Tampere University

Eeva-Leena Pohls

TOWARDS A CIRCULAR TEXTILE ECO-SYSTEM

Drivers and barriers of national textile circulation

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ABSTRACT

Eeva-Leena Pohls: Towards a circular textile ecosystem: Drivers and barriers of national textile circulation
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Textile and clothing industry is an extremely resource intensive field of industry, which consumes enormous amounts of water, chemicals and energy throughout the supply chain. Fast fashion and the resulting need to produce textile products at the lowest cost possible constantly threaten both the environmental and social wellbeing. Therefore, large-scale and systemic changes are needed in both virgin fibre-based production and fast fashion-based consumption patterns for the textile industry to truly transition towards sustainability and circularity.

The aim of this thesis was to explore the current status of Finnish textile circulation ecosystem – the community of actors whose operations involve circular economy of textiles – and the drivers and barriers of national textile circulation. As textile circulation involves a multitude of technological processes, technologies that enable textile circulation were examined as the key driver type to boost the transition towards a circular textile industry. In addition, drivers and barriers were examined extensively from business-related, organizational, regulatory, linguistic, visual and psychological points of view. The data utilized in this thesis was compiled by the author for an ecosystem study, commissioned by Circular Economy Catalysts: From Innovation to Business Ecosystems (CICAT2025) project.

The theoretical part of this thesis is divided into two sections. The first section consists of a description of material flows and sustainability issues of linear textile and fashion industry. The second part provides necessary background information about the circularity of textiles and garments, including aspects such as waste hierarchy, ecosystem approach and technological processes of textile circulation. The empirical part of this thesis was carried out as a qualitative single-case study, in which the inspected case was the Finnish textile industry and the textile circulation related activities within the field. The research was executed by interviewing actors that represent different parts of the Finnish textile circulation ecosystem. The interviews were carried out in 2019 within a time frame of 5 months.

The actor interviews resulted in a visualized example of the variety of necessary actor types within the ecosystem and in a realistic overview of the current activities in Finland. The results showed that there is both need and interest for developing various technologies within the field of textile circulation. Technologies that guarantee the collected textile fraction's quality during collection phase, textile sorting and identification technologies and mechanical and chemical recycling methods were all considered as relevant technologies, alongside with digital solutions, such as product passports and online textile lending services. Collaborative projects, circular design education, clear verbal and visual communication, transparency and trust were also experienced as drivers for adopting textile circulation and its technologies as a part of today's textile industry.

It can be concluded, that a wide spectrum of simultaneous drivers are needed for a traditional field of industry to successfully implement circularity into its operations. Even though a certain driver can be a strong accelerating force as itself, a boost from other driver types is often needed to create a strong enough momentum for change. The results proved the complexity of ecosystems, the challenges of defining their boundaries and the vast spectrum of varying elements that affect the operations within the studied ecosystem. Even though some of the recognized drivers and barriers were related exclusively to the circular ecosystem of textiles, some of the drivers could surely be beneficial for the circularity transitions of other manufacturing industries as well.

Keywords: textiles, clothing, circular economy, ecosystem

TIIVISTELMÄ

Eeva-Leena Pohls: Kohti kiertotalouden mukaista tekstiiliekosysteemiä: Kansallisen tekstiilikierron ajurit ja esteet
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Tekstiili- ja vaatetusteollisuus on äärimmäisen resurssi-intensiivinen teollisuudenala, jonka tuotantoketjut kuluttavat valtavia määriä vettä, kemikaaleja ja energiaa. Pikamuoti ja siitä johtuva tarve tuottaa tekstiilejä halvimmalla mahdollisella hinnalla uhkaavat jatkuvasti sekä ympäristön että ihmisten hyvinvointia. Laajamittaisia, systeemisiä muutoksia tarvitaan tämän vuoksi sekä neitseellisten tekstiilikuitujen tuottamiseen että pikamuotiin pohjautuviin kulutustottumuksiin, jotta tekstiiliteollisuus voi alkaa muuntumaan kestävämpään, kiertotalouden mukaiseen suuntaan.

Tämän diplomityön tarkoituksena oli tutkia suomalaisen tekstiilikierron ekosysteemin – kotimaisen tekstiilien kiertotalouden toimijaverkoston – nykytilaa ja kansallisen tekstiilikierron ajureita ja esteitä. Tekstiilikierto muodostuu useista teknologisista prosesseista, minkä vuoksi tekstiilikiertoa mahdollistavia teknologioita tutkittiin pääajureina siirtymälle kohti kiertotalouden mukaista tekstiiliteollisuutta. Tämän lisäksi ajureita ja esteitä tutkittiin liiketoiminnallisesta, hallinnollisesta, lainsäädännöllisestä, kielellisestä, visuaalisesta ja psykologisesta näkökulmasta. Diplomityössä käytetty data on kerätty Circular Economy Catalysts: From Innovation to Business Ecosystems (CICAT2025) -projektin puitteissa tehtyä ekosysteemikartoitusta varten.

Diplomityön teoreettinen osuus on jaettu kahteen osioon. Ensimmäinen osio käsittelee lineaarisen tekstiili- ja vaatetusteollisuuden materiaalivirtoja sekä kestävyysongelmia. Toinen osio valottaa tekstiilien ja vaatteiden kiertotalouden perusteita muun muassa etusijajärjestyksen, ekosysteeminäkökulman ja tekstiilikierron teknologisien prosessien kautta. Diplomityön empiirinen osuus suoritettiin kvalitatiivisena tapaustutkimuksena, jossa kohteena oli suomalainen tekstiiliteollisuus ja alan kiertotalouteen liittyvät toiminnot. Tutkimus suoritettiin haastattelemalla toimijoita, jotka edustavat eri näkökulmia ja osa-alueita suomalaisessa tekstiilikierron ekosysteemissä. Haastattelut suoritettiin vuonna 2019 viiden kuukauden aikavälillä.

Toimijahaastattelujen avulla saatiin luotua visualisoitu esimerkki tekstiilikierron ekosysteemille tarpeellisista toimijatyypeistä ja realistinen katsaus tämänhetkisiin tekstiilikierron toimintoihin Suomessa. Tulokset osoittivat, että useille tekstiilikiertoa mahdollistaville teknologioille ja näiden kehittämiselle on sekä kiinnostusta että tarvetta. Keräysvaiheessa tekstiilien laatua takaavat teknologiat, lajittelu- ja tunnistusteknologiat, mekaaninen sekä kemiallinen tekstiilikierrätys ja digitaaliset ratkaisut, kuten sähköinen tuotetietopassi tai online-vaatelainaus, koettiin erittäin tarpeellisiksi. Yhteistyöprojektit, kiertotalouden mukainen design-opetus, selkeä sanallinen ja kuvallinen viestintä, läpinäkyvyys ja luottamus koettiin myös tarpeellisiksi ajureiksi, jotta tekstiilikierto ja sen teknologiat omaksuttaisiin osaksi nykyistä tekstiiliteollisuutta.

Vaaditaan valtava kirjo samaan aikaan vaikuttavia ajureita, jotta perinteinen teollisuudenala alkaa muuntamaan toimintojaan onnistuneesti kiertotalouden mukaiseksi. Vaikka tietty ajuri olisi yksinäänkin vahva, kiihdyttävä voima, vaaditaan usein sysäys myös muilta ajurityypeiltä, jotta muutos kasvaa tarpeeksi voimakkaaksi. Tulokset osoittivat myös ekosysteemien monimutkaisuuden sekä tutkittavan ekosysteemin rajojen määrittämiseen liittyvät haasteet, ja auttoivat hahmottamaan tutkitun ekosysteemin toimintoihin vaikuttavien tekijöiden laajaa kirjoa. Vaikka osa tässä diplomityössä tunnistetuista ajureista on ominaisia juuri tekstiilien kiertotalouden ekosysteemille, monet käsitellyistä ajureista voisivat varmasti vauhdittaa muidenkin valmistavien teollisuudenalojen siirtymiä kohti kiertotaloutta.

Avainsanat: tekstiilit, vaatteet, kiertotalous, ekosysteemi

PREFACE

An enormous thank you to all the interviewees who took part in this Master's thesis study and contributed to the research with their expertise. It is encouraging to know, that the Finnish textile ecosystem has determined, innovative and solution-oriented actors and individuals within it, pushing the industry towards sustainable practices. An equally gigantic thank you to my thesis supervisors Essi Sarlin and Leena Aarikka-Stenroos, who took time to advise and guide me throughout the research process. Without your encouragement I would probably still be neck-deep in research data. Thank you also to the work colleagues in our research group for sharing their views and knowledge on different aspects and for good laughs at the office. Last but not least, warm and tight hugs to my lovely friends and family. Thank you for reminding me that there is more to life than sitting in front of the laptop, whilst also occasionally giving me a gentle nudge and reminding, that the thesis is not going to write itself.

Creating this thesis has been an eye-opening experience. Not only have I made it to the finish line of my Master's degree studies, but I have managed to gain an extensive insight on an interesting and important topic that combines both my textile technology and environmental engineering studies. Moreover, doing this research has made me rethink my own impact and choices as a consumer even further. Considering this as a job well done in terms of textile circulation related education and consumer guidance, even if the target is the author herself!

Tampere, 29 April 2020

Eeva-Leena Pohls

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1. INTRODUCTION

1.1 Background

Textile and clothing industry represents a massive share of world's manufacturing industry and the production volumes of textile fibres have been increasing continuously through the past years (Bick *et al.*, 2018; Ellen MacArthur Foundation, 2017). Technological advances in production processes and a global supply chain have made textile manufacturing faster and cheaper than ever, whereas globalization and digitalization have made buying and accessing the newest trends ridiculously easy for the consumers. However, these same factors have stirred up an alarming phenomenon of fast fashion: garments are being produced with an increasing speed and decreasing cost but with lower quality and durability requirements to meet the seasonal demands and trends defined by the fashion industry (Bick *et al.*, 2018; Brewer, 2019). As a consequence, the global textile and fashion industry has become one of the most polluting fields of industries, which constantly threatens the wellbeing of both the environment and the people (Boström & Micheletti, 2016; Bick *et al.*, 2018; Ellen MacArthur Foundation, 2017; Koszewska, 2018). Thus, large-scale and systemic changes are needed in both production and consumption patterns for the textile industry to truly take a leap towards sustainability (Boström & Micheletti, 2016; European Environment Agency, 2019).

Textile and clothing industry is a highly resource intensive field of industry, which consumes massive amounts of water, chemicals and energy throughout the supply chain and therefore, contributes significantly to climate change and environmental degradation (Boström & Micheletti, 2016; Ellen MacArthur Foundation, 2017). In addition, textile and clothing industry is at its current state responsible for multiple violations of social justice within the production areas, which are often located in low- and middle-income countries. Fast fashion driven textile industry is unfortunately known to require cheap labour in order to provide rapidly changing clothing collections, leading far too often to problems such as failed workplace safety and insufficient salaries for the workers (Bick *et al.*, 2018; Boström & Micheletti, 2016; Brewer, 2019).

Not so surprisingly, as the clothing collection cycles have quickened, the amount of times a garment is worn during its first life has plummeted remarkably. An extensive report published by Ellen MacArthur Foundation (2017) cautions that whereas clothing sales

have doubled throughout the years 2000 to 2015 (figure 1), the average amount of times a garment is worn has decreased by 36%. If the current trend holds, fibre production and textile sales are expected to triple by year 2050. Correspondingly, taking into consideration the decline in garments' utilization time, the number of discarded textiles is also expected to demonstrate explosive growth (Ellen MacArthur Foundation, 2017).

