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The Effect of Circularity and Automation on the Textile System in Sweden

A study on competence demand and gender distribution in textile sorting

Master's Thesis within the master program Industrial Ecology

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Abstract

This study explores the transition towards a circular textile system in Sweden and examines how a transitions towards a circular economy may impact the competence demand and gender distribution, with a focus on textile sorting processes. For the industry to achieve circularity, textile recycling is essential to increase resource efficiency and extend the life cycle of textile materials. Due to new regulations by the European Commission, including the mandatory collection of textile waste beginning January 2025, textile waste volumes are expected to rise, creating a need for efficient handling solutions. Therefore, the aim of this study is to contribute to an understanding of how the transition to a circular economy in the textile system may influence competence demand and gender distribution in Sweden, particularly within textile sorting processes. This study was conducted through a literature review combined with exploratory interviews with actors connected to the Swedish textile system. The results highlight the need for new competencies in the textile system in order to enable efficient use of new technology in an automatic textile sorting process as well as in other parts of the textile system. To achieve this, a systems perspective and increased collaboration to enable efficient handling throughout the lifecycle of textile products. In the textile sorting process, cross-functional, technical, and creative skills are necessary for the workforce to adapt to technological advancements. Additionally, there is potential for the gender distribution in the textile system to become more balanced. However, to achieve gender equality, more men are needed in textile sorting roles, while more women are required in technology development roles.

Keywords: textile sorting, automation, circular economy, competencies, gender balance, systems perspective, technology assessment, textile waste management

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Johanna Bångsbo, Linköping, January 2025.

Contents

1 Introduction

Over the past 15 years, the production volume of clothing has doubled, and the lifecycle have shortened, resulting in generation of large amounts of waste (Ellen MacArthur Foundation, 2017). Textile waste is most often landfilled or incinerated in poorer countries lacking the capacity to process the textile waste sustainably (Charnley et al., 2024). The current linear textile industry is globalized and one of the most resource intensive industries, contributing to global pollution, waste generation and resource depletion, causing a detrimental environmental and social impact. Moreover, it is one of the most labor-intensive industries, characterized by poor working conditions with most of its production situated in low-cost countries (Ellen MacArthur Foundation, 2017; European Environment Agency, 2022).

Thus, the industry fails to take advantage of economic opportunities, since textiles are not used to its full potential when discarded, which highlights the need for innovation and business models (Ellen MacArthur Foundation, 2017). A critical component of being able to circulate textile products is therefore efficient textile sorting. Manual textile sorting is dominating, but the demand for more accurate sorting for recycling is increasing, requiring cost efficient automated textile sorting processes (McKinsey, 2022).

In response to those challenges, the European Commission is introducing new regulations to transition from a linear to a circular textile industry. These regulations intend to stimulate the design of longer-lasting textile products that can be repaired and recycled, while obligating producers to take responsibility for their products along the value chain, including capacities for recycling to minimize incineration and landfill (Directorate-General for Environment, 2022). To begin with, it will be mandatory for members of the EU to collect and sort textile waste separately, starting 1 January 2025, (Directorate-General for Communication n.d.-c).

To investigate how to increase circularity in the textile industry following the EU regulations, RISE Research Institutes Sweden (RISE) coordinates the project *Framework for circular textiles*. The project's objective is to establish a framework for textile recycling and science-based assessment of the recyclability of textile materials and products (RISE, 2022). The project involves 19 project partners, who represent different fields in the textile value chain, such as fashion, raw material developers, textile sorters, workwear, and IT (RISE, 2022). In collaboration with these actors, RISE is investigating how to establish a framework for textile recycling in combination with the assessment of the recyclability and circularity of materials and products. This will determine the pathway a textile could take in the sorting process, to use the material at the highest applicable value, for example reuse or recycling. As there are currently no standardized quality criteria for recovered textiles, efforts will also be made to create a market for secondary raw materials and to encourage their use in not only the textile industry but also in other industries such as the automotive- and furniture industry.

To enable this, a system change is necessary. A system change may require new competencies for people in the system to enable a circular textile system in Sweden and beyond. This change entails unintended consequences for the workforce in the system. Hence, this study will explore how the EU regulations and technological development within automation and digitization may affect the competence demand and gender distribution within the textile system in Sweden, focusing on textile sorting.

1.1 Aim

The aim of this study is to contribute to an understanding of how a transition towards a circular economy of the textile system may affect the competence demand and gender distribution in Sweden, with a focus on the textile sorting processes.

1.2 Research questions

RQ 1: What may the future textile system in Sweden look like?

RQ 2: How may the system change affect the competence demand in the textile system, focusing on the textile sorting processes?

RQ 3: How may the system change affect the gender distribution of the people within the textile sorting processes?

1.3 Research delimitations

The scope of this master thesis will focus on the flow of textile waste from households in Sweden. Textile sorting is the focus of the study, but other aspects and activities that affect the textile sorting are included to gain a system perspective. In terms of technological development, the most likely technology to be used for textile sorting in Sweden will be analysed, hence no in-depth analysis of other existing technologies.

2 Background

The background presents the definition of textile products and the manufacturing steps, as well circular economy and system innovation to provide an understanding of the regulatory framework affecting the textile system.

2.1 From Raw Material to Textile Products

In this section, the activities that constitute the manufacturing of textile products from raw material to finished product, are summarized in Figure 1. Textile products are defined by the European Commission as *"...products containing at least 80% by weight of textile fibers, include leisure apparel and clothing accessories, household/interior textiles (such as towels, tablecloths, curtains, rugs, bedlinen, pillows, duvets, and upholstery textiles) as well as technical textiles"* (Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs, n.d.). In this study, the focus primarily lies on clothes and home textiles, since discarded post-consumer clothing and home textiles are the largest source of textile waste, accounting for 85% of all textile waste (McKinsey, 2022).

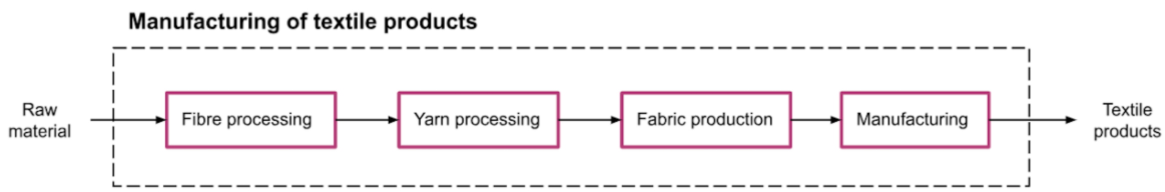

Figure 1. A scheme of the textile value chain, from raw material to finished textile product inspired by Kadolph (2014), EURATEX (2024), and Charnley et al. (2024).

Textile fibers can be divided into natural and manufactured fibres. Firstly, natural fibres grow in fibre form, and the raw material is derived from plants and animals. This category of fibres can further be grouped into cellulosic fibres, such as cotton and flax, or protein-based fibres such as wool or silk (Kadolph, 2014). Cultivation of fibres such as cotton requires large quantities of water and fertilisers, pesticides, and land area (European Environment Agency, 2022). To be able to produce textiles from the fibres, the fibres need to go through preprocessing steps, including removing grease and dirt from wool, or separating the cotton fibers from the seeds. In manufacturing, there are standardized classification methods of determining the quality of fibers through measuring characteristics. One characteristic is the fiber length, since longer fibres result in a higher tensile strength when spun into yarn (Kadolph, 2014).

Secondly, manufactured fibres are formed fibres and are made from chemical compounds in manufacturing facilities which at one step in the manufacturing process is not a fibre. There are two types of manufactured fibres; synthetic and regenerated. Examples of synthetic fibres are polyester, polyurethane, and acrylic. Regenerated fibres include for example lyocell and viscose. The difference between regenerated and synthetic fibres are the raw material from which the fibres are formed. Regenerated fibres are processed into fibre form by using naturally occurring polymers of cellulose or protein as raw material, such as wood pulp, while synthetic fibres often use petroleum-based chemicals as raw material. Both synthetic and regenerated fibres are manufactured through polymerisation. Polymerisation is the process where small molecules, in other words monomers, connect through a chemical reaction to form a to produce one by large molecule, a polymer. The polymer can then be extruded into fibres, where the extruder decides the cross section of the fibre. This way, fibres can be assigned different performance or aesthetic properties. Manufactured fibres are versatile and can meet performance expectations not possible to achieve using natural fibres and can often be produced quickly in quantity and quality to meet market demand (Kadolph, 2014).

The textile industry is dominated by synthetic fibres, which account for 64 % of all fibres used by global production volume, with polyester accounting for the majority (Statista, 2023a). Further, natural fibres account for 29%, which is mostly cotton, but also wool, flax and other fibre types. Finally, cellulose-based man-made fibres, i.e. regenerated fibres, account for 6% of the production volume (Boschmeier et al., 2023).

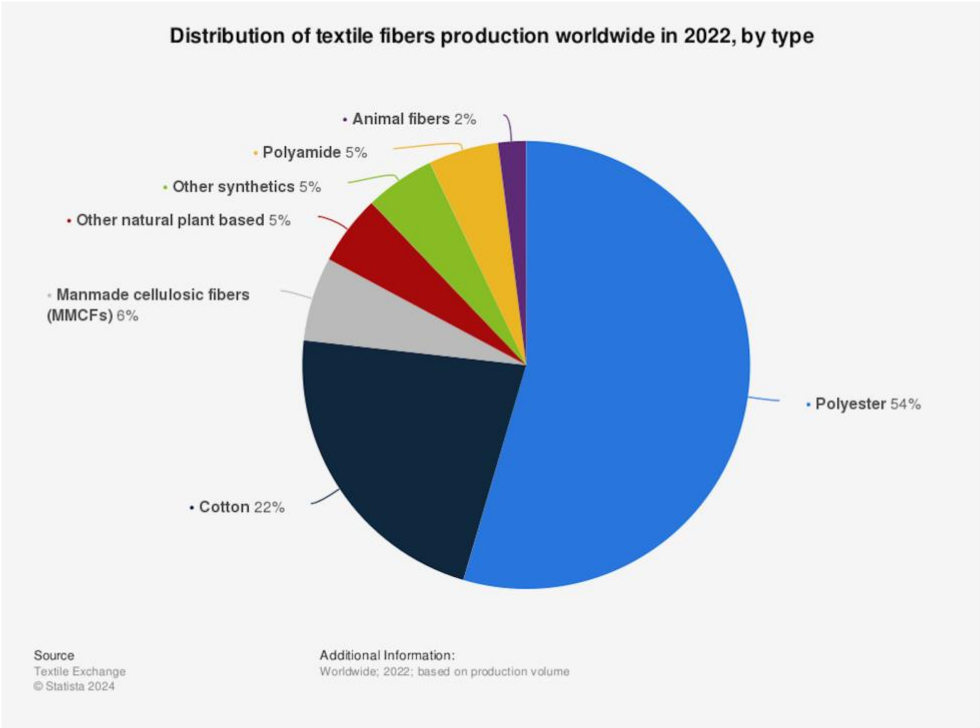

Figure 2. Distribution of textile fibres production worldwide in 2022 (Statista, 2023a).

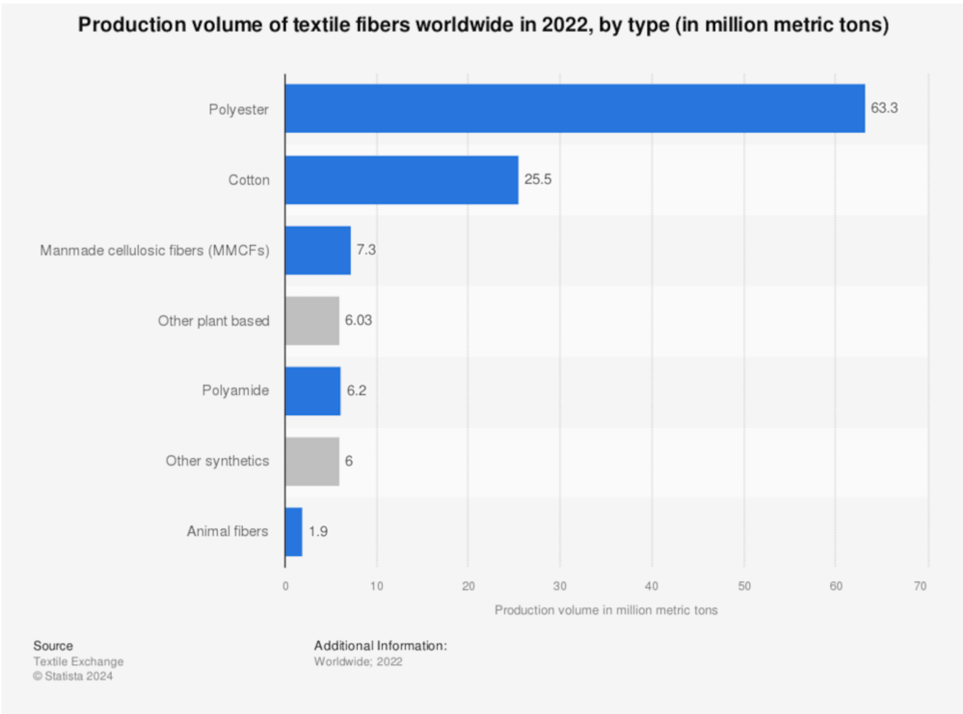

Figure 3. Production volume of textile fibres worldwide in 2022, by type in tons (Statista, 2023b).

Next, fibres can be processed into yarns and fabrics. Most textile products are produced from yarns, and different fibre types can be blended in both fabrics and yarns to achieve certain performance characteristics. Reasons for blending fibres include reducing fibre cost, achieving a certain fabric appearance, comfort and durability (Kadolph, 2014). The main reason for material blends in clothing is customer preference for wearing comfort (Boschmeier et al., 2023). For example, cotton can be blended with polyester to increase the durability while maintaining the comfort of cotton (Kadolph, 2014).

