Sustainable clothing futures

Mapping of textile actors in sorting and recycling of textiles in Europe

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Textile, reuse, sorting, recycling, clothes

Preface

This report is part of a series of reports in the project *Sustainable clothing futures*, a project with four partners: IVL Swedish Environmental Research Institute, Profu, Lund University and the Swedish School of Textiles, funded by Formas. This report has been written by IVL Swedish Environmental Research Institute and is one deliverable in WP2 *Production and recycling*. Upcoming deliverables are a Life Cycle Assessment (LCA), a multi-dimension synthesis and a peer reviewed article on LCA.

With kind regards,
IVL SWEDISH ENVIRONMENTAL RESEARCH INSTITUTE.

Maja Dahlbom

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Sammanfattning

Konsumtionen av textil är kopplat till flera miljöproblem, inte minst slängs det onödigt mycket användbara textilier som hade kunnat återanvändas eller materialåtervinnas. En europé slänger i genomsnitt 11 kg textil årligen. Syftet med denna rapport, som en del av forskningsprojektet *Framtidens Hållbara Kläder*, var att kartlägga aktörer som arbetar med sortering och återvinning av använda textilier inom den Europa. Kartläggningen av aktörer gjordes genom litteratur- och marknadsstudier. Ytterligare information om aktörer och dess kapaciteter erhölls från enkäter, som skickades till samtliga kartlagda aktörer, samt genom intervjuer med sex utvalda aktörer. Totalt identifierades 12 sorterare och 33 återvinnare, med kapaciteter på 560 000 ton respektive 1.3 miljoner ton per år. I intervjuerna framkom det flera utmaningar med sortering och återvinning av textil, bland annat att klädesplagg idag ofta består av flera olika fibertyper, något som dagens teknik för sortering och återvinning har svårt att hantera. Intervjuerna belyste dock att det finns stor potential för att öka återvinningen, förutsatt att det finns kvalitativt material på marknaden. Från 2025 ska textilier börja samlas in separat inom Europa, vilket troligen kommer öka de tillgängliga mängderna textil för sortering och återvinning. Tillsammans med ökad insamling och teknikutveckling, med möjlighet att separera olika fibertyper, skulle mer textiler kunnat återvinnas inom Europa i framtiden.

Sökord: framtidens hållbara kläder, textilsortering, textilåtervinning, Europas textilindustri

Abstract

The consumption of textiles is linked to several environmental problems, not the least the amounts of reusable textiles that are discarded, which could have been reused or recycled. Europeans discard on average 11 kg of textiles annually. The aim with this report, as a part of the research project *Sustainable clothing futures*, was to identify European actors working with sorting and recycling of textiles. The identification was conducted through literature and market studies. Additional information regarding actors and their capacities were obtained from questionnaires, which were sent to all identified actors, as well as through interviews with six selected actors. A total of 12 sorters and 33 recyclers were identified, with capacities of 560 000 tons and 1.3 million tons per year, respectively. In the interviews, a couple of challenges were identified, one of them being that today's clothes often consists of several fibre types, something that is difficult to manage with today's sorting and recycling techniques. However, the interviews highlighted that there is great potential for scaling up, given that there is high quality material on the market. From 2025, all member starts in the EU shall provide separate collection for textiles, which most likely will increase the amounts of textile available for sorting and recycling. Increased collection and technological development, with the ability to separate fibre types, more textiles could be recycled within Europe in the future.

Keywords: sustainable clothing futures, textile recycling, textile sorting, European textile industry

Introduction

The clothing sector of today is characterised by linear supply chains, low use rates, fast fashion trends, high resource use, and large environmental impacts. Between the years 2000 and 2015 the total production of clothes doubled. Also in the same time period, the number of times a garment was used before thrown away decreased by 36 percent (Ellen MacArthur Foundation, 2022). In the European Union there are approximately 171 000 companies in the textile industry, employing 1.7 million people (European Environment Agency, 2021 a). Europeans consume on average 26 kg of textiles, and discard about 11 kg of textiles per person and year. In 2018 only, the domestic textile production of the EU-27 was nearly 1 million tons together with an import of 5 million tons from China, Turkey, Bangladesh, and India as the most important trade partners. In the same year, the amount of separate textile waste collected was estimated to be 1.6-2.5 million tons in EU-27, which is a third of the amount of textile put on the market. The remaining two-thirds are either stocked, incinerated or landfilled (European Environment Agency, 2021 b).

Textiles can consist of synthetic fibres, natural fibres or manmade cellulosic fibres (MMCF). Since the mid-1990s, synthetic fibres have dominated the global market. In 2020 the total fibre production was 109 million tons, of which 68 tons were synthetic fibres (62 percent). Synthetic fibres are polyester, polyamide, acrylics, elastane, polypropylene. Polyester stands for the majority of produced fibres globally, with a market share of 54 percent in 2021. Natural fibres including cotton, wool, silk, down and other plant-based fibres like linen and hemp had a market share of 30 percent of the total fibre production in 2021. Out of the natural fibres, cotton is the most common and was the second most produced fibre, after polyester, in 2021 at 22 percent. MMCF (viscose, acetate, lyocell, modal and cupro) stands for only 6 percent of the total fibre production. (Textile Exchange, 2022)

To produce clothing there is a great need for resources: water, land, raw materials and chemicals. To produce one cotton shirt takes 2 700 litres of water, the same amount one person drinks in 2.5 years (World Resources Institute, 2017). The textile industry (including footwear and household textiles) comes in fourth place regarding the use of primary raw material and water in the supply chain (after food, housing, and transport) according to European Environment Agency (2021 a). Looking at the pressure on land use, the production of textiles is the second highest, after food. Regarding greenhouse gas emissions, it comes in fifth place. Estimations have been made saying that 20 percent of the global water pollution is caused by dyeing and finishing textile products. Many of the used chemical in textile production are classified as hazardous for human health and for the environment. Following the production there is environmental impact of distribution, retail, transport, laundry, discarding and the following sorting or waste management processes of the textiles (European Environment Agency, 2021 a).

According to the Waste Framework Directive (2008/98/EC) waste, including textiles, shall firstly be prevented, and secondly prepared for reuse, hence the need for reuse of textiles is large. A majority (50-75 percent) of the collected textile waste could be reused, either within the EU or outside of the EU (European Environment Agency, 2021 b). Less than 1 percent of the collected textiles are currently recycled into new clothes according to Ellen MacArthur Foundation (Ellen MacArthur Foundation, 2017). The remaining part of the collected textile waste is either downcycled into insulation or filling material or end up in the residual waste stream where they either get incinerated or landfilled (European Environment Agency, 2021 b). McKinsey have estimated that 70 percent of the textile waste (reuse excluded) in Europe can technically be fibre-to-fibre recycled by 2030. But, as many textiles consist of mixed fibre types, technologies must improve to be able to recycle 70 percent of this material (McKinsey & Company, 2022).

Textile waste can be divided into two categories: pre-consumer waste and post-consumer waste. Pre-consumer waste refers to textiles waste generated in the manufacturing, operations, and distribution processes. Pre-consumer textile waste also includes unsold pieces of clothing. Post-consumer textile waste refers to used textiles, which have been discarded by the consumer (Riemens, Lemieux, Lamouri, & Garnier, 2021). Today there is no standardised mapping or classification methodology for reporting textile waste in the EU, furthermore there is no requirement for the member states to report their textile waste.

Reducing environmental impacts from textiles while maintaining economic and social benefits calls for a systemic change toward circularity. New solutions and practices for producing, using, reusing, and recycling clothes need to be developed, that can contribute to more efficient resource use and reduced negative environmental impact. The scale up of new technologies, business models, and practices for sorting and recycling of textiles will contribute with knowledge about the textile value chain in Europe and create the need for new professions such as pre-sorting, upgrading and repair services, recycling engineers, and remake designers.

Objectives and scope

The study has two main research objectives, listed as follows:

- Identify and map European actors in the textile sorting and recycling industry, as well as to further study current capacities and future scaling projections of selected actors in depth.
- Identify emerging initiatives globally, focusing on innovative collection methodology, automated sorting development, and novel recycling technologies.

The research will be conducted via a literature and market study, seeking to identify technical feasibility/scalability, financial competitiveness, market, consumer and society acceptance, resource use and climate impact, etc. of the identified actors and initiatives. The literature and market study will be followed by interviews with selected key actors in sorting and recycling of textiles, giving in-depth information about their technologies and possible future scaling.

Also, by mapping current value chains, the study seeks to create understanding regarding the willingness and ability to source recycled materials and fibres more locally for each market. The interviews will be used for following system dynamics modelling (included in an upcoming delivery within the project), and to gauge the market and scalability potential of the operations and emerging initiatives from the perspective of the industry. This report also strives to initiate the creation of a life-cycle inventory (published separately) for at least one of the technologies that, in turn, will enable a comparison of recycling and virgin production in terms of resource use and environmental impact.

The scope of this study is post-consumer-textiles, and for recycling the scope is fibre-to-fibre-recycling. Regarding the mapping, the scope is actors in Europe, which also have their main operation in Europe. Downcycling of textiles or recycling of other materials than textiles (PET-bottles for example), as well as pre-consumer-textiles, is outside of the study’s scope.

Background

A textile garment or product becomes waste when "the holder discards or intends or is required to discard"[1] the garment or product. The textile waste can either be "pre-consumer" or "post-consumer", and therefore handled in different waste streams. Recycling of post-consumer waste textiles is done in three steps. Firstly, the textile material is sent to a textile collection point by the consumer, which then is collected by a collection-actor for example a charity, distributer, or retailer. Secondly the textile waste is manually sorted into different categories depending on if the textiles are possible to reuse. The third step is sorting for recycling, which can be done automatically and manually. The sorting is based on fibre composition. Following step include further manufacturing (e.g., weaving, sewing, etc.) (Textile Exchange, 2021). In the following sub-sections, summaries are given of the different steps, which covers the textile value chain from collection to recycled material in the three main steps: collection, sorting and recycling. Note that this report divide collection and sorting into two different steps, as it may not be performed by the same actor.