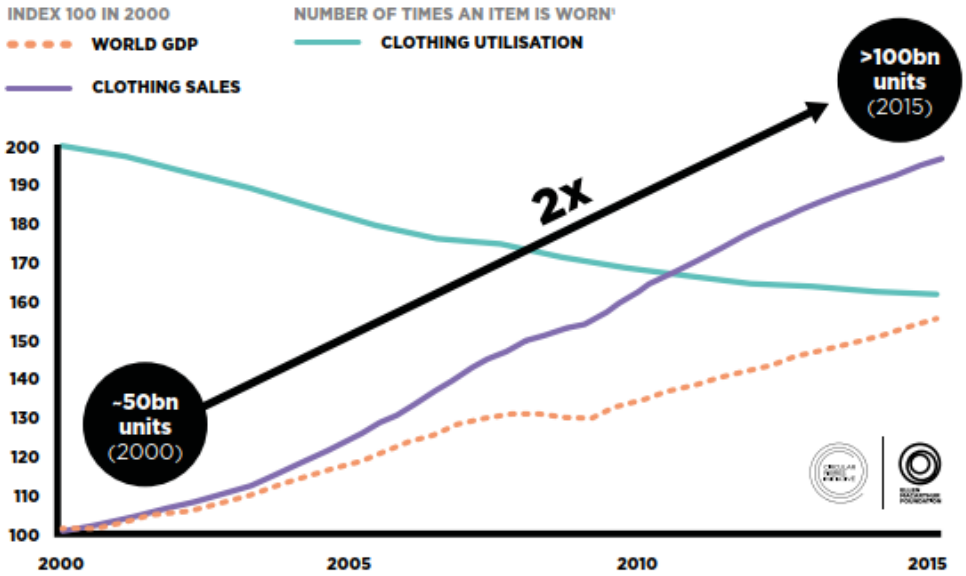

Figure 1. *Growth of clothing sales and decline in clothing utilization between years 2000 and 2015 (Ellen MacArthur Foundation, 2017).*

According to a study published in 2015 (Dahlbo *et al*., 2015), over 71 million kilograms of *end-of-life textiles,* including both the reusable garments and other textiles that have been discarded by their user and the textile waste that is beyond re-using, were generated in Finland alone in 2012. Only 23% of the amount was directed to charitable organizations for reuse, whereas the remaining 77% was discarded as waste. Instead of utilizing these humongous masses as raw material, the textile waste streams were routed either to energy recovery, which can exploit only a minor fraction of the resources originally bound into the textile, or to landfill, which according to waste hierarchy is the least sustainable and favourable end-of-life option (Dahlbo *et al*., 2015; Dahlbo *et al*., 2017; United States Environmental Protection Agency, 2017).

Considering the burden virgin fibre manufacturing imposes on the biosphere and human wellbeing, it is no wonder that textile circulation and textile fibre recovery have gained widespread interest among textile industry and consumers. The world simply cannot facilitate any longer textile and clothing industry that is mainly based on *linear economy*:

the traditional economy model, in which the textile's life cycle only extends from its cradle, fibre manufacturing, until its grave, the disposal. Instead, *circular economy* should be integrated into all parts of the textile production chain by designing products with multiple life cycles, prolonging the time of usage and by treating discarded textiles as valuable raw material instead of waste – by creating an effective system of *textile circulation* (European Environment Agency, 2017; Koszewska, 2018). Efforts and dedication are needed from both the industry and the consumers for the cradle-to-cradle principles of circular economy to become the new norm (Boström & Micheletti, 2016; European Environment Agency, 2017; Vehmas *et al.*, 2018).

Various obstacles are yet to be crossed in order to achieve a sustainable textile industry that does not rely on virgin fibre production and excess consumption: technological improvements, re-evaluating regulations and switches in attitudes are all called for (Boström & Micheletti, 2016; European Environment Agency, 2017). Luckily, sustainability is gradually rising as a consumer trend, and textile circulation innovations are emerging due to active and determined research. Even though these developments are making textile circulation more and more alluring and accessible, unleashing the full potential of textiles' circularity still requires actions on both national and international level. The change towards circularity does not only call for operational changes from individual actors, but it is essential to rethink and reform the linear processes of the whole textile and clothing industry. Hopefully already in the near future textile circulation ceases to exist just as a minor side path, but as an essential and ordinary part of the textile industry and its production chains – all the way from textile design to fibre recovery and textiles' new life.

1.2 Aim of the research

Circularity of textiles is steadily increasing its attractiveness in Finland, and the topic has been addressed strongly at European Union (EU) level. A reform of EU's Waste Framework Directive demands that from year 2025 onwards, separate collection of textiles needs to be arranged (European Environment Agency, 2018). The directive and a clear deadline for action have successfully managed to stir the Finnish textile industry and emphasize the need for a functioning textile circulation system: in addition to the separate collection, the processes and facilities for sorting end-of-life textiles and processing and utilizing textile waste simply need to exist by 2025 the latest. However, the field of actors who are involved in textile circulation, and therefore, compose the *ecosystem of textile circulation*, can still be considered rather scattered instead of forming a clear entity. Ecosystems typically consist of a mixed set of actors that are interlinked by a network

of relationships, co-evolving throughout the ecosystem's life cycle (Basole *et al.* 2015). As the textile circulation ecosystem is gradually forming in Finland, highlighting these actor connections and the operations within the ecosystem can be helpful for understanding better the potential of the ecosystem. Current technologies and infrastructure do not yet provide a sufficient capacity to meet the demands that a thorough processing and circulation of end-of-life textiles would pose. Especially in a country such as Finland, with only limited textile manufacturing industry, interactive collaboration between the domestic actors is needed – alongside with a thorough understanding of the possibilities and current limitations of the national textile circulation ecosystem.

The aim of this research was to create an extensive overview of the current composition and structure of the textile circulation ecosystem in Finland and the activities within it. The emphasis was set on examining the drivers and barriers that currently either accelerate or hinder the transition towards a more sustainable, circular textile industry. The drivers and barriers observed in this study were divided into seven main categories: technology, business, organization and management, regulation, linguistics, visuality and psychology. As textile circulation is strongly dependent on different technological processes, the emphasis of the driver and barrier examination was on the technologies that enable textile circulation, and the challenges that said technologies are still facing. Acknowledging and highlighting the positive drivers and hindering barriers will hopefully facilitate further research and targeted measures on the most crucial barriers.

The research was carried out by interviewing actors from different parts of the textile circulation ecosystem, by participating in seminars and other events in which textile circulation related matters were discussed and by reviewing existing research data and publications. The data gathered from these sources was expected to provide answers to the following research questions:

RQ1: *What is the current composition and structure of Finland's textile circulation ecosystem and what kind of operations are being performed within it?*

RQ2: *Which technologies are currently enabling textile circulation in Finland?*

RQ3: *Which drivers and barriers within Finnish textile circulation ecosystem either accelerate or decelerate the transition towards a circular textile industry?*

The information that was gained by finding answers to these research questions will hopefully assist in perceiving the Finnish textile circulation ecosystem in a realistic manner and examining its potential and current challenges with a pragmatic approach.

This research was executed as a Master's Thesis study at Tampere University, commissioned by CICAT2025 project. CICAT2025, *Circular Economy Catalysts: From Innovation to Business Ecosystems*, supports Finland's agenda of transitioning from linear economy towards circular economy and becoming one of the leading countries in the field of circular economy. The aim of the project is to provide solutions to companies and policymakers by exploring and highlighting catalysts that occur in different ecosystems within varying fields of industries. The term *catalyst* is used in the project as a metaphor for an enabler that serves as a positive driving force for the circular economy transition. The project is being carried out in co-operation between various Finnish universities and is funded by The Strategic Research Council at the Academy of Finland (CICAT2025, 2019).

1.3 Scope of the research

The concept of ecosystems – in the context of organizational and technological systems instead of the traditional biological ecosystem – has emerged as a promising way to examine large networks and actor interactions, rather than focusing on the operations of each actor separately (Moore, 1993). However, systematic analysis of such ecosystems can be quite problematic: as Phillips & Ritala remark in their 2019 study concerning ecosystem research methodologies, approaching networks as ecosystems sets challenges concerning the ecosystem boundaries, qualities of the actor relationships and evaluation of ecosystem dynamics. In this study, the ecosystem examination was executed in a simplified way by compiling a visualized example of the textile circulation ecosystem and the occurring actor types, with the focal point being on the interviewed actors. Rather than doing a full-scale ecosystem analysis, the purpose was to provide an example of the necessary actor types and their relations within the Finnish textile circulation ecosystem.

Textile industry and its different sections are widely spread around the world and operations between different actors often require international co-operation. The field of actors involved in textile circulation is no exception to this, as different countries often have their own fields of expertise and are focused on different processes of textile circulation. However, the scope of this research was confined to concern only Finnish actors. The purpose was to achieve a more thorough and comprehensive inspection of the national status – acknowledging that most of the said actors operate also on the global field. The

boundaries of this study were defined to domestic actors operating within the fields of textile reuse, textile recycling and textile circulation related research. Examined processes included for example collection and sorting of end-of-life textiles, coordinating material flows, reusing and reselling textiles as products or as material, textile waste processing and recycling, recycled fibre utilization, clothing lending services and textile circulation related research. The selection of actors chosen for the empirical part of this research is justified in more detail in the research methodology chapter, alongside with a description of their ecosystem roles and represented processes.

Even though a noticeable share of global textile waste is being created during industrial textile production, the main focus in this research was on *post-consumer textiles:* garments and other household textiles, either in reusable or un-reusable condition, that have been discarded by the user. Unlike industrial textile waste, which is relatively homogeneous and created during processes such as cutting and finishing and collected at the production premises, post-consumer textiles create an extremely heterogeneous material flow (Dahlbo *et al.*, 2015). Therefore, post-consumer textiles pose more challenges for example in terms of processing, identifying textile materials and predicting material flow volumes. Even though post-consumers textiles were in the centre of this study, industrial textile waste was also occasionally addressed if the material flow was closely linked to the practicalities of the circulation of post-consumer textiles.

When circular economy is being discussed, the concept of bioeconomy often flows closely beside. Innovations within the field of bioeconomy have taken huge leaps forward, and novel, biomass-derived regenerated fibres have been a valuable add to the spectrum of utilized textile fibres, such as the conventional petroleum-based fibres and resource-devouring cotton. Utilization of cellulose-rich secondary resource streams from agriculture and paper industry takes us closer to finding alternative, more sustainable solutions to the conventional textile fibres. Utilizing excess biomass as a raw material for textile fibre manufacturing is a loyal practice to the principles of circular economy and therefore, an important part of the transition towards a sustainable textile and clothing industry (Kruus & Hakala, 2017). Nevertheless, the focus of this research lays on the circulation of conventional textile fibre streams: prolonging textiles' life cycle as much as possible, utilizing existing, conventional textile fibres as a raw material in recycling processes and utilizing these recycled textile fibres in textile production.

1.4 Structure of the thesis

This Master's thesis consists of a theoretical part concerning both linear economy and circular economy-based textile industry, and an empirical part, which explores the Finnish textile circulation ecosystem and the drivers and barriers that affect the operations within it. A simplified structure of this thesis is presented in figure 2.

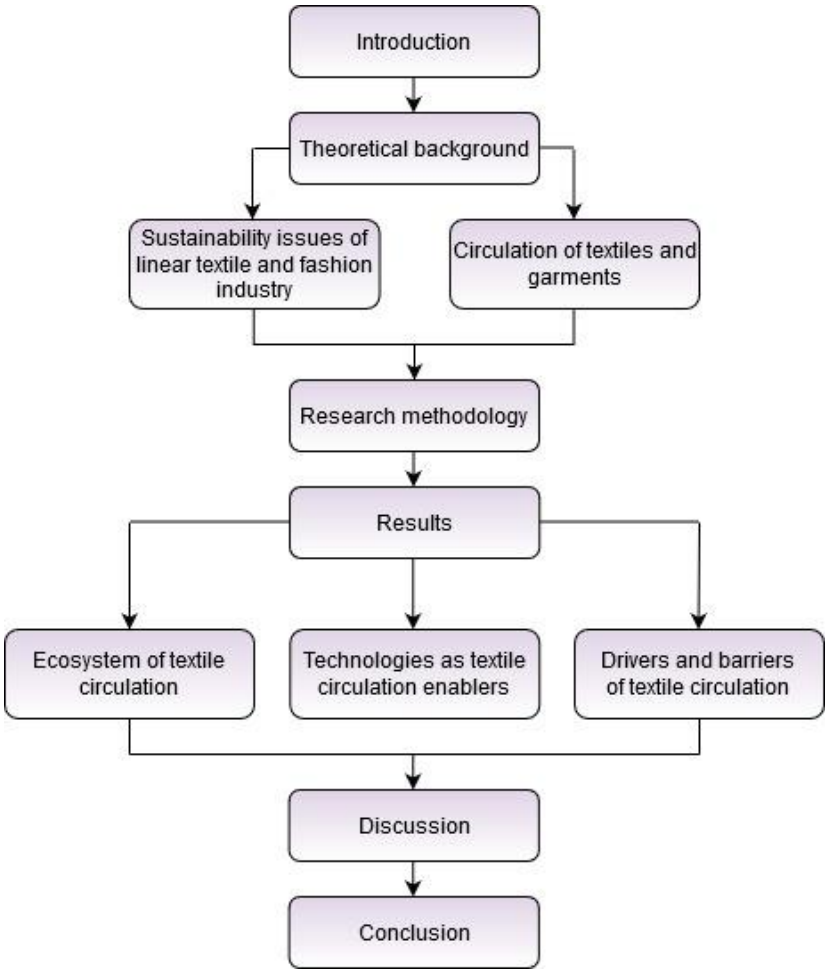

Figure 2. *Structure of the thesis.*

The theoretical background is discussed in chapters 2 and 3, which provide essential background information about the impacts of linear textile industry, and mutually, about the possibilities of textile circulation. Section 2.1 creates an overview of the current linear economy-based textile manufacturing industry by describing production volumes, the most commonly produced fibres and types of material flows. Sections 2.2 and 2.3 highlight environmental and social sustainability issues related to linear textile production –

the key factors, due to which integrating circular thinking and actions into textile production and utilization are needed. Chapter 3 enlightens relevant aspects related to the circularity of textiles and garments in relation to the aim and scope of this study. Chapter 3.1 describes the concept of circular economy and chapter 3.2 presents the principles of waste hierarchy, which is often referred to as a guideline for circular economy-based material utilization. Chapter 3.3 presents the circulation of textiles and garments as an ecosystem and explains the types of material streams involved and circulated within the studied ecosystem, and lastly, chapter 3.4 describes the technological processes of textile circulation.