According to Kadolph (2014), a fabric may be defined as a *"...pliable planelike structure that can be made into two- or three-dimensional products that require some shaping and flexibility"*. Different manufacturing methods allow for a variety of fabric constructions. Fabrics can be constructed from yarns into knits, wovens and laces as well as of fibres and can then form felts, fibre webs or non-wovens. Lastly, fabrics can be made from solutions to form films and foams. In turn, these fabric types can be combined into composites, which are commonly a combination of a solution together with fibres, yarns or fabrics. Once the fabric is produced, performance and aesthetic characteristics can be achieved through treatments of the fabric, a process known as finishing. Finishing includes dyeing, printing, and it is also possible to achieve, for example, water-repellency, flame-retardancy, mould- or mildew control, antimicrobial control or less wrinkling (Kadolph, 2014. Fabrics are then cut and merged, most often by sewing, and non-textile parts, for example buttons, can be added during the manufacturing of the textile products (Ellen McArthur, 2017, Kadolph, 2014).

2.2 Circular Economy

There are several definitions of circular economy. According to Kirchherr et al. (2017), a circular economy can be explained as an economic system based on business models that replace "end-of-life" with reducing, reusing and recovering materials, such as within production, distribution and consumption processes. This approach operates on three levels (micro, meso, and macro) of society with the objective to achieve sustainable development. It seeks to create environmental quality, promote economic prosperity and social equity, benefiting both current and future generations.

Circular economy can also be divided into three key principles driven by design choices (Ellen MacArthur Foundation, n.d). The first principle is *Eliminate waste and pollution,* which means that negative impact from economic activity that can damage human health and natural systems can be eliminated through design, for example designing out greenhouse gases and hazardous substances. Secondly, the principle *Circulate products and materials* means a circular economy favours activities that keep the value of energy labour and materials. This can be accomplished through designing for durability, reuse, remanufacturing, and recycling in order to circulate materials within the economy for longer, either as products, components or raw materials. In addition, the use of biobased materials is encouraged as they can circulate between the economy and the natural system. Lastly, the principle *Regenerate nature* not only means to protect nature, but also to improve it. This includes actions to avoid the use of non-renewable resources as well as to preserve and enhance renewable resources. For example, actions include returning valuable nutrients to the soil, and replacing fossil fuel with renewable energy sources.

The Butterfly diagram (Figure 4) is an illustration of a circular economy. It is divided into the biological- and technical cycles. In the biological cycle, biological materials that can not be used more can be circulated back to within the same cycle, for example by composting while the technical cycle focuses on maintaining and reusing products and materials. This opens up for business models based on sharing or repairing. When the product can no longer be used, it can be broken down into components or raw materials and be recycled in order for the material to stay in the economy (Ellen MacArthur Foundation, 2021).

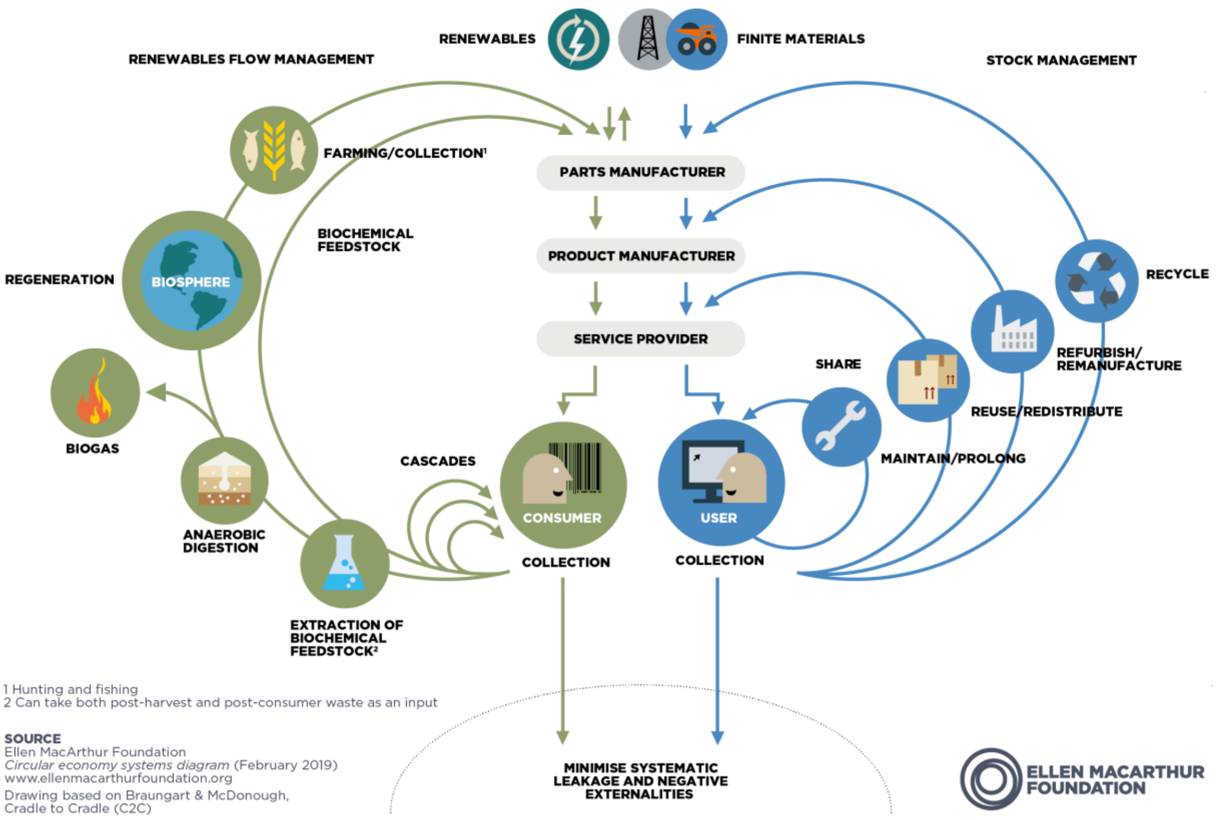

Figure 4. The Circular Economy Butterfly Diagram (Ellen MacArthur Foundation, 2021).

2.3 System Innovation

System innovation are co-evolution processes, which can be understood as an interplay between the three levels (micro, meso and macro) in society. Thus, change on multiple levels are necessary for a system change. To begin with, the macro level refers to the adjustment of the overall industry composition on a national and global level. The meso level includes focusing on eco-industrial parks (EIP) as systems (Kirchherr et al. 2017). Eco-industrial parks can be explained as manufacturing or service businesses located in the same area, who through collaboration work on managing environmental and resource issues. The eco-industrial parks also seek to benefit neighbouring communities to assure a positive net impact of the development (European Environment Agency, n.d.). Finally, the change on micro level focuses on how to increase circularity within individual companies, consumers, and products (Kirchherr et al. 2017).

System innovation can be further explained by the Multi-Level Perspective (MLP). The Multi-Level Perspective (MLP) is a framework used to analyze and understand transitions in complex socio-technical systems. Sociotechnical systems consist of several elements, for example regulation, technology, user practices and markets, cultural meaning, infrastructure, supply networks, and maintenance networks. System innovation requires a shift of the elements that a sociotechnical system is constituted of. Therefore, not only a shift in technology is not enough for change. Technologies not yet being taken up can partly be explained by economic, social, infrastructural, and regulative reasons (Geels, 2005). Hence, a shift towards a circular economy needs to involve several levels of society since current systems are locked-in on multiple levels of the socio-technical system (Kirchherr et al. 2017).

2.4 Regulatory Framework

The European Union presented The Green Deal in December 2019 as part of the efforts to become the first climate neutral continent. The objectives of the European Green Deal are to achieve no net emissions of greenhouse gases by 2050, decoupling economic growth from resource use and ensure that no person or no place is left behind (Directorate-General for Communication, n.d.-a). To contribute to the overarching objectives, The Green Deal consists of initiatives such as the Green Deal Industrial Plan and The Circular Economy Action Plan (CEAP). The Green Deal Industrial Plan facilitates the circular transition for industries in the EU through simplifying the regulatory environment and the access to funding, enhancing skills, as well as promoting open trade for resilient supply chains (Directorate-General for Communication, n.d.-b). The Circular Economy Action Plan (CEAP) was introduced in March 2020 to increase recycling and reuse of products in the EU. It includes, for instance, making *sustainable products* the norm in the EU, empowering consumers, reducing waste, and leading global efforts on a circular economy (Directorate-General for Environment, 2020).

A sustainable product consumes less energy, has a longer lifespan, is easily repairable andd recyclable, and components can be disassembled and repurposed. It contains fewer harmful substances and more recycled material and has a lower carbon and environmental footprint throughout its entire lifecycle (Directorate-General for Communication n.d.-c). The focus of the Circular Economy Action Plan lies on the most resource intensive industries with high potential for circularity, including batteries and vehicles, plastic, construction, food, and textiles (Directorate-General for Environment, 2020).

2.4.1 Waste Framework Directive

The European Commission has proposed an amendment to the Waste Framework Directive in 2023, targeting textile waste in alignment with the *Strategy for Sustainable and Circular textiles*. This has resulted in a mandate for EU member countries to separately collect and sort textile waste separately from January 2025 (Directorate-General for Communication n.d.-c).

The Waste Framework Directive contains the *Waste Hierarchy* (Figure 5), which is a hierarchy of strategies ranked from most to least favourable according in terms of circularity (Directorate-General for Communication n.d.-c).

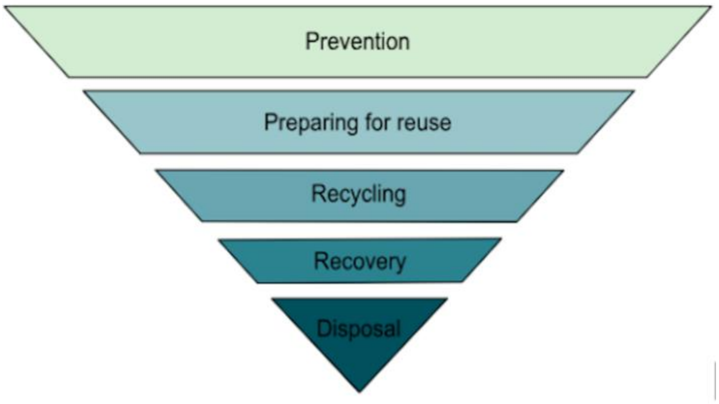

Figure 5. The Waste Hierarchy, adapted from Directorate-General for Communication (n.d.-c).

2.4.2 Strategy for Sustainable and Circular Textiles

As part of the broader circular economy plan in the EU, *The Strategy for sustainable and circular textiles* implements the commitments of the European Green Deal, The Green Deal Industrial Plan and the Circular economy action plan. *The Strategy for sustainable and circular textiles* is a series of initiatives designed to address overproduction and overconsumption, discourage the destruction of unsold or returned textiles, and restrict textile waste exports. Regulations include for example the Ecodesign for Sustainable Products Regulation (ESPR) and Extended Producer Responsibility (EPR). The entire life cycle of textile products is in focus, from design and production to consumption, reuse, and recycling. Thus, products need to be adapted for climate neutrality and circularity, and discarding and incinerating unsold clothes will be prohibited in the EU (Directorate-General for Environment, 2022).

2.4.2.1 Extended Producer Responsibility (EPR)

The European Commission has decided to implement an *Extended Producer Responsibility* (EPR) scheme for textiles to fund end-of-life handling, such as collection, sorting, reuse, and recycling. Producers will be required to pay varying amounts to the EPR scheme based on the environmental performance of their textile products. The objective of the proposed rules is to ensure that textile products are sorted, prioritised for reuse and repair, and recycled if they cannot be further used Directorate-General for Communication (n.d.-c).

2.4.2.2 Ecodesign for Sustainable Products Regulation (ESPR)

The *Ecodesign for sustainable products regulation* (ESPR) provides incentives to encourage the design of more sustainable products. These regulations will include design specifications for products, such as increased durability, enhanced repairability and recyclability, and a mandatory minimum level of recycled materials. Furthermore, circular business models (Directorate-General for Environment, 2022). Circular business models may be understood as models based on the circular economy principles and can include elements such as sharing or leasing and timeless, durable design. This will, alongside reuse and repair initiatives, be promoted through incentivization (Regulation of the European Parliament and of the Council 2024/1781; SOU 2020:72).

Within the ESPR, there is a focus on developing technologies that enhance circularity and sustainability in the textile industry. One of the key technologies is the Digital Product Passport (DPP), which intends to enhance transparency across the entire textile value chain, providing clear information on materials, production processes, and sustainability practices. The DPP intends to streamline and reduce the consumption of raw materials by prioritizing the use of recycled and sustainable fibers in textiles. It also encourages the production of durable textile products, ensuring they are designed for long-term use and multiple life cycles. By focusing on minimizing textile waste, the DPP promotes recycling, repair, and reuse, contributing to a more sustainable and circular textile industry (Legardeur, J., & Ospital, P., 2024).

The DPP will be contained in a data carrier attached to the textile product and offer information about the environmental sustainability of the product. This information contains aspects such as repairability and recycled content (Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs (2023). This information can assist consumers and businesses in making informed decisions when purchasing, repairing, and recycling products. The DPP can foster product differentiation based on quality, allowing sustainable and durable products to increase its competitiveness against products produced by fast fashion brands (Legardeur, J., & Ospital, P., 2024).

In terms of time horizon, a deployment of DPP may be divided into three phases. A short-term horizon could mean a deployment of a *“minimal and simple DPP”* in 2027. This could be followed by deployment of *“advanced DPP”* in 2030 and finally a *“full circular DPP”* in 2033 (Legardeur, J., & Ospital, P., 2024).