Textile recycling in three steps:

1. Collection
2. Sorting (manual, automatic)
3. Recycling (mechanical, chemical, thermal)

Collection

In the EU, textile collection has mainly been initiated by charities and commercial actors. Municipalities have recently carried out collection for textiles as well. The collection system often includes bring banks, which can be placed public ground. Over the counter collection at retailers or secondhand shops is also a common collection system. The actors require the collected textiles to be clean and re-wearable to able to sell the textiles on the global reuse market (Köhler, et al., 2021). According to Köhler et al (2021) the best 10 percent in quality of re-wearable textiles provides over half of the economic value of a typical bag of donated textiles.

In 2018, the amount of collected textile waste was estimated to be 1.6-2.5 million tons in EU-27, which is a third of the amount of textiles put on the market. The

[1] According to the definition in the Consolidated text: Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives (Text with EEA relevance).

amount of textile waste is likely to be higher since the amounts of textile in the residual waste is not included (European Environment Agency, 2021 b). In a couple of years, the situation should have changed and most likely there is a better overview of the amounts since all member states are obliged to set up a separate collection for textile waste by 1st of January 2025, according to the Waste Framework Directive[2] (European Parliament, 2020).

Sorting

The sorting of post-consumer-textiles is a vital process as the material needs to be assessed based on its reuse potential. Generally, manual sorting and automatic sorting have different purposes, as manual sorting tends to sort primarily for reuse and automatic sorting primarily for recycling. Textiles for reuse need to be assessed manually to control the quality. Textiles for recycling need to have a known fibre composition, since there are requirements of fibre composition of the inbound material to the recycling process. (Watson, et al., 2020).

Today, most textiles are sorted manually as few actors with automatic sorting techniques exists on a larger scale (Köhler, et al., 2021). Although, it is most likely that manual sorting will remain a first step in the processing of textile waste in the future as reuse has a greater economic value as well as more environmental benefits than recycling. While a manual sorting personnel can sort 100-150 kg of textiles each hour, an automated technique can sort 900-1500 kg per person and hour. When garments or textile products are found non-reusable, they are put into different material categories, which either will be sent to material recycling or energy recovery. To get economic value in the recycling of textiles, except better recycling technologies, there is a need for sorting technologies that can sort textiles by fibre type and colour. (Köhler, et al., 2021) While the quantity of textile that is collected is expected to increase, the percentage that can be reused is decreasing, since the number of reusable garments is predicted to stay at present level. (ECOTLC, 2020).

Within EU, member states must have a separate textile collection from 2025, however, no requirements for textile reuse or recycling have been stipulated yet (Interreg North-West Europe Fibersort project, 2019).

[2] Directive 2008/98/EC on waste, as amended by Directive (EU) 2018/851 of the European Parliament and of the Council of 30 May 2018.

Manual sorting

Manual sorting of textiles refers to when textile is being sorted by hand, by feeling the materials and reading the labels (ECOTLC, 2020). In manual sorting the need for highly trained staff is crucial, it takes months to train staff to sort the textiles rapidly in categories based on type, size, style, and quality. Many sorting facilities sort the textiles in over a hundred different categories for reuse in different markets. A lot of the manual sorting of European textile waste is carried out in the Baltic States and Eastern Europe, where the labour cost is lower than in western Europe (Watson, et al., 2020).

Automatic sorting

Automatic sorting technologies enables faster and more precise sorting, compared to manual sorting. The spectrometer is an instrument that analyses the material composition via electromagnetic waves, and interactions and measurements of the wave and chemical structures. A spectrum is created which represents the sample's chemical structure. This calls for a library of material samples and can include sorting categories such as pure material (100 percent cotton), mix of material (40 percent / 60 percent cotton/polyester) or family materials (cellulose fibres). The most common spectrometer is the spectroscopy using near infrared light (NIR). It has been deemed the most relevant technology today, which uses near infrared light to differentiate materials. The technology has previously been used quite a lot within other waste process industries, as is thus already compatible with the operating conditions found in waste sorting. Other technologies include raman, mid infrared, terahertz, and nuclear magnetic resonance. However, these have been deemed more expensive and less research have also been conducted (ECOTLC, 2020).

Recycling

Recycling is often defined as the processing of waste material for the original purpose or other purposes, excluding energy recovery and reuse (Textile Exchange, 2021). Textile recycling, in turn, often refers to the reprocessing of pre- or post-consumer textile waste for usage in new products (Sandin & Peters, 2018). The terminology differs, and several methods and ways of categorising currently exist when discussing the topic of textile recycling (Sandin & Peters, 2018) (Textile Exchange, 2021). Typically, textile recycling can be divided into *mechanical recycling*, *chemical recycling*, or *thermal recycling*, with the latter being less common. Mechanical recycling includes unravelling (with or without purifying) or cutting and griding. Thermal recycling includes thermo-chemical or thermo-mechanical and chemical recycling include either polymer or monomer recycling (Duhoux, et al., 2021). This is arguably a simplification of reality, as many recycling processes contain a mixture of the three options (Sandin & Peters, 2018). Also, *biological recycling* is mentioned as a new and evolving process with very limited information; this study will focus on the former three technologies (Textile Exchange, 2021).

Another way to categorise material recycling is based on the nature of the disassembly of the material (Figure 1). For example, disassembling of the textile product and subsequent use of the fabric in new products is called *fabric recycling* and disassembling of the fabric, where the fibres are preserved, is called *fibre recycling*. The fibre can also be dissolved into polymers, *polymer recycling*, or into even smaller bits, *oligomer* or *monomer recycling* (Sandin & Peters, 2018).

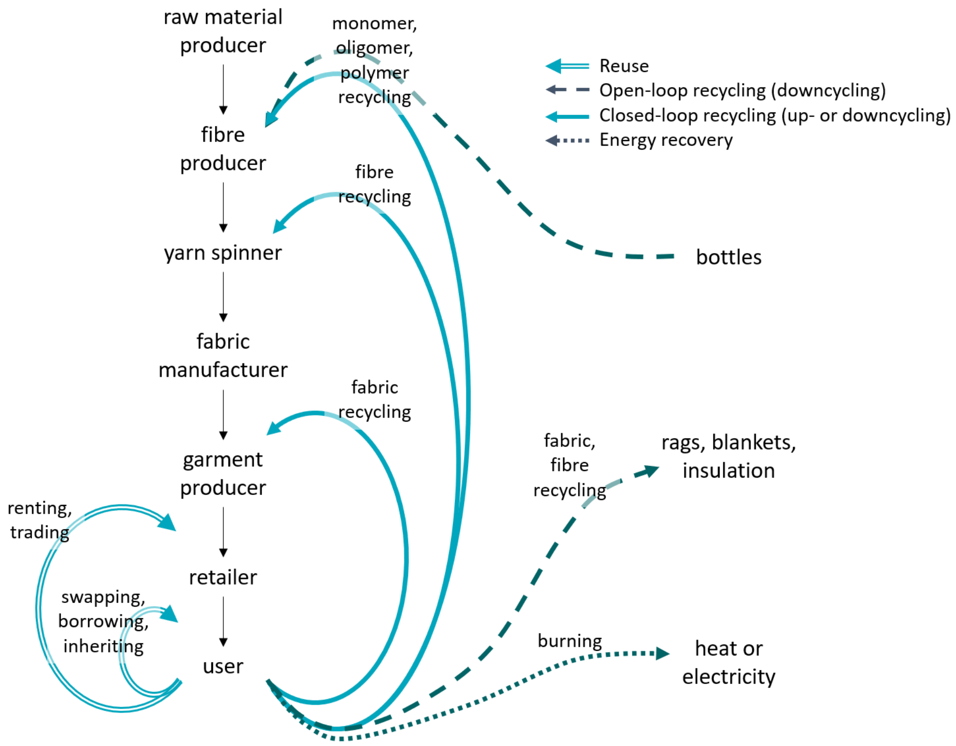

Figure 1. A classification of recycling and reuse in the textile value chain, adapted from Sandin & Peters (2018).

Recycling of textiles is often seen as a key solution to the problem with textile waste, which is reflected in the fast-paced innovative market of recyclers. Recently, the potential future recycling capacity of textiles in Europe was estimated to technically be able to recycle 70 percent of all textile waste by 2030. This can reduce the carbon footprint up to 90 percent for some fibre types (compared to virgin fibres), as well as reduce the land, water, and chemical use (McKinsey & Company, 2022).

However, it is important to remember that the first step of the waste hierarchy is even more crucial, i.e., minimise the waste creation by means of reducing the amounts of new textile products produced and consumed. According to the vision of the EU Textile Strategy[3], "By 2030 […] fast fashion is out of fashion, […]" which implies both overproduction and overconsumption must be reduced. Instead, the amount of textile being reused should rise, i.e., prolonging the practical service life of textile products by transferring them to new owners (Sandin & Peters, 2018).

Common recycling routes

Mechanical recycling is the more commonly applied recycling method and can be described as the shredding of textiles (also called *garneting, tearing, opening* or *grinding*). It means processing the waste without changing its chemical structure, e.g., via cutting of scraps and usually entails tearing and cutting materials into any size or shape. Common waste streams are both pre-consumer and post-consumer sources, while the latter is more challenging due to various fabric blends and colours (Textile Exchange, 2021). Before the textiles can enter the recycling process, all hardware such as buttons and zippers must be removed (Statens offentliga utredningar, 2020).