Empirical part of this thesis was carried out in a qualitative manner, based primarily on actor interviews. Chapter 4 explains the methodology behind the empirical part. Section 4.1 defines the research design, while section 4.2 describes the utilized data types and data gathering processes and provides brief descriptions of the interviewed actors. Lastly, section 4.3 guides through the process of data analysis.

Chapters 5, 6 and 7 present the results gained from the empirical part and aim to provide answers to the stated research questions. Firstly, chapter 5 creates a visualized example of the structure and actor types within the Finnish textile circulation ecosystem and identifies possible actor and operation deficiencies. Technological developments and innovations can be perceived as one of the key enablers for a circular textile ecosystem, and therefore, current and novel textile circulation technologies are highlighted separately in chapter 6. Chapter 7 analyses other drivers and barriers that either accelerate or decelerate the national transition towards a circular textile industry.

The results of this research are summarized and discussed in chapter 8, pondering the impacts of the addressed drivers and barriers and possibilities for further actions and research. Ultimately, the outcome and success of this study are evaluated in chapter 9 and limitations of the study and topics for future research are addressed.

2. SUSTAINABILITY ISSUES OF LINEAR TEXTILE AND FASHION INDUSTRY

"*Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs*" – as World Commission on Environment and Development defined sustainable development in "Our Common Future" report in 1987 (WCED, 1987). Said definition has laid a rock-solid foundation for worldwide sustainability thinking and actions, setting off a multitude of ambitious aspirations, such as United Nations' 2030 Agenda for Sustainable Development. Agenda 2030 declares 17 *Sustainable Development Goals* (SDGs) that are aimed to be achieved globally by year 2030. The most common way of approaching the concept of sustainability is to examine its three intertwined dimensions: environmental, social and economic. SDGs (figure 3) represent all these dimensions by addressing a spectrum of aspirations that need to be achieved in order to guarantee human welfare and prosperity and to tackle climate change and environmental degradation (United Nations).

Figure 3. *United Nation's 17 sustainable development goals, which are aimed to be achieved globally by year 2030 (United Nations).*

Acknowledging the importance of these goals and acting for them is crucial within every field of industry, if global sustainability is wished to be reached. However, doing so urges drastic changes to the dominant economic model, which is mainly linear and based on

ownership and consumption of goods produced from virgin resources (European Environment Agency, 2017; Koszewska, 2018). Especially fast-paced production industries, such as textile and fashion industry, which have for decades relied mainly on utilizing virgin feedstock, are now facing a major obstacle as sustainability and actions of circular economy are being demanded (Ellen MacArthur Foundation, 2017). Despite the recent positive changes in the way both consumers and companies have started to perceive sustainable choices (Vehmas *et al.,* 2018), textile and fashion industry can still be considered distressingly far from sustainable and has both direct and indirect effects on the actualization of the SDGs (UNECE, 2018). These same sustainability issues are the exact drivers that accelerate the need for shifting the weight from linear textile and fashion industry to creating an effective system of textile circulation (Koszewska, 2018).

All human activities are inevitably defined by the tolerance and resources of the planet, and overall sustainability can therefore be considered to rely on the well-being of the Earth. As presented in figure 4, *planetary boundaries*, a framework launched in 2009, are guidelines for operating within the environmental boundaries set by our unique Earth (Steffen *et al.*, 2015).

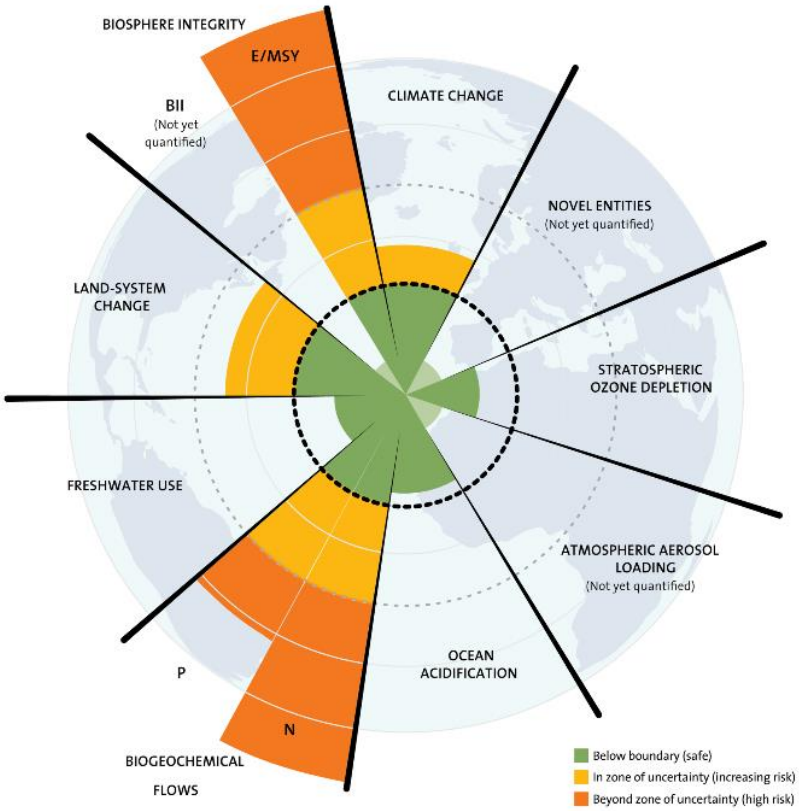

Figure 4. *Nine planetary boundaries, depicting processes that regulate the Earth system (J. Lokrantz & Azote based on Steffen et al., 2015).*

The nine boundaries represent the fields within which humans can safely operate, taking into consideration Earth's tolerance towards processes such as anthropogenic climate change and land-system change. Clear breaches of any of these risk limits endanger the ecosystems that are crucial for the Earth and humankind and therefore, violate the core principles of sustainability. As can be remarked from figure 4, sectors of climate change, land-system change, biochemical flows of nitrogen and phosphorus and biosphere integrity, consisting of biodiversity loss and extinction rates, are already past the safe operating limits. Some of the sectors are even past the boundary of high uncertainty, meaning that the recovery of ecosystems within these fields cannot be fully guaranteed (Steffen *et al.*, 2015). The breaches of these boundaries are caused by a multitude of anthropogenic actions – transport, industrial activity and agriculture to name a few – and textile and fashion industry is contributing significantly with its own share (Sandin *et al.*, 2015; Steffen *et al.*, 2015).

The Earth Overshoot Day provides another tangible baseline for operating within the boundaries. The overshoot day, calculated for both global average and for each country, marks the day of the year when the anthropogenic consumption of natural resources exceeds Earth's annual, sustainable bio-capacity. The overshoot day of Finland in 2019 was 5.4.2019 – almost four months earlier compared to the global overshoot day in 2019, almost a week earlier than the corresponding day in 2018 and earlier than ever in Finland's recorded history (Ministry of the Environment, 2019). If the overshoot trend remains constant and the production and consumption patterns are not changed on both national and global level, the recovery of ecosystems and operating within the safe zone of the planetary boundaries will only become increasingly challenging to accomplish.

The following sub-chapters consist of the background theory that is needed in order to comprehend the necessity of changing the dominant economy model within textile and fashion industry and creating a functioning textile circulation ecosystem. For grasping the magnitude of the problem at hand, sub-chapter 2.1 presents an overview of fashion industry's material flows and linear textile production. Environmental and societal sustainability issues linked to virgin fibre production and linear textile and fashion industry are discussed in further detail in chapters 2.2 and 2.3.

2.1 Material flows of textile and fashion industry

Textile industry usually refers to production of both yarns and fabrics, suitable for a spectrum of applications from fashion to technical textiles, whereas fashion or garment industry specifically means production of garments and household textiles (Šajn, 2019). Dominating portion of all produced textiles is manufactured for the needs of fashion industry,

with clothing representing more than 60% of all utilized textiles (Ellen MacArthur Foundation, 2017).

In 2015, 53 million tonnes of textile fibres were produced for the needs of fashion industry alone (figure 5): less than 3% of the fibre feedstock consisted of recycled fibres from various sources, while over 97% consisted of virgin fibre feedstock. Plastic fibres, such as polyester, acrylic, nylon and polyamide, presented 63% of produced fibres, cotton 26% and the remaining 11% included a variety of natural and man-made fibres, such as viscose and wool (Ellen MacArthur Foundation, 2017). Naturally, material flows of fashion industry are not restricted only to the utilized fibres. Dyeing the textiles and finishing them with various coating agents requires large volumes of chemicals, and logistics of the textiles require cardboard boxes, plastic wraps and other practicalities linked to the storing and transportation of the textiles (Šajn, 2019).

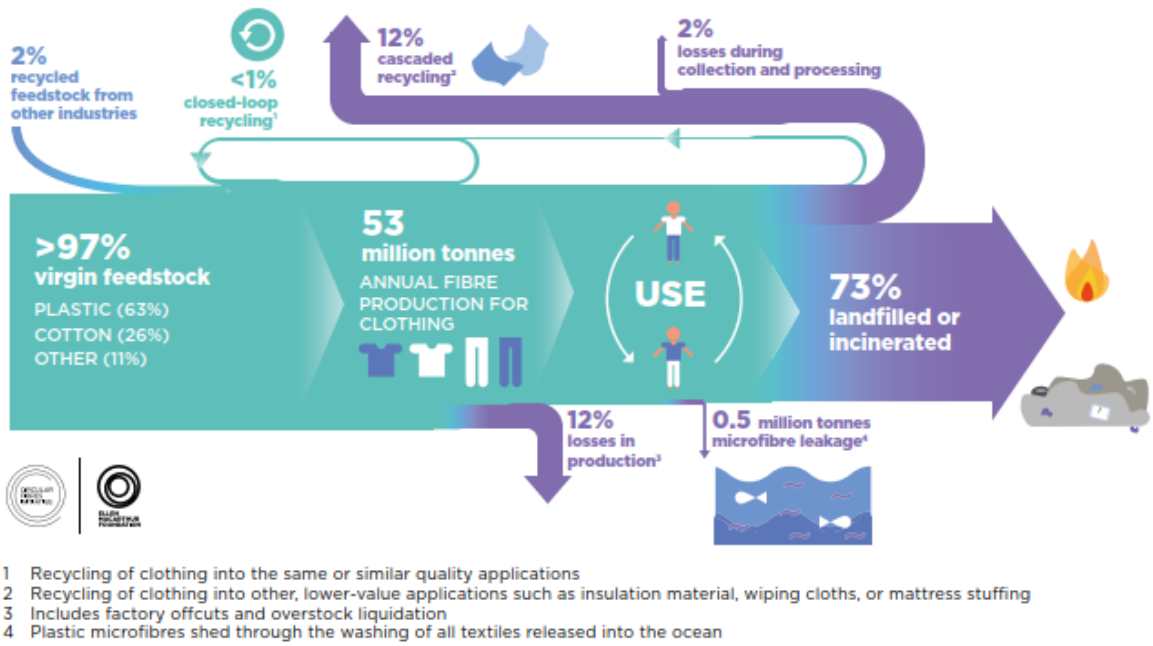

Figure 5. *Global textile fibre flows in 2015 (Ellen MacArthur Foundation, 2017).*

Textile waste flows consist of industrial textile waste, such as excess cuttings generated during clothing production, and post-consumer textile waste, which consists of discarded consumer garments and other textile goods. According to figure 5, while 12% of the annual produced fibres ended up as industrial textile waste, an overwhelming percentage of 73%, equalling over 38 million tonnes of fibre feedstock, ended up either being landfilled or incinerated as post-consumer textile waste (Ellen MacArthur Foundation, 2017).