3 Methodology

The methodology has been inspired by a Technology Assessment method, described in section 3.1, and the data has been collected in a literature study, described in section 3.2.1, in combination with exploratory interviews, described in section 3.2.2.

3.1 Technology Assessment

The method used in this study is inspired by a Technology Assessment method, as described by Woensel (2021). Technology Assessment is a foresight-based method used for studying and assessing eventual effects of new technology and its applications on society in the future. It can be used to inform policy makers on areas for possible policy actions, policy options, and assessment of their disadvantages, benefits and general impacts. This way, undesirable but possible futures can be handled.

First step is to analyse the system to see the bigger picture. When performing this step, for example by brainstorming together with colleagues, it is adviced to use the guiding questions *what, who, why, where, when,* and *how* when exploring the system. This also includes to explore the topic and its scope, as well at mapping the system with included stakeholders and actors. Moreover, the STEEPED wheel (Figure 6) can be used for scoping the impact by technological development. It is used to analyse the policy issue from all possible perspectives and consists of societal, technological, economic, environmental, political/legal, ethical, and demographic aspects (Woensel, 2021).

This study focuses on what the regulations affecting the circularity of the textile system might mean in terms of technological development and how this in turn may affect the roles of the workforce in the system, both in terms of competencies and gender distribution. Therefore, parts of the STEEPED wheel were used, mainly the *demographic* and *economic* aspects, which more specifically includes gender, as well as skills dependency and jobs.

Next, trends and evidence of the topic are scanned, and stakeholders analysed to form scenarios. Stakeholders refer to anyone who the policy issue affects, and mapping of affected stakeholders can be done through brainstorming sessions. Stakeholder participations is necessary for envisioning possible future developments, and they are asked for their opinions and emotions on the topic, which is suggested to be done through brainstorming sessions as well. In combination with thoughts from the brainstorming sessions, current evidence the base for formulating scenarios. It is advised to formulate a diverse range of scenarios, which can be disruptive or aspirational. Scenarios are not forecasts, but rather images of possible future developments (Woensel, 2021).

In this study, brainstorming sessions with stakeholders were in this study replaced with one-by-one interviews, which in combination with a literature study were formulated into one main scenario. Technology Assessment consists of additional steps relevant to policymaking and has hence been excluded from this study.

Figure 6. The STEEPED wheel (Woensel, 2021).

3.2 Data Collection

Data was collected through a literature review conducted in parallel with interviews.

3.2.1 Literature Study

A literature study was conducted in this study. The literature study was conducted through research databases and search engines, primarily Chalmers Library, Google Scholar, and Scopus, but also Google. When searching, keywords included for example "textile sorting automation" and "skills OR competenc* automation textile". Further, literature was found in the reference lists of research articles, including not only other research articles but also websites and grey literature. In addition, grey literature such as reports, and internal documents were shared by the project leader at RISE or recommended by the interview participants during the interviews. Google has been used for searching.

Due to the rapid development within the industry, efforts have been made to include as recent information as possible. Likewise, efforts have been made to include as geographically close literature as possible, focusing on Sweden.

3.2.2 Interview Study

As part of the project *Framework for circular textiles*, the interviewees were limited to RISE's network. RISE network consists of researchers and other roles internally, as well as external actors from the industry. Specifically, the external roles mean representatives knowledgeable in the field of RISE's projects, and who have an impact on the development of the organisation they represent. The supervisor at RISE, who is also the project leader, distributed the contacts from RISE's network to this study. The interviewees were chosen since they have knowledge in the subject of the master thesis project. Interviews were held with representatives from the categories "Research and Innovation" and "Sorting". Research and innovation include academia and research institutes while sorting refers to textile sorting facilities. One of the requested interviewees, who represented the "Producer of products" category was not included in the interview study.

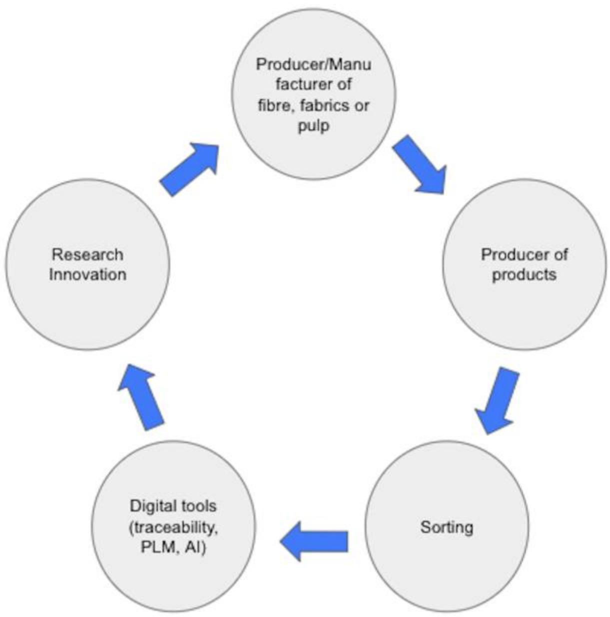

Figure 7. RISE's categories of project partners, based on RISE's work.

The order of the interviews was planned and then held via online video calls through Teams in the order presented in Table 1. First, two interviews were held with two employees at RISE to serve as a foundation for the following interviews, while the rest of the interviews were held in no particular order. All interviews were recorded and transcribed using Teams' recording and transcription functions and afterwards translated from Swedish to English by the author of this study. The interviews were conducted within the period of two weeks during spring 2024 and each lasted for 45 to 90 minutes. In the results, the interviewees will be referred to by their orgnaisational affiliation.

Table 1. The interviews listed in the order as held along with organizational affiliation, role and objectives of the interview.

Organisation	**Role**	**Main objective of the interview**
RISE-a	Project member	Gaining knowledge about the future textile system and related EU-projects.
RISE-b	Researcher	Gaining knowledge about how to improve gender distribution and equality through industry examples.
Björkåfrihet	N/A	The manual textile sorting process.
Wargön Innovation	Project Manager	Innovation within automation of the textile sorting process.
Science Park Borås	Project Coordinator	The future textile system.
Nordiska Textilakademin (NTA)	Program Leader Sustainabilty	Current education and how it is shaped to meet the competence demand in the textile system.

Through the literature study, knowledge gaps were identified, on which the interview questions were based on. The interview method was inspired by an exploratory approach. An exploratory interview introduces a question, a research area to be mapped or a complex problem and has little structure. The interview material is then used as a starting point to set the directions for further research and initiate searching for new information (Kvale & Brinkmann, 2014). For interview questions, the research questions were combined with a set of follow-up questions that were sent to the interviewees approximately 3 days before the scheduled interview. The follow-up questions served as a guide for inspiration and context. In the beginning of each interview, the interviewees were asked to choose one of the questions as a starting point and were encouraged to explore their thoughts connected to the topics. Not all of the research questions were asked to each intervieww, but were adapted to the interviewee's area of expertise, hence not everyone answered all of the research questions.

After the interviews, the material was sorted according to the research questions. The results from RQ2 and RQ3 were based on RQ1 and when analysing the interviews, efforts were made to present all perspectives in the results in cases of conflicting information. In case clarification of interview material was needed, the interviewees were once again contacted.

In addition to the interviews, a minor part of the results have been complemented through data collection at a project meeting, during which project partners provided updates on the progress of their contributions to the project. The project meeting were held in Borås 2024-05-23 at the initiative of the project leader.

3.3 Ethical Statement

Ethical considerations were made before the interview started. Project partners from *Framework for circular textiles* were expected to participate in related activities, including the interviews for this master thesis. Project partners with suitable background for the aim of the master thesis were chosen and asked by the project leader to be interviewed. Interviewees not part of the project were asked for voluntary participation. The purpose of the interview was explained as well as the intended use of the information, and that the information was only to be used in this study and analysed by the author only. Each interview on Teams began by asking the interviewees for their approval to record and transcribe the interviews. These recordings and transcriptions were deleted once the interviews were analysed. In addition, the interviewees were asked what degree of anonymity they would like, as how they wanted to be referred to in the master thesis. Further, all interviewees were informed on their ability to withdraw their consent of participation in the interviews at any time. Before online publication, this study was reviewed by the interviewees for validation in order to avoid misconceptions.

4 Results

The results are presented in three sections. The first section explores the current textile system in Sweden, while the following section explores how it may change for the future because of the EU regulations and technological development. The third section focuses on competencies that may be needed in the future textile system, and how the gender distribution may be impacted.

4.1 The Current Textile System in Sweden and Challenges for a Circular Economy

The first section explores the current textile system in Sweden by putting it in the context of the EU and the rest of the world. Thereby, this section includes activities before textile sorting, during and after textile sorting, and analyses the challenges for a circular economy with regards to consumer behavior, collection, sorting and recycling. Figure 8 illustrates an overview where the textile system (Figure 9), textile industry, activities, aspects, and types of actors related to the flow of information and textile material in society is included. Information includes, for example, the communication between actors such as the producer of products ordering a certain product by the manufacturer. Each activity includes several actors, and one actor can also be involved in more than one activity. Further, there are aspects that all have an impact on the activities in the system. These aspects are technological development, trends and consumer behavior, laws and regulations, and costs, but also education, which is connected to the workforce in the textile industry and will be focused on in the last section of the result chapter.

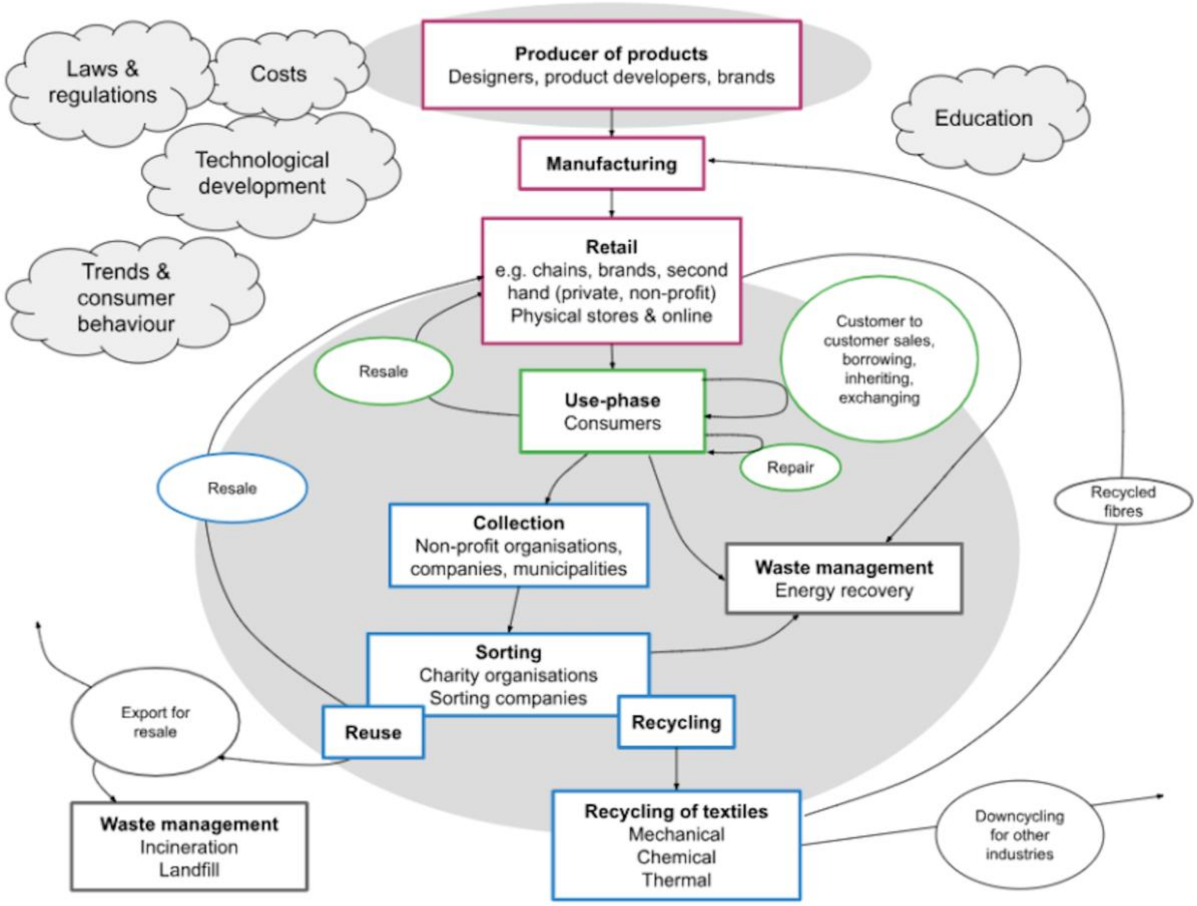

Figure 8. Overview of activities, aspects, and types of actors related to the flow of textile products and material in society, based on the literature study and interviews.

The current textile system is explored with a focus on textile sorting as an enabler for a circular use of textile material in society. To begin with, understanding the textile material flows in the textile system in Sweden, it has been illustrated as a flow chart in Figure 9. The textile system is defined by the system boundary and the illustration within the boundary refers to activities present in the system. The size of the textile material flows varies between activities as well as the input and output from the system, as illustrated by the arrows of various sizes.

