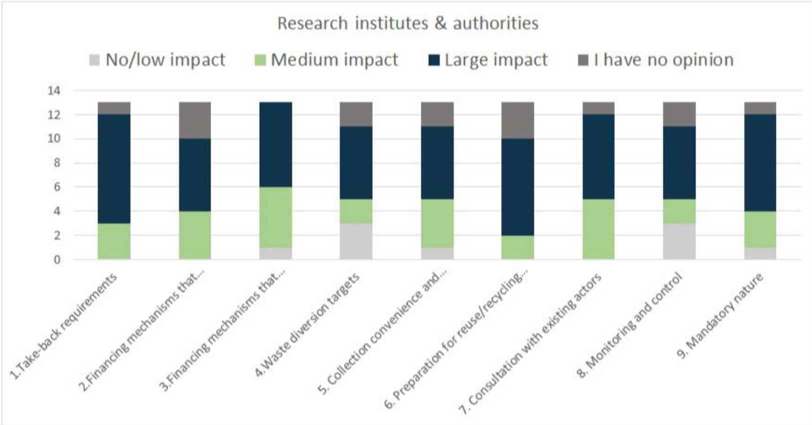

Figure 10: Frequency diagram related to what component of the EPR-system that will have the largest impact for Research institutes & authorities.

Recycling & collecting companies:
From the frequency diagram shown in figure 11 below, Recycling and Collecting companies considered that component 1. Take-back requirements will have large impact of the nine components. Component 8. Monitoring and control was considered to have the lowest impact.

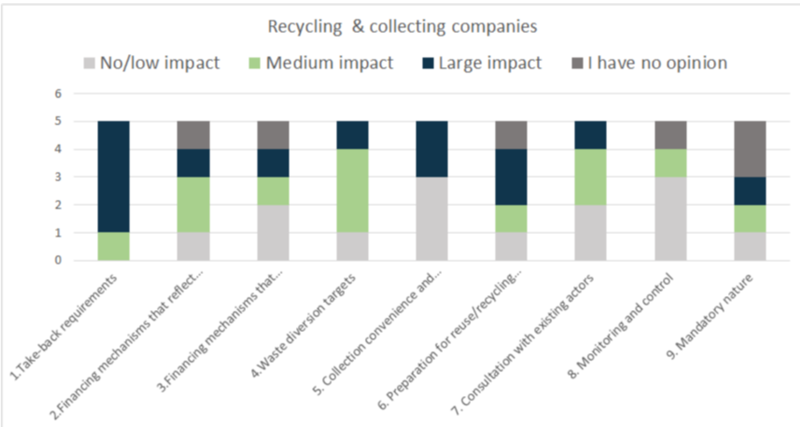

Figure 11: Frequency diagram related to what component of the EPR-system that will have the largest impact for Recycling & collecting companies.

Summary of trends observed from questionnaires
From the frequency diagrams, some trends can be spotted. The stakeholder groups research institutes & authorities and recycling & collecting companies had a common view on what components they considered the one with the largest impact, which is component 1. Take-back requirements. In addition, the both stakeholder groups shared the opinion that the component with no/low impact was component 8. Monitoring and control.

Another observed trend is that the participating retailers have a contradicting view of the impact of the components than research institutes & authorities and recycling & collecting companies, regarding on what component will have large impact. Retailers considered component 1. Take-back requirement to have no or low impact.

4.3.2 Refunded Virgin Payment

In this section, the stakeholders' opinions regarding Refunded Virgin Payments are presented. Based on the outcomes from the questionnaires, the overall view on a RVP system is deemed positive from the researcher's perspective. The majority of the retailers have high ambition levels related to recycled content in their products of synthetic textile blends. Two of the retailers stated that their aim is to have 100% recycled content where it is possible by 2030, that is, were the material content does not impact the product's life time. Two other retailers explained that their goal is to have 100% sustainable textile materials in their products by 2025, and by sustainable, they mean that the products should consist of recycled or plant-based materials. One retailer already have a clear measurement method for increasing the recycled content, as the company has a KPI set specifically for recycled content.

A majority of the participating retailers currently work with increasing the recycled content in their products of synthetic textile blends, as they introduce more materials with recycled content in their operations and phase-out non-recycled content. This is done by both purchasing of recycled material as well as buy-back of their own recycled material. One retailer mention that they work a lot with their suppliers related to transparency, and that they are constantly sourcing for materials together with their partners. However, some of the retailers explained that their current focus is not related to increasing the use of recycled content, but rather to change the operations to focus on other areas, such as processes that cause large CO2 emissions. Two retailers explained that they have no current strategy set for increasing the use of recycled content in their products of synthetic textile blends specifically. From the interview, the interviewee within retailers stated that a Refunded virgin payment system would be a positive recognition for them, as they already use a large amount of recycled materials in their products of synthetic textile blends. Sometimes, there is a choice between recycled or non-recycled content that has to be made, where only the price differs. In this situation, a well-functioning RVP system will be beneficial. From the perspective of research institutes & authorities, a majority believe the level of recycled content in products of synthetic textile blends will be high, that is, higher than 50% in the future.

Municipalities and recycling & collecting companies answered the question if they think that the Refunded virgin payment will have an impact on the company's operations. The answers are presented in figure 12 below. The reason for excluding retailers and research institutes & authorities is that all retailers are deemed to be positively affected by the RVP system, and the research institutes & authorities are not directly handling any products of synthetic textile blends, thus their operations cannot be affected.

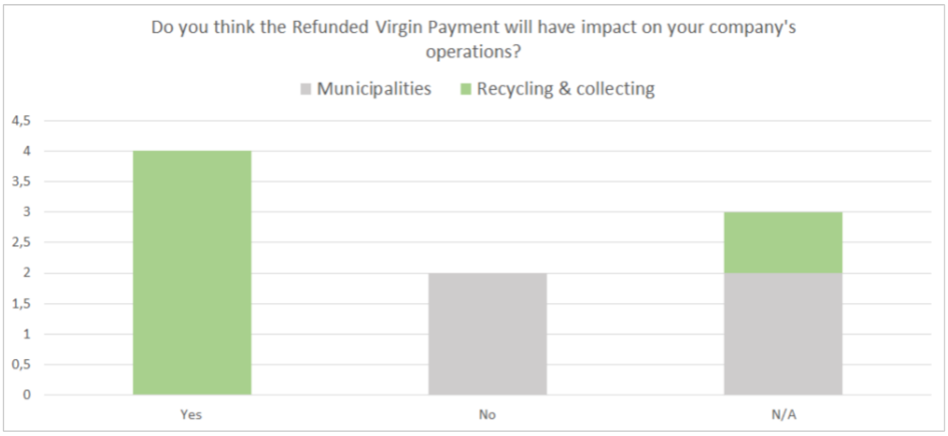

Figure 12: Frequency diagram related to how municipalities and recycling & collecting companies think that the Refunded virgin payment will affect the company's operations.

From the frequency diagram in figure 12, the assumption is divided among the stakeholder groups. It is clear that recycling & collecting companies assume that Refunded virgin payments will have an impact on their operations. However, municipalities do not think the refunded virgin payment will have an impact. One-third of the respondent's had no answer to the question, which could correlate to the fact that the respondent has not the sufficient information or knowledge of the subject. Another reason can be that the municipalities are not directly handling the products of synthetic textile blends by themselves, but rather outsource the operations to a recycling & collecting company.

4.3.3 Incineration tax on waste

From figure 13 below, it can be shown that the major part of the three stakeholder groups thought that the incineration tax will not affect their handling of synthetic textile blends. Additionally, it can be shown that many of the stakeholder groups did not answer, probably because they do not know if the tax will affect their handling of synthetic textile blends.