When the production is approached from a consumer textile point-of-view, the average linear life cycle for a ready textile product and its life cycle from fibre production to disposal can be presented as in figure 6.

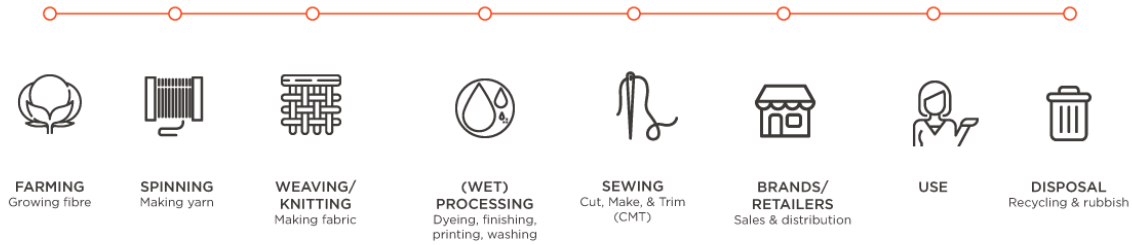

Figure 6. *Consumer textile product's standard life cycle, following the linear take-make-dispose model (Common Objective, 2019).*

The production process consists of growing or manufacturing the fibres, spinning them into yarns, constructing the yarns into a fabric or a knit form and treating the fabrics and knits with necessary dyes, prints, coatings and washes. The fabrics and knits are then cut, sewn and trimmed into the product itself, distributed to storages and retail stores and sold to the customers. Finally, after usage phase, the textile product is disposed of – most often as rubbish (Common Objective, 2019).

2.2 Environmental impact of linear textile production

Aviation and marine transport have sparked up a lot of concern relating to their climate change inducing emissions, and textile production certainly does not pale in comparison. In 2015, around 98 million tonnes of non-renewable resources were required to sustain the textile industry. Greenhouse gas (GHG) emissions from textile production reached up to 1.2 billion tonnes of carbon dioxide equivalent during the same year, exceeding the emissions of all international flights and marine cargo combined and presenting 2% of the whole carbon budget. If the production continues to run on the same pace, it is estimated that the production of garments could be using more than 26% of the carbon budget by 2050 (Ellen MacArthur Foundation, 2017). Furthermore, this percentage is associated only with the scenario of keeping the average global warming under 2 °C, and not in the more recently recommended maximum increase of 1.5 °C (UNFCCC, 2015). If the carbon budget was scaled down to the more ambitious limit of 1.5 °C, current clothing production's share of the carbon budget would naturally be even higher.

In addition to the overall climate change potential, the environmental impacts of linear, fast fashion-based textile production stretch all the way from fibre acquisition to the disposal of textile products (Bick *et al*., 2018). When buying a garment or a household textile, consumers rarely get to know the actual amount of resources and ancillary inputs needed for the production process. Especially cotton can often be mistaken as an automatically environmentally friendly option due to it being a natural cellulose fibre. After all, cotton is just a plant like any other, needing water and nutrients to grow and getting sometimes exposed to pests. However, what makes a difference is the industrial scale of cotton growing and the land area it requires (Šajn, 2019; Water Footprint Network, 2016). Due to amount of sunlight and warm climate that is needed for cotton farming, growing cotton has become centred upon specific countries: for example, India, United States, China, Brazil, Pakistan and Turkey are all major representatives of cotton farming (Statista, 2019). However, multiple cultivation regions within these countries are already dealing with freshwater scarcity (Ellen MacArthur Foundation, 2017; Water Footprint Network, 2016). Irrigating the thirsty cotton crops in these regions consumes massive amounts of water due to the large farming areas (Šajn, 2019) and global warming induced heatwaves, that are only expected to multiply in frequency (IPCC, 2018).

Efficient cotton farming requires also humongous volumes of chemicals in order to keep the number of weeds, insects and plant diseases on a controllable level (Šajn, 2019). According to Ellen MacArthur Foundation (2017), cotton farming accounts for 2.5% of all agricultural land use but up to 16% of worldwide pesticide use. It is estimated that the annual production of cotton consumes 8 million tonnes of fertilizers and 200 000 tonnes of pesticides (Ellen MacArthur Foundation (2017). Unfortunately, in addition to keeping pests at bay, the chemical cocktail sprayed onto the farming fields can have eco-toxic properties on local ecosystems and soil microbiota, causing soil exhaustion and polluting nearby waterways (Koszewska, 2018; Water Footprint Network, 2016). Claiming new land areas for cotton farming affects also natural growing habitats, leading often to depletion of biodiversity as the diversity of native flora and fauna diminishes (Laitala *et al., 2018*).

Producing polyester and other petroleum-derived fibres, such as acrylic or polyamide, does not contribute as much to the usage of land or water as growing cotton does, but a corresponding toll is taken on other environmental fields (Šajn, 2019). Petroleum-derived fibres are highly carbon intensive and consume already scarce and non-renewable fossil resources, and production process can be considered as a significant source of carbon dioxide emissions (Koszewska, 2018; Sandin & Peters, 2018). The production of petroleum-derived fibres and other man-made fibres also requires enormous amounts of

chemicals, some of which have eco-toxic properties (Ellen MacArthur Foundation, 2017). Furthermore, a significant share of marine micro-plastic originates from textile products that are manufactured from man-made fibres. Whereas natural fibres release biodegradable micro fibres, the micro fibres that detach from man-made fibres are non-biodegradable and therefore, a great cause of concern (Brewer, 2019; Ellen MacArthur Foundation, 2017; Šajn, 2019).

The usage of chemicals is not limited only to the production of fibres: treatment processes, such as dyeing and finishing also require humongous amounts of chemicals, increasing the amount of chemical use up to 43 million tonnes annually. Dyeing and treatment processes of textiles are estimated to contribute up to 20% of all industrial water pollution on a global scale (Ellen MacArthur Foundation, 2017; Šajn, 2019). Due to insufficient supervision, textile treatment processes are too often executed uninspected and effluents are fed into waterways un-purified, doing significant damage to both aquatic and terrestrial ecosystems. Dyes and coating agents can contain for example heavy metals and carcinogenic compounds, and can cause eutrophication, freshwater spoilage and marine eco-toxicity (Bick *et al*., 2018; Brewer, 2019; Water Footprint Network, 2016).

Spinning fibres into yarns or filaments and knitting or weaving yarns or filaments into fabric requires effective machinery and often large amounts of energy. In addition, energy usage extends also to sewing machines and other processing and treatment machinery required during the production (Šajn, 2019). The exact environmental impact of these processes if naturally highly dependent on the composition of the energy mix that is utilized for the production.

Transportation and distribution of the textile raw materials and final products has a direct impact on the environment, as textiles are usually distributed around the world from the production premises to the retail stores on different continents (Brewer, 2019). Road freight, air freight and ocean cargo are used as means to transport textile goods around the world, consuming high levels of fuel and therefore, causing GHG emissions (Koszewska, 2018; Šajn, 2019). In addition, the environmental impact of transportation and distribution phase is characterized also by materials used for packaging, tags and bags, the warehouses required for storing the goods and the volumes of parcels that are delivered to the consumers (Jacometti, 2019; Šajn, 2019).

The ways consumers use and maintain their textiles and garments can also have a considerable environmental impact. For example, maintenance actions, such as machine washing and tumble drying, require water, energy and chemicals. In addition, household

laundry contributes to marine micro fibre pollution, as microfibers get loose from the textile products and end up into the waterways. Consumers can affect the magnitude of these impacts in a reducing manner by avoiding unnecessary washing and lowering the washing temperatures (Jacometti, 2019; Laitala *et al., 2018*). According to figure 5 that was presented in chapter 2.1, approximately 0.5 million tonnes of micro fibres were leaked into the waterways in 2015 during the usage phase and washing (Ellen MacArthur Foundation, 2017). Even though modern water treatment is able to remove majority of the micro fibres, alarming quantities still end up into bodies of water via various effluents and end up being ingested by aquatic organisms. As a result, the plastic fibres keep on moving further up in the food chain (Brewer, 2019; Šajn, 2019).

The current end-of-life treatment of textiles consists mainly of directing the textiles either to incineration or to landfills, depending on the country (Jacometti, 2019; Šajn, 2019). As shown in figure 5, majority of the material inputs going into clothing production are lost after the usage phase and losses occur also as cutting waste during garment production. Additionally, garments that have already been produced might never become sold for various reasons and end up being disposed of (Koszewska, 2018). According to Ellen MacArthur Foundation (2017), approximately one truckful of textiles is landfilled or incinerated each second. Whereas carefully maintained and sealed landfills prevent hazardous leachates from entering the soil and enable methane collection for future utilization, especially open dump landfilling poses considerable environmental risks. Open dumps contribute to global warming in a significant manner, due to GHG methane being released into the atmosphere as a result of decomposing waste and spontaneous combustions (EPA; EPA, 2017; Waste Act 646/2011, 2011).

As informed, there are severe environmental impacts associated to each phase of a textile product's life cycle, and due to this, it is essential to value the products and utilize them for as long as possible. When new textile goods are produced, they should be manufactured utilizing as little virgin feedstock as possible to reduce the drastic environmental impacts of fibre production. Underutilizing garments, and consequently, the vast amounts of resources tied to them, is associated especially with developed, higher-income countries (Koszewska, 2018). A study by Sandin *et al*. (2015) estimates, that in western countries, the environmental impact per one usage of a garment should be reduced by 30% - 100% – depending on the type of the impact – by year 2050, if the industry wishes to operate in a sustainable manner within the safe operating zone of planetary boundaries.

2.3 Societal impact of linear textile production

Textile and fashion industry provides employment for hundreds of millions of people, out of which the share of fashion industry alone represents over 300 million employees (Ellen MacArthur Foundation, 2017). Majority of the world's clothing is produced in low- and middle-income countries, and this is also where the societal impacts of fast fashion strike the hardest (Bick *et al.*, 2018). The social impacts of fast fashion-based linear textile production are in many cases dependent on the environmental impacts, as the wellbeing of people is directly affected by the state of the environment and the provided ecosystem services.

Especially the chemicals that are used during textile and fibre production can have negative effects on the workers and people living around the fibre cultivation areas and manufacturing facilities. The pesticides and synthetic fertilizers that are used for growing cotton intensively for the needs of the fashion industry do not only damage the environment, but also cause health risks to the cotton farmers and pickers on the fields (Koszewska, 2018; Moretto *et al*., 2018), as some of these chemicals are known to have carcinogenic properties (Ellen MacArthur Foundation, 2017). In addition, textile production-based wastewater discharges affect drastically the local communities surrounding the production facilities. Unfortunately, not sufficiently enough treated, and even untreated waste waters from textile dyeing and finishing processes are too often discharged to the rivers that are used for fishing, drinking and bathing – threatening thus the livelihood of local people and causing severe health symptoms (Bick *et al*., 2018; Boström & Micheletti, 2016; Brewer, 2019; Ellen MacArthur Foundation, 2017). Moreover, when arable land is used for cultivating cotton, the land area that could be used to feed world's growing population naturally decreases (Laitala *et al.*, 2018). Therefore, intensive fibre production may threaten people's livelihood by affecting global and local food security.

The health burden caused by fast fashion production can also be observed as occupational hazards. The people working in the production facilities may face multiple risks due to poorly managed and controlled working conditions (Bick *et al*., 2018; Boström & Micheletti, 2016). Chemicals used in the production processes of synthetic fibres and dyeing and finishing processes can be extremely harmful for human health, if the generated fumes and skin contacts are not monitored sufficiently and protective equipment is not provided for the workers (Ellen MacArthur Foundation, 2017; European Environment Agency, 2019). For example, carbon disulphide that is used in large quantities in viscose manufacturing process has been proven to have both eco-toxicity potential and to cause

human toxicity symptoms, such as cardiovascular and nervous system symptoms, hormonal disruptions and fertility issues (Ellen MacArthur Foundation, 2017). Furthermore, the workers may be exposed to respiratory hazards caused by the combination of poor ventilation and textile dust, leading to respiratory irritation and lung diseases. Moreover, the workers may experience musculoskeletal injuries due to repetitive work tasks (Bick *et al*, 2018).