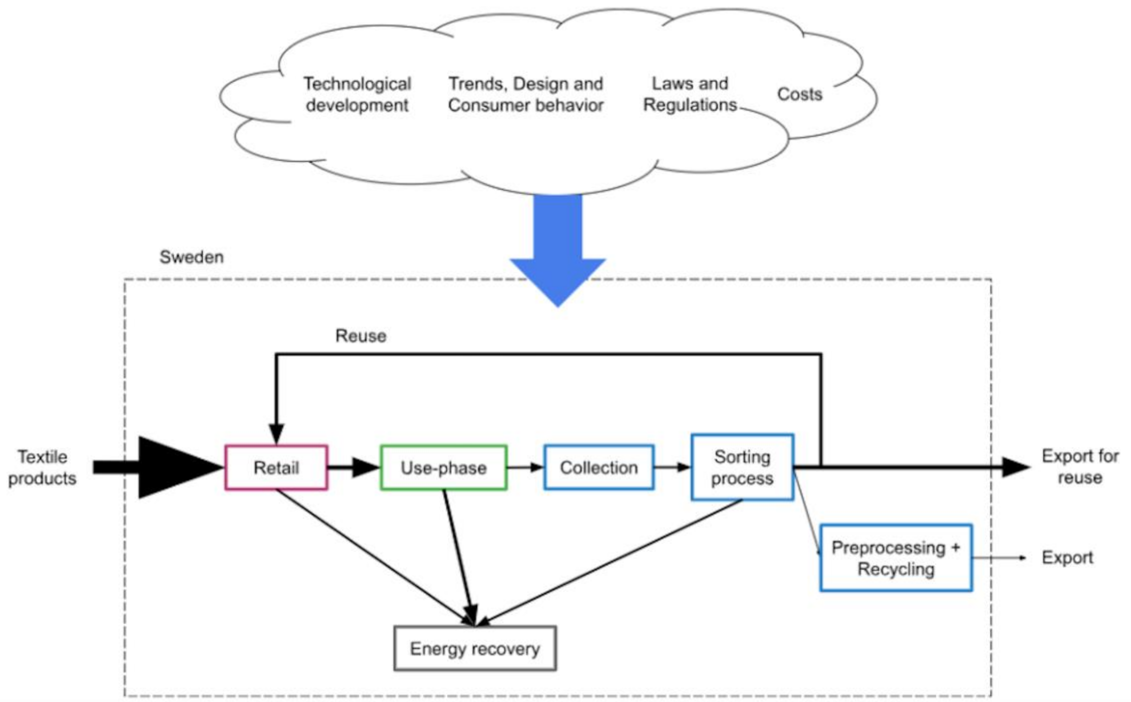

Figure 9. A flowchart of the textile system in Sweden today, based on the literature study and interviews.

Based on these illustrations, the textile system in Sweden will be explained in more detail in the following sections.

4.1.1 Sweden and the EU in a Global Context

The textile industry is globalised and to understand the challenges that are faced in Sweden and the EU in the transition towards a circular textile system, it is necessary to understand the connection to the rest of the world. The inflow of textile products to the EU and Swedish textile system is mainly dependent on imports from outside the EU (EURATEX, 2024). Imports of textile products (115 billion EUR) are almost double the value of exports (64 billion EUR) from the EU. The total import of textile products to Sweden reached 1.7 billion US dollars in 2022 (Statista, 2024c). Most imports to the EU are made from China, who contribute to a third of the textile product value imported into the EU (Boschmeier et al., 2023; EURATEX, 2024). China is the top exporter of textiles globally, with a market share of 44% (148 billion USD) followed by the EU who ranks second at 21% (71 billion USD) (Statista, 2024a; Statista, 2024b).

Although textile manufacturing takes place in the EU, it has to a large extent been distributed to developing countries (Gangoda et al., 2023). Most textile manufacturing is situated in Asia, where eight of the top ten textile exporting countries can be found (Boschmeier et al., 2023).

Other countries have lost the advantage of cheap labour and are therefore struggling to compete with low-cost countries such as Bangladesh and Vietnam. Textile manufacturing in the EU is mostly concentrated in Germany, Spain, France, Italy and Portugal, while in Sweden, on the other hand, textile manufacturing is limited (Directorate-General for Environment, 2022; SOU 2020:72). For instance, the national textile manufacturing accounts for only 3.4% of the total net inflow of textiles into the national market (SOU 2020:72). This may be explained by textile being characterised by a low level of technological innovation in textile manufacturing, thus is compensated by low labour costs as a competitive advantage (Anzolin, 2021; Gangoda et al. 2023).

The textile industry in the EU and Sweden are important in terms of job opportunities. Of the total workforce, 5% is working in the textile industry, which contains 9% of all companies in the EU. This corresponds to 1.5 million employees distributed among the 160,000 textiles and clothing companies, with 99.7% of the companies being micro, small- and medium-sized companies (SME)[1] (Boschmeier et al., 2023; EURATEX, 2024). Furthermore, Sweden follows a similar distribution by company size, with 89% being micro-sized companies. A majority (59%) of the workforce is employed for working in physical stores, and the entire textile industry employs a total of 62,000 people (full-time positions) (SOU 2020:72).

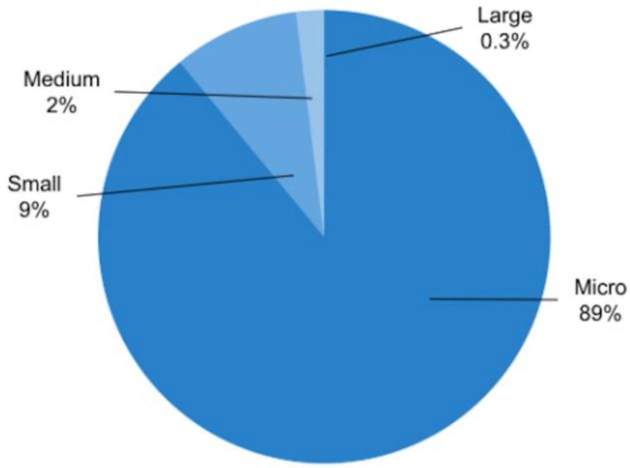

Figure 10. Size distribution of textile-related companies in the EU by approximate share (%), adapted from EURATEX (2024).

[1] Small- and medium sized enterprises (SME), Medium: ≤250 employees, turnover ≤€50 million, and balance sheet total ≤ €43 million. Small: ≤50 employees, turnover or a balance sheet total ≤ €10 million. Micro: ≤10 employees, turnover or a balance sheet total ≤€2 million.

4.1.2 Before sorting

To understand the inflow of textile products into the sorting process, it is crucial to understand the life cycle of textiles, including drivers for consumption as well as the steps before the textile products enter the textile sorting process. The purpose of this section is to describe these parts.

4.1.2.1 Product Destruction Prior to the Use-phase

Online retail and new business models such as fast-fashion have led to increased product destruction, which refers to the disposal of products prior to the use-phase (Roberts et al., 2022). It has been estimated that 21% of textile products put on the EU market remain unsold (European Environment Agency, 2024b). Selling textile products online is especially challenging, since consumers are presented with limited information online compared in a physical store where they can inspect, touch or try on the textile product. This contributes to a high return rate, on average 20% in the EU and 70% of these products are returned because of poor fit or style (Duhoux & Lingås, 2024). Out of the total amount of textile products put on the market in the EU, 4-9% is discarded (European Environment Agency, 2024b). Especially in the competitive market amongst online retailers, product destruction is used as a strategy by both producers and retailers to discard excess inventory and customer returns. This can be explained by cheap labour in low-income countries in combination with low-cost materials allowing for companies to increase the manufacturing of textile products as a response to a sudden increase in customer demand. Increasing the manufacturing volume is a strategy to avoid stockouts, thus avoiding the risk of customer dissatisfaction and a loss of market share. Often, this leads to overproduction and as a consequence of consumers desiring to stay up to date with the latest trends, textile products of past trends are discarded due to their unlikeliness of being sold (Roberts et al., 2022).

4.1.2.2 Consumption of new Textile Products

Textile products entering the Swedish textile system are supplied by both national and international actors and are accessed by consumers in both physical stores and online. The national market is dominated by fast fashion chain H&M, with a national market share of 61%. There are other chains such as Lindex and Gina Tricot, but also brands that import textile products (SOU 2020:72). During recent years, new online actors such as Shein and Temu, both from China, have entered the online market, providing an even larger supply at a faster pace compared to previous generations of producers of products such as H&M (Business of Fashion & McKinsey, 2023).

Textile products were the most popular online category in 2023, with 40% of internet users in the EU having purchased from this product category during this year (EURATEX, 2024). In a study by the Swedish Environmental Protection Agency (2020), slightly less than half (47%) of the respondents ordered clothes online, with more young people doing so compared to older people. Online actors such as Shein and Temu have become increasingly popular among consumers for their low prices and large supply of products (Business of Fashion & McKinsey, 2023). Although less money is spent on clothing, the amount of textile products purchased have increased by almost 30% during the last 20 years, resulting in almost a third of owned clothes are never or rarely used (Miliute-Plepiene & Fjellander, 2024; Swedish environmental protection agency, 2023).

The motivation behind the consumption of textile products varies among consumers. Consumers in Sweden reported that they purchase clothes because their old clothes are worn out (66%), wrong size (39%) or have lost interest in them (28%) (Swedish Environmental Protection Agency, 2020). As mentioned before, there is a desire among consumers to stay up to date with the latest trends (Roberts et al., 2022). Trends are to a large extent driven by social media. Newer fast-fashion actors, such as Shein and Temu, are faster to respond to and produce textile products in alignment with current social media trends in comparison to older fast-fashion actors, thus driving the consumption. As a result of the fast turnover of trends, clothing is often discarded of after only being used a few times (Business of Fashion & McKinsey, 2023).

4.1.2.3 Consumer Textile Waste

Textile products are often discarded due to wear and tear, being outgrown, torn, going out of style, or because the consumer is tired of the garment or lacks storage space, and over half of these textiles could have been used further (SOU 2020:72). Cheap products of low-quality cost less to discard of than to disassemble or repair (Roberts et al., 2022). The decision of how a textile product is discarded is influenced by factors such as knowledge and habits, but also available collection options, and economic considerations (SOU 2020:72). A minor part of textile products are being donated for reuse, but most often textile products are discarded through the household waste and subsequently incinerated (Swedish Environmental Protection Agency, 2020). There is potential for more textile products to be reused, as it is estimated that nearly 40% of textiles in household waste could have been suitable for reuse (Miliute-Plepiene & Fjellander, 2024). More than 7.5 kg textiles per person are discarded in Sweden per year

(Swedish environmental protection agency, 2023). Slightly more than half (55%) of the respondents discard textiles through the household waste as a consequence of lacking the knowledge of what to do with the textiles (Swedish Environmental Protection Agency, 2020). Others (31%) stated convenience as the reason for discarding textiles through the household waste (Swedish Environmental Protection Agency, 2020). The amount of discarded textile is almost double the amount of which is donated (Miliute-Plepiene & Fjellander, 2024). Half of the respondents answered that they donate textiles that are no longer used. However, the majority (90%) answered that they would consider donating textiles for reuse (Swedish Environmental Protection Agency, 2020).

4.1.2.4 Consumption of Secondhand Textile Products

Similar to the consumption of new textile products, the consumption of textile products for reuse via secondhand is increasing. Textile products are the most common product bought on the secondhand market, but still accounts for less than 5-7% of the total consumption of all secondhand goods (Miliute-Plepiene & Fjellander, 2024). Less than a fourth (23%) of the respondents partly buys secondhand, compared to the majority (58%) that buys new clothes only. Further, a minority (17%) buy around half the clothes or more secondhand (Swedish Environmental Protection Agency, 2020).

Consumers mention various reasons that motivate their decision to buy textile products secondhand. A motivation to buy fast-fashion, affordability is a primary factor influencing the decision to choose secondhand (Swedish Environmental Protection Agency, 2020). Buying second-hand clothing also offers environmental benefits, which can influence purchasing decisions, particularly among women and individuals with higher education. Comparing men and women, almost twice as many women buy secondhand clothing, both in physical stores and online. Many consumers avoid secondhand clothing due to concerns about hygiene or discomfort with wearing previously owned clothing. Additionally, second-hand shopping can be time-consuming, with 47% of respondents indicating that difficulty in finding suitable items within a reasonable timeframe limits their purchases.

Despite these challenges, there is an interest in buying second-hand if environmental benefits are made clear. A majority (90%) of respondents expressed willingness to increase their second-hand purchases if they knew it would positively impact the environment, showing a potential for an increased demand for secondhand textile products (Swedish Environmental Protection Agency, 2020).

4.1.2.5 Collection of Textiles

Historically, the collection of textile products for reuse to sell secondhand have in Sweden been dominated by nonprofit organisations (Persson & Hinton, 2023). The textile collection performed by non-profit organisations are often unselective of which clothing brands that are accepted, and the textile products are most often collected through containers at waste disposal sites (Coscieme et al., 2022; Jäämaa & Kaipia, 2022; Miliute-Plepiene & Fjellander, 2024). These organisations are working to integrate people into the labour market. These organisations receive tax reductions and subsidies and are legally required to reinvest their entire profit into social benefit, typically shelter and food for marginalised people in Sweden. During recent years, the Swedish secondhand market has become more competitive due to the entrance of more actors, and thereby becoming increasingly commercialised. There are examples of Swedish non-profit organisations putting efforts into improving efficiency of their organisation to compete with for-profit actors, but this may imply a trade-off in terms of social benefit such as worker integration (Persson & Hinton, 2023).

Moreover, a minor part of reusable textiles are also collected directly by private collectors or retailer initiatives, which can be either brand-selective or nonselective. Brand-selective collection means that the producing company takes back products sold by the own company. This collection typically occurs through the brand itself or a third-party textile collector (Coscieme et al., 2022; Zhuravleva & Aminoff, 2021). This type of collection occurs both in physical stores, and through online reselling platforms such as Sellpy (Miliute-Plepiene & Fjellander, 2024). Sellpy has received 210 million in investments from H&M since its launch in 2015, contributing to the ability to up-scale and invest in technological solutions. On the contrary, non-profit organisations lack investments needed to invest in technological innovation and business models (Persson & Hinton, 2023). Further, clothing is exchanged directly between individuals, which also can be performed via online platforms such as Blocket, Tradera, and Facebook groups (Miliute-Plepiene & Fjellander, 2024).