Chemical recycling, also called *advanced recycling and recovery*, is defined as technologies that return the textile waste to its basic chemical building blocks (Textile Exchange, 2021). It often refers to when the fibre polymers are depolymerised (when synthetic polymers) or dissolved (when cellulosic fibres). The material, now on molecular level, is then repolymerised and respun into new fibres. More often than not, the textile waste has undergone a mechanical pre-treatment step before reaching a chemical recycling process (Sandin & Peters, 2018). Chemical recycling can further be categorised as either solvent-based purification (turning plastic into a polymer state), chemical depolymerisation (turning plastic to monomers via chemical reaction), or thermal depolymerisation (also called *pyrolysis* and *gasification*, turning plastic into monomers and hydrocarbons) (Textile Exchange, 2021).

Thermal recycling is not to be confused with thermal recovery, i.e., when textile waste is incinerated for heat or electricity generation. Instead, thermal recycling often refers to the process of melting polyetentereftalat (PET), pellets, or chips into fibres. The pellets and chips have often been grinded into their shapes in a previous mechanical pre-treatment step, why this type of recycling is sometimes

[3] COM(2022) 141 final

categorised as mechanical recycling. (Sandin & Peters, 2018). Recycled polyester is commonly used in textiles today. In 2021, the production of recycled polyester was almost 15 percent of the total fibre production globally, of which most of the recycled polyester is PET-bottles based (99 percent). (Textile Exchange, 2022). However, this is not fibre-to-fibre recycling, since the input material is not textiles, and will not be covered in this report.

Applications

Currently, cotton and polyester are the two most common materials to recycle, followed by polyamide and wool. Recycling of these materials is found in both mature and emerging processes, some funded in early 1900. In the 1940s even more mechanical recycling processes emerged, and over the decades the number of mechanical recyclers increased, with the greatest increase between the years 2000-2019. The number of chemical recyclers was low during the 20th century, but they started to pop up from 1990 and increased in number (Interreg North-West Europe Fibersort project, 2020).

Method

The conducted study can be divided into two subparts, both conducted in 2022. Firstly, European actors within the sorting and recycling industry, as well as emerging initiatives globally, were identified and mapped via a literature and market study. Secondly, the literature study was followed by interviews with identified key stakeholders among the European actors.

Mapping of actors

Actors, in Europe and outside of Europe, were mapped via a literature and market review, along with complementary searches on the internet. Literature was retrieved from Google Scholar, as well as searches on the internet. Literature from 2015 and later were included. Examples of search words used were textile recycling, fibre-to-fibre-recycling, textile-to-textile-recycling, sorting of textiles. During the search and reading of literature, a snowball sampling was used to identify more actors. Examples of sources used included the overview of *End-Markets for Fibersort Materials* (Circular Economy, 2022) (mentioned in the application for this research project as Fibersort project (2020)) and Textile Exchange's *Preferred Fiber & Materials Market Report 2021*.

The relevant actors were listed in a document with information about their country of origin, processes, contact information, etc. The identified selection of stakeholders was then grouped based on their business category: manual sorting, automatic sorting, mechanical recycling or chemical recycling. After the initial mapping, a screening of the actors was done, and the list of actors was minimised. The screening excluded actors that did not work with post-consumer textiles or did not recycle textiles with the intention to make new textile (i.e., making textiles from PET bottles or downcycling textiles), nor actors working only with leather or down.

Interviews with actors

After completing the mapping of actors in Europe, a set of criteria was defined to facilitate the selection of actors for interviews. For all actors, the criteria of post-consumer-textiles as inbound material was applied as well as that the actor's main facility should be in Europe. For the recyclers one criteria was that the outbound material needed to be in a form that could become new clothes again (outbound materials that were downcycled into rags or other applications were excluded). This was based on whether the actors had a clear profile of fibre-to-fibre recycling. Also, actors involved in research projects on non-existing processes, or processes only existing on lab scale, were excluded from the interviews, as there were enough actors with processes existing on pilot or commercial scale to interview. Another aspect in the selection was to have actors from a variety of countries. Below follows a list of criteria for the different categories of actors:

- *Manual sorting actors*: actors that sort large amounts of textiles and work internationally.
- *Automatic sorting actors*: actors that use an automatic sorting process on a commercial scale or have plans to.
- *Mechanical recycling actors*: large capacity, clear fibre-to-fibre profile, focus on different fibre-types.
- *Chemical recycling actors*: large capacity, innovative process, clear fibre-to-fibre profile.

Based on these criteria, three actors in each category were chosen to approach with an interview request. A total of twelve actors were contacted. The actors were contacted by email. Out of twelve contacted, ten replied and six chose to further participate by being interviewed (Table 1). The interviews were held online over Microsoft Teams between 2022-09-14 and 2022-10-14. After the interviews the actors' answers were formulated into text which was sent to the interviewed actor for approval to avoid inaccuracies in the report. All the interviewed actors were informed about the purpose of the research project and that their data would only be used for this report. See Appendix A for interview questions.

Table 1. Interviewed actors.

Actor	Business	Country
Altex	Mechanical recycling	Germany
Boer group	Manual sorting	The Netherlands Germany
LSJH	Automatic sorting Mechanical Recycling	Finland
Renewcell	Chemical recycling	Sweden
Siptex	Automatic sorting	Sweden
Wolkat	Manual sorting Mechanical recycling	The Netherlands

The remaining actors, who were not chosen for an interview, were contacted and asked to answer written questions of fill out a table regarding their process and capacity (See Appendix A for questions and the table). Some actors did not list an e-mail address on their website, and were therefore not contacted. All the contacted actors were informed about the purpose of the research project and that their contribution would be anonymous. Out of 20 contacted (who had listed an e-mail address), 5 replied and 4 answered our questions. The capacities are included in the estimated capacities in section *Capacities* in the results.

Results

In this section, identified actors in Europe are presented, as well as examples of emerging global initiatives in collection, sorting and recycling of textiles. Results from the interviews are presented in the subheadings *Sorting actors* and *Recycling actors* under *Interviews*.

Mapping of actors in Europe

The mapping of key actors in Europe identified 43 actors. Nine of these are manual sorters, five automatic sorters, 25 mechanical recyclers, 10 chemical recyclers and one thermal recycler. Two actor was identified to work with both manual sorting and automatic sorting, two with both manual sorting and mechanical recycling, two with both mechanical and chemical recycling, and one actor with both mechanical and thermal recycling. The number of manual sorters is most likely higher, but due to lack of information about these actors, only twelve could be identified. See full table of identified actors in Appendix B.

The identified actors have been divided into two subcategories in the visualisation below: textile sorting (hand symbol) and textile recycling (recycling symbol) (Figure 2). Results show that Italy has the most sorting and recycling actors, of which a majority is mechanical recyclers. The Netherlands has second to most actors, with both manual and automatic sorters and mechanical and chemical recyclers. Only one thermal recycler could be identified, an actor based in Spain. Note that actors could be present in more than one country, and some actors work with more than one operation.

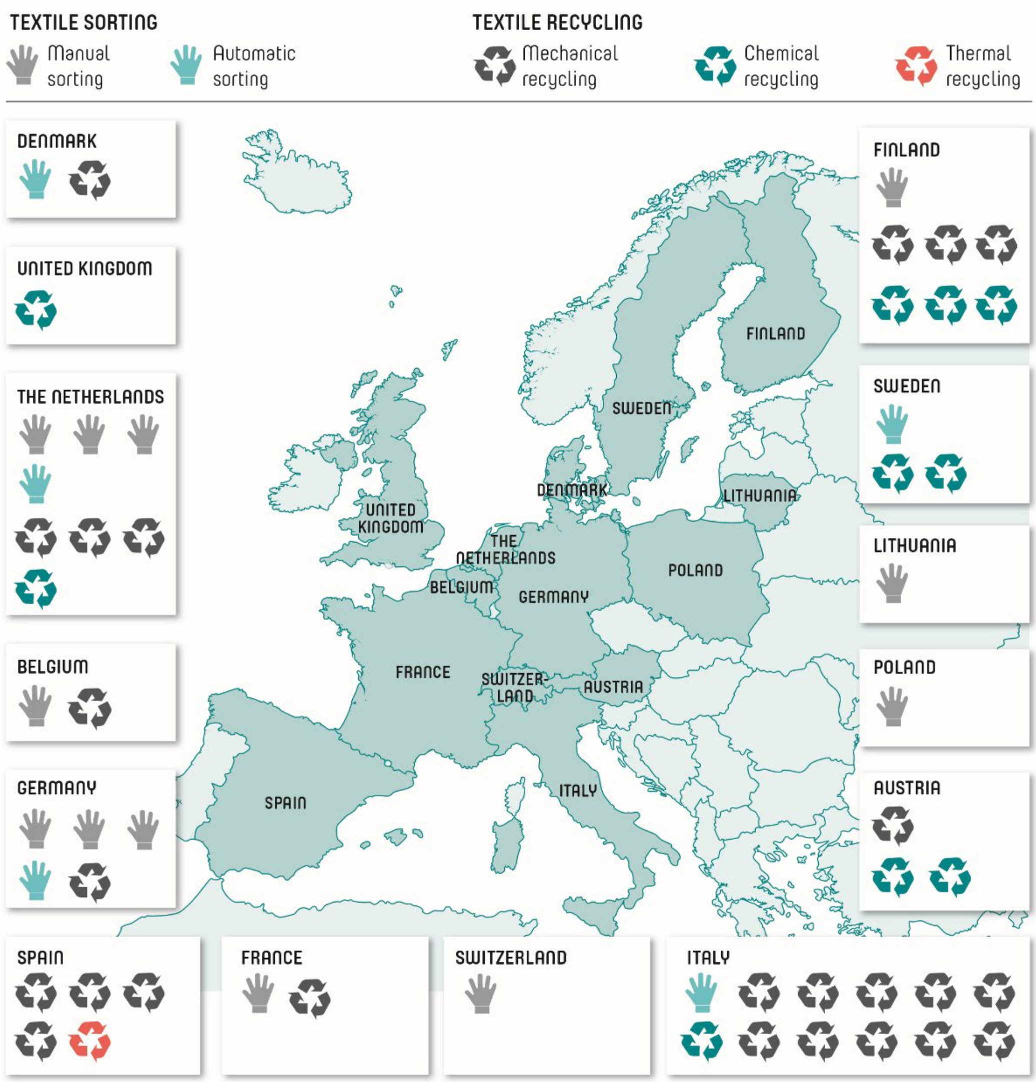

Figure 2. Visualisation of the mapped actors working with sorting and recycling of textiles within Europe (countries with a darker colour has one or more actor), with explanations of the different symbols and colours.