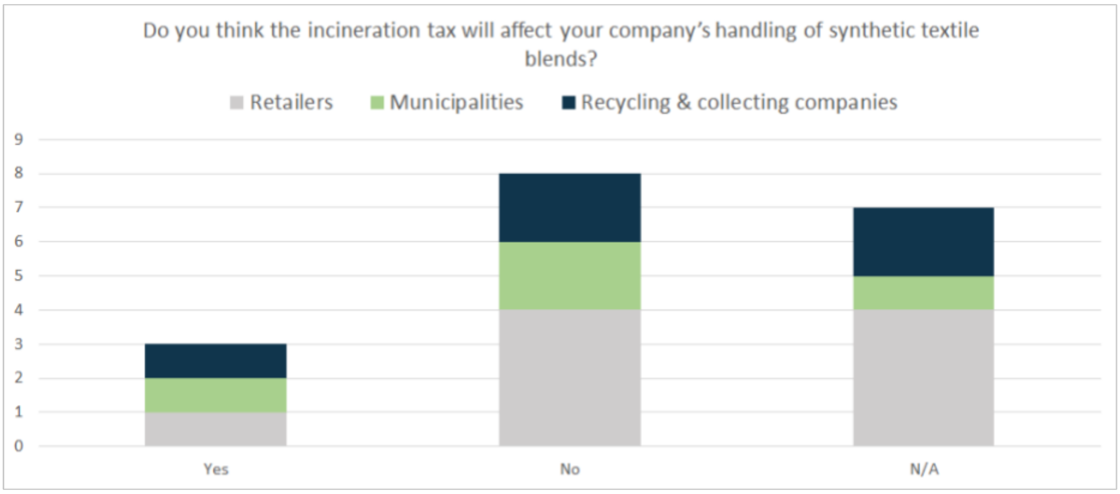

Figure 13: Frequency diagram related to stakeholder's impact on incineration tax.

From the questionnaires, research institutes & authorities had the chance to briefly express their opinion regarding how they think the incineration tax will affect the recycling of synthetic textile blends, where different opinions were stated. Some of the stakeholders believe that the incineration tax will decrease the amount of products of synthetic textile blends that is incinerated today. Further, that the incineration tax will bring awareness of the need for recycling. One researcher though that it is important to the industry to realise that paying the tax is a very small action in relation to what the environment have to pay for incineration. On the other hand, some of the stakeholders disagreed and believe that the incineration tax will have minor or limited impact, since there is a low bill to pay. Some stakeholders raises two different concerns related to the economics of the incineration tax. One concern is that companies will store there synthetic textile blends instead of paying the tax, and by that reduce cost. Another concern is that the incineration tax will affect smaller businesses since they do not have the resources to participate in other alternatives for treating the synthetic textile blends.

Another interesting view that two of the stakeholders brought up is that the incineration tax is closely linked to the chemicals used in products of synthetic textile blends. This because it will be consequences for the products that have a hazardous chemical content and should not be included in the circular system As long as the recycling method of synthetic textile blends can not make sure that no hazardous chemicals are included, the products needs to be incinerated.

4.3.4 Chemical tax in footwear and clothing

From figure 14, it can be shown that the major part of the three stakeholder groups thought that the chemical tax will not affect their handling of synthetic textile blends. It can further be shown that a large part of the retailers thinks that the chemical tax will effect their waste handling. Additionally, it can be shown that many of the stakeholder groups did not answer, probably because they do not know if the tax will affect there handling.

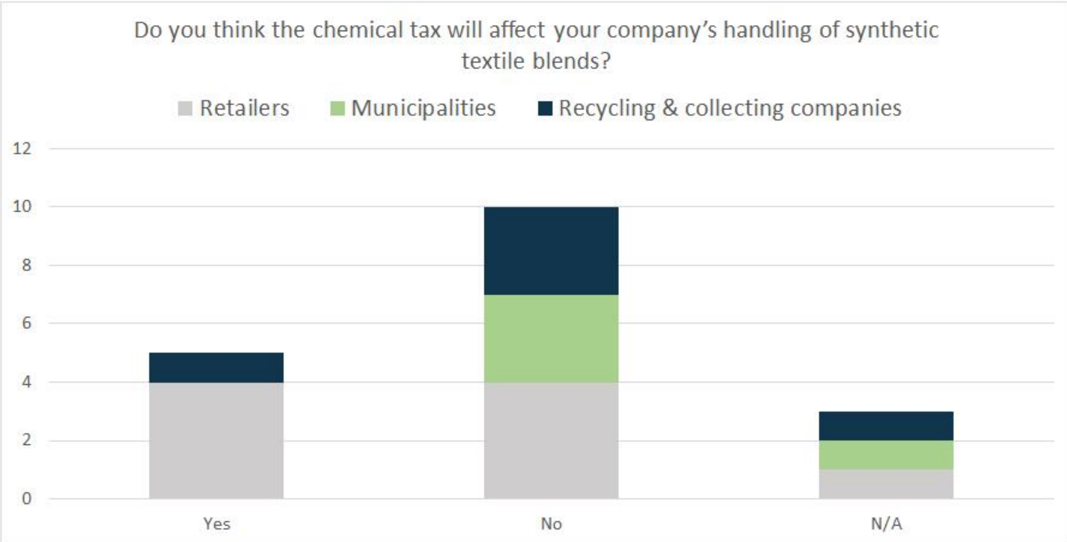

Figure 14: Frequency diagram related to stakeholder's impact on chemical tax on clothing and footwear.

From the questionnaires, research institutes & authorities had the chance to briefly express their opinion regarding how they think the chemical tax, in its current proposal, will affect the recycling of synthetic textile blends. Several stakeholders are critical regarding the chemical tax. One stakeholder brings up the issues regarding lack of information, as most textiles are manufactured oversees and the tax would rely on too much perfect information about products of synthetic textile blends. The stakeholder raises concerns that there is a risk that some companies will pay the tax even if their products do not contain any of the substances, as it might become too expensive with administration and testing. Some stakeholders have a more optimistic view on the implementation of a chemical tax, as it might lead to better material content and more transparency regarding the product content, a factor that is important for recycling according to the stakeholders. The opinion of one stakeholder is divided. On one hand, in a long-term perspective if the tax is working properly, it should affect recycling of synthetic textile blends positively as health hazardous substances is foreseen to decrease. But on the other hand, it is also a risk that the tax is added onto the price for the consumer as it is costly with analysis and difficult to be really sure of exact chemical content in the products, and hence, the tax will paid which will still make it difficult to recycle synthetic textile blends.

From the interview, one researcher was not convinced that the proposal made for chemical tax for textiles and footwear is the best way to tackle the problem. The textile industry is a complex industry with a lot of suppliers involved along the value chain. Further it was explained that it is up to each company to prove that the products do not contain a specific chemical. This will lead to that the companies will pay the tax because it is the cheapest alternative. Firstly, in order to prove it has to be several analyses that are very expensive, up to 5000 SEK per analyse. Secondly, the proposal does not describe what needs to be done in order to be approved. The proposal has announced that it is not their job to describe how to verify the content. This can leads to confusion and unexpected costs for additional analyses. This outcome from a proposed tax can be recognized in the electronic tax.

According to the interviewee within research institutes & authorities, many companies have poor control of their value chain, and therefore the interviewee believes that a better way to go is to ensure that companies have a transparent relationship to their suppliers. Further, that they work in a systematic way to phase out hazardous chemicals, that is, restriction lists, risk analyses and sampling to secure the chemical content. One example of that could be to ensure that the companies purifies their waste water.

4.3.5 Initiative with largest impact

The frequency diagram, shown in figure 15, visualise which of the four external initiatives that will have the largest impact according to the stakeholder groups.