Alongside the health problems, producing garments and textiles with fast pace and with trodden costs is reflected also on the workers' rights. The workers, majority of whom are women and girls, must often endure working in unsafe conditions, whilst receiving insufficient salary and working excruciatingly long days – not to mention the underlying problem of child labour (Bick *et al*., 2018; Boström & Micheletti, 2016). Failed work safety supervision has already led to multiple tragic accidents, one of the most impactful ones being the collapse of the Rana Plaza building in Bangladesh in 2013. Even though the building was not structurally designed for industrial activities, it contained multiple textile factories and the operations were continued despite cracks appearing in the building structure. Neglect of the potential hazard resulted in the collapse of the working premises and caused the death of 1138 and injury of 2500 workers. The incident kicked off Fashion Revolution – a movement that has successfully encouraged consumers to ask, "*Who made my Clothes?*", thus demanding manufacturers to make their production chain more transparent, from employees' working conditions to material sourcing (Fashion Revolution).

3. CIRCULATION OF TEXTILES AND GARMENTS

This chapter provides a theoretical background concerning the principles of textile circulation and its characteristics as an ecosystem. Addressed aspects include the concept of circular economy, the model of waste hierarchy, which is the guideline for all material utilization in Finland, a description of textile circulation as an ecosystem and an overview of the technological processes that are necessary for textile circulation.

3.1 Circular economy

Circular economy is an economy model, which aims to reduce the negative impacts of the current, linear take-make-waste economy model by focusing on long-term resilience and perceiving the Earth and anthropogenic activities as a regenerative, circular system. In an ideal scenario, Earth's resources would circulate in the circular economy system in a closed loop as various biological and technical resource cycles, with no additional resource inputs and with no leakages out of the system (Ellen MacArthur Foundation; Geissdoerfer *et al*., 2016). Although creating a fully cyclic system is an excellent goal for moving towards sustainability, achieving and sustaining it infinitely can be considered as quite unrealistic in practice (Korhonen *et al.*, 2018).

The linear end-of-life option of disposal is avoided in a circular economy for as long as possible by following a cradle-to-cradle concept: reducing, reusing, recycling and recovering materials throughout different processes (Korhonen *et al.*, 2018). The processes can be operated on a range of levels, all the way from consumer and companies to a regional, national or international level (Ghisellini *et al.*, 2016; Kirchherr *et al*, 2017). Circular economy strives to facilitate sustainable development by decoupling economic, value-bringing activities from the utilization of finite resources, for example by favouring renewable energy sources and by eliminating waste with careful design (Ghisellini *et al.*, 2016). However, the importance of economic activities is acknowledged as an essential part of sustainability. Therefore, circular economy aims to generate prosperity and economic opportunities all the while maintaining environmental quality and social equity (Bocken *et al*., 2016; Ellen MacArthur Foundation; Kirchherr *et al*, 2017).

The transition from a linear economy towards a circular economy and maintaining effective, reverse resource loops back to the system can be enhanced especially with circular product design and circular business models (Bocken *et al*., 2016). Circular design aims to facilitate the product's reuse and recycling with careful and standardized

material and component choices and with design for longevity. Moreover, circular design promotes the materials' reverse cycles back to the natural and industrial production systems via utilization of by-products and waste and via ease of sorting and separation of different materials. Circular design should also be intertwined tightly with circular business model strategies. New, circular business models are required to replace some of the traditional, linear ones, whilst also providing new business opportunities in order to maintain a functioning economic system (Bocken *et al*., 2016; Ellen MacArthur Foundation; Geissdoerfer *et al*., 2016). Especially companies with larger market share and visibility are wished to act as trend-setters for implementing circular business models. Bringing new, circular business models into mainstream is likely to inspire other actors to adopt said models into their operations and therefore, to facilitate the global expansion of circular business models. However, the transition towards a circular economy requires also other enablers and overall favourable system conditions. Support is needed for example in the form of financing, collaboration and innovative leadership. To set off a systemic change towards circularity, influencing is needed from various agents: policy makers, educational institutions, powerful individuals within companies and responsible consumers (Ellen MacArthur Foundation; Geissdoerfer *et al*., 2016; Kirchherr *et al*, 2017).

3.2 Waste hierarchy

Reducing the amount of actual, disposable waste acts as a core foundation for both circular economy and sustainable waste management. Furthermore, finding alternative ways to elevate various sorts of material streams to higher refinery levels is a priority that is constantly worked on. In order to prolong a product's or a material's life cycle and to use resources as efficiently as possible, a pyramid model of *waste hierarchy* (figure 7) is often referred to when a product is being designed or the most suitable treatment option for each material stream is being chosen (EPA, 2017).

Waste hierarchy presents a list of priorities, according to which material streams are recommended to be utilized and treated after they no longer serve the needs of the holder. By following the priorities presented in the waste hierarchy, the resources can be kept looping within the circular system as effectively as possible (EPA, 2017). Roughly, these priorities can be divided into precautionary approach of waste prevention, different stages of resource recovery and the final, undesirable option of waste disposal.

There are many variations of the waste hierarchy model with an altering number of hierarchical priorities, depending on the included sub-stages. The core structure from waste

prevention to disposal is always the same, but the number of priorities usually alters between 5 - 7 levels.

Figure 7. *The pyramid model of waste hierarchy (EPA, 2017).*

The most preferable option in the hierarchy is to *avoid and reduce* waste – to preserve precious natural resources by preventing the material or product from becoming waste in the first place. Prevention of waste includes also all the activities, that encourage the first holder to re-use a product or to extend its lifetime. Prevention of waste can be enhanced in numerous ways, on both industrial and consumer level. Waste prevention and reduction on industrial scale are often closely knit with careful planning and production management. Production volumes that are in harmony with the demand, modularity, smart packing and product-as-a-service based business models are all effective examples of elongating product's life span and cutting off excess waste streams. For example, technological achievements in the field of 3D printing have also had a huge impact on optimizing material usage and reducing the amount of generated waste. On consumer level, the first priority is rather simple to execute: by avoiding excess consumption and purchasing a product only if it is really needed. Favouring recycled and later on recyclable products, carefully maintaining already purchased products and utilizing repair and rental services are also actions with which consumers can avoid and reduce the generation of excess waste (EPA, 2017; Ghisellini *et al.*, 2016; Waste Act 646/2011, 2011).

The second-most favourable option from the pyramid of priorities is the process step of *reuse*. Even though reusing a product is an important part of waste prevention, on the second priority level it does not refer to the first holder of the product, but to another

holder, who is re-utilizing the same product, material or a component for its original purpose of utilization. Re-using a product refers to utilization without modification - the product can usually be utilized as is, without further processing or other resource consumption. Sometimes, however, the option of *preparing for reuse* is also presented in the waste hierarchy. This stage is closely linked to reuse itself, as preparing for reuse includes maintenance procedures such as inspecting, cleaning or minor repairing, after which the product or component can be reused. If a product is prepared for an industrial reuse, it usually goes through a thorough inspection and is re-directed back to use with a guarantee that the prepared product achieves the same properties and functions as it did during its first life (EPA, 2017; Waste Act 646/2011, 2011). On consumer level, donating or re-selling products that are no longer needed is an excellent way to extend the life cycle of a still functional product by allowing it to be “second-handed” – reused by the next holder.

Recycling is the third-most favourable option in the hierarchy. Recycling includes all the processes through which waste is reformed into a product or a material, which can be used for either its original purpose or for some other function. In everyday language, recycling as a word is often misused and mixed with all the actions that involve passing a material or a product for somebody else to use, whether this requires processing or not. However, recycling always requires heavier processing than the possible minor preparations required for the reuse of a product. Recycling processes vary greatly for each material stream: depending on the substance or material that is wished to be recovered, the methods can be for example mechanical, such as grinding or shredding, chemical, thermal, microbe-based biological recovery processes or combinations of these. In a broader sense, the term material recovery can be used to cover both recycling and some aspects of reuse, meaning that the material is after a certain level of processing still being used in its own material form. Processes of material recovery are the last functions in the waste hierarchy that keep the resources in their original form and the material flows circulating (EPA, 2017; Waste Act 646/2011, 2011).

If waste cannot be recovered in its material form, it is still possible to gain some value of the resources via *energy recovery*. Energy recovery includes thermo-chemical, chemical and bio-chemical processes, through which waste is processed to generate electricity, heat or fuel. In addition, the ash that is being generated as a by-product in thermo-chemical recovery process can in some cases be utilized for other purposes. Energy recovery should be considered as a waste treatment option only if the material is no longer technologically or economically possible or reasonable to keep in the resource circulation. Nevertheless, if the product or substance is beyond material recovery, energy recovery

serves well its purpose of producing valuable energy sources, and therefore, replacing a portion of other resources that would be utilized for energy production (EPA, 2017; Waste Act 646/2011, 2011).

Only at the bottom of the hierarchy, when all the other options have been considered to be unsuitable, should *disposal of the waste* be the action to take. Disposal of the waste is most commonly executed as landfilling the material, or in some cases as incineration without energy recovery. Sometimes a product or substance can be too hazardous even for direct landfilling or incineration, and it requires a waste treatment process such as microbial stabilization before the final disposal. If a product or a substance needs to be disposed of, the disposal is required to be done in the most environmentally secure way possible and without posing any risks on human health (EPA, 2017; Waste Act 646/2011, 2011). Since the ban in 2016, which prohibited landfilling of organic waste in Finland, Finnish waste management system has taken leaps forward: landfilling has decreased drastically in Finland, and a corresponding emphasis has been put on material recovery and energy recovery (Tilastokeskus, 2019). However, on the global scale landfilling continues to exist as the dominant end-of-life option for waste and as a constant cause for environmental concern. As it is unlikely that landfills will cease to exist as the dominant waste disposal method anywhere soon, investments in implementing better landfill technologies and increasing global landfilling supervision are needed (EPA; EPA, 2017; Waste Act 646/2011, 2011).

3.3 Textile circulation as an ecosystem

The ecosystem of textile circulation refers in this study to all the actors and processes that contribute either directly or indirectly, knowingly or unknowingly to the actualization of textile circulation related operations and the business opportunities tied to them. Chapter 3.3.1 sheds light upon the ecosystem approach to textile circulation, and chapter 3.3.2 discusses the material streams circulating within the studied ecosystem.

3.3.1 Business ecosystem approach to textile circulation

An ecosystem approach functions as a clarifying concept, when the relationships in complex, multi-actor systems are being studied. Whereas the conventional network approach entails direct and indirect connections between the actors of a specific network, the ecosystem approach broadens these boundaries by acknowledging the interdependencies between various networks and their actors. Therefore, an ecosystem can consist of multiple networks, involving a diverse range of companies, individuals, institutions and technologies that co-evolve throughout the ecosystem's life cycle. The actors involved in the

ecosystem can be interdependent due to varying reasons, such as shared values and aims or a certain technological platform. The ecosystem boundaries evolve constantly, as cross-industry connections can occur, and the same actors can belong to several ecosystems simultaneously (Aarikka-Stenroos & Ritala, 2017; Moore, 1993).

The concept of a *business ecosystem*, originating from the traditional biological ecosystem, was first introduced in 1993 by Moore. According to Moore (1993), business ecosystems evolve gradually into a structured community, and their life cycles follow a four-stage cycle: birth, expansion, leadership and self-renewal, or alternatively, death. During the first stage, the birth of a business ecosystem, the focus lays on defining what the new, innovative product or service can offer to customers and how it can be delivered. During the second stage, expansion, the ecosystem expands to new territories and possibly starts fighting over the territory with other ecosystems. Third stage, leadership, is based on constant innovation: creating value that is crucial for the whole ecosystem's survival. The last stage of the now mature business ecosystem, self-renewal or death, involves being threatened by new, fresh ecosystems. If the mature ecosystem is unable to bring new ideas and value into it, it will most likely lose the battle to the competing ecosystems (Moore, 1993).