Collectors

The number of collectors varies greatly within each country in Europe, with both locally centralised collectors per each country (for example charities' containers and in-store collection), as well as some common stakeholders also working internationally (Human Bridge, Red Cross etc.). In the mapping of sorting and recycling actors it turned out that four of the identified sorting actors also work with collection of textiles: I:CO, LSJH, SOEX and TEXAID.

With the new European Union's Waste Framework Directive (European Commission, 2022), mandating that EU member states sets up separate collection for used textiles and garments by January 1st, 2025, the textile collection in Europe is also bound to change significantly within a few years. As such, this report will only briefly discuss the topic, giving more room for the other actors in the sections *sorting* and *recycling* below.

Few countries in Europe have a separate collection structure set up for textiles that is easily available for residents. One example of this is France, which has a national Extended Producer Responsibility (EPR) scheme for textiles and footwear that has been in place since 2007. The EPR obliges producers to provide for, or contribute to, the waste management of textiles and footwear that are placed on the market for consumers (Refashion, 2021). Additionally, The Netherlands will introduce an EPR on clothes from 2023. The responsibility will no longer be on the municipalities, as the manufacturers and importers will be responsible for collecting, recycling, reusing and manage the waste from the clothing placed on the market. Also, fashion chains will be responsible for the collection and recycling of discarded clothing (Netherlands Enterprise Agency, n.d.). Sweden has investigated a producer responsibility for textile waste collection. The investigation was submitted to the Swedish Government in 2020 and is currently under preparation by the Government's Office (Statens offentliga utredningar, 2020). With the new EU Directive requirement on separate collection of textiles, more countries are sure to follow in France's, the Netherland's and Sweden's footsteps.

Sorting actors

The Baltic States (Estonia, Latvia and Lithuania) imported over 90 000 tons of used textiles in 2018 for the purpose of sorting or processing. All three states are in the top five importers in Europe in terms of kg per capita: Lithuania at number one, followed by the Netherlands, Latvia, Estonia, and Hungary. A quarter of the amounts imported to the Baltic States came from the Nordic countries. All of the textiles imported for the purpose of sorting and processing are sorted manually (Watson, et al., 2020).

The mapping of manual sorting actors in Europe turned out to be difficult, due to absence of information regarding the actors on the internet. However, more could be found on automatic sorting. It is assumed that the number of manual sorters identified in this mapping therefore is significantly lower than in reality. According to Köhler et al. (2021) France alone had 54 manual sorting centres during 2018. One manual sorting actor that was identified in the mapping was VIVE Textile Recycling in Poland, which seems to be a large facility with a capacity to process 500 tons of textiles per day (VIVE Textile Recycling, 2019). Unfortunately, VIVE Textile recycling did not answer our interview request. One example of an automatic sorting technology is *Fibersort*, which is briefly presented in the textbox below. In this chapter the capacities for textile sorting are presented, followed by information regarding the interviewed sorting actors: Boer Group, LSJH and Sysav (owner of the Siptex facility).

Fibersort (automatic sorting)

About: The Fibersort Interreg North-West Europe project (2016-2020), also known as the *Fibersort project,* was funded by European Commission Interreg North-West Europe. The consortium consisted of six partners: *Valvan Baling Systems, Wieland Textiles & Smart Fibersorting, Circle Economy, Leger des Heils ReShare, Procotex Corporation,* and *Worn Again Technologies*. (Circle Economy, 2022).

Aim: To optimise, validate and launch the Fibersort technology (NIR technology) on a global market and map current and potential companies for the end-market of the Fibersort materials (compiled in an Excel-document, which has been used in the mapping in this report). (Circle Economy, 2022).

Fibersort technology: Can sort textiles made of cotton, polyester, acrylic, wool, viscose, and polyamide as well as blended combinations of the materials. (Interreg North-West Europe Fibersort project, 2020). The technology is used at the test and development facility *Wargön Innovation* in Sweden, where textiles are sorted for reuse, redesign, and recycling (Wargön Innovation, n.d. a).

Capacities

In the mapping of textile sorters in Europe, two identified actors work both with manual and automatic sorting. Capacities from seven actors could be identified. The capacities were gathered from the interviews, mail answers and/or the actors' websites or press releases (see Appendix C for references). The total capacity for the seven sorters sorting post-consumer textiles has been estimated to 560 000 tons per year from now to 2025, of which 230 000 tons will be automatic sorting. Important to note is that not all manual sorters across Europe have been mapped, and the estimated capacity for manual sorters is most likely significantly lower than the actual capacity, hence why the estimation is questionable. The estimated capacity is a lot lower than the estimated amount of collected textiles in EU-27, which is 1.6-2.5 million tons (European Environment Agency, 2021 b).

According to McKinsey's estimations, in 2022, around 2 million tons of post-consumer household textile waste is collected in EU (including Switzerland). Their data show that around 40 percent of the collected textiles is exported to outside of the EU. The rest (60 percent) enters manual sorting in the EU. Around 1.2 million tons textile waste enters the manual sorting to be resold, of which 0.5 million tons is not resold and therefore may be available for recycling (McKinsey & Company, 2022). For the future, McKinsey predicts an increase of gross textile waste due to higher GDP and higher collection rate, increased from 30 percent to 50 percent mainly due to the regulation of separate collection of textiles but also due to organised producer responsibility (OPR). They predict regulation will decrease the exports of collected textiles from 40 percent to 10 percent. McKinsey believes that the share of textiles from manual sorting to recycling will increase since a larger share of the inbound material will have lower quality. By 2030, McKinsey predicts that around 3.5 million tons enter the manual sorting step, where around half of the textiles gets resold and the other half, sent to recycling (McKinsey & Company, 2022).

Interviews

Three sorting actors were interviewed: Boer group, LSJH and Siptex. The interviews contain information about their operations, capacities, future plans and predictions.

Boer group

Boer Group is a group of twelve companies in the industry of collection, sorting and preparing textiles for reuse and recycling. Companies that are part of the group are: *Frankenhuis B.V., FWS GmbH, ALTA West, Textrade, Tardis Vintage B.V., Boer Group Recycling Solutions B.V., Curitas België, Curitas Nederland, EVADAM, Marbo Used Clothing B.V., Gebotex B.V.* and *Euro Used Clothing B.V*. The companies are based in the Netherlands, Germany and Belgium. Within Boer Group there are several sorting facilities: 3 in the Netherlands, 2 in Germany, 1 in Belgium and 1 in France (joint venture). Together, all sorting facilities have a capacity of approximately 100 000 tons per year according to Business development manager Nicole Kösegi.

Boer group

Interviewee: Nicole Kösegi, Business development manager
Type of actor: a group of mainly manual sorters, but also one mechanical recycler
Country: The Netherlands, Germany and Belgium
Capacity manual sorting: 100 000 tons / year
Capacity recycling: 7 000 tons / year
Inbound material: Textiles, clothes, shoes and home textiles

During 2021, due to the pandemic the maximum sorting capacity wasn´t reached. Most of the sorted material went to reuse (65 percent), followed by recycling (26 percent) and lastly incineration with energy recovery (9 percent). None of the textiles went to landfill. Clothes and home textiles that cannot be reused were sent to recycling. Frankenhuis is a mechanical recycler within the Boer group, with a capacity of approximately 7 000 tons per year. Textiles for recycling which were not sent to Frankenhuis were sold to other recycling companies in Europe and Asia. All sorted material for reuse and recycling is sold on the market, meaning that there is a demand for the material. There is also demand for specific fibre types, like 100 percent cotton, from recycling companies. Every sorting facility has their own market, in total the Boer Group sells sorted material to 40-45 markets all around the world (Kösegi, 2022).

The inbound material is mainly collected from kerbside bins or containers in western Europe, a small part is collected in stores. The material must have high quality, meaning most of it needs to be in a condition suitable for reuse, otherwise is it not profitable to conduct the manual multi-step sorting. Textile waste from industrial processes is directly delivered to recycling at Frankenhuis since the material is not intended for reuse (Kösegi, 2022).

The sorting is mainly done manually, but the feeding system is automatic. Identification of material type and style is performed manually. The material for reuse is sorted into 300-350 different categories, similar to categories used in stores, all depending on what the market demands. The material for recycling is also sorted by product categories, knowing that products consist of a typical fibre composition, for example a t-shirt that is cotton rich. In addition to this, the material needs another type of pre-treatment: buttons and zippers must be removed before going into the recycling process; however, this process is integrated in the current recycling process and not in the sorting process. In some of the facilities hand scanners with NIR technology are used to identify the products fibre composition. Only a small part of the material is fibre-to-fibre recycled (Kösegi, 2022).

Regulation differs in the operating countries; in the Netherlands an EPR will be implemented from 2023, aiming to increase of reuse and recycling of textiles. In Germany, the government is looking at an EPR, starting with conducting a study on the textile industry in the country. Regarding the future Kösegi tells:

"In the countries where Boer Group is present, there are many ongoing pilots or research projects on both automatic sorting and recycling. However, the capacity for automatic sorting and recycling textiles on a commercial scale is low and the investment in such technologies are lacking" (Kösegi, 2022).

According to the increasing demand for textiles sorted by fibre type, the introduction of automatic sorting (with NIR technology for example) is key to provide what the market wants in the future, which Boer Group monitors. Regarding recycling, Frankenhuis will expand its capacity in 2023 (Kösegi, 2022).