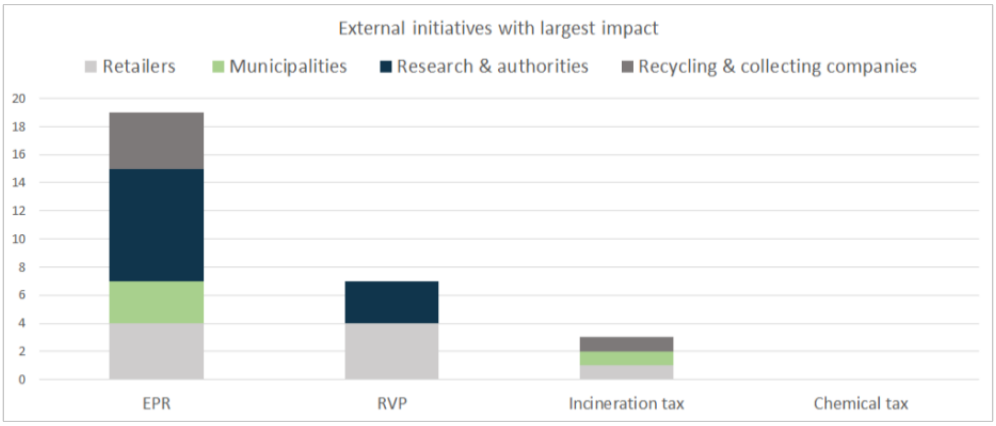

Figure 15: Frequency diagram showing how many stakeholders within each group and which external initiatives they think will have the largest impact.

4.3.5.1 Summary of trends observed in questionnaires

A common trend among the stakeholders is that the EPR policy is assumed to have the largest impact. All stakeholder groups except retailers thought that EPR will have the largest impact. Retailers had four votes on EPR and five votes on RVP as the policy with largest impact. Another trend that could be found is that none of the stakeholders though that the chemical tax would have the largest impact.

5
Discussion

In this chapter, a discussion will be held regarding the different points of interest in the master's thesis. This chapter is divided into three parts; first a discussion regarding the validity of the research, where the methods and the results are discussed. This is then followed by sustainability and ethical aspects, and eventually, recommendations for future research is discussed.

5.1 Validity of research

In this section the validity of the research is discussed and divided into two the parts: methodology and the results.

5.1.1 Methodology used in the study

The methodology used in the empirical study is a six stage systematic approach. The six stages were well defined and easy to follow along the study. The systematic approach is useful for building new theories, which is the biggest advantage of this theory and why the approach was used. This systematic approach was combined with three sub methods, coding, affinity grouping and univariate analysis to complement the survey. The researchers were aware that these sub methods could have an impact on the systematic approach theory. Another research methodology that could have been used is grounded theory, and there is a possibility that the theory would have given other results.

5.1.2 Stakeholder groups

When defining the stakeholder groups, the division could have been different. Firstly, as the work with the master's thesis continued, the researchers figured that the stakeholder group of recycling & collecting companies should probably have been divided into two stakeholder groups. This would increase the understanding for the reader, as the collecting companies (such as e.g charities) often send their material to recycling companies for incineration of the products of synthetic textile blends that are of too poor quality for reuse. If divided, the mapping of material and money would look different and perhaps have a more realistic layout. Secondly, due to the current division, it was difficult to differentiate between municipalities and recycling & collecting companies, as recycling companies often are in charge of the operation of the waste handling since they are assigned the service by the municipality. Further, it would have been of value to add chemists or chemistry companies as a stakeholder group to find out their drivers and barriers for recycling of synthetic textile blends.

5.1.3 Questionnaire

First of all, in order to gain a fair judgement of what the different stakeholder groups think about recycling of synthetic textile blends, a higher respondent rate would have been needed. The low response rate increased the risk of not being representation, that is missing thoughts, knowledge and opinions that could have been important for the research. Further, it is an uncertainty whether the right person with the right knowledge has answered the questionnaire. If a respondent perceives difficulties in answering a question, there was no one present who could supervise which could be seen as a disadvantages and result in partially correct answers. On the other hand, it was clearly stated in the introduction of the questionnaire that the respondent could reach out to the researchers if questions arised, which was done by several of the respondents. The outcome of adding the answer alternative "N/A" led to the fact that it was hard for the researchers to understand the reason behind the answer since it could have had three different meanings:

1. Lack of knowledge regarding the subject.
2. The question was too sensitive to answer.
3. The stated alternatives did not match the actual truth.

To enable for the respondents to further express their thoughts or explain their answers, it could have been valuable to add an open question after each section such as "Do you have any comments or reflections regarding your answers on the questions above?". If the question had been added, it would give the researchers more information about why the respondent answered the question in a specific way. However, it would have been more time-consuming and was therefore not prioritised.

5.1.4 Affinity diagram

The collected qualitative data from the questionnaires and the interviews was first open coded and then grouped with the method affinity grouping. One thing to consider is that the affinity grouping is a subjective method and is, in this master's thesis, based on the researchers opinions. If the data was coded and grouped by other than the researchers, the items, issues and themes may have looked different. According to the affinity diagram method, all items found from the coding should be put on sticky notes. This was not done in the study which affected the work negatively as it was harder to get an overview and move around the items. The coding and the affinity grouping of the qualitative data was more time-consuming than expected. As the coding and affinity grouping were made for both the questionnaires and the interviews, the time was doubled. To facilitate the coding and affinity grouping, a software for analysing qualitative data could have been used but was not considered by the researchers.

5.1.5 Interviews

A critical part of conducting an interview is to get access to the right persons that could answer the questions. Important people are likely to be busy and important data are likely to be classified. Further,interviews are based on what people say, not what they do. This fact can not be assumed to be the truth which make the validity of the data a disadvantage. Discovered consequences during the online interviews was the remoteness and for some interviews the loss of visual contact. If the interviews had been recorded and transcribed, it would have been easier to analyse specific thoughts and statements made by the interviewee. Additionally, if recorded and transcribed, the data collected would probably have been more accurate, instead of relying on the notes written during the interviews.

5.1.6 Results

The empirical study investigated and analysed the recycling of products of synthetic textile blends. The result from the empirical study are based on the stakeholders thoughts and opinions.

5.1.7 Money and waste flow

One important discussion point regarding the money and material mapping is the lack of data. Firstly, the low response rate from three of the stakeholder groups made it difficult to get an overview that could be generalised to reflect the reality. Secondly, of those who answered, there were too many who could not provide the accurate data needed to make a reasonable assessment of the reality. It was clear that of those that answered the questionnaire, quite a few could provide actual data as several of the respondents chose to answer "N/A".

As municipalities are responsible for the household waste treatment in Sweden, but can assign this assignment to whatever stakeholder they want, and this varies throughout the country, it is very difficult to expect that this is what the situation looks like in Sweden overall. For instance, there are a lot of different initiatives for collecting of textiles and footwear.

5.1.8 Recycling of products of synthetic textile blends

Regarding recycling of products of synthetic textile blends, the researchers found out that it is an extremely complex issue to deal with. A lot of the findings from the master's thesis are applicable on textile waste in general. As there is currently no commercial solution for treating textile waste with a thermochemical recycling process, more complex product groups such as synthetic textile blends are not prioritised yet by the stakeholders addressed in this master's thesis. The focus in the retail industry is based on creating more durable and long-lasting products of synthetic textile blends, to follow the waste hierarchy, in which material recycling is considered as a lower priority than reduction of waste and reuse. All these steps should, according to the waste hierarchy, be done before the products of synthetic textile blends have been used for so long that the best option for the products are to be send to a material recycling facility, due to poor quality. However, this research must continue in parallel, as large quantities of products of synthetic textile blends are put on the market every year, and if the products are used extensively, they will reach their end-of-life in a limited time period, no matter how well the consumer treat their products of synthetic textile blends.

5.1.9 External initiatives

New requirements from the EU Commision require new initiatives. The four chosen external initiatives ERP, RVP, incineration tax on waste and chemical tax in clothing and footwear were chosen by the researcher's themselves. The initiatives were considered relevant as they probably will affect the recycling of synthetic textile blends. The fact that these requirements are new, for instance, the incineration tax on waste has been in effect since April 2020, or not yet active in Sweden, as for the other three initiatives, made the research complicated. The researchers can only put up a hypothesis in how they will work and what effect they might will have, if implemented in such a way that they are described in this master's thesis. By other means, the stakeholder groups have given their thoughts and opinions based on this fact, and not based on what the actual policy will look like in the future.

5.2 Sustainability aspect

This master's thesis is related to the three pillars of sustainability, that is, economic, environmental and social.