The quality of textiles can differ depending on the method of collection. Textiles which are collected by staff through direct contact with the consumer are generally of higher quality in comparison to textiles left in containers at waste disposal sites. Textiles left at waste disposal sites are often of lower quality and might be contaminated and affected by moisture (Miliute-Plepiene & Fjellander, 2024). The trade-off between customer service and collecting efficiency have to be considered when deciding on a collection system, thus suggesting a semi-centralised system where consumers are responsible for the last mile (Jäämaa & Kaipia, 2022).

There is a growing consciousness about textile as a resource, which has led to increasing collection rates. In 2016, 38,000 tonnes of textile products were collected by non-profit organisations in Sweden, equalling 3.8 kg per person (Swedish Environmental Protection agency, 2023). Followingly, each person buys only 0.13 kg textiles secondhand, which implies a surplus of secondhand textiles which can be explained by the high consumption of new clothes in Sweden (Miliute-Plepiene & Fjellander, 2024; Swedish environmental protection agency, 2023). The remaining amount of textile, around 70-90% of the total collected volume that can not be reused domestically, is exported to large-scale sorting facilities in Europe, typically in the Baltics. Thus, collected textiles are leaving the textile system in Sweden. Textiles may also leave through illegal collection, but to what extent is unknown (Science Park Borås, 2023; Zhuravleva & Aminoff, 2021). The reason for textile export is due to lower labour costs in comparison to Swedish sorting actors, low demand from Swedish customers and a larger market for used textiles in Europe (Miliute-Plepiene & Fjellander, 2024). Some apparel manufacturing countries, such as Bangladesh and China, have enacted prohibitions on the importation of post-consumer textiles, further motivating the need for a circular textile system in Sweden and EU (Charnley et al., 2024).

There is currently a lack of incentives to collect low-value post-consumer textiles, since existing trade rules are designed for a linear economy (Charnley et al., 2024). Therefore, new infrastructure and incentives for textile collection, transport, sorting and recycling are suggested (Hole & Hole, 2020). A part of the solution can be the EPR scheme, which can provide incentives for collecting textiles. However, there is no guarantee for high collection rates. France is the only country in Europe that has implemented an EPR scheme to fund collection and handling of post-consumer textiles. In France, the total fraction of post-consumer textiles collected is 38%, which can be compared to 75% in Germany. This may indicate that even with an EPR scheme, there is a need for convenient home collection. To increase collection, there is a need to explore drivers for consumers to donate textiles, such as the environmental and social benefits connected to textile collection (Charnley et al., 2024).

4.1.3 Textile Sorting

After the textile products have been collected, the products have to be sorted. Textile sorting in Europe is fragmented, with many textile sorting actors involved. The five largest textile sorters in Europe sort more than 80,000 tonnes per year and make up a market share of only 25%, while the middle segment who sort 25-80,000 tonnes per year accounts for 30%. Small collectors and sorters make up 40-50% of the market and each actor is handling low annual volumes below 25,000 tonnes per year (McKinsey, 2022). The predominance of small collectors and sorters creates an increased competition for the textile waste, resulting in small inflows and outflows of each textile sorting process, which in turn inhibits up-scaling of new sorting technologies (Science Park Borås, 2023). One example of a large-scale actor is Texaid, who handles 80,000 tonnes of textiles annually on the European market and operates within collecting, sorting, repairing, reselling, and recycling textiles and shoes globally, employing a total of 1,200 people across the group (Texaid, n.d.).

Traditionally, textile sorting is a manual process where textiles are distinguished between reusable and recyclable, as well as waste fractions which are subsequently incinerated. In general, it can be considered an accurate method, but challenging in terms of economic viability due to high labour costs (Boschmeier et al., 2023). The textile sorting process is a labour-intensive process of several steps for manually sorting textiles, shoes, and accessories. Sorting can result in up to 300 different categories, and the categories depend on the quality, condition, and type of the product. In more detail, categories include product type, garment condition colour, textile construction, size, brand, and style (Texaid, n.d.). To perform the manual textile sorting for the secondhand market takes approximately 6 months of training and longer to become efficient (Köhler et al., 2021). Some sorters hold more refined skills and are therefore able to sort textiles for recycling and waste. Sorting for recycling is based on the feel of the material, or when available, the material composition label (Texaid, n.d.).

4.1.3.1 Example: Björkåfrihet's Current Textile Sorting Process

To illustrate a Swedish example of an existing manual textile sorting process (Figure 11), Björkåfrihet has been interviewed. Björkåfrihet is non-profit organisation specialising in collecting, sorting as reselling in their own secondhand shops and is one of the textile sorting actors in the Swedish textile system. Textile products are donated to Björkåfrihet by private persons, commonly by bringing bags of textiles to textile collection containers often situated at waste collection sites. The collected volume in 2023 amounted to 2,500 tonnes and approximately 5 tonnes are sorted each day. Relying on donations, Björkåfrihet has little control over what is donated and goes into their textile sorting process.

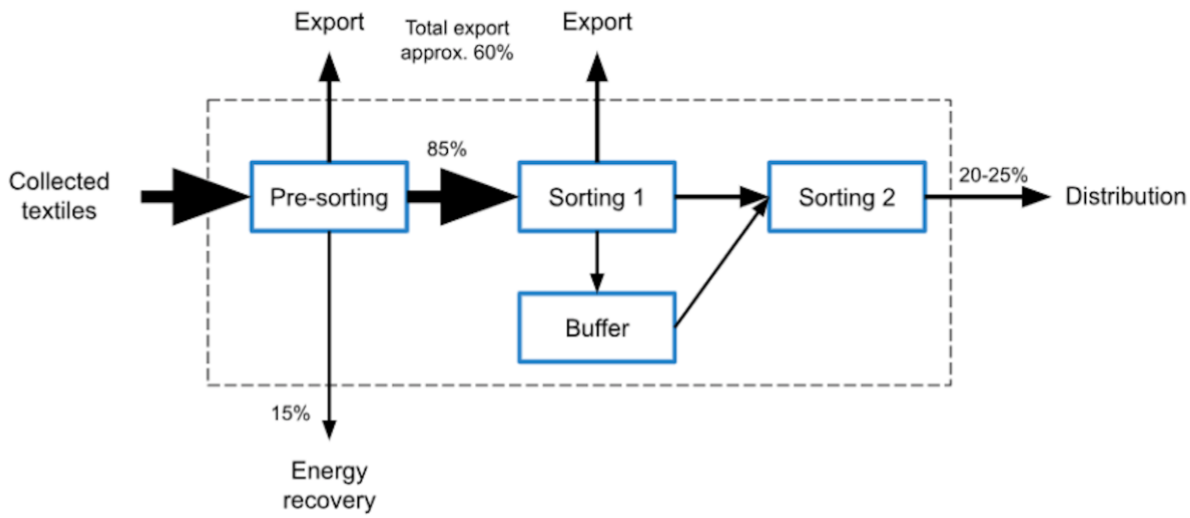

Figure 11. Björkåfrihet's textile sorting process based on interview with Björkåfrihet.

The first step in the sorting process is here referred to as pre-sorting. After collection of the donated bags of textiles, the bags are opened, and non-textile waste and clothes that are wet or mouldy are manually removed at the sorting facility. The fraction removed in this step corresponds to approximately 15% of the collected total amount and is subsequently energy recovered. Next, the pre-sorting step is followed by the next sorting step where there are only textile products left and equals approximately 85% of the total collected amount. The textiles are placed on a conveyor belt and manually sorted into categories, which are either stored as a buffer or directly passed onto the next step. The categories womenswear, menswear, and trend passed directly while childrenswear, home textiles, accessories and sport are stored as a buffer in order to supply the secondhand shops in case of a decrease in the amount of textiles collected.

Since the amount of textile collected exceeds the limited demand from the secondhand shops, approximately 60% of the total amount of textile products per year are exported, as described in the interview with Björkåfrihet. In comparison, export rates for reuse and national reuse rates varies in similar organisations to Björkåfrihet in Sweden. In a study by Miliute-Plepiene & Fjellander (2024), exports rates for reuse varies between 41 and 80%, while reuse rates varies from 0 to 26%. As mentioned by the interviewee representing Björkåfrihet, textile products may be exported based on cultural aspects, if deemed unsellable on the Swedish market. Alternatively, export of clothes collected in Sweden can also be explained a demand from the European market, due to a high level of trendiness of clothing donated by Swedish consumers (Miliute-Plepiene & Fjellander, 2024).

Textile collectors and sorters make the highest profit by selling volumes to the second-hand markets (McKinsey & Company, 2022). Of the amount of textile products collected, a small share is funding the entire handling (Sandberg & Pal, 2024). In Björkåfrihet's case, the 20-25% share of textiles sold in stores cover the cost in combination with earnings from exports. This last share of textile products is sorted due to their potential to be resold on the national market and are in the last sorting step prepared to be distributed to company-owned secondhand shops. To determine the price-level in the sorting process, templates are used by the sorters which are based on criteria such as condition, brand, and level of trendiness (Björkåfrihet).

4.1.4 After Sorting

When sorting textile products, three main pathways are identified. These pathways are reuse, recycling, and disposal, which will be the focus in this section.

4.1.4.1 Reuse

After sorting, textile products are being resold. Some non-profit organisations notice an increase in the amount of clothing donations of such low quality that these items cannot be resold. Consequently, these organisations are forced to incinerate unusable clothing, incurring extra costs as a result, and thereby reducing the funds available for social benefit. The decline in the quality of donated clothing can be attributed to two main trends. First, the surge in affordable fast fashion has introduced a larger volume of low-quality clothing that wears out quickly and is less desirable for second-hand use. Low prices of new clothes have shaped consumer expectations that secondhand clothing should cost even less, which is problematic since it decreases the quality of new clothes and in turn results in low quality clothing that is more challenging to sell on the secondhand market. Secondly, the increase in resale actors have given people more options to sell higher-quality items for profit, resulting in fewer of these garments being donated (Persson & Hinton, 2023).

4.1.4.2 Textile Recycling

In a circular system, textile recycling is crucial. Currently, less than 1% of collected textile products are recycled into new clothing (Directorate-General for Environment, 2022). "Closed-loop" recycling of textile materials can be described as the process in which the output is reused for clothing or home textile applications. In contrast, "open-loop" recycling involves repurposing the output material for uses outside of new textile production, often resulting in downcycling into lower-value products (Dukovska-Popovska et al., 2023; Huygens et al., 2023; Köhler et al., 2021). At the current state of technological development, closed-loop recycling technology exists for textile materials made from one fibre type and to some extent blended materials (Charnley et al., 2024). For closed-loop purposes, most recycling technologies require a minimum fibre purity. It is estimated that 50 to 60% of all cotton or polyester textiles have a purity level of 100%, and pure fibre textiles are relatively straightforward to recycle for closed-loop purposes in comparison to textiles with blended fibres (McKinsey, 2022). In addition, textiles made from cotton generally have more recycling possibilities, contrary to textiles made from polyester (Charnley et al., 2024). Of the discarded textiles in Sweden, more than half are made of pure cotton, making them suitable for recycling (SOU 2020:72). However, the variety of fibre types and chemicals used in textiles increases the cost of recycling, contributing to the fact that the cost of recycled fibres is higher than for virgin fibres (Hole & Hole, 2020).

Investments are needed to up-scale recycling technologies and broaden the span of textiles that can be recycled. Not all recycling technologies can process all kinds of textiles. Several factors need to be considered, for example material construction and fibre blends (McKinsey, 2022). There is a lacking demand from large producers of products to use fabrics based on recycled fibres. Producers of products prefer predictable quality and large quantities, hence recycled fibres are believed to be a risk. In addition, there is currently a lack of fibres suitable for a vast range of textile applications. This leads to textile recycling being perceived as too high of a risk for investors, resulting in missed out investments followed by hindered up-scaling of recycling technologies and little chance to compete with virgin fibres (Reike et al., 2022). Moreover, lacking consumer awareness and incentives to recycle puts further pressure on the system to change (Hole & Hole, 2020; Reike et al., 2022).

4.1.4.3 Preprocessing

Before entering a textile recycling process, textile products need to be preprocessed before entering a suitable recycling process (Charnley et al., 2024). Since available textile recycling technologies have strict input requirements, removal of disruptors through a preprocessing step is a necessity. Disruptors are, for example, decorations and functional elements such as zippers and buttons. This poses a technological barrier and is together with pre-sorting and other sorting operations considered costly due to its labour intensiveness (Dukovska-Popovska et al. 2023; Zhuravleva & Aminoff, 2021). There is ongoing research on how to innovate new semi-automated preprocessing methods to disassemble textile products, such as personal protective equipment (CISUTAC, n.d.). In addition, standardisation of preprocessing methods is challenging since the output of the pre-processing method is determined by the recycling method (Texaid, n.d.).

4.1.4.4 Mechanical Recycling

Mechanical recycling cuts, shreds and opens up the textiles to create fibres as the output of the process (Sandberg & Pal, 2024). Mechanical recycling is cost-effective and can process a diverse range of textile fibre types at large volumes, hence has the potential of reaching scale. However, this presumes a market demand and acceptance of blended fibres (Charnley et al., 2024; McKinsey, 2022). Typically, conventional mechanical recycling results in downcycling into products such as rags, insulation panels, and mats. The market for mechanically recycled textiles is reaching saturation, thus large-scale fibre-to-fibre recycling is a necessity (Dukovska-Popovska et al., 2023; Köhler et al., 2021). In general, this method is energy efficient but has a low ability to return used fibres to virgin quality since fibre length is reduced by 30-40%, making these fibres most suitable for open-loop purposes, given the current state of technology development (Charnley et al., 2024). To be spinnable, fibres must reach a certain length and be sufficiently even and strong. These requirements explain why recycled fibres often have to be blended with virgin fibres to reach the desired yarn quality. Since input of virgin material is needed, it results in a limited number of circular cycles (Charnley et al., 2024; Reike et al., 2022). Furthermore, there are companies currently exploring the process of "soft" mechanical recycling which only results in a 10-15% degradation of the fibre length. However, this method can require ten times longer process, making it more resource intensive than conventional mechanical recycling. Although "soft" mechanical recycling is more expensive, it has the potential to regain long fibres which can be spun without the need for blending with virgin fibres (McKinsey, 2022). These methods are used for textiles of high purity and are most commonly used for cotton or other natural fibres (Huygens et al., 2023).