LSJH

> ## LSJH
>
> **Interviewee:** Sini Ilmonen, Senior Specialist, Circular Business, Product and Business Development
> **Type of actor:** Collector, automatic sorting
> **Country:** Finland
> **Capacity sorting:** up to 5 000 tons / year
> **Capacity mechanical recycling:** 5 000 tons / year
> **Inbound material:** Textiles, clothes, shoes, and home textiles

Lounais-Suomen Jätehuolto (LSJH) is a municipality owned waste management company in Southwest of Finland. The company is owned by 18 municipalities. One of their waste flows are end-of-life textiles from households, which LSJH have collected separately since 2015 in their area, according to, Sini Ilmonen Senior Specialist in Circular Business, Product and Business Development. They do not only collect textiles within the 18 owning municipalities, but also receive pre-sorted textiles from 16 other municipal waste management companies around Finland, with which they cover an area of 4 million people. At the beginning of 2023 all the municipal waste management companies will collect end-of-life textiles separately and pre-sort them, as Finland is setting up the separate collection of textiles. LSJH is working on an agreement with all of Finland’s municipal waste companies to receive and process the textile waste for recycling. This calls for more sorting and larger capacities to handle the material. LSJH collects only household textiles. Textiles from private companies, such as laundries, hotels, hospitals etc. are processed by the Finnish textile recycling company Rester.

The collection occurs at recycling centres, sorting stations, shopping centres or flea markets around the cities. It is the households themselves that are responsible for the sorting and disposal of the textiles. In some municipalities a fee is paid for disposal of textiles. All types of textiles are collected and then sorted by municipal waste management companies or charities. After collection, the textiles are manually pre-sorted for reuse or recycling and include removal of unwanted material (e.g., wet material). The pre-sorting is done directly on the collection site, or at a sorting facility, depending on the system in the region or municipality (Ilmonen, 2022).

After pre-sorting, the material is sent to LSJH's sorting facility and is again sorted manually into different fractions: reuse in Finland, recycling, storage or incineration with energy recovery. Together with manual sorting, they have small handheld NIR-scanners to scan the fibre composition. The textiles are sorted based on colour, structure and/or fibre type. At the moment, 10 percent of the materials are sorted for reuse, 30 percent for instant recycling, 30 percent for incineration and 30 percent for storage, see Table 2. The textiles that go to storage in a warehouse are sorted according to fibre and are of a quality that is expected to be suitable for recycling in the future, when recycling technologies have been further developed. LSJH is supporting recycling companies in product development, so they can sort according to the companies' expected future needs. All of the sorting is based on the available utilisation solutions and the market demand (Ilmonen, 2022).

Table 2. Sorted amounts at LSJH, a forecast for 2022.

Process	Amount (tons)
Inbound material (2022) (1)	800
Sorting for reuse	10%
Sorting for instant recycling	30%
Storage, until recycled	30%
Incineration	30%
Capacity Recycling of post-consumer-textiles	5 000 / year

(1) Forecast for 2022

The material which is suitable for recycling is treated mechanically into fibres by shredding. The most difficult textiles are mixed fibre compositions since there are no buyers for mixed fibres. LSJH´s capacity for the mechanical processing is currently 5 000 tons per year, but they want to scale up to be able to handle all the household textile waste in Finland and provide services to the Baltic states. The plan is to build a new plant in Turku, Topinpuisto Circular Economy centre, with a capacity of almost 20 000 tons per year, which will be up and running by 2025. In this new plant the sorting will be automated as much as possible, but there is always need for manual sorting as well. After sorting, the textiles may be processed more than just shredding, depending on what the market demands, but the outgoing product will be recycled raw materials suitable either for recyclers or subsequent producers in the textile value chain. The aim is that the outbound materials are mainly sent to the Baltic states. Even though LSJH wants to prioritise local production, Finland does not have a lot of textile production. However, many fractions go to many smaller companies in Finland, like spinneries and chemical recyclers. LSJH is also involved in many research and development projects and offer the recycled raw materials for research use. LSJH do not sell their outbound material outside Europe (Ilmonen, 2022).

Ilmonen sees a trend in increasing textile collection and recycling; in 2015 when LSJH started to collect textiles, there were almost no markets for the material. But today, some of the recycled fibres are highly demanded. There is also a discussion about textile waste amongst actors and also at EU-level regarding sorting. Ilmonen says that at the moment sorting is primarily intended for reuse, and that there is a need for education how to sort for recycling as well. In the future the amount of textile waste will increase, which LSJH will be able to manage with their scaled-up plant. Ilmonen says that they also are looking into importing textile waste for the new plant, since the collected amounts in Finland won't reach the total capacity. Ilmonen believes that an EPR, as it is implemented for other waste streams in Finland, would not be beneficial for textiles in the country at the moment:

"As there is a functioning infrastructure already, an EPR would rather disturb the infrastructure due to a new parallel collection and sorting system organised by producers" (Ilmonen, 2022).

Siptex

Siptex is an automatic textile sorting facility in Malmö, Sweden. The facility is a result of a larger Swedish research-project and is today operated by the municipality owned waste management company *Sysav*. The sorting facility was constructed in 2019. The capacity for sorting is 4.5 tons per hour and the maximum sorting capacity is 24 000 tons per year (three shift operation) according to marketing communicator Anna Vilén. Today the facility operates with one shift.

> ## Siptex
>
> **Interviewee:** Anna Vilén, Marketing communicator at Sysav
> **Type of actor:** Automatic sorting
> **Country:** Sweden
> **Capacity sorting:** 24 000 tons / year
> **Inbound material:** textiles, clothing, and home textiles

Pre-sorting is required before post-consumer textile waste can enter the automatic sorting. Pre-sorting is not done at the facility but by manual sorters in nearby Europe. Textiles that cannot be reused but recycled are sent to Siptex. There is no need for removal of buttons and zippers before the sorting. Siptex have strict restrictions for the inbound material

"If any of the unwanted textiles enter their sorting stream, risks are that the quality gets compromised" (Vilén, 2022).

Examples of unwanted materials are wet or dirty materials, plastic bags or packaging, padded materials, shoes, mats or materials treated with flame retardants. Multi-layered and padded materials cannot be sorted in the automatic sorting due to the mix of materials. The inbound materials into the sorting process are mainly post-consumer-textiles from consumers leftover materials from the textile industry. All commonly used fibre types could be managed in the sorting process (Vilén, 2022).

The textiles are illuminated by NIR light, which is reflected in different ways depending on the material fibre type. A sensor identifies the fibre type by comparison with reference spectra and compressed air blows the textile into the right container (Nellström, Grahn Lydig, Sandin Albertsson, & Johann Bolinius, 2022). The three sorting categories currently are: cotton, polyester and acrylics, and they can be sorted at the same time. The sorted materials they offer to their customers today are 95 percent cotton, 70 percent cotton, 95 percent polyester, 60 percent polyester and 95 percent acrylic - fibres that there is an aftermarket demand for. After sorting, the material is baled and transported to recyclers. None of the sorted material has been incinerated as of today (Vilén, 2022).

In 2023, Siptex aim scale up to two working shifts, but is of course dependent on availability of inbound material. There exists competition and challenges of the inbound material, it is difficult to disrupt already established textile value chains, where the manual sorting is included. Therefore, Sysav also considers introducing a pre-sorting at the facility. Vilén believes that common EU wide legislation regarding circularity will increase their inbound material volumes. However, with larger volumes of inbound material, larger fractions of low qualitative material are expected. Regarding the demand for Siptex's outbound material, it is solely dependent on the existing recycling technologies. Right now, the most demand is for 95 percent cotton, but as the recycling technologies develop and can manage more impurities their demand will most likely change. Recycling technologies are getting more advanced and might in the future not be dependent on specific fibre compositions like Siptex is, making recyclers able to source from manual sorters instead (Vilén, 2022).

Recycling actors

Several established as well as emerging recycling actors were identified within Europe, showing that mechanical recycling is more common than chemical recycling (25 respective 10 actors). Only one thermal recycling actor was identified. Three of these actors were interviewed about their technology and future scaling possibilities, which is presented under *Capacities*, along with estimated capacities.

Additionally, one geographical region in Europe was identified due to its extensive work with mechanical textile recycling, see more in the textbox below.

Capacities

The region of Prato, Italy

About: Prato is a city in Italy where recycling of textiles may have its origin. Mechanical recycling of wool has been going on since the 1840s in Prato. Today, the region of Prato process 22 000 tons of recycled wool per year (Interreg North-West Europe Fibersort project, 2020).

Cardato Recycled: For fibres and textiles produced in Prato there is a special trademark called *Cardato*, additionally there is a trademark for recycled material called *Cardato Recycled.* For a company to display the Cardato Recycled, the fibres or yarns must fulfil the three following quality criteria (Cardato, 2022):

- The product must be produced in the Prato district.
- Be made with at least 65 percent recycled material (clothing or textile scraps).
- Have measured the environmental impact of its entire production cycle, considering three aspects: water, energy and CO_2 consumption levels.

Companies with the trademark Cardato Recycled: there are five companies that fulfil the criteria; *3C Filati*, *Filati Naturali*, *Filati Omega*, *In.Tes.Pra Industria Tessuti Pratesi Spa* and *Lanificio Paulte*. All of the companies use post-consumer waste and recycle it to fibres or yarns that can be made into new clothes (Cardato, 2022).

In the mapping of textile sorters in Europe, two identified actors work both with mechanical and chemical recycling. Capacities from 17 actors could be identified. The capacities were gathered from the interviews, mail answers and/or the actors' websites (see Appendix C for references). The total capacity of the 17 fibre-to-fibre recycling actors has been estimated to 1.3 million tons per year from now to 2025, of which 1 000 000 tons are mechanical recycling and 250 000 tons are chemical recycling. The estimations for chemical recycling up to 2025 per year is like what Köhler et al. (2021) account for, which also is 250 000 tons but by 2023 per year. Regarding the capacity for mechanical recycling in Europe by 2025, the number is most likely higher since this mapping were only able to identify one third of the total number of actors' capacities.