One economic aspect is the loss of value for the 73% of clothing that today is incinerated or put into landfill, this material should be utilised in a better way. It is a well known fact that chemical recycling processes are costly in comparison with other solutions such as reuse. Reusing the products is a significantly cheaper alternative and also better form an environmental perspective, as the product life span is increased. It is important to put the cost of the thermochemical recycling process in relation to the value that is lost today as it is incinerated or put into landfills. To offset the cost for a recycling process, it should be preferable to find symbiosis with other industries and if possible, using existing process infrastructure.

From an environmental point of view, recycling of synthetic textile blends could reduce the use of virgin materials and well as reducing waste, energy, pesticides and fertilisers used in the production phase that stands for 80% of the environmental impact (Elander et al., 2017). A thermochemical process could potentially mean that taking steps upwards in the waste hierarchy, meaning, one step upwards from energy recovery or two steps upwards from landfill.

The social aspect are mainly integrated in the empirical study were the stakeholders' view on recycling of synthetic textile blends was investigated. Four different stakeholder groups were chosen for the study which gave an overall impression and a result that reflects the reality more accurately, as several views were taken into consideration. Since a large quantity of synthetic textile blends needs to be collected in order to be recycled, there are some factors that need to be evaluated. A recycling process could potentially compete with non-profit collection actors such as second-hand shops. These actors create work opportunities as well as favors reuse of textile products. On the other hand, products that can be reused should not enter the recycling process. But as long as the quality assessment of the outworn product lies on the individual, it can be hard to determine whether the product should go to reuse or end up as waste and by that, there is a risk for competition with non-profit actors. Further, the social aspect is complex as it covers many different areas for example labour right where the textile industry suffers from ethical issues like low wages, long hours, unhealthy and unsafe work conditions. More attention in terms of investigations and development within the textile industry, in which recycling of products of synthetic textile blends is included, will hopefully gain the ethical issues.

5.3 Recommendations for future research

For future research, efforts should be made on technical development focusing on developing and verifying the output of the thermochemical process technology for synthetic textile blends. It needs to be examined whether the technical specifications can be identical to the conditions that can be applied for plastics recycling, to investigate if there is a possible and realistic synergy with the plastics industry. Further, it has to be viewed with a more extensive systems perspective in order to understand the complex situation. To merge these initiatives together and create hands-on projects, a platform could be developed including all the relevant stakeholders. Regulations and external initiatives need to be established and implemented to solve issues and steer the textile value chain in a more sustainable direction. One example can be to define the financial responsibilities for up scaling of more sustainable processes and merging of projects. The sustainability aspect for recycling of synthetic textile blends needs to be analysed and identified. To communicate the suitability for the thermochemical process, life cycle assessments and environmental calculations can be performed. Lastly, new innovations and a re-thinking concept in mind are vital to the development within recycling as well as the textile industry as a whole.

6
Conclusion

The aim of this master's thesis was to investigate the current state, the impact of stakeholder's and external initiatives regarding recycling of products of synthetic textile blends. During an empirical study involving questionnaires and interviews with relevant stakeholders, these issues were investigated with the specific product groups in mind.

At present, there is no large-scale handling of products of synthetic textile blends, meaning that there is no collecting or recycling system. However, there are many interesting initiatives ongoing. The focus in the industry is mainly to increase the content of recycled materials in the products as well as trying to prolong the lifetime of the products.

Both drivers and barriers have been identified within each stakeholder group. The drivers are:

- Change into circular business models
- Resource efficiency
- Change in customer behavior
- Collaboration between stakeholders
- External initiatives
- Economic aspects

The barriers are seen as the most interesting findings because they have to be solved in order to gain a well-functioning and flexible handling of synthetic textile blends. The seven barriers found in this master's thesis are:

- Lack of sustainable infrastructure
- Lack of technology
- Complex products
- No economic feasibility
- Low volumes of synthetic textile blends
- Knowledge gap
- Low market value for post-consumer textiles

The most important barrier is deemed to be lack of infrastructure, which was revealed through the survey where all stakeholders agreed. With regard to sustainable infrastructure, it is defined as a combination of communication, trust and collaboration as well as transport and logistics.
The researchers of this master's thesis have identified two possible scenarios for re-

cycling of products of synthetic textile blends, with respect to the possible return refinery in Stenugnsund. The first scenario is to include the synthetic textile blends in a thermochemical process where the molecules can be used as recycled raw materials to produce valuable chemicals and materials. The second scenario is to use the synthetic textile blends as fuel to other processes, which is a proposal investigated by Thunman et. al (2019).

There are various options for end-of-life treatment of textiles: either business as usual with incineration and landfill, or at best, solutions higher up in the waste hierarchy meaning more reuse and fibre recycling. However, it is believed that the latter is far from the market at the moment. To close this gap in the middle, between incineration and fibre recycling, thermochemical recycling could possibly be an alternative. If the recycling process, after technological development and adjustments, proves to be a successful alternative, meaning that the output generated is of high quality and the conditions used are aligned with the conditions for thermochemical recycling of plastics, it could be considered. For that, the researchers of this master's thesis see two possible alternatives: the textile waste could be directly integrated into a thermochemical process in a return refinery, if the recycling process after technological development and adjustments, proves to be a successful alternative, meaning that the output generated is of high quality and the conditions used are aligned with the conditions for thermochemical recycling of plastics. If not, a second option might be that the textile waste serve as fuel to run a plastic return refinery. Nevertheless, both alternatives require much more technical evaluation. It is also important to point out that even if the above suggestions might overcome some of the barriers mentioned, there is still a need for a sustainable infrastructure, more knowledge related to different areas and that the economic aspects need to be reviewed, especially since the monomers that come out of the thermochemical process must have a desirable market value, and replace virgin feedstock.

To achieve a possible recycling of products of synthetic textile blends, regulations and restrictions must be put into place, which is currently ongoing due to the inquiry of the producer responsibility and the EU legislation that municipalities must collect textiles separately by 2025. It is of outmost importance that the legislations that are set up work well in practice and put the environmental benefits of recycling first, without becoming bureaucratic or symbolic. Additionally, a two-way system like Refunded Virgin Payments that give leading players recognition is assumed to be important, in order to be able to drive the development forward towards changing the products and thus their complexity.

As long as crucial information regarding available quantities, end-of-life treatment and finances related to these factors are not shared, it is extremely difficult to investigate the issue of possible recycling of products of synthetic textile blends. The excessive lack of data and transparency regarding these factors reinforces the image that the textile industry is a relatively immature industry.

References

Barla, F., Nikolakopoulos, A., & Kokossis, A. (2017). *Design of circular economy plants – the case of waste textiles to chemicals* (Vol. 40). Elsevier. doi: 10.1016/B978-0-444-63965-3.50324-X

Belleza, E., & Luukka, E. (2018). *Svenska textilflöden - textilflöden från välgörenhet och utvalda verksamheter. smed report.* (No. 2). Naturvårdsverket. Retrieved from http://naturvardsverket.diva-portal.org/smash/get/diva2:1241255/FULLTEXT01.pdf

Beyer, H., & Holtzblatt, K. (2016). *Contextual design: Design for life* (2nd ed.). Elsevier. doi: 10.1016/B978-0-12-800894-2.00006-5

Bryman, A. (2015). *Social research methods* (4th ed.). Oxford University Press.

Bryman, A., & Bell, E. (2011). *Business research methods* (3rd ed.). Oxford University Press.

de la Motte, H., Bour, L. S., Perzon, E., Sandin, G., & Spak, B. (2019). *Mot en textil cirkulär ekonomi: Resumé av forskningsläget* (No. 104). Retrieved from https://www.circularsweden.se/nyheter/aktuellt/forskningslaget-for-en-cirkular-textilkedja

Denscombe, M. (2014). *The good research guide.* Open University Press.