The concept of a business ecosystem has been broadened since and several other types of ecosystems have been addressed too, varying greatly in terms of actor types, processes and ways of interaction. For example, innovation ecosystems consist of innovation-enabling actors and technologies, but the actual value creation is often uncertain due to the ecosystem's innovative nature. Business ecosystems, on the other hand, are often characterized by value co-creation, collaboration, competition and supply chain-related aspects (Aarikka-Stenroos & Ritala, 2017). A new ecosystem can be born for example around a certain technology or resource, novel innovations or knowledge sharing (Phillips & Ritala, 2019). Depending on the boundaries set for the studied ecosystem, the ecosystem can involve a wide variety of actor types, ranging for example from research institutes to companies, non-profit organizations, investors and policymakers.

In the context of Finnish textile circulation, the ecosystem is being built on a solid foundation of sustainable textile production and consumption, and circulation of end-of-life textiles. The processes within the ecosystem are strongly based on the waste hierarchy stages, which are often linked to circular economy: *reduce*, *reuse* and *recycle* – a trio that also goes by the concept name of *3 R's* (Ghisellini *et al.*, 2016; Kirchherr *et al.*, 2017). Figure 8, by Fontell & Heikkilä (2017), illustrates a model for a circular business ecosystem of textiles and provides an example of how the 3 R's of textile circulation can be actualized – all the while creating business opportunities around them. Reduction of

excess consumption, maintenance of products and avoiding generation of waste are naturally top priorities, that act as a backbone for textile circulation – addedly, the aspect of waste reduction flows aside as a resource-saving, business-enhancing element. Nevertheless, when textile circulation is inspected as an ecosystem, the most dominant business opportunities are related to process paths of textile reuse and textile recycling.

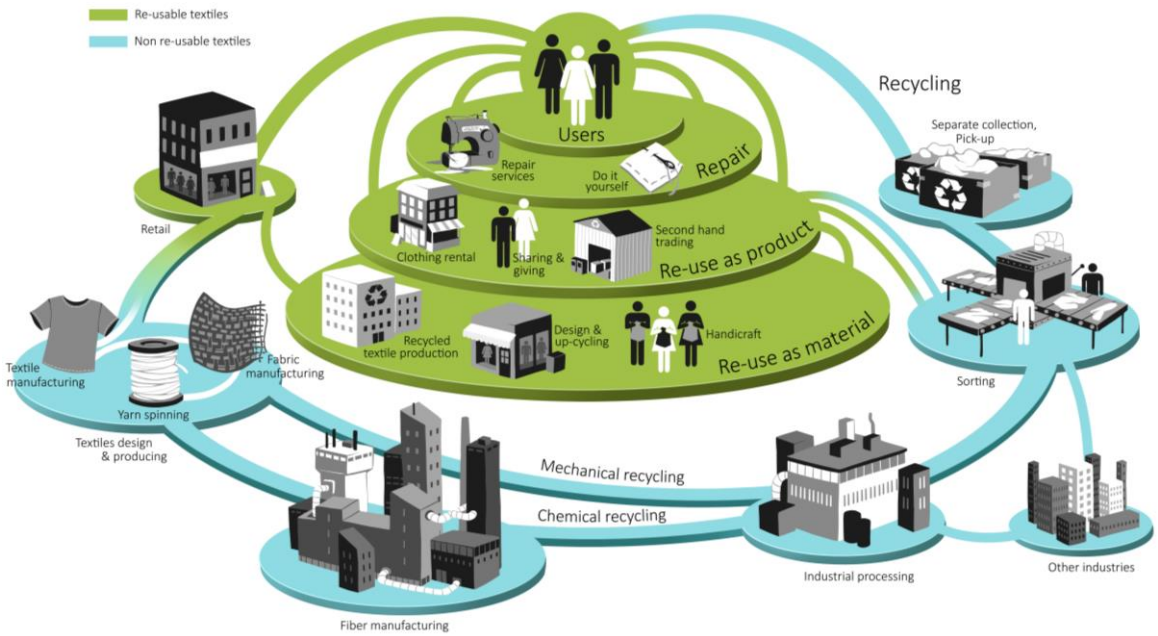

Figure 8. *Circular business ecosystem of textiles (Fontell & Heikkilä, 2017).*

The modelled processes, including activities such as second-hand trading, repairing, collecting, sorting, recycling and manufacturing textiles from recycled fibres, form the core of textile circulation and provide business opportunities for a large variety of different actors within the ecosystem (Fontell & Heikkilä, 2017). The different technological processes for the circulation of both re-usable and recyclable textiles are explained in further detail in chapter 3.4. As figure 8 suggests, textile circulation is an extremely user-oriented ecosystem. The users of the textile products – consumers and professional and organizational users – provide also the raw material stream for manufacturing new products or donate textile products for next users (Fontell & Heikkilä, 2017). In addition to the consumers' central role in Finland's textile circulation ecosystem, various other actor types are naturally also needed. Textile circulation entails multiple different processes and requires utilization of various technologies throughout the circulation. Therefore, a multitude of different types of actors and industries are linked to the ecosystem and expertise and know-how are required from multiple fields and backgrounds.

3.3.2 Material streams of the textile circulation ecosystem

When a technology-based ecosystem is being inspected, it is common that material streams of varying sorts are involved and circulated within the ecosystem (Aarikka-Stenroos & Ritala, 2017). In the context of textile circulation, the material flows consist of both reusable and non-reusable textiles that are donated or discarded by their users. Additionally, when the ecosystem is observed from a wider, circular economy-based point of view, sustainably manufactured, high-quality virgin fibres with a clear purpose are naturally also counted as a material stream.

Textile waste streams, which in a circular economy model are approached as possible business-enabling raw material streams, can be divided in three main categories based on their source of origin: post-industrial waste, pre-consumer waste and post-consumer waste. Post-industrial waste includes the cuttings and excess materials created during textile and clothing production, and the quality of the fraction is usually relatively homogenous. Pre-consumer waste includes defective and low quality products at production premises and unsold products at retail stores. Post-consumer waste includes the textiles and garments that the consumer decides to dispose of for one reason or another. Therefore, the quality of post-consumer textile waste may vary drastically, as textile products may have been disposed of due to them being too worn out or spoiled, or due to them simply not serving or pleasing the consumer anymore (Koszewska, 2018).

When reusable and non-reusable post-consumer textiles are collected as a mixed batch – as end-of-life textiles that the user has discarded – certain regulatory matters related to the definition of waste need to be taken into consideration. In the Finnish Waste Act (646/2011), set by the Finnish Ministry of Environment in 2011 and amended in 2014, waste is defined as follows:

"*For the purposes of this Act, **waste** means any substance or object which the holder discards, intends to discard or is required to discard*."

Based on the definition, all the textiles that the holder has discarded would be regarded as waste, whether they are reusable or non-reusable. However, alongside promoting safe and effective waste management, the purpose of Waste Act is also to support sustainable use of valuable natural resources (Waste Act 646/2011). Therefore, the Waste Act states the following increment to the definition of waste:

"Further provisions by types of waste, on when a substance or object no longer constitutes waste, may be given by government decree, if:

1) *the substance or object has undergone a recovery operation;*
2) *the substance or object is commonly used for a specific purpose;*
3) *a market or demand exists for the substance or the object;*
4) *the substance or object fulfils technical requirements for specific purposes and meets the existing regulations applicable to similar products; and*
5) *the use thereof will not, assessed overall, pose any hazard or harm to human health or the environment."*

Even though end-of-life textiles would otherwise be considered as waste, reusable textile items that have been inspected and separated from non-reusable textiles can be utilized as products due to the increment – after all, textile products are commonly used and resold widely on the second-hand market. Currently, either *product* or *waste status* is granted for the collected textiles based on the purpose in which they have been collected. With a permission, reusable, clean and intact textiles can be collected as products without the waste status being applied. However, the actor that collects reusable textiles is obliged to define this purpose clearly in the sorting guidance, and the person who donates the textiles must knowingly donate them for reuse purposes. Naturally, the quality of the textiles might still not always meet the criteria of the purpose due to the differences in how the original users perceive the quality of the donated textiles (Salmenperä, 2017).

When non-reusable textiles are collected purely for recycling purposes, the material stream is considered as waste, and therefore, the waste legislation applies to it. However, if both reusable and non-reusable textiles are donated and collected together as a mixed batch of end-of-life textile, with both the reuse and recycling purposes in mind, the whole batch of textiles is also considered as waste until having been sorted (Salmenperä, 2017). Therefore, if an actor decides to collect end-of-life textiles from the consumers, it is necessary for the actor to register themselves as a waste management operator.

3.4 Technological processes of textile circulation

Although all the 3 R's contribute to circularity of textiles, the technological processes of textile circulation are often divided into processes that enable reuse and processes that

enable recycling. Figure 9, created by Sandin & Peters (2018), illustrates the classification of various textile reuse and recycling routes in correspondence with the typical textile product's manufacturing process.

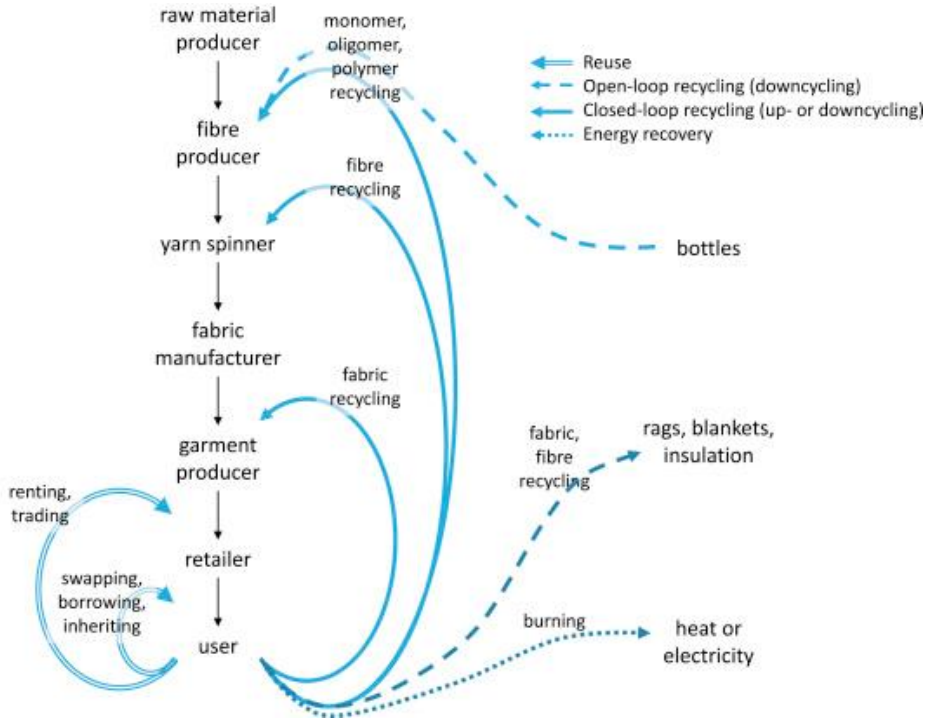

Figure 9. *A classification of textile reuse and recycling routes and an example of a textile product's circular life cycle (Sandin & Peters, 2018).*

Whereas figure 6, presented in chapter 2.1, illustrates the average linear life cycle for a consumer textile product and its life cycle from fibre production to disposal, figure 9 can be considered as its circular economy-based counterpart. In a textile product's circular life cycle fibres and textiles are circulated as long as possible, looping back to different parts of the value chain until the processes of reuse or recycling are no longer technologically, environmentally or economically feasible.

At the end of the initial usage phase of the textile product, the circulation begins after the user donates or discards the product. Currently, reusable textiles can be delivered either to collection bins or premises of various non-profit organizations or to other actors who collect reusable textiles. The collection points are often located in centralized recycling points or for example in proximity to a commercial centre (Fontell & Heikkilä, 2017; Salmenperä, 2017). When the textiles have been collected from the bins or from other donation points, the textiles are moved to sorting facilities. Depending of the volumes going through the sorting facility and the operating principle of the actor, the collected textiles

go through various stages of sorting, such as pre-sorting, fine sorting and extra fine sorting. Sorting process is a crucial part of the circulation, as it determines whether the textile product will continue its journey via reuse, via recycling or whether it can be utilized only via energy recovery (Fontell & Heikkilä, 2017; Sandin & Peters, 2018).