For the future, McKinsey predicts that 70 percent of the textile waste 2030 technically can be recycled, depending on the maturity of the recycling technologies. Their estimations are not based on actors capacitates; hence it is not possible to compare the estimated capacities of this report with McKinsey's prediction.

Interviews

Three recycling actors were interviewed: Altex, Renewcell and Wolkat. The interviews contain information about their operations, capacities, future plans and predictions.

Altex

Altex is a mechanical recycling company based in Germany; they are one of the biggest mechanical recyclers in Europe with a capacity of 25 000 – 26 000 ton per year (Table 3). Around 5-10 percent of this is post-consumer textile, which they buy from sorting companies in Germany and the Netherlands. Altex can manage all kind of textiles; old garments, fibre production spill (for example cotton waste from denim production in India and Pakistan), textile spill from the automotive industry, down products etc. The inbound material is cut in several different lines which results in either fibres, pulp or, in combination with the sister company (Gronauer Filz), non-woven material. Altex have five tearing lines to recycle: textile waste, fibre waste, denim/garment textile, spill from production of non-vowens and spill from weaving production. They also have two blending lines for blended materials: blends for automotive industry and blended coloured wipes, as an example. Additionally, they have a few smaller lines and single machines to increase flexibility and offer more opportunities according to Jan Stienemann who is responsible for the project management.

> **Altex**
>
> **Interviewee:** Jan Stienemann, Project manager
> **Type of actor:** Mechanical recycling
> **Country:** Germany
> **Capacity recycling:** 25 000 ton / year
> **Inbound material:** All kind of textiles

Table 3. Altex's capacity for mechanical recycling

Process	Capacity (tons)
Inbound material (2021)	25 000 – 26 000 (per year)
Outbound material (2021)	24 000 (per year)
Recycling of post-consumer-textiles	384 (per month); 4 600 (per year)
Recycling total	2 000 (per month)

The inbound post-consumer textiles are collected in containers, mainly in Germany but also in the Netherlands. The capacity for the post-consumer textiles line is 384 tons per month. Before entering the recycling process, there is no need to remove buttons and zippers, as this is done in the process after shredding, with a centrifugal force together with a special air technique. In the recycling process there is a loss of 5-10 percent of the material as dust, which is used in other industries like paper production. The outbound material can be divided into different fibre lengths, pressed into bales, depending on the costumers needs. Altex's costumers, both for inbound and outbound material, are operating worldwide (Stienemann, 2022).

"The demand for recycled cotton for denim production is increasing. The number of recyclers and producers of textiles with recycled content increase in Europe, hence the increasing demand" (Stienemann, 2022).

Altex are planning to scale up with a new line, which would increase the capacity with 20 percent compared to the existing line. They are also looking into the possibility of removing smaller coloured parts, like tags, from white t-shirts, since white cotton is in demand in the market. The small, coloured parts need to be removed from the garment before recycling, if they could do the removal themselves it would mean one less step in the pre-sorting. Additionally, they plan to make their own non-woven out of old garments, which otherwise would be incinerated (Stienemann, 2022).

Renewcell

Renewcell

Interviewee: Harald Cavalli-Björkman, Strategy Director
Type of actor: Chemical recycling
Country: Sweden
Capacity recycling: 60 000 tons / year (ramping up)
Inbound material: Post-consumer cellulose-based textile material

Renewcell is a chemical recycling company, who own several patents and know-how on the process that transform cellulose-based material, 100 percent recycled cotton waste, into dissolving pulp, a product known as Circulose. Renewcell currently source bales of textiles with a fibre content prerequisite of a minimum of 95 percent cotton to go into their process. The bales are delivered as pre-sorted 400 kg bales. They source from sorting actors such as Sysav (Siptex, automatic sorting facility, see previous chapter) and Bank & Vogue (manual sorter from Canada), which mainly sort post-consumer waste. Additionally, they source pre-consumer waste directly from textile production. They control their quality on the inbound material by taking and analysing samples. The automatically and manually sorted inbound materials are equally good or bad according to Cavalli-Björkman, Strategy Director; the quality depends on the sorter and not whether the sorting is performed automatically or manually. Renewcell source a very small part of their inbound material from Europe, but they state that the origin of the textile is difficult to track since streams from Europe often are exported for sorting to other continents due to high labour costs in EU.

The recycling process consists of shredding, wet processing, separation and drying. The first step includes shredding the material and separating the heavier components such as zippers, buttons etc. Wet processing treats the shredded material in water and chemicals. The chemicals are commonly used chemicals found in the Swedish paper and pulp industries. The most important properties that are controlled for the output are: viscosity, reactivity and brightness. The brightness is adjusted according to the demand of the customer. In the third step, smaller impurities such as polyester, elastane and other unwanted fibres are separated. The separated material can be up to 5 percent of the total mass. The separated waste is incinerated with energy recovery at a nearby factory. Lastly, the mass is dried with heat and pressure. The pulp is then cut into sheets that later are packed into bales and sold. The sheets are in turn made into regenerated fibres (such as viscose, lyocell, modal, acetate and cupro). All the products are currently mainly exported to outside EU, mainly to China, but Renewcell have one contract and ongoing negotiations with potential European buyers as well. Regenerated fibres made from Renewcells product is not only replacing conventional regenerated fibres, but they also see a demand for replacing cotton. As an example, Levi's replaced 40 percent of the cotton in their jeans with viscose made with Circulose.

> *"Nearshoring is a trend to build resilience and therefore Europe might be a larger man-made cellulosic fibre producer in the future, which calls for an increasing need for Renewcells product." (Cavalli-Björkman, 2022).*

The maximum potential production capacity during 2021 for Renewcell was 4 500 tons and the company is focusing on scaling up the capacity. Their commercial-scale factory in Sundsvall which started up in 2022 have an initial production capacity of 60 000 tons per year. By 2023/2024 their goal is to have a capacity of 120 000 tons yearly, and for 2030 the target is 360 000 tons. The global demand for regenerated fibres from recycled cotton will be 7 million tons by 2030 according to Cavalli-Björkman. Another goal is to lower the prerequisite on inbound material to a minimum of 90 percent cotton to be able to source more material.

Wolkat

Wolkat is based in Netherlands and works for the circular economy in the textile sector. Except conducting mechanical recycling, Wolkat conducts manual sorting for recycling and pre-processing, fibre spinning and weaving, and can supply customers with yarns, fabrics or textile products containing recycled material. Textile products being mainly pillowcases and bags according to Innovation Manager Remi Veldhoven.

Wolkat

Interviewee: Remi Veldhoven, Innovation manager
Type of actor: Manual sorting, mechanical recycling
Country: The Netherlands
Capacity recycling: 0 in Europe
Inbound material: Textiles

Collection of material occurs in different streams. Wolkat have their own in-store collection service via *Drop & Loop* as well as collaboration with municipalities. The first sorting step is done in the Netherlands and includes sorting into nine fractions: reusable items, white t-shirts, coloured t-shirts, single shoes, shoes (pair), jeans, knits, multi-layered pieces, and non-textiles. White and coloured T-shirts are downcycled into industrial wipes, shoes (pair) and reusable items are sold in the second-hand market within the country. The remaining fractions are sent to Tangier, Morocco, where the second sorting step and further recycling operations take place. The sorting results in around 50 percent reuse, which is sold in the Netherlands as well as abroad, and 50 percent recycling (Veldhoven, 2022).

The second sorting step is sorting for recycling and takes place in Tangier, where they have a sorting capacity of 40 tons per day (approximately 12 000 tons per year). The sorted fractions arriving from the Netherlands are further sorted manually according to colour and roughly raw material content in the following streams: items with high cotton content, high acrylic content, denim and synthetic blend content. After the sorting, hardware like zippers and buttons are manually removed. In the mechanical recycling the material is shredded, resulting in recycled fibres. These recycled fibres can be used in nonwoven materials or (preferably) in yarns made into woven materials (Veldhoven, 2022).

When spinning the recycled fibres into yarn, a share of virgin fibre is included, thinner fibres need more virgin materials and thicker fibres need less virgin material. The share of virgin fibres is also depending on quality requirements for the end-product. Today Wolkat offer four different types of yarns: synthetic blends, high acrylic content (>80 percent acrylic), high cotton content (>80 percent cotton) and recycled denim (98 percent cotton, 1 percent elastane / 1 percent polyester). The weaving operation depends on customer demand and design; however, the warp is mainly 100 percent recycled PET bottles or a pre-consumer recycled cotton/recycled PET blend, and the weft is the yarn containing recycled fibres (Veldhoven, 2022).

Wolkat have invested in two smaller material scanners due to legislation regarding knowledge of material content in a finished product. They have also conducted tests with automatic sorting technologies. Veldhoven sees an increasing demand from costumers, due to producer responsibility legislation in the Netherlands. Also, sorters tend to be more collaborative today, previously they used to be more competitive. This is thought to be a result of the lower share of items being reusable and that sorters need to collaborate on finding ways to make use of the non-reusable waste streams. Regarding the demand, Veldhoven tells:

> *"Wolkat see a market demand for recycled materials and a demand for more detailed information on the final fibre composition of the outbound materials" (Veldhoven, 2022).*

Wolkat also see a request for yarns for clothing, and are therefore investigating opportunities for yarn spinning. Regarding scaling up Wolkat are focusing on the sorting operation as well as the yarn spinning. If they would invest in automatic sorting, the need for manual labour would decrease. Wolkat have gained a strong position in the Netherlands as have today a high recognition in the textile business (Veldhoven, 2022).

Emerging global initiatives

The mapping of emerging global initiatives regarding new techniques for collection, sorting and recycling identified nine techniques that are described below. The prerequisites were for the technique to be innovative and complementary to the techniques already identified in the mapping of actors in Europe. The information gathered was mainly from the actors' own websites. The trends identified are separation technologies as well as automatic process steps.