Djurfeldt, G., Larsson, R., & Stjärnhagen, O. (2006). *Statistisk verktygslåda - samhällsvetenskaplug orsaksanalys med kvantitativa metoder.*

Econyl®. (2020). *The process.* Retrieved from https://www.econyl.com/the-process/

Elander, M., Tojo, N., Tekie, H., & Hennlock, M. (2017). *Impact assessment of policies promoting fiber-to-fiber recycling of textiles.* (No. 2017:3). Mistra Future Fashion. Retrieved from http://mistrafuturefashion.com/wp-content/uploads/2017/06/MFF-report-2017-2-Impact-Assessment-of-policies-promoting-fiber-to-fiber-recycling-of-textiles.pdf

Ellen MacArthur Foundation. (2013). *Towards the circular economy vol.1.* Retrieved from https://www.ellenmacarthurfoundation.org/assets/downloads/publications/Ellen-MacArthur-Foundation-Towards-the-Circular-Economy-vol.1.pdf

Ellen MacArthur Foundation. (2017a). *A new textiles economy: Redesigning fashions future.* Retrieved from http://www.ellenmacarthurfoundation.org/publications

Ellen MacArthur Foundation. (2017b). *What is a circular economy? a framework for an economy that is restorative and regenerative by design.* Retrieved from https://www.ellenmacarthurfoundation.org/circular-economy/concept

Ellen MacArthur Foundation. (2019). *Completing the picture how the circular economy tackles climate change.* Retrieved from https://www.ellenmacarthurfoundation.org/publications

Englund, F., Wedin, H., Ribul, M., de la Motte, H., & Åsa Östlund. (2018). *Textile tagging to enable automated sorting and beyond - a report to facilitate an active dialogue within the circular textile industry* (No. 2018:1). Mistra Future Fashion. Retrieved from http://mistrafuturefashion.com/wp-content/uploads/2018/03/AutoSort-report-D4.3.4_3.pdf

European Commission. (2018). *New waste rules will make EU global front-runner in waste management and recycling.* Retrieved from https://ec.europa.eu/info/news/new-waste-rules-will-make-eu-global-front-runner-waste-management-and-recycling-2018-apr-18_en

Fletcher, K., & Tham, M. (2015). *Routledge handbook of sustainability and fashion.* Retrieved from https://books.google.se/books?id=1-tTBAAAQBAJ&pg=PA224&lpg=PA224&dq=cotton+and+polyester+is+90+percent+of+all++textile+fibers&source=bl&ots=tz5lXnUMh0&sig=ACfU3U3IWaIRVSfVQ_FHseWITaYuiNc1tg&hl=sv&sa=X&ved=2ahUKEwiI1Km7wJTnAhWAxcQBHYhtD28Q6AEwAHoECAYQAQ#v=onepage&q&f=false

Flynn, B. B., Sakakibara, S., Schroeder, R. G., Bates, K. A., & Flynn, E. (1990). *Empirical research methods in operations management* (Vol. 9). doi: 10.1016/0272-6963(90)90098-X

Gardetti, M. A. (2019). *Introduction and the concept of circular economy.* Woodhead Publishing. doi: 10.1016/B978-0-08-102630-4.00001-7

Hultén, J., Johansson, M., Dunsö, O., & Jensen, C. (2016). *Plockanalyser av textilier i hushållens restavfall: En kartläggning av mängder och typ av kläder, hemtextilier och skor. smed report no 176.* Naturvårdsverket. Retrieved from http://urn.kb.se/resolve?urn=urn:nbn:se:naturvardsverket:diva-6801

Hyosung TNC. (2020). *Nylon yarn business division.* Retrieved from http://www.hyosungtnc.com/en/fiber/nylon.do

I:Collect. (2020). *About us.* Retrieved from https://www.ico-spirit.com/en/

Ioniqa. (2020). *How it works!* Retrieved from https://ioniqa.com/

IVA Kungliga Ingenjörsvetenskapsakademien. (2020). *Resurseffektiv textil i sverige: Textil från avfall till resurs.* (No. IVA-M 511). Retrieved from https://www.iva.se/globalassets/bilder/projekt/resurseffektivitet-och-cirkular-ekonomi/201911-iva-rece-branschrapport-textil-l.pdf

IVL Svenska Miljöinstitutet. (2017). *Automatiserad sortering ska öka textilåtervinningen.* Retrieved from https://www.youtube.com/watch?v=-zZ1mtIDUo8&t=8s

Johanneberg Science Park. (2020). *Klimatledande processindustri.* Retrieved from https://www.johannebergsciencepark.com/node/17801

Kadolph, S. J., & Langford, A. L. (2013). *Textiles: Pearson new international edition.* Pearson Education Limited.

Karlsson, M. (2007a). *Kurskompendium. lyssna till kundens röst: Att identifiera, analysera och kommunicera kunden och användarens krav på tekniska produkter och system.* Institutionen för produkt- och produktionsutveckling Chalmers

Tekniska Högskola.
Karlsson, M. (2007b). *Metodappendix.* Retrieved from http://www.cse.chalmers.se/research/group/idc/ituniv/kurser/07/analys/Metodappendix.pdf
Lindhqvist, T. (2000). *Extended producer responsibility in cleaner production: Policy principle to promote environmental improvements of product systems* (2nd ed.). Retrieved from https://lup.lub.lu.se/search/publication/19692
Lopez, G., Artetxe, M., Amutio, M., Alvarez, J., Bilbao, J., & Olazar, M. (2017). *Recent advances in the gasification of waste plastics: A critical overview* (Vol. 82). doi: 10.1016/j.rser.2017.09.032
Mistra Future Fashion. (2019). *Forskning för systemskifte i modebranschen.* Retrieved from http://mistrafuturefashion.com/sv/hem/
Myrorna. (2018). *Försäljning av textil.* Retrieved from https://www.myrorna.se/tagg/export/
Naturvårdsverket. (2016). *Förslag om hantering av textilier: Redovisning av regeringsuppdrag.* Retrieved from http://www.naturvardsverket.se/upload/miljoarbete-i-samhallet/miljoarbete-i-sverige/regeringsuppdrag/2016/redovisade/redovisning-regeringsuppdrag-hantering-textilier-2016-09-26.pdf
Naturvårdsverket. (2020). *Producer responsibility.* Retrieved from https://www.naturvardsverket.se/Miljoarbete-i-samhallet/Miljoarbete-i-Sverige/Uppdelat-efter-omrade/Avfall/Producentansvar/
Nordin, H. L., Lindkvist, L., Boss, A., Bauman, H., Boberg, N., & Magnusson, E. (2019). *Kartläggning av plastavfallsflöden, återvinningsmetoder och marknader: kunskapsunderlag för ett returraffinaderi* (No. U 6209). Retrieved from https://research.chalmers.se/en/publication/514353
Peters, G., & Sandin, G. (2018). *Environmental impact of textile reuse and recycling - a review* (Vol. 184). doi: 10.1016/j.jclepro.2018.02.266
Radhakrishnan, S. (2019). *Denim recycling.* Springer. doi: 10.1007/978-981-10-2146-6
Regeringen. (2019). *Kommittédirektiv: Ett producentansvar för textil.* Retrieved from https://www.regeringen.se/4ae68c/contentassets/ed534990577740479348c54c724dad6d/ett-producentansvar-for-textil-dir.-201996
Regeringskansliet. (2019). *Skatt på avfallsförbränning införs under 2020.* Retrieved from https://www.regeringen.se/pressmeddelanden/2019/09/skatt-pa-avfallsforbranning-infors-under-2020/
Regeringskansliet. (2020a). *Nya eu-regler om avfall gynnar en mer cirkulär ekonomi.* Retrieved from https://www.regeringen.se/artiklar/2019/10/nya-eu-regler-om-avfall-gynnar-en-mer-cirkular-ekonomi/
Regeringskansliet. (2020b). *Skatt på modet – för att få bort skadliga kemikalier.* Retrieved from https://www.regeringen.se/49597f/contentassets/5184c042af094e7281343c2b8d31a68e/skatt-pa-modet--for-att-fa-bort-skadliga-kemikalier-sou-202020.pdf
Re:newcell. (2019). *The process.* Retrieved from https://renewcell.com//
Skatteverket. (2019). *Avfallsförbränningsskatt.* Retrieved from https://www

.skatteverket.se/foretagochorganisationer/skatter/punktskatter/nyheterinompunktskatter/2019/nyheterinompunktskatter/avfallsforbranningsskatt.5.7eada0316ed67d7282e7.html