4.1.4.5 Chemical Recycling

Although textile recycling is currently dominated by mechanical recycling, chemical recycling is scaling up. Chemical recycling is considered to have low energy efficiency but high ability to return the material to virgin quality. However, the chemical recycling processes are facing technological and economical limitations, such as the requirement of high purity input material (McKinsey, 2022). There are various chemical recycling processes, each depending which input material is to be recycled. Input materials can be either synthetic and natural fibres, for example polyester or polyamide but also natural fibres such as cotton. The products from chemical recycling are for example monomers, polymers, or man-made cellulosic pulp (Huygens et al., 2023). In Sweden, there are few scaled textile recyclers and one of them are Södra, who is utilising blended cellulosic and wood in their chemical recycling process to produce pulp for textile fibers used in applications such as clothing (Charnley et al., 2024; Södra, 2024). In comparison to virgin fibres, fibres produced from chemical recycling are more expensive and production costs can increase if further purification is needed if the feedstock is contaminated (Charnley et al., 2024).

4.1.4.6 Thermal Recycling

There are also the thermal recycling options, thermo-mechanical recycling and thermo-chemical, but currently used to a very limited extent for textiles (Sandberg & Pal, 2024). Thermo-mechanical recycling combines pressure and heat. Synthetic textile can be melted while the polymers are recovered and this way, new fibres can be shaped. The thermo-mechanical recycling method has a low energy requirement and leads to less material degradation compared to mechanical recycling. This method is considered mature and used at scale, for example for PET-bottles. The input requirements into the process are strict, requiring high purity materials, limiting the feedstock available for use. In addition, thermo-chemical recycling may have potential for textiles. Thermo-chemical recycling produces syngas through gasification of the material and would only be able to be used for open-loop purposes in the case of textiles (McKinsey, 2022).

4.1.4.7 Disposal

Textile products that can not be reused or are suitable as input material into recycling processes are incinerated or landfilled. As mentioned by Björkåfrihet, textiles are sorted as waste due to poor condition. Likewise, textile products such as workwear can have been treated with harmful chemicals to achieve certain performance properties and are thus not fit for recirculation (SOU 2020:72). Textile sorting companies in the EU indicate that textile waste that are sorted for incineration with energy recovery or landfill is low, 5-10% are generated after the sorting process. Energy recovery means that electricity and heat is generated from waste incineration, but also from landfilling through gas capture and utilisation (Huygens et al., 2023). In addition, 41% of used textiles in the EU are exported to Asia, and the exported amount from the EU has tripled from 550,000 in 2000 to 1.7 million tonnes the following two decades (European Environment Agency, 2024a). Textiles are exported from Europe to countries that lack efficient waste handling and capacity to recycle the textile waste, where they are ultimately landfill or incinerated. Due to the EU regulations affecting the textile system, it is estimated that exports of unsorted textile waste may decline because of regulated waste shipments. Moreover, around 90% could be sorted in the EU instead and less of the approximate 10% of what is incinerated or landfilled in will be so in the future, since part of this fraction can probably be recycled (McKinsey, 2022).

4.2 Textile Sorting in the Future Textile System

The focus of this section is to explore what the future textile system may look like, as illustrated by Figure 12. This includes technological development to enable a circular system, with the focus on textile sorting. Even though textile products or textile material may be exported, a difference from the current system would be that a demand would have been created, in order to avoid being exported to landfill (McKinsey, 2022).

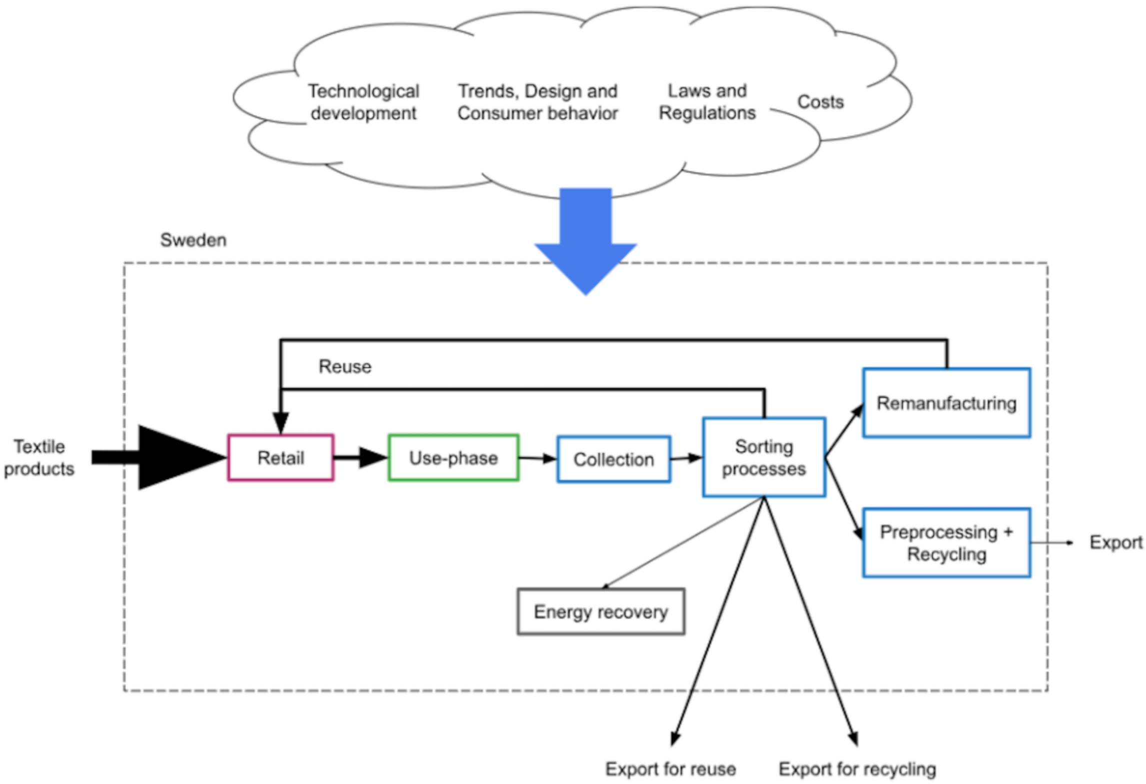

Figure 12. The future textile system is Sweden. Own work based on interviews and literature study.

The amount of textile waste in Europe is expected to increase from 8.5 million tonnes to 9 million tonnes in 2030 due to consumption, population growth, and growth of GDP. In addition, the amount of textile waste collected from households may increase by 50% following the implementation of the EU regulations on separate collection of textile waste in 2025 (McKinsey, 2022). This implies an expected increase in manual sorting capacity from 65,000 to 90,000 tonnes per year. Workers who sort textiles manually are estimated to sort 100 to 150 kilos per hour, while with an automated sorting system may be able to handle 900 to 1,500 kilos per worker (Köhler et al. 2021). One of the interviewees mentions the expected increase in volume of textile waste and the low maturity of the technology as two important challenges in enabling a circular textile system. Especially, the sorting process for recycling requires automation since manual textile sorting for secondhand is more economically viable today (RISE-a). The number of textile sorting jobs are likely to increase with the increasing amount of collected textiles, since automated textile sorting technology is currently not mature enough to substitute manual workers (Köhler et al., 2021). In general, manual textile sorting can be considered an accurate method, but challenging in terms of economic viability due to high labour costs (Boschmeier et al., 2023). However, with industry demand for recycled fibres, manual sorting lacks the precision and effectiveness needed for separation of textile materials in alignment with existing recycling technologies, thus motivating the need for automated textile sorting (Sandberg & Pal, 2024).

Among the total textile waste existing today, one report estimates that 25-37% could be recycled in 2030. Considering the recyclable amount, 70% may be closed-loop recycled, while the remaining 30% may be recycled for open-loop purposes, given an increased level of technological maturity (McKinsey, 2022). Increasing the recyclability of new textile products can be enabled through changes in design methods, for example by avoiding materials which can not be separated in the recycling process, there is potential to ease the recycling process (The Business of Fashion & McKinsey, 2023). Even though closed-loop recycling is considered the most preferable option, open-loop recycling methods are still expected to play a role since not all textile materials will be possible to recycle. By using open-loop methods, incineration and landfilling of textile waste can be avoided (McKinsey, 2022).

How to enable recycled textile material to be used as raw material by meeting industry-specific performance requirements in industries such as textile-, automotive-, and furniture industry is studied within the project at RISE. Today, no systems for standardising the quality of recycled textile material exists, but there is potential for this to be developed in order to expand the areas of use.

4.2.1 Technological Development within Textile Sorting

The exact implementation of a textile sorting system remains uncertain. One approach could involve designing a textile sorting process adapted to automated technology from the start. In addition, the existing manual sorting process could be enhanced with digital tools to support workers within the current system (Wargön Innovation). Manual textile sorting may be digitally assisted by hand-held scanners. In comparison to fully automated sorting, there are advantages with digitally assisted manual sorting. Theoretically, sorting for high-quality recycling can be performed simultaneously as sorting for reuse instead of needing a new facility and processing step. This may reduce costs as well as the need for physical space at the sorting facility. However, this may be less cost-efficient than a two-step process of manual sorting for reuse, and additional process for automated sorting for the fraction that should be recycled. This can be explained by the labour costs for both reusable and recyclable fractions (Köhler et al., 2021).

Driven by automation, there is a trend towards more specialised sorting (Sandberg & Pal, 2024). Specialised sorting opens up for an expansion of the number of sorting categories. These categories could for example be to sort depending on manufacturing method (e.g. knitted or woven, or even more refined categories such fabric types such as jersey and fleece), and fibre composition as well as different fibre blend fractions (Nørup et al., 2018). This sorting process has the potential to enable new actors to enter the textile system and to develop specialized roles, as highlighted during an interview with a representative from Wargön Innovation. For instance, specialized actors could focus on waste treatment methods such as pre-sorting or reconditioning specific garment types for the second-hand market, for example, removing pilling from cotton T-shirts. Consequently, these actors may have specific interests in particular textile materials or products, creating a need to expand the range of sorting categories (Wargön Innovation).

The near-infrared spectroscopy (NIR) is one of the most promising technologies in development for textiles and its use is predicted to increase. The NIR technology can be used for on-line identification of the textile composition through scanning the textile surface. By developing an algorithm, textiles can then be sorted depending on material content (Köhler et al. 2021; Boschmeier et al., 2023). Among the organisations already using NIR technology for textile sorting is the municipality-owned company Sysav in Sweden, who processes pre-sorted textile waste at the rate of 8000 tonnes annually but has the capacity of handling a maximum 24,000 tonnes (Huygens et al, 2023; Sysav, n.d.). Although the technology is used, a pilot study by Cura et al. (2021) indicates that there are currently limitations to accurate material detection using the NIR scanner.

To begin with, materials with a low percentage (<10%) are less likely to be recognised, for example elastane which is often incorporated into the core of the yarn, thus not visible on the fabric surface. Furthermore, sheer, loose knits and coated fabrics may need additional handling, and in the pilot study, these textiles were handled manually on the conveyor belt. The sheer fabrics and loose knits needed to be folded for the conveyor belt not to be scanned through the fabric, while coated fabrics were folded for both the right and the wrong sides to be turned towards the scanner because of different materials. Coated textiles are generally unsuitable to recycle using the same process as for uncoated textiles and would therefore need to be identified regardless of their base material. Textiles with finishes gave the same results. Moreover, the technology is not able to detect the material composition if the textile is dyed with carbon black (Cura et al., 2021).

Within the project *Framework for circular textiles,* possible automated sorting processes are investigated. The process could potentially consist of a conveyor belt with sensors connected to digital tools. The digital tools could include AI (print, colour, area), NIR used in combination with RGB (fibre and treatment, colour), and a scale to measure weight may also be included, as presented during the project meeting. Furthermore, Texaid (n.d) expects the sorting process to include metal detectors, and a rejection mechanism using compressed air as well. This process can lead to textiles being sorted into different boxes depending on sorting category, and later stored in compressed bales. In the sorting process, capability to perform scanning of both internal and external aspects of the textile product is necessary. In other words, an automatic textile sorting process should be able to recognise colour, weight, feedstock format, fabric structure, composition, disruptors, and contamination that have occurred during use-phase (Texaid, n.d.).

Furthermore, an automated or digitally enhanced textile sorting system should be able to scan the DPP (Texaid, n.d.). Introducing the DPP textile products requires a data carrier, such as RFID (Science Park Borås). If an RFID-tag is used, it may be classified as electronic waste, which would add to the complexity of the textile recycling process (RISE-a). As discussed with the project partners, the information content could include, for example recycled content, dye, treatment, yarn, fabric construction, fibre length, production year, certification, and origin, but uncertainties remain. According to one of the interviewees, the DPP is also expected to provide information on clothing categories, which could facilitate automated sorting into categories, for example to sort specific into specific garment categories such as jeans. However, a technological barrier may be faced since the DPP is of limited use when deciding the sorting pathway whether the textile product should be recycled or not. To determine this, complementary technology is needed (Science Park Borås). However, there are still uncertainties concerning what information the DPP will provide and how it will affect the textile sorting processes (RISE-a).