Collection

Xiao Huang Gou Environmental Technology Company (XHG) was established in China, 2017. The company work towards facilitating circular flows by smart recycling terminals with bins powered with AI. The recycling bins are equipped with cameras to recognise the waste, the bin can weigh the waste and is also able to disinfect the content before being handled. Textiles are one of the collected fractions. To use the recycling system, users must be registered to an app. Through the app they can see the closest recycling terminal or book pick-up of their sorted waste. Users are also encouraged to sort their household waste by being paid (Little Yellow Dog, 2020).

Sorting

A possible technology for future sorting is the Radio Frequency Identification (RFID). It differs from NIR, as it uses radiolabels to store information remotely in microchips (RFID chips) in the textiles. RFID labels are implanted into the products, something that is becoming increasingly used within the clothing industry. (ECOTLC, 2020). RFID have the possibility to sort textiles for reuse on colour and size, but also chemical content or how the textile have been dyed, which can be valuable in chemical recycling of textiles. The technology could efficiently sort textiles in many different fractions, a fast and accurate sorting technique to ensure high value material both for reuse and recycling. Additionally, RFID can be useful for manufacturers, wholesalers and retailers as information about the textile will follow through the whole life cycle of the textile and the value chain. (Schwarz Bour & Jönsson, 2020). It has the possibility to become both a simple and inexpensive solution, however, it must be used by all brands and a lot of standardisations is needed before it could potentially become large-scale (ECOTLC, 2020).

Artificial intelligence (AI) via robots is another upcoming technology, as well as sorting by colour by a simple camera, and X-ray fluorescence or spark spectrometry to identify brominated plastics (ECOTLC, 2020). Wargön Innovation in Sweden have an ongoing research project in which they investigate whether AI, machine learning and automation can develop the textile sorting and valuation of reusable garments. With this technology, robots may have the potential to identify the brand and assess quality, wear, odour, and demand for the specific garment to optimise the pricing of the garment. (Wargön Innovation, n.d. b).

Hyper-spectral imaging is common in the automatic sorting of minerals, papers and plastic materials. The sorting-method has been tried out on sorting textile waste for example in the Resyntex project. The method was concluded to be promising. Hyper-spectral imagining identifies materials by hyperspectral sensors such as high-resolution cameras with the signal resolution of spectrometers (Englund, Wedin, Ribul, de la Motte, & Östlund, 2018).

Recycling

The recycling actors has been divided in mechanical, chemical and other recycling technologies and are presented below.

Mechanical recycling

The Billie System is a recycling technology used by Novotex Textiles Limited. Novotex was founded in Hong Kong and have their operations in multiple cities across Asia. The system can process up to a maximum of three tones of recycled fibres per day. The Billie recycling system differs from other recycling systems as it is marketed as waterless, chemical waste-free and almost entirely automated. The steps of the process include textile waste sanitation, hardware removal, automatic colour sorting, fibre processing, UV light sanitation and lastly sliver processing. The input material is post-consumer textile waste, preferably 100 percent natural fibres due to the high quality. But the system could also handle natural fibre blends. The output material has until now been used for different purposes, such as for creating knitwear and for textile products to hotels and resorts (which then have also provided the input material). The end product usually contains virgin material in a mix with the recycled fibres (The Billie Upcycling, n.d.).

Chemical recycling

BlockTexx is a recycling company that focuses on post-consumer textile waste. BlockTexx have built the first textile recycling plant in Australia. The first year of operations, the anticipation was to recycle 4 000 tons of textiles at their first facility in Queensland. BlockTexx collaborates with councils around Australia to collect textiles such as clothing, sheets, linen, towels, and pillowcases. They want the clothing separated from the rest. They also collect from laundries and workwear companies. The company is the first to commercialise a separation process. Unfortunately, there is limited information about the process. It is named S.O.F.T (separation of fibre technology) and is a chemical recycling process. The input fibre is either 100 percent polyester or 100 percent cotton or a blend of the two fibre types. After the separation, the cotton is broken down to cellulose and the polyester goes through a heating and liquifying process to transform it into plastic pellets. The end-product can be applied into different products such as clothing, paint, and furniture (BlockTexx, 2022). According to an interview with the news site *Inside waste* the co-founders believe that over the next four years, BlockTexx will be able to recycle 50 000 tons of textiles (Wheeler, 2021).

Refiberd was founded in 2020. Their integrated recycling system uses AI, robotics, and chemical recycling to turn post-consumer textile waste into 100 percent recycled polyester and cellulose thread. Refiberd state on their website that no pre-consumer waste nor PET-bottles are used as raw material, but all being post-consumer textiles (Refiberd, n.d.). According to *Fashion for good*, Refiberd have a sorting line which uses spectroscopy and image processing to identify material composition of the collected post-consumer waste (Fashion For Good, 2022).

Other recycling

Circ (previously Tyton Biosciences) is a recycling company situated in Virginia, USA. They have developed a hydrothermal recycling technology that is able to separate polyester and cotton blended textiles. The process breaks down the different fibres to their monomer structure. For cotton that is cellulose and for polyester purified terephthalic acid. Today Circ operates a pilot plant which aims to have a recycling capacity of 65 000 tons per year by 2025. Their ambition is to produce yarn of the recycled fibres to replace virgin material in textiles (Circ, 2022).

Spintex was founded 2018 in the UK and their technology is inspired by the spiders spinning process. The silk from spiders is stored inside the spider as a gel and consists of proteins and water, due to the physical pull force through tight spinnerets, the liquid turns into a solid thread. Spintex have developed a process that mimic a spider spinnerets' ability to create a fibre. In the making of the fibres no heat or hazardous chemicals are needed, and the only by-product is water. (Spintex, 2020). The Spintex technology uses virgin silk as their input material as well as post-consumer silk. The recycling process contains a water-based solution that dissolves the silk (Fashion For Good, 2022). Compared to regular silk production, Spintex's process requires far less energy. In 2020, the company was still finetuning their process and looking for funding to scale up (Oxford Trust, 2020).

Discussion

Regarding the report's first main research objective, it succeeded to identify 12 sorting actors and 35 recycling actors. The sorting actors had an estimated total capacity of 560 000 ton per year from now on to 2025. The capacity is estimated based on actors' maximum capacity, meaning that all of the capacity may not be in use today or by 2025, the same goes for the estimated recycling capacity. This represents 22-35 percent of the total collected textiles in the EU according to European Environment Agency (2021 b). Regarding the manual sorters, this study succeeded to cover around 40 percent of the McKinsey's estimated amounts for manual sorting in the EU (including Switzerland). The estimated capacity for sorting lacks inforamtion from many manual sorters, and should therefore not be seen as a complete capacity for the manual sorting.

A majority (50-75 percent) of the collected textile materials go to reuse after sorting, according to Köhler et al. (2021), whilst the rest goes to energy recovery or downcycling. These numbers seem reasonable compared to the numbers provided by the Boer Group, the number seems reasonable since 65 percent of their inbound material are sent to reuse, 26 percent to recycling and 9 percent to incineration. Regarding the other interviewed sorting actors, LSJH and Sysav, the numbers are not comparable since their main operations are to sort for recycling. Boer Group state that they have plans to introduce automated sorting as they see an increase of demand for textiles sorted by fibre type. Whilst Sysav have plans on including a manual pre-sorting step for its automated sorting to ensure the quality of the inbound material to the automatic process.

According to literature, the actual number of mechanical recyclers in Europe should be higher than those identified in the present report. However, the prerequisites for the selection of the mapping were for the actor to handle post-consumer waste and strive towards fibre-to-fibre recycling (see more in the Appendix). The capacity of the identified recycling actors has here been estimated to 1.3 million tons per year, but could be higher when including other types of textile recycling than only fibre-to-fibre recycling. However, the capacity for chemical recycling, 250 000 ton per year, is believed to be more representative since 8 out of 10 actors' capacities are included. In this report, the estimated capacity for recycling exceeds the estimated capacity for sorting by 740 000 tons. Although the capacity for sorting is expected to be higher, it calls for a need to scale up the sorting capacity in Europe, in order to reach the full recycling potential. But, as Sysav mentioned, the sorting capacity is dependent on the amount of inbound material, which in turn is dependent on how much textile that is collected and the quality of the collected material. If there is a lack of sorted material to go into the recycling processes, companies may do as Renewcell and source materials from outside of EU.

As identified both in literature and interviews, the largest share of the collected textiles goes to reuse, both inside and outside of Europe. As a recycling actor, it can be difficult to source back textiles that have been exported outside of Europe for the purpose of reuse, even when the textile eventually is discarded. Renewcell raised the question whether the sourced materials are of European origin or not. The origin of the textiles is difficult to determine as the textiles often are exported outside of Europe for sorting. One aspect of local sourcing of materials was raised by both LSJH and Renewcell, who both believe in sourcing materials from the nearby countries. LSJH wants to prioritise local production and Renewcell believes that nearshoring is a way to build resilience.

As collection of household textiles is introduced by 2025, the amount of collected textiles, and the material available for sorting and recycling, will increase. One drawback with scaling up collection might be increasing competition among sorters, if not more recycling technologies are commercial by then. Another drawback, which both Sysav and McKinsey (2022) mention is that the average quality of the collected textiles will decrease when the amounts increase. One explanation to this may be that non-reusable textiles that previously have been disposed in the residual waste now will be collected separately. Global actors have, with the help of AI-powered wastebins, been able to control the quality of the textile waste. The waste management system has also been able to encourage the user to sort correctly.

LSJH, as well as Boer Group and Altex, see a trend in more textile projects and actors working with collection, sorting and recycling. Although Boer Group see many commercial actors in the industry, the capacity is low as well as the willingness to invest in such technologies. Both LSJH and Sysav sort textiles according to customers' demands, which in turn is based on the recycling technologies and the possibility to handle impurities and even mixed fibres. According to Sysav, as recycling technologies get better, they can handle more impurities and the need for specific fibre types will decrease and may leave room for the recyclers to source directly from manual sorters. As Renewcell already source from both manual and automatic sorters, they have not noticed any differences of quality in between the two sorting alternatives. The most important thing, According to Renewcell, is to collect enough cotton rich post-consumer textiles to meet the demand from the textile producers.