Socialdemokraterna. (2019). *Utkast till sakpolitisk överenskommelse mellan socialdemokraterna, centerpartiet, liberalerna och miljöpartiet de gröna.* Retrieved from https://www.socialdemokraterna.se/download/18.1f5c787116e356cdd25a4c/1573213453963/Januariavtalet.pdf

Soex. (2020). *Recycling germany.* Retrieved from https://www.soex.de/en/recycling-germany/

Sveriges Riksdag. (2020). *Miljöbalk (1998:808).* Retrieved from https://www.riksdagen.se/sv/dokument-lagar/dokument/svensk-forfattningssamling/miljobalk-1998808_sfs-1998-808

Södra. (2019). *Upptäckten – en tröja kan bli en tröja igen.* Retrieved from https://www.sodra.com/sv/massa/nyehteroncemore/once-more-nyhetsarkiv/upptackten--en-troja-kan-bli-en-troja-igen/

Teijin Frontier Group. (2020). *Eco circle™ fibers.* Retrieved from https://www2.teijin-frontier.com/english/sozai/specifics/ecopet-plus.html

The Global Goals for sustainable development. (2020a). *Goal 12: Responsible consumption and production.* Retrieved from https://www.globalgoals.org/12-responsible-consumption-and-production

The Global Goals for sustainable development. (2020b). *Goal 9: Industry, innovation and infrastructure.* Retrieved from https://www.globalgoals.org/9-industry-innovation-and-infrastructure

Thunman, H., Vilches, T. B., Seemann, M., Maric, J., Vela, I. C., Pissot, S., & Nguyen, H. (2019). *Circular use of plastics-transformation of existing petrochemical clusters into thermochemical recycling plants with 100% plastics recovery* (Vol. 22) (No. e00124). doi: 10.1016/j.susmat.2019.e00124

Vadicherla, T., Saravanan, D., Muthu, M. R., & Suganya, K. (2016). *Fashion renovation via upcycling.* Springer, Singapore. doi: 10.1007/978-981-10-2146-6_1

Vela, I. C., Maric, J., & Seemann, M. (2019). *Valorisation of textile waste via steam gasification in a fluidized bed reactor.* Retrieved from https://research.chalmers.se/publication/511379

Åsa Östlund, Syrén, P.-O., Jönsson, C., Ribitsch, D., & Syrén, M. (2017). *Re:mix – separation and recycling of textile waste fiber blends* (No. 2017:6). Retrieved from http://mistrafuturefashion.com/wp-content/uploads/2017/12/ReMix_Report.pdf

Åsa Östlund, Wedin, H., Bohlin, L., Berlin, J., Jönsson, C., Posner, S., … Sandin, G. (2015). *Textilåtervinning: Tekniska möjligheter och utmaningar* (No. 6685). Naturvårdsverket. Retrieved from http://www.naturvardsverket.se/Documents/publikationer6400/978-91-620-6685-7.pdf

A

Appendix

A.1 Questionnaire structure for retailers

1. Description of the master's thesis
This survey is a part of a master's thesis at Chalmers University of Technology. Together with RISE Research Institutes of Sweden, we want to investigate a possible recycling route in Sweden for products of synthetic textile blends. This master's thesis is a part of a larger project that are developing plans for a plastic return refinery (i.e. thermochemical recycling) in Stenungsund where a stream of synthetic textile blends could be added. By including textiles in the effort, the input could be expanded or supplemented by synergies with other material streams. Products of synthetic textile blends (mix of synthetic fibres) = footwear, outdoor clothing and sportswear. Thank you for your participation! We appreciate your response.

If you have any questions, please contact us:
ingrid.larsson@ri.se
johanna.karlqvist@ri.se

2. Present state analysis
(a) How much of your products are considered products of synthetic textile blends?
i. 0-19 %
ii. 20-39 %
iii. 40-59 %
iv. 60-79 %
v. 80-100 %
vi. N/A

(b) How much of these products are not sold according to your company's core business and handled in another way?
i. 0-24 %
ii. 25-49 %
iii. 50-74 %
iv. 75-100 %
v. N/A

(c) What is the route for those products?
i. Reuse

ii. Taken care of by external collecting or recycling companies
iii. Sent to mechanical recycling
iv. Sent to chemical recycling
v. Sent to incineration
vi. Sent to landfill
vii. N/A

(d) What is the cost related to this option?
i. Expense
ii. Income
iii. N/A

(e) If possible, estimate the price/kg.

3. Impact of stakeholders
(a) What are the most important drivers for your company to recycle products of synthetic textile blends?

(b) What are potential barriers for your company to recycle products of synthetic textile blends?

4. Regulations
Extended Producer Responsibility
(a) What level of impact will these nine components have on your company's operations?
i. No/Low impact
ii. Medium impact
iii. Large impact
iv. I have no opinion.

Refunded Virgin Payments
(b) What ambition level does your company have regarding recycled content in products of synthetic textile blends by 2030?

(c) What is your corporate strategy to increase the level of recycled content in your products of synthetic textile blends?

Incineration tax
(d) Are your products of synthetic textile blends incinerated in Sweden today?
i.Yes
ii.No
ii.N/A

(e) Do you think the incineration tax will affect your company's handling of prod-

ucts of synthetic textile blends?
i. Yes
ii. No
ii. N/A

Chemical tax
(f) Do you think the chemical tax will affect your company's handling of products of synthetic textile blends?
i. Yes
ii. No
ii. N/A

(g) If yes, please specify if possible.

Regulations - Largest impact
(h) What policy do you think will have the largest impact on your company's operations?
i. Extended producer responsibility for textiles
ii. Refunded virgin payments
iii. Incineration tax on waste
iv. Chemical tax in clothing and footwear

5. Comments and reflections
(a) Do you have any comments or reflections regarding how to increase the recycling of products of synthetic textile blends?

A.2 Questionnaire structure for municipalities

1. Description of the master's thesis
This survey is a part of a master's thesis at Chalmers University of Technology. Together with RISE Research Institutes of Sweden, we want to investigate a possible recycling route in Sweden for products of synthetic textile blends. This master's thesis is a part of a larger project that are developing plans for a plastic return refinery (i.e. thermochemical recycling) in Stenungsund where a stream of synthetic textile blends could be added. By including textiles in the effort, the input could be expanded or supplemented by synergies with other material streams. Products of synthetic textile blends (mix of synthetic fibres) = footwear, outdoor clothing and sportswear. Thank you for your participation! We appreciate your response.
If you have any questions, please contact us:
ingrid.larsson@ri.se
johanna.karlqvist@ri.se

2. Present state analysis
(a) Do you collect textile fractions separately?
i. Yes
ii. No
ii. N/A

(b) If yes, please specify how.
(c) What is the economic balance of the municipal waste treatment?
i. Expense
ii. Income
iii. N/A

(d) What is the end-of-life option for the municipality waste today?
i. Reuse
ii. Sorting
iii. Mechanical recycling
iv. Chemical recycling
v. Incineration
vi. Landfill
vii. N/A

3. Impact of stakeholders
(a) What is the most important driver for your municipality to recycle products of synthetic textile blends in Sweden?
(b) What are potential barriers for your municipality to recycle products of synthetic textile blends in Sweden?

4. Regulations
Extended Producer Responsibility
(a) What level of impact will these nine components have on your municipalities

waste treatment?
i. No/Low impact
ii. Medium impact
iii. Large impact
iv. I have no opinion

Refunded Virgin Payments
(b) Do you think the Refunded Virgin Payments will have impact on the current municipality waste treatment?
i. Yes
ii. No
ii. N/A

Incineration tax
(c) Do you think the incineration tax will affect the current municipal waste strategy?
i. Yes
ii. No
iii. N/A

Chemical tax
(d) Do you think the chemical tax will affect the current municipal waste strategy?
i. Yes
ii. No
iii. N/A

Regulations-Largest impact
(e) What policy do you think will have the largest impact on the municipal waste handling strategy?
i. Extended producer responsibility for textiles
ii. Refunded virgin payments
iii. Incineration tax on waste
iv. Chemical tax in clothing and footwear

5.Comments and reflections
(a) Do you have any comments or reflections regarding how to increase the recycling of products of synthetic textile blends?