Processes of textile reuse include a variety of activities, that lengthen the life of a textile product and during which the textile product is transferred to a new owner for usage. As addressed in chapter 3.2.2, reuse of textile products can occur with or without modifying the product: said modifications can include for example mending or reworking. Processes of textile reuse include for example renting, borrowing, swapping or purchasing a reusable textile product, that has already been owned or used by another user. The processes of reuse are facilitated for example by second-hand boutiques, flea markets, online marketplaces, retail stores of charitable organizations and clothing libraries (Fontell & Heikkilä, 2017; Sandin & Peters, 2018).

When a post-consumer textile product cannot be utilized via reuse, it is directed to textile recycling as textile waste. Non-reusable textiles face many more process steps before they can be re-utilized in a textile form: textile recycling includes all the processes that are needed before textile waste can be utilized in new textile products or alternatively in other, non-textile product applications (Blackburn, 2009; Sandin & Peters, 2018). The recycling phase begins by transforming the textiles into fibre form via a mechanical recycling process. The textiles are cut and shredded open, providing looser yarn and fibre mass that can be utilized in further processing and fibre manufacturing. Depending on the desired fibre or fibre mixture, textiles are opened in batches based on for example material purity or colour (Fontell & Heikkilä, 2017; Sandin & Peters, 2018).

Textile recycling methods are most often divided into mechanical, chemical and thermal recycling technologies. However, often a mixed combination of these methods is used, depending on the desired outcome. For example, chemical recycling usually refers either to the depolymerizing process of petrochemical fibres or to the dissolving process of natural or synthetic cellulosic fibres, and then repolymerizing the monomers or oligomers into a spinnable form. Either or, the mechanical opening process is needed for transforming the textiles into raw material for the chemical recycling process. Lastly, thermal recycling often refers to melt extruding PET bottle-originated chips into new fibres. However, producing PET chips also requires mechanical grinding (Fontell & Heikkilä, 2017; Sandin & Peters, 2018).

In addition to the technology-based classification of recycling, the methods can also be classified based on the application in which the textiles will be re-utilized, or based on

the quality of the outcome. For example, if the recycling process results in a lower value or lower quality product than in the original application, the recycling process is classified as *downcycling*. Currently, a lot of textile recycling processes result in downcycled products, such as rags, insulation materials and upholstery. As the opposite, if the recycling process results in a higher value or higher quality product than in the original application, the recycling process is classified as *upcycling*. Most often, polymer, oligomer and monomer recycling can be considered as upcycling, as they typically result in a fibre quality that is either better or similar quality compared to virgin fibres. Another way for classifying recycling methods is dividing the processes into either *closed-loop* or *open-loop recycling*. Closed-loop recycling indicates that the recycled material that is gained from the original textile product can be used in an identical product with similar quality properties, meaning that the raw material only moves in a closed circle through the circular value chain. Open-loop recycling, or cascade recycling, indicates that the recycled material's properties differ from the properties required for the original purpose, and the recycled material is therefore utilized in other types of products (Sandin & Peters, 2018).

Depending on the recycled material, the fibres are spun into yarns or extruded as filaments with the desired tensile properties. The length of the recycled fibre is one of the key components for achieving a durable yarn: the shorter the fibre is, the easier it breaks away from the twist of the yarn and causes brittleness and weak spots to the yarn (Boncamper, 2011). The yarns and filaments are utilized in fabric manufacturing, which includes various weaving and knitting processes and the production of nonwovens. Lastly, the fabrics and knits are used in textile product manufacturing and the ready products are transferred to the retailers. The recycled fibre-based products start their new lives with the new users, and the circulation continues when these products are once more donated or discarded (Fontell & Heikkilä, 2017).

If the textiles are unsuitable even for recycling, they are discarded together with normal municipal waste and incinerated for energy recovery. Despite the more favourable end-of-life options, it is worth pointing out that energy recovery from textile waste should not be completely demonized. Clear misuse of textile incineration as a way of quick riddance should not be mixed with reasonable waste treatment, in which material flows are treated in the most suitable way possible that the given circumstances allow. Even if the textile fibres might go through multiple life cycles in various recycled products, inevitably a certain point is reached, after which a textile is too worn, too dirty or even too hazardous for human safety, and thus, unsuitable for reusing or recycling. In this case, incineration plays an important part as textile waste's treatment option (Sandin & Peters, 2018).

4. RESEARCH METHODOLOGY

4.1 Research design

As Salkind (2010) suggests concerning the choice of research designs, a versatile way to approach large entities is to examine them as bounded systems in the form of a case study. Case study approach can be suitable especially for studies that are executed with an exploratory purpose in mind. Case studies help to understand different processes, complexities and their effects on the participants by examining the cases within their local contexts – whether the case consists of one single entity or of multiple objects within one entity. Both quantitative and qualitative data can be used for a case study; however, many case studies tend to be qualitative due to the purpose of exploring a certain phenomenon. Interviews, observations and documents are often utilized as data collection methods, alongside with websites that provide information about the phenomenon (Greenfield & Greener, 2012; Salkind, 2010).

Due to the ecosystem approach of this study, the topic of textile circulation was approached as a single-case study, in which the case consisted of various objects – actors and processes – within one entity: Finnish ecosystem of textile circulation. The boundaries of the study were narrowed down to the textile circulation operations executed in Finland, including activities from the fields of textile re-use and recycling and the related research. The boundaries of the ecosystem were set to the circulation of existing textile products and fibres and to sustainable production of new textile products by utilizing conventional virgin and recycled textile fibres. Material innovations and technologies concerning alternative raw material options for conventional fibres, such as turning agricultural waste into textiles, were excluded from this study. However, it is acknowledged that these processes, too, will be needed in order to replace some of the current virgin textile materials and manufacturing processes.

The methodological approach for this research was solely qualitative and executed via a set of interviews, exploring different actors' perspectives on the textile industry that is transitioning from linearity towards circularity. Wider scale textile circulation is a relatively fresh and a continuously developing part of Finnish textile industry. For this reason, interviewing companies, organizations and specialists can be pointed out as the key data sourcing method for this research (Greenfield & Greener, 2012; Salkind, 2010). Actor interviews are an excellent way of mapping the ecosystem's current status and composition and examining realistically the practical issues within the studied ecosystem.

This research was conducted during a period starting from February 2019 until April 2020. The research was commenced by building a theoretical background concerning the topic. Earlier research results from textile circulation related projects – especially the knowledge created by Telaketju network project and its predecessors – and related event participation were utilized as valuable sources of secondary data, that also laid the base for interviewee selection and further data analysis. The interviewees were contacted during spring and summer 2019, and the primary research data, the interviews, was collected over a period of five months, from May 2019 to September 2019.

4.2 Data gathering

All data sources utilized in this study are listed in table 1, divided into primary and secondary data sources. The table describes the type of data source and the number of sources from each utilized data type.

Table 1. Overview of the data sources utilized in this study.

Data type	Number of data sources
Primary data:	
Interviews with ecosystem actors	Interviews (12)
Secondary data:	
Observation	Workshop discussions (2), seminar and webinar presentations (3), panel discussions (2), tour around the interviewed actor's premises (2)
Research reports and publications	Research and project reports (12), journal articles (21), briefings and press releases (2)
Literature	Books (4)
Media data	Websites (10)
Other	Acts, directives and agreements (4), statistics (2)

As mentioned, interviewing ecosystem actors formed the primary research data for this research, and event participation and research publications reinforced the interviews as secondary background data. Data sourcing processes of the primary and secondary data utilized in this study are explained in further detail in chapters 4.2.1 and 4.2.2.

4.2.1 Primary data

The contacted and interviewed ecosystem actors were chosen based on existing publications, curated by earlier textile circulation related research projects, information presented on companies' websites and event participation observations. A list of interviewed actors and their representatives is presented in table 2.

Table 2. Interviewed actors and their representatives.

Company or organization	Interviewee	Position	Date and location
Pirkanmaan Kierrätys ja Työtoiminta Ry: Nextiili textile workshop	Helena Käppi	Workplace Counsellor	03.05.2019, Tampere
Southwest Finland Waste Management	Sini Ilmonen	Circular economy Specialist	20.06.2019, Turku
UFF	Maija Makkonen Jari Töyrynen	Communications Specialist Clothes collection Manager	27.06.2019, Klaukkala
Finlayson	Elli Ojala	Corporate responsibility Manager	27.06.2019, Helsinki
Finnish Textile & Fashion	Satumaija Mäki	Circular economy Specialist	02.07.2019, Helsinki
Turku University of Applied Sciences	Inka Mäkiö	Designer	18.07.2019, Turku
Aalto University	Marja Rissanen	Project Researcher	24.07.2019, Espoo
Vaatepuu	Soile-Maria Linnemäki	Chief Executive Officer	30.07.2019, Online interview
Lahti University of Applied Sciences	Kirsti Cura	Development Manager	02.08.2019, Lahti
Pure Waste	Noora Alhainen	Project & Management Representative	21.08.2019, Online interview
Infinited Fiber Company	Ali Harlin	Research Professor & Founding member	29.08.2019, Online interview
VTT	Pirjo Heikkilä	Senior Scientist & Project Manager	12.09.2019, Tampere

Contacted actors were chosen with the aim of covering as wide selection of different processes and aspects within textile circulation ecosystem as possible. However, not all

the contacted actors took part in this research, and therefore, it is acknowledged that the interviewed actors do not reflect the whole spectrum of textile circulation. In addition, the number of interviewed participants was limited by the time frame set for this Master's thesis study.

A brief introduction of each of the 12 interviewed actors, in an alphabetical order, is presented next as a justification for the interviewee selection. The introductions are purposed to provide a description of the selected actors' roles in the textile circulation ecosystem and a background context for their points of view.

Aalto University

Aalto University is a research institute, which contributes to the textile circulation ecosystem by providing textile design education and necessary skills to the students and by developing processing technologies. One of the technologies being developed at Aalto University is a chemical recycling technology Ioncell™, which enables using cellulose-based textile waste as a raw material for new fibres. The technology was originally developed for the needs of paper and pulp industry. However, further research showed that cellulose-based textiles also function as suitable raw material for the process, and Ioncell™'s potential in turning textile waste into high-quality, chemically recycled textile fibres has proven to be noteworthy. Ioncell™ as a technology is still run in a laboratory scale, but pilot scale equipment and machinery are already being assembled in Aalto University premises (Rissanen, 2019).

Finlayson

Finlayson is a brand known for its household textiles, such as bed linen, curtains and kitchen textiles. Finlayson resists throw-away culture by creating high-quality, long-lasting products. The production itself is outsourced to international partners, but Finlayson designs the outlook, materials and the overall spirit of their products. Majority of Finlayson's products are made of cotton, but their goal is to reduce the share that cotton presents in the product selection – recycled fibres are already used in selected products. The consumers can drop off their old bed sheets and jeans at Finlayson's boutiques: the bed sheets are reworked into rag rugs in Finland, and the jeans are recycled in Belgium and used as a raw material for towels. Finlayson has also experimented with circular business models by testing out a leasing service, with which the customers could rent Finlayson's products, such as towels and bed linen (Ojala, 2019).

Finnish Textile and Fashion

Finnish Textile and Fashion (Suomen Tekstiili ja Muoti, STJM) is a central organization for the textile and fashion industry in Finland. STJM provides services to its member companies and aims to guarantee the consistency of a favourable business environment regarding Finnish textile and fashion industry. STJM monitors the industry and its trends, technological advances and other occurrences, and aims to forward this information to the member companies. One of the offered services is networking companies within textile industry with each other, but also, contacting other fields of industries. STJM aims also to influence textile circulation related regulations and their preparation process in order to guarantee a feasible operating ground for the member companies (Mäki, 2019).

Infinited Fiber Company

Infinited Fiber Company (IFC) is a VTT start-up that possesses a technology for the chemical recycling of cotton. The Infinited Fiber recycling process includes dissolving textile waste with a cellulose carbamate technology and re-fiberizing it back into high-quality regenerated cellulose fibres. IFC is a technology licensing company, and the goal is to scale up the technology in co-operation with other manufacturing actors. IFC has moved from the laboratory phase to the pilot phase, and an IFC-invested facility will be launched in Tervasaari, Valkeakoski. Although the technology can be utilized for other cellulose-rich fractions too, it has been tuned especially towards textile waste to meet the sustainability demands of textile industry. IFC strives to enable turning old cotton-based textiles into new textile fibres, that both look and feel like cotton (Harlin, 2019).