Since the demand of sorted textiles is based on the available recycling technologies, cotton rich materials are currently the most wanted. According to Renewcell, the demand for their end-product is larger than the supply of post-consumer cotton, which is an indication for of the need to scale up textile collection and sorting. Additionally, Altex see an increased demand for recycled cotton as production of recycled denim is increasing. Boer Group and Sysav, too, see a demand for specific cotton content of 95-100 percent cotton. Polyester is also a fibre in demand. But, as LSJH said, the most difficult textile to handle is the mixed fibres since there are no buyers for this material. The study among global emerging initiates shows proof of taking on the challenge of separating and recycling cotton and polyester blends.

Conclusion

This report has identified 12 sorting actors, with a total capacity of 560 000 tons per year from now up to 2025. The actual sorting capacity in Europe is estimated to be significantly higher as the manual sorting actors were difficult to identify. Further, 33 recycling actors have been identified and are at a commercial scale in fibre-to-fibre-recycling post-consumer textiles in Europe, with a total capacity of 1.3 million tons per year from now up to 2025. The estimated capacity for mechanical recycling has been estimated to approximately 1 million ton per year and chemical recycling to 250 000 tons per year. There are many actors in the research and development phase of textile recycling, these actors are not included in this mapping, but should not be missed when talking about the future of the textile industry in Europe. Many actors promise large capacities within a few years, and together with the upcoming requirement of separate collection of textiles in 2025 in the EU, the textile sorting and recycling industry in Europe will most likely thrive moving forward.

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Appendix A: Interview and e-mail questions

Interview questions to sorting actors

- What capacity do you have for sorting?
- How much textile did you have inbound and outbound in 2021?
- What sorting technology do you use?
- Which material do you take into your process? Which fibre types? (Inbound)
- What type of material do you get out of your process? (Outbound)
- How much of the outbound textiles went to reuse or recycling?
- What types of materials are in demand in the market, and can you supply the market with them?
- Do you work both nationally and globally, if so with which countries?
- How has the market for sorting (and recycling) of textiles developed in your country in recent years?
- Are there policies or regulations that favour the sorting and recycling of textiles at national level in your country?
- Do you have any plans with your technology for sorting? Future potential/scaling?

Interview questions to recycling actors

- What capacity do you have for recycling? (Capacity for fibre-to-fibre-recycling?)
- How much textile did you have inbound and outbound in 2021?
- What recycling technology do you use?
- Which material do you take into your process? Which fibre types? (Inbound)
- What type of material do you get out of your process? (Outbound)
- What types of materials are in demand in the market, and can you supply the market with them?
- Do you work both nationally and globally, if so with which countries?
- How has the market for recycling (and sorting if you know) of textiles developed in your country in recent years?
- Are there policies or regulations that favour the sorting and recycling of textiles at national level in your country?
- Do you have any plans with your technology for sorting? Future potential/scaling?

E-mail questions to sorting actors

- What technology do you use? (Manual, semi-automatic or automatic sorting)
- What is your total capacity? (tons / year)
- Total amount of inbound textiles in 2021? (tons)
- Total amount of outbound textiles in 2021? (tons)
- Has the textile been processed before it comes to you? If yes, how?
- How much of you sorted textiles were sent for reuse in Europe 2021? (tons)
- How much of your sorted textiles were sent to recycling in Europe 2021? (tons)
- What factions do you sort? (Fibre type e.g.?)

E-mail table to fill out to recycling actors

		Post-consumer-textiles (tons / year)	Other textiles (tons / year)	Comment
Basic facts	Data year 2021	-----	-----	
	Mechanical or chemical process?	-----	-----	
	Amount fibre-to-fibre recycling			
	Amount fibre-to-other recycling (downcycling)			
	Total capacity			
Inputs	Cotton			
	Wool			
	Polyester			
	Polyamide			
	Acrylics			
	Viscose			
	Other material			
	Poly-cotton blends			
	Wool blends			
	Other blends			
Outputs	Shredded material			
	Yarn / thread			
	Fabric			
	Other (what?)			

Appendix B: Mapped actors

Table B1. Mapped actors within the business of sorting and recycling post-consumer textiles in Europe (alphabetical order).

Actor	Country	Business
3C Filati	Italy	Mechanical recycling
Altex Textil-Recycling	Germany	Mechanical recycling
Antex	Spain	Mechanical recycling Thermal recycling
Aquafil (ECONYL)	Italy	Chemical recycling
Boer Group	The Netherlands Germany Belgium France	Manual sorting
Brightloops (Loop.a life)	The Netherlands	Mechanical recycling
Comistra	Italy	Mechanical recycling
CuRe Technology	The Netherlands	Chemical recycling
Filati Naturali	Italy	Mechanical recycling
Filati Omega	Italy	Mechanical recycling
Filatures du parc	France	Mechanical recycling
Frankenhuis	The Netherlands	Mechanical recycling
Green line	Italy	Automatic sorting
I:CO	Germany	Collection Manual sorting
IN.TES.PRA. Industria Tessuti Pratesi S.p.A.	Italy	Mechanical recycling
Infinited fiber (Infinna)	Finland	Chemical recycling
Ioncell	Finland	Chemical recycling
Lanificio Paultex	Italy	Mechanical recycling
Lenzing (Tencel, EcoVero, Veocel)	Austria	Chemical recycling
LSJH	Finland	Collection Manual sorting Mechanical recycling
NewRetex	Denmark	Automatic sorting
Nylstar (MERYL RECYCLED)	Spain	Mechanical recycling
Procotex	Belgium	Mechanical recycling
PurFi	Austria	Mechanical recycling Chemical recycling
RE.Verso (NFB Bonetti)	Italy	Mechanical recycling
Recover	Spain	Mechanical recycling
Renewcell (Circulose)	Sweden	Chemical recycling
RePlaza	Lithuania	Manual sorting

Rester	Finland	Mechanical recycling
Sinterama (Newlife)	Italy	Mechanical recycling
SOEX	Germany	Collection Manual sorting Automatic sorting
Spinnova	Finland	Mechanical recycling Chemical recycling
Sysav (SIPTex)	Sweden	Automatic sorting
Södra (OnceMore)	Sweden	Chemical recycling
Tesma Cashmere	Italy	Mechanical recycling
TEXAID	Switzerland	Collection Manual sorting
TEXCAR	Italy	Mechanical recycling
Textil Santanderina	Spain	Mechanical recycling
Textile change	Denmark	Mechanical recycling
Wieland	The Netherlands	Manual sorting Automatic sorting
VIVE Textile recycling	Poland	Manual sorting
Wolkat	The Netherlands	Manual sorting Mechanical recycling
Worn again	UK	Chemical recycling

Appendix C: References for capacities

Table C1. References to actors' capacities for sorting textile waste.

Actor	Reference
Boer Group	Interview with Nicole Kösegi (2022).
LSJH	Interview with Sini Ilmonen (2022).
Sysav (Siptex)	Interview with Anna Vilén (2022).
SOEX	Hatchett, W. (2022). *Textile Recycling International acquires Soex UK*. Retrieved from MRW: https://www.mrw.co.uk/news/textile-recycling-international-acquires-soex-12-05-2022/
TEXAID	E-mail answer from TEXAID (2022).
Wieland	Recycling Today. (2022). *Wieland to boost melting capacity in Germany*. Retrieved from Recycling Today: https://www.recyclingtoday.com/article/weiland-copper-recycling-germany-expansion/
VIVE Textile Recycling	VIVE Textile Recycling. (2019). *About the company*. Retrieved from VIVE Textile Recycling: https://www.vivetextilerecycling.pl/about-the-company/?lang=en

Table C2. References to actors' capacities for recycling textile waste.

Actor	Reference
Altex Textil-Recycling	Interview with Jan Stienemann (2022).
CuRe Technology	DuFor Resins BV. (n.d.). *Chemical Recycling versus CuRe Polyester Rejuventation*. Retrieved from Dufor: https://www.dufor.nl/chemical-recycling/
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Infinited fiber (Infinna)	Infinited fiber. (2022). *Infinited Fiber picks site of shut paper plant in Finnish Lapland for its planned EUR 400 million textile fiber factory investment*. Retrieved from Infinited fiber: https://infinitedfiber.com/blog/2022/06/20/infinited-fiber-picks-site-of-shut-paper-plant-in-finnish-lapland-for-its-planned-eur-400-million-textile-fiber-factory-investment/
Ioncell	Ioncell. (n.d). *Climate Innovation Insights*. Retrieved from Ioncell: https://v.fastcdn.co/u/8a9cc0ca/43420992-0-7.-SPS-insights-Ionc.pdf
LSJH	Interview with Sini Ilmonen (2022).
Procotex	Procotex. (2022). *Spinning*. Retrieved from Procotex: https://en.procotex.com/industries/spinning/
PurFi	E-mail answer from PurFi (2022).

Recover	Textile Exchange. (2022). *Recover*. Retrieved from Textile Exchange: https://textileexchange.org/recover-2/
Renewcell (Circulose)	Interview with Harald Cavalli-Björkman (2022).
Rester	E-mail answer from Rester (2022).
Södra (OnceMore)	E-mail answer from Södra (2022).
Textil Santanderina	Textil Santanderina. (n.d.). *S360º A new circular textile cycle*. Retrieved from Textil Santanderina: https://textilsantanderina.com/s360/
Worn again	Professional Clothing Industry Association Worldwide (PCIAW). (2022). *Worn Again Technologies: The Circular Textile Economy Is Rapidly Approaching*. Retrieved from PCIAW: https://pciaw.org/worn-again-technologies-the-circular-textile-economy-is-rapidly-approaching/

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