A.3 Questionnaire structure for research institutes & authorities

1. Description of the master's thesis
This survey is a part of a master's thesis at Chalmers University of Technology. Together with RISE Research Institutes of Sweden, we want to investigate a possible recycling route in Sweden for products of synthetic textile blends. This master's thesis is a part of a larger project that are developing plans for a plastic return refinery (i.e. thermochemical recycling) in Stenungsund where a stream of synthetic textile blends could be added. By including textiles in the effort, the input could be expanded or supplemented by synergies with other material streams. Products of synthetic textile blends (mix of synthetic fibres) = footwear, outdoor clothing and sportswear. Thank you for your participation! We appreciate your response.

If you have any questions, please contact us:
ingrid.larsson@ri.se
johanna.karlqvist@ri.se

2. Impact of stakeholders
(a) In your opinion, what is the most important driver to recycle products of synthetic textile blends in Sweden?

(b) In your opinion, what are potential barriers to recycle products of synthetic textile blends in Sweden?

(c) Do you see any obstacles with thermochemical monomeric recycling of products of synthetic textile blends?

3. Regulations
Extended Producer Responsibility
(a) What level of impact do you think these nine components will have on the recycling of products of synthetic textile blends in Sweden?
i. No/Low impact
ii. Medium impact
iii. Large impact
iv. I have no opinion.

Refunded Virgin Payments
(b) What ambition levels of recycled content do you consider appropriate for products of synthetic textile blends by 2030?

Incineration tax
(c) How do you think the incineration tax will affect incineration of products of synthetic textile blends in Sweden?

Chemical tax
(d) How do you think the chemical tax will affect the recycling of products of synthetic textile blends in Sweden?

Regulations-Largest impact
(e) What policy do you think will have the largest impact on companies handling of products of synthetic textile blends?
i. Extended producer responsibility for textiles
ii. Refunded virgin payments
iii. Incineration tax on waste
iv. Chemical tax in clothing and footwear

4.Comments and reflections
(a) Do you have any comments or reflections regarding how to increase the recycling of products of synthetic textile blends?

A.4 Questions for recycling & collecting companies

1. Description of the master's thesis
This survey is a part of a master's thesis at Chalmers University of Technology. Together with RISE Research Institutes of Sweden, we want to investigate a possible recycling route in Sweden for products of synthetic textile blends. This master's thesis is a part of a larger project that are developing plans for a plastic return refinery (i.e. thermochemical recycling) in Stenungsund where a stream of synthetic textile blends could be added. By including textiles in the effort, the input could be expanded or supplemented by synergies with other material streams. Products of synthetic textile blends (mix of synthetic fibres) = footwear, outdoor clothing and sportswear. Thank you for your participation! We appreciate your response.

If you have any questions, please contact us:
ingrid.larsson@ri.se
johanna.karlqvist@ri.se

2. Present state analysis
(a) Does your company collect and handle textiles separately?
i. Yes
ii. No
iii. N/A

(b) In the incoming textile streams, how large quantities are estimated to be products of synthetic textile blends? Please answer in tonnes/year.

(c) How do you handle the incoming textile streams today?
i. Reuse
ii. Mechanical recycling
iii. Chemical recycling
iv. Incineration
v. Landfill
vi. N/A

(d) How do you handle the incoming products of synthetic textile blends today?
i. Reuse
ii. Mechanical recycling
iii. Chemical recycling
iv. Incineration
v. Landfill
vi. N/A

(e) What is the economic balance of the incoming textile streams?
i. Expense
ii. Income

iii. N/A

(f) If no reuse is possible, what is the main reason?

(g) If no recycling (mechanical or chemical) is possible, what is the main reason?

(h) Where does the incoming textile stream come from?
i. Industry
ii. Households
iii. Equally between industry and households
iv. N/A

3. Impact of stakeholders
(a) What are the most important drivers for your company to recycle products of synthetic textile blends?

(b) What are potential barriers for your company to recycle products of synthetic textile blends?

4. Regulations
Extended Producer Responsibility
(a) What level of impact will these nine components have on your company's operations?
i. No/Low impact
ii. Medium impact
iii. Large impact
iv. I have no opinion.

Refunded Virgin Payments
(b) Do you think the Refunded Virgin Payments will affect your company's operations?
i. Yes
ii. No
iii. N/A

Incineration tax
(c) Do you think the incineration tax will affect the current corporate incineration strategy?
i. Yes
ii. No
iii. N/A

(d) If yes, please specify if possible.

Chemical tax
(e) Do you think the chemical tax will affect your current corporate waste handling

strategy?
i. Yes
ii. No
iii. N/A

(f) If yes, please specify if possible.

Regulations - Largest impact
(g) What policy do you think will have the largest impact on your company's operations?
i. Extended producer responsibility for textiles
ii. Refunded virgin payments
iii. Incineration tax on waste
iv. Chemical tax in clothing and footwear

5. Comments and reflections
(a) Do you have any comments or reflections regarding how to increase the recycling of products of synthetic textile blends?

A.5 Interview guide

1. Description of the master's thesis
This interview is a part of a master's thesis at Chalmers University of Technology. Together with RISE Research Institutes of Sweden, we want to investigate a possible recycling route in Sweden for products of synthetic textile blends. This master's thesis is a part of a larger project that are developing plans for a plastic return refinery (i.e. thermochemical recycling) in Stenungsund where a stream of synthetic textile blends could be added. By including textiles in the effort, the input could be expanded or supplemented by synergies with other material streams. Products of synthetic textile blends (mix of synthetic fibres) = footwear, outdoor clothing and sportswear.

2. Introduction
(a) Background to project
We are two master's students at Chalmers, currently performing our master's thesis at RISE.

(b) Aim of the master's thesis
We are investigating a possible recycling route for products of synthetic textile blends. We want to know what you think about recycling of these products.

(c) Scope of the interview
i. The interview is divided into three parts; general information about you and your company, your view on the barriers found in our project and an in-depth question.

3. General questions
(a) Is it ok to use parts of this interview in our master's thesis report?
i. Notes will be taken during the interview and you will remain anonymous throughout the master's thesis.

(b) What is your job title?

(c) What do you work with?

4. Discussion of the barriers
(a) Based on your business, do you agree on the barriers for recycling of products of synthetic textile blends found from the questionnaire?

(b) Do you want to add any barrier for recycling of products of synthetic textile blends?
(c) What are the most important factors to achieve a sustainable infrastructure for recycling of products of synthetic textile blends?

A.6 Coding session - Drivers

Item no.	Item [Stakeholder]
1	Become more circular [R1, A1, A3]
2	Take care of our sold textiles in a better way [R1]
3	Environmental impact [R2, C2]
4	Our driver right now is not to recycle our materials [R3]
5	Use as much as possible of recycled materials in our products [R3]
6	Reduce waste [R4, A1]
7	Reduce landfill [R4]
8	Local possibility to handle recycling [R5]
9	Environmental responsibility [R6]
10	Income from selling high quality material for recycling [R6]
11	To reuse rawmaterial [R7]
12	So that products doesn't end up in landfills [R8]
13	Local recycling reduces the footprint [R9]
14	Follow waste hierarchy [M1]
15	Image/History [M2]
16	Closed material loops [M3, A4]
17	Use less virgin material [M3, A1]
18	Circular business model [M3]
19	Protect nature capital [M3]
20	Minimise household waste [M4]
21	Optimise use of resources [A2]
22	Move into circular economy [A3]
23	Promote circular economy [A4]
24	Fast fashion [A4]
25	Overconsumtion [A4]
26	Textiles that get discarded before their expected lifetime [A4]
27	International market for technology development [A5]