As concerned during the project meeting with the project partners, the DPP and NIR may eventually not match due to the condition of the textile product. Condition adds to the complexity of determining the disposition route, for example, a design detail could be challenging to distinguish from stains. Based on the information from the fabric identified by NIR, a recommendation of which pathway the textile should take can be presented. This can depend on the textile product's condition as well as if it has been altered. One interviewee mentioned that the introduction of RFID may create a need for different pathways for the collected textile products in the sorting textile process depending on if the textiles are equipped with an RFID or not. This could mean that the sorting processes for textile products without is one flow, while new textiles equipped with RFID-tags is another flow. With time, a break-even may be reached where there are more products equipped with a RFID-tag than not, entering the sorting process. This may open for more textile products being sorted automatically (Science Park Borås).

4.2.2 Systems-level Collaboration for a Circular Transition

To enable the circular transition, the EU needs to strengthen its capabilities in separate collection, sorting, reuse, and recycling. To achieve this, investments are required to build infrastructure and develop technological solutions (Directorate-General for Communication, n.d.-b). However, high investment costs require high utilisation (Sandberg & Pal, 2024). To reach scale, post-consumer textile volumes for recycling would benefit from being aggregated (Charnley et al., 2024). Preferably, textile sorting needs a stable and predictable inflow (Sandberg & Pal, 2024). Collected textile material varies in quality and quantity which requires advanced sorting solutions and knowledge. Understanding the supply and demand as well as the sorting facilities is essential to be able to deliver an exact textile fraction at a desired volume. Collaboration in a specific geographic area, such as the Nordic countries could favour local recycling solutions to avoid further exporting (Dukovska-Popovska et al. 2023).

Furthermore, RISE studies the possibilities of new platforms to increase accessibility and utilisation of textile materials is suggested in the project *Framework for circular textiles*. This way, recycled material for industries, such as the ones mentioned in 4.2, can have access to recycled material matching the quality requirements of the specific industries. According to the interviewee from Wargön Innovation, AI is currently used by producing companies for trend and market analysis, but its application in the resale market is still emerging and not widely adopted across the industry. Examples like Benify and ThredUp demonstrate its potential in this space. Additionally, Wargön is actively exploring ways to apply AI as part of their test and demo site offering but is not a producing company.

Moreover, the industry's focus on short-lived trends hinders the transition from conventional linear business models (SOU 2020:72). Designers and engineers will face challenges in combining recyclability, durability and product desirability. A textile product that does not appeal to consumers even though it is designed according to the principles for circular economy, such as being recyclable, does not fit within the frame of circular economy (Koszewska, 2018). Research suggests that two systems with two kinds of materials may be relevant. Of these two systems, there would be one system focusing on “fast” fashion and recyclability, and another “slow” system focusing on quality. This would require competence of understanding material flows and the potential of the material, and not only materials and technology available. In addition, a deepened understanding of the use-pattern of clothing is needed to understand which system to design according to (Sandvik and Stubbs, 2019).

Organisations in the textile system can not become circular on their own without global collaboration (Sandvik & Stubbs, 2019). To induce a systemic change towards a circular economy, a strong, global, cross-sectoral collaboration between stakeholders is recommended. Collaboration is needed to facilitate data and knowledge sharing, funds for new recycling technologies, risk-sharing as well as industrial symbiosis. Supply chain transparency and material traceability is an enabler for circular design and can be achieved through digital technology (Charnley et al., 2024). To increase transparency in the value chain, the DPP is planned to be implemented. There are currently uncertainties among representatives from SMEs in Sweden about what kind of information the DPP will need to contain. Depending on what these information requirements may look like, the information can be challenging to obtain from manufacturers, for example chemical content (Nordiska Textilakademin et al., n.d.).

This may imply challenges for the accessibility and legitimacy of the information that should be added throughout the value chain (Science Park Borås, 2023).

However, increased transparency could facilitate the measuring of environmental impact of circular supply chains, and more advanced life–cycle analyses are needed, for example regarding the decision of using recycled or virgin fibres (Sandberg & Pal, 2024). In efforts towards a circular economy, a systems perspective and joint efforts involving different actors is essential. This means to work from both ends, in other words, to design for recyclable clothing while also developing new technology to enable fibre-to-fibre recycling, such as recycling technologies less sensitive to material blends (RISE-a).

4.3 Competencies and Gender Distribution in the Textile System

Previously, the textile system in Sweden and what it may look like in the future has been explored with a focus on textile sorting. Building upon this exploration, RQ2 and RQ3 will be addressed by analyzing how these potential system changes may influence the demand for competencies and affect gender distribution, with a focus on textile sorting. This analysis will provide insights into how shifts toward a circular economy and automation might reshape both workforce requirements and the gender distribution within textile sorting and beyond.

4.3.1 The Actors Providing the Textile System with Competence

Nationally, there are a number of educational options specifically providing the textile system in Sweden with competence. The courses that are taught range from short courses by independent organisations to advanced level degrees at higher education institutes.

The Swedish School of Textiles, as part of University of Borås is the only university in Sweden specifically targeting the fashion and textile industry. The education at the Swedish School of Textiles is targeted at preparing students for the Swedish and international fashion and textile industry, inclding roles within product development, buying, production, and material innovation. There are different programmes each focusing on different parts of the textile value chain. Some of the programmes focus on the part of the value chain closest to the consumers, preparing students to work in areas such as management, marketing, business development, retail, and social media. In addition, there are fashion- and textile design programmes as well. Moreover, there are technical programmes within textile engineering and textile production and innovation, focusing on equipping the students with technical competence to work in roles within sustainability challenges, such as methods to turn textile waste to resources and raw materials. The textile innovation programme contains courses in digital technology, as well as knowledge of laws and regulations for textile products. There is also a focus on material innovation, and products and processes in the textile industry to enable local and flexible production (Högskolan i Borås, n.d.).

There is also Nordiska Textilakademin (NTA), which offers higher vocational education. In close consultation with actors in the industry, NTA has the ability to respond to short term competence demand in the industry. NTA offers a number of courses, both educational programmes, short courses and company exclusive courses covering the roles in the industry, ranging from design to production. The courses are targeted at upskilling people already working in the industry, as well as those who are interested to work there in the future (Nordiska Textilakademin).

4.3.1.1 Gender Distribution

Both Nordiska Textilakedemin (NTA) and the Swedish School of Textiles demonstrate an unbalanced gender distribution. However, within the more technically focused programs at NTA, such as *Kvalitets- och produktutvecklare* (Quality and Product Developer) and *Textiltekniker/Processoperatör* (Textile Technician/Process Operator), male applicants make up a larger, though still minority, share. Specifically, men comprise approximately 20% of applicants in the *Kvalitets- och produktutvecklare* program and 17% in *Textiltekniker/Processoperatör*. These figures highlight a concentration of male students in technical fields, though they remain a smaller portion of the applicant pool compared to their female counterparts. NTA is actively working to increase their gender balance by specifically marketing their educational programmes towards men (Nordiska Textilakademin). Although there is a majority of women studying textile-related subjects, the predominance of women is not necessarily reflected on higher levels in the organisation among professors at the Swedish School of Textiles, or among actors in the textile system (Science Park Borås). In Europe, women represent 70% of all employees in the textile industry (Directorate-General for Environment, 2022).

4.3.2 Competence Demand in the Textile System

Future trends regarding competencies are identified in the textile industry, such as digitalization, sustainability, circularity and resource efficiency, as well as new business- and consumption models (Koszewska, 2018). Representatives from SMEs in the Swedish textile system express that there is a lack of competencies in these areas (Nordiska Textilakademin, et al., n.d.). The textile system in Sweden demonstrates a knowledge gap across various roles, including designers, buyers, production managers, and business leaders. Thus, this disparity results in inadequate consideration of sustainability in key decision-making processes (SOU 2020:72).

This can be explained by the fact that they lack knowledge in how to make strategic decisions based on climate data and circular value chains (Nordiska Textilakademin et al., n.d.).

Furthermore, technical competence of how to use digital tools may be needed across different roles in the textile system (Nordiska Textilakademin et al., n.d.). This includes roles within, for example, automated sorting for textile waste, AI-powered platforms for reuse, and to implement and maintain the Digital Product Passport (DPP) (Nordiska Textilakademin et al., n.d.). Digitalisation opens up for development of the secondhand market with data analysis of demand and the potential for match-making between products and customers. Producers have product data on all products that are introduced to the market which may allow for producers to create their own small-scale secondhand businesses. This way, the sorting step could eventually be passed by (RISE-a).

Research by Gangoda et al. (2023) on automation in another textile-related field, specifically in clothing manufacturing, highlights a risk that a knowledge gap may exist in academia, resulting in a workforce that lacks the necessary skills. Consequently, individuals in higher-level positions, such as designers, patternmakers, and technicians, possess insufficient technological proficiency. With an increasing degree of automation and digital tools, cross-disciplinary competencies may be required. With a higher demand for cross-disciplinary knowledge, a designer's role could, for example, mean to combine design expertise with skills in 3D prototyping, electronic devices in clothing, and other technology-related fields. As a consequence of the introduction of AI, concerns are raised about the potential loss of creative thinking processes amongst workers. AI could potentially replace tasks such as pattern making and designing, leading to a decline in core competencies and limiting further advancements of the processes. Nevertheless, industry experts interviewed in the study do not anticipate that AI will fully take over human creativity and the design process (Gangoda et al., 2023).

Similar to the research on automation in apparel manufacturing, the interviewees agreed that creativity may not become entirely replaced by technology. This could imply that realising the aesthetic potential for a textile, for example reusing parts of it in a new design is a competence needed in textile sorting **(**Wargön Innovation; Science Park Borås; RISE-a). Manual textile sorting is expected to remain crucial despite efforts to automate the textile sorting process and reduce manual labour. Textile sorting demands a high level of multi-disciplinary expertise and requires a flexible assessment by knowledgeable professionals with extensive understanding of fashion, trends, and materials (SOU 2020:72). When sorting for reuse, there might be clothing that has a low potential for reselling in its current state, but through using the material, it can be redesigned to appeal to the consumer. By having creative skills, the sorter can visualise the potential for a material to be used in redesign, thus hindering the textile product from being passed on to lower levels in the waste hierarchy (Science Park Borås). Thus, a new textile sorting process may require the need for creative competence to work with garments instead of fabrics as raw material (Sandvik and Stubbs, 2019). A more varied material flow entails the need for organisational competence, including communication ways and mandate to make decisions (Nordiska Textilakademin et al., n.d.).

4.3.3 How to Meet the Competence Demand

To enable effective textile sorting, future competence demands require education and training (SOU 2020:72). Inspiration for how to develop training for workers within automated textile sorting processes may be found in clothing manufacturing. With increasing automation and digitalization, there is a need for workers within clothing manufacturing to improve hard skills to be able to operate new machinery and software. Key elements in designing training programs were to enhance skills and motivate employees to excel in their field. In the case of apparel manufacturing, there is a habit of introducing new technology casually, leaving most of the learning to the individual. It has also been shown that it is necessary for people conducting the training to understand how the machinery and software is used practically, to respond to field-specific questions by workers (Gangoda et al., 2023).

When introducing a new technology, early involvement of the workforce is necessary to study the usability of the technology. This can be done through a participatory approach to the implementation of digital technology, adapting the system in iterative loops for target groups, such as machine operators (Gries et al., 2022). It may be of importance to adapt the digital technology to the operator. Older, more experienced workers may face challenges in meeting the increasing demands for digital skills, whereas younger workers often adapt more readily. The report emphasizes the importance of lifelong learning, recommending that workers continuously update and expand their skill sets. This involves not only enhancing existing competencies but also acquiring new skills that align with evolving technological requirements (Directorate-General for Employment, Social Affairs and Inclusion, 2024). Furthermore, peer-to-peer learning, since it requires little time and budget, so that subject-related problems can be solved with relevance to the field and with more productive engagement (Gangoda et al., 2023).

Today, learning is occurring internally through knowledge-sharing in SMEs in Sweden, and learning-by-doing in collaboration with customers and suppliers. Emphasis on professional learning. Learning also happens with the help from, and hosted by, an external part (Nordiska Textilakademin et al., n.d.).

A broader challenge lies in the tendency of companies to offer training to their workforce in response to immediate needs, as indicated in both apparel manufacturing and the textile system in Sweden (Gangoda et al., 2023; Nordiska Textilakademin et al., n.d.). Research has indicated that this approach has resulted in a gap in basic digital skills amongst workers in apparel manufacturing. The limited skill training is a consequence of limited time and budget, as well as the access to specialists who are knowledgeable in both the technology and the subject matter (Gangoda et al., 2023). The companies in the study have problems identifying the competence demand, and especially acting on the demand identified. This may be explained by the fact that small companies have limited resources and time to work strategically with competence demand. This often leads to a response to external change reactively, and a short-sighted perspective expecting immediate return on competence investment (Nordiska Textilakademin et al., n.d.). Instead, it is necessary to engage in lifelong learning to improve existing skills, as well as training to gain new skills (Directorate-General for Employment, Social Affairs and Inclusion, 2024).

Furthermore, training does mostly not include how functions may change over time, leaving employees unprepared for the future. To equip the workforce for further technological change, training should include information about how functions may evolve over time and how automation and AI may impact their role, motivating and guiding employees to prepare for the future. Unskilled workers face a substantial risk of job displacement due to their potential inability to meet the competency demands associated with emerging technologies. The future technical and computer skills required of workers in clothing manufacturing are expected to fluctuate, given their limited capacity to transition to roles that may also become automated. This transition indicates a gradual reduction in the number of human workers, ultimately progressing towards full automation. As mentioned before, it is important to focus on cross-functional competencies, such as learning to work with a variety of digital tools**.** It is important for workers to develop multiple skills to increase the flexibility to shift job function if their current role is threatened by AI. However, leaving the responsibility solely on the employee is not considered a sustainable solution, as it can pose challenges for employees and is perceived as unfair to require individuals to dedicate their own time to uncompensated job training (Gangoda et al. 2023).