Item no.	Item [Stakeholder]
28	Reduced environmental footprint ... challenging products [A6]
29	Recycling could be discussed, but handling ... complex products [A7]
30	Use material for energy [A8]
31	Use material for fuel [A8]
32	Use material for chemical raw material [A8]
33	Use material as processable material fractions [A8]
34	The future [A9]
35	Circular system for textiles [A10, A14]
36	Work across industries [A10]
37	Recycled textile fraction could be used as a resource for another industry [A10]
38	Chemical and textile clusters in Sweden can collaborate [A10]
39	Generate new work opportunities [A10]
40	Producer responsibility on textiles [A10, A14]
41	Need for resources to cover global fiber demand [A10]
42	Simple separation [A11]
43	Lower the production and consumtion of fossil-based plastics [A12]
44	Find new raw material [A12]
45	Treat waste as value [A12]
46	Demand from customer through large retailers [A13]
47	Recycling in Sweden saves transport [A14]
48	Ban on incineration A14
49	Sustainability [C1, C5]
50	Income [C1]
51	To help society lessen its environmental impact from its waste [C2]
52	We wish that our waste could be recycled, for the climate [C3]
53	Recycling of metals [C4]
54	Circular economy [C5]

Issues [Item no.]	Drivers [Issues]
Location [8, 13, 47]	Change into circular business models [Location, Circularity, Circular business models, Environmental aspect, better handling of sold products]
Reduce landfill [7, 12]	Resource efficiency [Reduce landfill, increase recycled content, reduce waste, efficient use of resources, resource optimisation, value waste as a resource, reduce use of non-renewable resources]
Increase recycled content [4, 5, 11]	Change in consumer behaviour [Customer behaviour, Image]
Environmental aspect [3, 9, 28, 29, 34, 51, 52, 53]	Collaboration between stakeholders [Technology, Co-operation, synergies with other industries]
Circularity [1,]	External initiatives [Regulations]
Better handling of sold products [2,]	Economic aspects [Economics]
Economics [10, 50,]	
Reduce waste [6, 20,]	
Efficient use of resources [16, 19]	
Image [15]	
Circular business model [18, 22, 23, 49, 54]	
Customer behaviour [24, 25, 26, 46]	
Reduce use of non-renewable resources [17, 43]	
Value waste as a resource [44, 45]	
Resource optimisation [21, 35, 41]	
Co-operation [38, 39]	
Technology [27, 42]	
Regulations [40, 48]	
Synergies with other industries [30, 31, 32, 33, 36, 37]	

Key	
R1-R9	Stakeholder 1-9 in Retailers
A1-A14	Stakeholder 1-14 in Research institutes & authorities
M1-M4	Stakeholder 1-4 in Municipalities
C1-C5	Stakeholder 1-5 in Recycling & collecting companies

A.7 Coding session - Barriers

Item no.	Items [Stakeholder]	Item no.	Items [Stakeholder]
1	The full production process is not available in Sweden [R1]	40	Difficult for users to identify polymer/plastics [A8]
2	We are missing spinners of yarn [R1]	41	Not made of one single material [A9]
3	Lack of effective sorting of fibers [R1]	42	Various chemicals, flame retardants [A9]
4	Lack of volumes [R2]	43	Lack of collection methods [A9]
5	Complexity [R2]	44	Complex products of mixed fibre and material [A10]
6	No good and easy way to separate materials [R3]	45	Laminates/coatings [A10]
7	Difficult to recycle material [R3]	46	Lack of chemical knowledge [A10]
8	There must be a scalable process applicable not only on the company of subject [R3]	47	Low volumes of material streams [A10]
9	We are a small company, difficult to impact on a large scale [R3]	48	Lack of continuity of material streams [A10]
10	Lack of proper recycle streams [R4]	49	Take waste from other countries is needed [A10]
11	Additional transport [R5]	50	Low value material [A11]
12	Cost [R5]	51	Process of separation not feasible [A11]
13	Taxes as location is in another country [R5]	52	Consist of many different material [A12]
14	Mix of materials [R6]	53	Separate products of synthetic textile blends in pure fractions [A12]
15	Components mounted in a way that makes separation difficult [R6]	54	Hard to recycle in high quality [A12]
16	Available technology [R7]	55	Preserve value of original material [A12]
17	We cannot recycle our products because no technology exist that can separate blended fibres [R8]	56	Develop effective and value-preserving recycling methods [A12]
18	We want to reuse it over and over again [R9]	57	Use effective and value-preserving recycling methods [A12]
19	The customer has the ownership of the product [R9]	58	Create high-quality secondary raw material [A12]
20	Follow waste hierarchy more important [M1]	59	Lack of raw material made from recycled materials [A13]
21	Focus is to increase reuse [M1]	60	Lack of value chain [A13]
22	Lack of collection system [M2]	61	Lack of collecting system [A13]
23	Lack of market [M2]	62	Lack of logistics system to a recycling plant that can handle them [A13]
24	Lack of location/place [M2]	63	Lack of chemical recycling facilities [A13]
25	Cost to implement household-based sorting [M3]	64	Unknown chemical content [A14]
26	Lack of customers for post-consumer textiles as secondary raw material [M4]	65	Products assembled by different components [A14]
27	Lack of location/place [M1]	66	Laminates, membranes etcetera [A14]
28	Slow technical development of recycling technique [A1]	67	Separation is difficult [A14]
29	Lower resource efficiency for recycling than incineration [A2]	68	Lack of knowledge for sorting different items [C1]
30	Low volumes [A3, A4]	69	Hard to handle the products correctly [C1]
31	Range of different polymers [A3, A8]	70	No known receicer of the material that is able to recycle them [C2]
32	Difficult to shape a business case [A4]	71	There is no waste stream or outlet for us to send out textile waste to recycling [C3]
33	High process cost [A4, A5]	72	Too expensive to sort out the products [C4]
34	Low cost raw material [A4, A5]	73	Too mixed products [C4]
35	No economical feasibility [A6]	74	Low amounts [C5]
36	Additives difficult in recycling processes [A7]	75	Lack of timing [C5]
37	Many types of products of synthetic textile blends [A8]	76	Logictics problem [C5]
38	Varying product use [A8]	77	Pricing [C5]
39	Wear and contamination [A8]		

Issues [Item no.]
Lack of technology [1, 2, 7, 21, 29]
Lack of separation technology [6, 17, 53, 67]
Not available in Sweden [1, 11,]
No common system [8, 9]
Lack of sorting technology [3,]
Lack of collecting system [22, 43, 61]
Mix of materials [6, 14, 31, 41, 52, 73]
Complex product group [5, 15, 37, 38, 42, 44, 45, 65, 66]
Low volumes of products of synthetic textile blends [4, 10, 30, 47, 59, 74]
Varying chemical content [36, 42,]
Knowledge lack of chemicals [46, 64]
Lack of recycling technology development [28]
Too low quality in recycled material [50, 54, 55, 56, 57, 58, 77]
Soiled textile product [39]
Lack of infrastructure [24, 27, 60, 62, 63, 71, 76]
Lack of sorting knowledge [40, 48, 68, 69]
Too expensive [12, 13, 25, 32, 33, 35, 51, 72]
Lack of continuity of waste streams [48, 49,]
Timing [75]
Follow waste hierarchy [18, 20, 21,]
Lack of market [23, 26, 34, 70]

Barriers [Issues]
Lack of sustainable infrastructure [Not available in Sweden, Lack of collectiing system, Lack of infrastructure, No common system, Follow waste hierarchy]
Lack of technology [Lack of technology, lack of separation technology, lack of sorting technology, lack of recycling technology development]
Complex products [Mix of materials, Complex product groups, varying chemical content]
No economic feasibility [Too expensive, Timing]
Too low volumes of synthetic textile blends [Low volumes of products of synthetic textile blends, lack of continuity of waste streams,]
Knowledge gap [Knowledge lack of chemicals, knowledge lack in sorting]
Low market value for post-consumer textiles [Lack of market, Soiled textile products, too low quality in recycled material]

Key	
R1-R9	Stakeholder 1-9 in Retailers
A1-A14	Stakeholder 1-14 in Research institutes & authorities
M1-M4	Stakeholder 1-4 in Municipalities
C1-C5	Stakeholder 1-5 in Recycling & collecting companies