The automation of textile sorting processes presents both challenges and opportunities, particularly for vulnerable groups who may face increased job insecurity (RISE-a). Although skilled operators will remain essential for sorting based on the waste hierarchy, automation could reduce overall labor demand within textile sorting (Texaid, n.d.). However, new opportunities of basic roles may emerge with new technology within the circular transition, such as semi-automated repair in stores for minor repair tasks. These roles will likely require workers to develop new skills to be able to operate these kinds of tools. Repairing clothing is a crucial component of a circular textile system, but currently a barrier since it is considered costly in comparison to purchasing new items. With emerging regulations and technological development, this approach may shift, making repair services more accessible and economically viable (RISE-a).

4.3.4 Automation and its Impact on Gender Balance

As mentioned before, a majority of employees in the textile industry in Europe are women. A report notes the need for increased gender balance on leadership positions in the textile industry (Directorate-General for Employment, Social Affairs and Inclusion, 2024). Following the financial crisis in 2009, as well as the covid-19 pandemic, research reveals a reduction of female employment in most industries, including the textile industry, in Europe (Anzolin, 2021; Barba & Iraizoz, 2020). Industries using more labour-intensive technology employ a larger share of women and technological change was the main contributor to a reduction in female employment opportunities, primarily attributed to increased productivity. During the recession, output growth exceeded employment growth in most industries, thereby requiring each worker to produce more than previously. In order to achieve gender equality, more men need to be employed in female-dominated industries, and vice versa (Barba & Iraizoz, 2020).

With increasing automation, some machines may eventually substitute labour but more often, machines substitute tasks, causing the jobs to change. The more routine a job involves, the more likely it is to be fully automated. From a European perspective, women tend to engage more in repetitive and routine tasks, and less likely to perform tasks that imply analytical input or abstract thinking. High skilled workers working with complex tasks are less likely to be substituted by technology and are most often complementary to the process of technological change. Thus, technological development shifts the demand to favour high skilled workers required for the introduction of new technology. This leaves women at a disadvantage on the job market, since women are underrepresented among STEM (Science Technology Engineering and Math) students, which can be explained by cultural and historical barriers, leading to missed opportunities in being involved in the technology transition (Anzolin, 2021).

Automation and large-scale textile sorting may change the gender balance. One example in the textile sorting process is the presorting, which currently lacks technological maturity and relies heavily on individual skills and expertise, thus limiting its potential for standardization (Sandberg & Pal, 2024). Developing this step of textile sorting with new technology could benefit the role by easing the physical burden on workers and enhancing efficiency (Björkåfrihet). Ultimately, facilitating work tasks through technology could broaden the range of workers capable of performing specific tasks, ultimately promoting a more diverse workforce (RISE-b). At Björkåfrihet, the gender distribution in the textile sorting process is currently 77% women and 23% men (Björkåfrihet). People motivated to work with textile sorting, both at Björkåfrihet and Wargön, are mostly women with an interest or background in the textile and fashion industry (Björkåfrihet; Wargön Innovation). Over the past 1.5 years, the interviewee from Björkåfrihet has observed a rise in the number of men interested in roles within textile sorting. This trend may be linked to the organisation's shift towards a more industrialised approach to benefit from economies of scale to increase efficiency (Björkåfrihet).

4.3.5 How to Attract Workforce

Moreover, research suggests cross-industry collaboration to address the slow adoption of technological development. Over the past decade, technological advancements have been minimal in clothing manufacturing and current technological development remains unsatisfactory both in developed and developing countries, with cost and accessibility mentioned as primary barriers. In the case of clothing manufacturing, it is suggested to attract workforce from other industries, such as the automotive industry or data analysts, who lack familiarity with the manufacturing process, and can contribute with new perspectives and foster innovation (Gangoda et al., 2023). However, the textile industry is described conservative in comparison to innovative and future-oriented industries, such as software and entertainment industries worldwide, thus creating competing interests between different industries to attract the workforce (Gries et al., 2022).

With the new technology being developed, and a change in the regulatory landscape, interesting career opportunities may be created. Following the mandatory collection of textiles for instance, the number of jobs created is estimated to be between 20 and 35 for each 1000 tonnes of textiles collected for reuse (Directorate-General for Environment, 2022). Attracting people to work in the textile system, work tasks should be considered interesting (RISE-b). Developing new technology may to some extent allow for humans to decide what processes to automate and what tasks that are interesting for humans to work with (Wargön Innovation). To make the work more interesting, career steps could be developed for employees who are experts in the core skills, to become proficient in the technology (Gangoda et al. 2023).

In the EU, fashion design jobs are popular amongst younger professionals while manufacturing and shop-level jobs are generally not viewed as attractive career choices. In comparison to other sectors within the EU, the textile industry is above average affected by demographic change due to an aging workforce. To attract younger people into the textile industry and secure the demand for workforce, it is needed to reconsider the image of the industry connected with environmental destruction, shallowness, and lack of value-adding activities in society (Directorate-General for Employment, Social Affairs and Inclusion, 2024). Also, textile sorting as a profession has low status in relation to the national ambitions in Sweden for sustainable treatment of textiles (SOU 2020:72). In terms of textile sorting, it may be necessary to analyse how the work is perceived by potential employees. The perception of a workplace may also differ between men and women, thus the need for reflection on how to shape the workplace to attract both, for example by analysing gender codes. In general, it has been easier to attract workforce to high-status jobs which traditionally are found in male-dominated industries, thus easier to attract women to male dominated industries than vice versa. It can be a good idea to think of how to attract people to work in the industry. Often, it is easier to attract women to male dominated industries (RISE-b). Men may enter a textile sorting company through starting to work in the warehouse and subsequently have the possibility to explore other internal job opportunities. By shifting focus from fashion and trends and putting emphasis on other parts of textile sorting, there may be potential to attract a more diverse workforce (Björkåfrihet; RISE-b).

5 Discussion

This study aimed to contribute to an understanding of how a transition towards a circular economy of the textile system may affect the competence demand and gender distribution in Sweden, with a focus on the textile sorting processes. The results presented in the previous sections indicate that automation is becoming increasingly prevalent in the textile sorting process, especially in sorting for recycling quantities. Subsequently, the role of humans is expected to shift and will likely create demands for new competencies across the system. While some tasks in textile sorting will be automated, humans will still be needed for complex decisions requiring creative and technical expertise, particularly in areas like textile reuse, where creativity can contribute to identifying new uses for materials. With new technology being introduced, technical skills are expected to become essential as workers will need to use digital tools to enhance decision-making in the textile sorting process and adapt to new technologies. This transition also emphasizes the importance of continuous learning and cross-functional skills, as the textile system may demand a workforce capable of using both manual skills and digital tools. Recruiting competencies from other fields may bring new perspectives and technology knowledge into the textile system, benefiting the technological development in the textile sorting process. In addition, early involvement of workers in technology development could facilitate smoother integration of new technologies, benefiting both employees and technology developers.

Following the introduction of new technology in textile sorting and the rest of the textile system, the results indicate that the gender balance in the textile system may shift. Potentially, introducing new technology such as automated textile sorting may lead to a more balanced gender distribution as traditionally male-dominated fields like technology and engineering intersect with the female-dominated textile industry. Thus, more men may be expected to be involved in the industry since they are overrepresented in STEM-subjects. This may lower the threshold for other men to enter the industry. However, to increase gender equality, both men and women are needed at several levels of the organisation, implying the need for more women in STEM-related subjects working with technological development as well as more men working with textile sorting. During the interviews, fashion was mentioned as a motivator to work in textile sorting, which could inspire women to seek out opportunities within technology development. Also, becoming a more industrialised workplace, more men may seek to work there.

The relevance of textile sorting is likely to increase over time as the EU regulations affecting the textile system may trigger changes in aspects such as design, consumer behavior, and technological development, leading to changing roles in the textile system. With new technologies facilitating the textile sorting process and enhancing transparency throughout the textile system, the role of textile sorting actors may evolve. Today, textile sorting can be considered a one-way flow from the producing companies to the sorters. Hence, the textile sorting actors have little influence over the inflow. For the system to become economically viable, there is a need to increase collaboration in order to create efficient material flows between actors. The technology that can be used in the textile sorting process may open up for sharing in collaboration with other actors involved in the textile system. Actors affected could include, for example, producers of products to improve the textile products and process to enable a circular system. Eventually, through sharing information, textile sorting actors may have the possibility to influence the textile products produced, potentially increasing the circularity of the system. Textile sorting actors may work as the link between the input and output of textile products, enabling collaboration with multiple actors in the system.

Possibly, if sorted textile products and textile waste are becoming more accessible to other actors, the textile sorting may be faced with the challenge of trade-off between sorting according to the waste hierarchy or meeting the demand for sorted textiles, challenging the circularity of the system. If the demand for used textile products rises, producers may be motivated to establish their own take-back initiatives, which could compete with the volumes required to scale up automated sorting technologies. Therefore, technological advancements in textile sorting, coupled with the upskilling of workers in the textile sector, can help mitigate negative environmental and social impacts. However, the development of efficient textile sorting processes should not be a justification to continue overproducing textile products.

These findings contribute to foresight of the textile system in Sweden, inspired by the technology assessment method. This kind of foresight might guide decision makers in anticipating, preventing, and preparing for unintended consequences of transitioning to a circular textile system, particularly regarding the implementation of automated textile sorting. On a societal level, efficiency of material flows can be improved as a result of circular handling of textiles materials. Improved textile sorting processes have potential to benefit other industries by providing high-quality recycled materials sorted and classified for specific applications, thereby reducing the reliance on virgin materials.

The method was designed as a literature study in combination with exploratory interviews and inspired by a Technology Assessment method. Due to limited prior research regarding competencies needed in an automated textile sorting process, interviews were conducted. Since there is currently no circular textile system in Sweden, the interviews were designed in an exploratory approach, to gain an understanding of how the future textile system might be shaped. The interviewees who participated in the interviews were assigned by RISE, leading to access to a network of actors in the textile system in Sweden. Thus, the interviewees were chosen since they are part of the development of a circular textile system, knowledgeable in their field or considered experts in Sweden.

To a large extent, this study is based on grey literature. Due to limited research on this topic, the literature study considers somewhat few scientific articles in comparison to the number of grey literature such as reports. The literature study could have benefitted from being narrowed, while the interviews could have been expanded to include more actors to gain additional perspectives. Furthermore, the interviewees could have been chosen by mapping actors according to the Technology Assessment method which potentially could have covered a larger and more diverse selection of actors in the textile system. This may have led to more variation in interview data.

For future research, it is recommended to explore how a circular textile system in Sweden and beyond can be enabled. More specifically, continuing to explore the role of the workforce within automated textile sorting processes. This could include exploring how the roles of textile sorters may evolve with the introduction of new technologies, as well as how other actors in the system can support efficient use of these technologies. Moreover, the number of workers required for the textile sorting process in Sweden remains uncertain due to the system transition. Consequently, it is necessary to investigate and assess the scale of the workforce needed in order to determine the recruitment and training requirements. Furthermore, investigating examples from other industries that have undergone a transition towards automation and addressing how they managed changes in competence demand could provide valuable insights. The global context of the textile system suggests that future research could benefit from adopting a broader systems perspective. Expanding the scope to include a wider range of actors in a global context, both within and outside the textile system, would offer a more comprehensive understanding of how circular material flows can be achieved in society.

6 Conclusions

Textile sorting is expected to become more automated but the need for manual sorters in the meantime may increase. This need can be explained by the low technological maturity of automated textile sorting technologies in combination with the mandatory separate textile collection to be introduced in January 2025. Although textile sorting is becoming more automated, creative competence may become more important. When sorting for reuse, creative competence can be helpful in order to visualise the potential for a textile material, for example to use garments as raw material when creating new products.

Throughout the textile system, technical competence is key. Technical competence may include knowledge of how to use digital tools that can facilitate decision making in both the textile sorting process and other parts of the textile system. Continuous learning is necessary to not be surpassed in terms of new technology. In addition, cross-functional skills are crucial to navigate in a changing industry, for example teaching manual sorters how to use digital tools. When developing new technology, early involvement of the workforce is an advantage for both workers and technology developers for adapting the technology. To stimulate innovation and technological development, recruiting people from other industries may be favourable.

Furthermore, the gender distribution in the textile system may change. The technological change in the textile system might imply a more equal gender distribution in the future, but not necessarily gender equal. Since there are currently more women in textile sorting and generally more men working in STEM-related fields, working to increase the number of male textile sorters and female technology developers may contribute to gender equality in the textile system. It has been noticed within textile sorting that by becoming more industrial, more men are attracted to the work. In addition, women working with textile sorting are sometimes motivated by their interest in fashion, which eventually could serve as an introduction to STEM-subjects in order to work with technology development in the textile system. Finally, to achieve this, actors within textile sorting as well as actors in other parts of the system may need to reflect on who they want to attract and how to bridge the gap between the image of their business with the preconceptions held by potential workers.

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Appendix

Interview questions

What may the future textile system in Sweden look like?

- What is the status of the technological development? For example, maturity level.
- What kind of technology is needed?
- Who are the actors in the textile system?
- What may the collection and sorting processes look like?
  - In which steps may technology be implemented?
  - Current bottlenecks?
- Roles within textile sorting?
- Degree of uncertainty regarding the technological development?
  - Time horizon? Manual labour vs automation of the textile sorting process.

Which competencies may be needed within textile sorting in a new (circular) textile system in Sweden? How can the competence demand be met?

- What competencies/skills will be needed for the individual to efficiently be able to sort textiles with new digital tools?
- How may other roles within the system facilitate the textile sorting process?

How can the competence demand be met?

- How to educate?
  - How could education be developed?
  - How may the new EU directives influence development of education?
  - Current gender distribution?

How may gender distribution be affected by the change of the system? How can equal gender distribution be enabled?

- Current gender distribution?

  → If imbalanced gender distribution:

  - Enablers?
  - Barriers?

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