Lahti University of Applied Sciences

Lahti University of Applied Sciences (LUAS) is a research institute, which contributes to the textile circulation ecosystem by doing research on textiles and circular economy and by providing students with necessary knowledge and skills to overcome future obstacles. Principles of textile circulation have been incorporated to both technology and design fields of study: as a contrast to technology developing, design students and researchers contribute to recyclability of garments via circular design. LUAS has taken part in Telaketju research projects by investigating the possibilities of textile identification and sorting technologies and by contributing to the research concerning business models and product design. LUAS has a laboratory scale sorting line in its premises: the line can be used to identify textile materials based on compiled material libraries, making it ideal for testing company commissions with small batches of end-of-life textile (Cura, 2019).

Pirkanmaan Kierrätys ja Työtoiminta ry: Nextiili textile workshop

Nextiili is textile workshop, owned by Pirkanmaan Kierrätys ja Työtoiminta ry, which operates as a non-profit non-governmental organization in the textile re-use market. Private citizens can donate their end-of-life textiles to Nextiili by bringing the textiles to either Nextiili or to the two co-operative recycling centers. The operating principle is based on rehabilitative work and sorting by hand. The received textiles are sorted into multiple different fractions: some of the re-usable items are sold at Nextiili's own shop and the remaining reusable or recyclable fractions are directed to other actors. Utilizable elements, such as zippers and patches are detached from non-reusable textiles and stored into Nextiili's material bank. The material bank can be utilized by Nextiili's customers and schools, pre-schools and kindergartens (Käppi, 2019).

Pure Waste

Pure Waste is a recycling actor and a clothing brand, whose operations include a versatile range of textile circulation related processes. In co-operation with global partners, the company recycles industrial textile waste mechanically, spins yarn of the recycled fibres and utilizes the yarn for their own production processes. The operating principle of Pure Waste is strongly based on utilizing recycled content in their products and changing the traditional, linear ways of textile industry. Pure Waste has taken part in Telaketju project's experiments concerning the utilization of post-consumer textile waste: for example, Pure Waste has launched a pilot clothing collection which contains raw material acquired from the collected and processed post-consumer textile waste (Alhainen, 2019).

Southwest Finland Waste Management

Southwest Finland Waste Management (Lounais-Suomen Jätehuolto, LSJH) is a waste management company owned by 17 municipalities, and it is responsible for treating residents' waste streams. Textile waste is one of the last waste streams that is still possible to separate from municipal waste and to use for recycling purposes, and LSJH has been the leading waste management company to push forwards the research for achieving a feasible textile recycling process for Finland's textile waste. LSJH has has taken part in Telaketju projects by experimenting with textile collection, sorting and recycling in close-knit co-operation for example with Turku University of Applied Sciences. LSJH will establish a pilot-scale mechanical textile recycling plant in Paimio. The piloting phase will include opening the sorted end-of-life textiles into fibrous raw material, which can then be then directed to further recycling and refinement processes (Ilmonen, 2019).

Turku University of Applied Sciences

Turku University of Applied Sciences (TUAS) is a research institute that contributes to the textile circulation ecosystem by doing research on various textile circulation related aspects and by providing students with necessary knowledge and skills to solve future problems within the industry. Textile related research is carried out either by the students as part of their studies or by the related research group: examined fields have included for example collection and sorting of end-of-life textiles. TUAS has taken part in Telaketju research projects, and co-operation is continuing strong especially with LSJH, including both student and professional experiments and event organizing. Research and experiments are executed in co-operation also with other members of Telaketju network and testing services are provided for different companies within Turku region (Mäkiö, 2019).

UFF

UFF is a private-owned, non-profit non-governmental organization that operates in the re-use and re-sale sector of consumer textiles. UFF's operating principle is based on the textile donations of private citizens and the collection area has expanded to cover almost the whole country. UFF sorts a necessary fraction of reusable garments and textiles for its retail stores, and the remaining textile donations are sold to UFF's partner organizations as wholesale. The profit gained from retail and wholesale of the donated clothes and other textiles is directed to climate work and global development projects. Donated textiles go through various rounds of sorting in UFF's sorting center in order to determine, whether the piece of clothing is re-usable and has market value or whether it should be utilized as a raw material via recycling processes (Makkonen & Töyrynen, 2019).

Vaatepuu

Vaatepuu is a Finnish clothing library, which is currently located in five Finnish cities. Vaatepuu's operating principle is based on the concept of "clothing as a service", offering the possibility of clothing lending for its customers. The service is subscription-based, and the selection consists of a wide selection of both everyday garments and occasion wear. Vaatepuu operates in co-operation mainly with Finnish brands and designers, but the selection includes also pieces from international designers. Borrowing garments helps the customers to find their own clothing style, which ultimately reduces the amount of unnecessary purchases. Vaatepuu also educates its customers on textile maintenance and properties of different textile materials and guides the customers on recognizing the signs of good quality in a garment (Linnemäki, 2019).

VTT Technical research centre of Finland

VTT is a national research institute, which contributes to the textile circulation ecosystem by coordinating and taking part in various research projects and engaging with different actors within the field. VTT has taken part in Telaketju research projects, and currently coordinates and helps different companies to develop their operations within the ecosystem and takes part in building the necessary knowledge base for different processes. VTT was originally founded to help the business and development of Finnish companies, and textile circulation will certainly contribute to both in the future. Textile circulation provides a wide field of possible research; once something is resolved, there will certainly be something new to do investigate and therefore, textile circulation is considered as a relatively long-term research topic for VTT (Heikkilä, 2019).

The interviews were conducted in a semi-structured way, following a set of questions that were mutual to all interviewees. Naturally, relevancy of the questions varied between different actors. Therefore, the emphasis in each interview was on the questions that were relevant for the interviewed actor's own operating field, and the rest of the questions were addressed in a bird's-eye view manner. Despite the un-relevancy of certain questions, having the same question set for each interviewee provided a wider spectrum of aspects and opinions concerning different parts of textile circulation. The question set, consisting of eight main questions and five sub-questions, is presented in appendix A.

Interview questions were sent to each interviewee in advance before the interview. This ensured that the interviewees had time to familiarize themselves with the discussed aspects and provide as thorough answers as possible. The interview situations consisted of going through the structured question set, but also of more free-flowing discussion concerning other textile circulation and circular economy related matters and elaborating remarks that were made during the question set. Nine of the twelve interviews were carried out face to face in various locations, two of which included also a tour around the interviewed actors' operating premises. The remaining three interviews were carried out via video call. All the twelve interviews were recorded on each interviewee's permission in order to make the process of data analysis smoother.

4.2.2 Secondary data

A variety of scientific articles and research publications were utilized as secondary data for obtaining necessary background knowledge about the topic and for creating the theoretical part of this research. Publications concerning sustainability issues of linear textile

industry and previous projects concerning textile circulation provided a solid understanding of the topic itself and a basis for interviewee selection. Scientific articles and other publications were utilized also for filling in more specific, technical details to the results section concerning textile circulation enabling technologies. Literature was also used for solidifying the theoretical part of this research. However, as the topic of circular economy of textiles is still relatively fresh, the presentation of the information is more focused on journal articles and research publications. In addition, media data, such as company presentations on websites, was utilized for obtaining information about the interviewees, their operations and about the discussed technologies in more detail.

Observation at events, such as seminars, webinars and workshops, was also used as a valuable secondary data sourcing method for this research. Attendance to events provided added information on possible interviewee candidates and their operations. Observation provided also a solid background for understanding the issues that sustainable textile production and textile circulation are currently struggling with. The attended events were not chosen in any other specific purpose in mind, but more as to attend as many textile circulation related events as possible and therefore, to broaden the view on the examined topic. The data from event participation was collected by either actively attending workshops and brainstorming with other attendees or by observing seminars and panel discussions and taking notes.

Full list of the attended events is presented in table 3 below.

Table 3. Overview of the event participation data.

Event	Event type	Date and location
Kasvua kiertotaloudesta	Workshop	25.03.2019, Espoo
Specializing in bio- and circular economy in Baltic Sea Region	Seminar	26.03.2019, Tampere
Telaketju: Ensimmäisen vaiheen tuloksien yhteenveto ja jatkosuunnitelmat	Webinar	12.04.2019, Online seminar
Vaatevallankumous: Vastuulliset vaatteet - Anniina Nurmen luento	Seminar	24.04.2019, Turku
Vaatevallankumous: Paneelikeskustelu	Panel discussion	27.04.2019, Tampere
European Society for Ecological Economics Conference: Co-creation - making ecological economics matter	Workshop	20.06.2019, Turku
Oslo Innovation Week 2019: Wood Looks Good on You!	Panel discussion	25.09.2019, Oslo

4.3 Data analysis

The interviews were prepared for analysis by transcribing the interview recordings. The transcriptions were created by compiling the interviewee's main answers from the question set and the other relevant remarks that were made during the discussion. These combined answers were arranged accordingly under corresponding questions in the same interview document that was sent to each interviewee beforehand. Filled-in interview document was again sent to each interviewee and the interviewees were encouraged to read through the answers, in case the transcription included misunderstandings or other humanly errors. If the interviewees wanted a piece of information corrected or a crucial, forgotten detail added to the interview document, these details were changed or added to the interview transcription.

After the interviewees' voluntary examination of their interview transcriptions, a thematic analysis was performed to the interview data. The interviews were first examined through individually, after which similarities within brought-up aspects were sought out and compiled based on occurring themes. Chapter 5, which provides results for the first research question, was divided in two parts: a visualized map of the studied ecosystem and a description of the current activities in Finland. The ecosystem visualization was created based on the interviewees' answers by using *Kumu* data visualization tool. The current textile circulation related operations in Finland were also examined based on the interview data, and the missing links of the value chain were discussed in relation to the model of circular business ecosystem of textiles, presented in chapter 3.3.1. The assortment of textile circulation technologies, presented in chapter 6, provided answers to the second research question. The technologies were compiled based on the interview data, acquiring only additional technical details from other publications. Lastly, the results for the third research question, concerning other textile circulation's drivers and barriers and presented in chapter 7, were curated purely from the interview data.

The results concerning drivers and barriers of textile circulation were divided into categories based roughly on the CICAT2025 project's categorization of catalysts: business, organization and management, regulation, linguistics and visuality (CICAT2025), with an added psychological aspect. The results were examined by identifying key driver and barrier categories that affect the transition towards a more circular textile industry and by inspecting how these drivers and barriers occur in the Finnish textile circulation ecosystem.

5. CIRCULAR TEXTILE ECOSYSTEM IN FINLAND

This chapter provides an overview of the Finnish textile circulation ecosystem's composition and structure and a description of the current activities within it. An example of the ecosystem structure is visualized in subchapter 5.1 and current activities within Finland and value chain's missing links from the field of actors are described in subchapter 5.2.

5.1 Ecosystem composition and structure

Finnish textile circulation ecosystem can be considered extremely versatile: it includes actors such as municipal and private waste management companies, commercial actors, non-profit organizations such as charitable organizations and unemployed' associations, cities, municipalities, service providers, designers and textile companies of various sizes. Therefore, textile circulation provides opportunities and co-operation possibilities to actors with very different roles. There is ongoing activity all over Finland concerning circular economy of textiles, but the operations are clearly centered to the large cities such as Helsinki, Tampere and Turku (Heikkilä, 2019).

Figure 10 presents an example of the current Finnish textile circulation ecosystem, visualized based on the interview data. The actors are colour-coded into seven main groups: companies, non-profit and central organizations, municipal actors, research institutes and universities, policy makers and regulators, funding providers, consumers and media. The actors are listed in table 4, based on the number presented in the figure. However, it should be acknowledged that the provided ecosystem figure is created only around the interviewed actors, and naturally, the depicted ecosystem composition reflects the selection of interviewees. There are certainly a lot more actors in the field of Finnish textile circulation – figure 10 includes merely the interviewed actors and examples of their textile circulation related stakeholders that were mentioned during the interviews. Furthermore, as some stakeholders were mentioned during the interviews as groups of actors rather than separate actors, the actors marked in figure 10 can be from either of these levels, thus distorting the size of the depicted ecosystem and different actors' linkages. In addition, even though global stakeholders were also mentioned during the interviews as essential parts of the interviewed actors' operations, figure 10 includes only the actors operating within Finland due to the confined research objective. The primary purpose of the figure is to provide an example of the composition and structure of the textile circulation ecosystem and linkages between the involved actors.

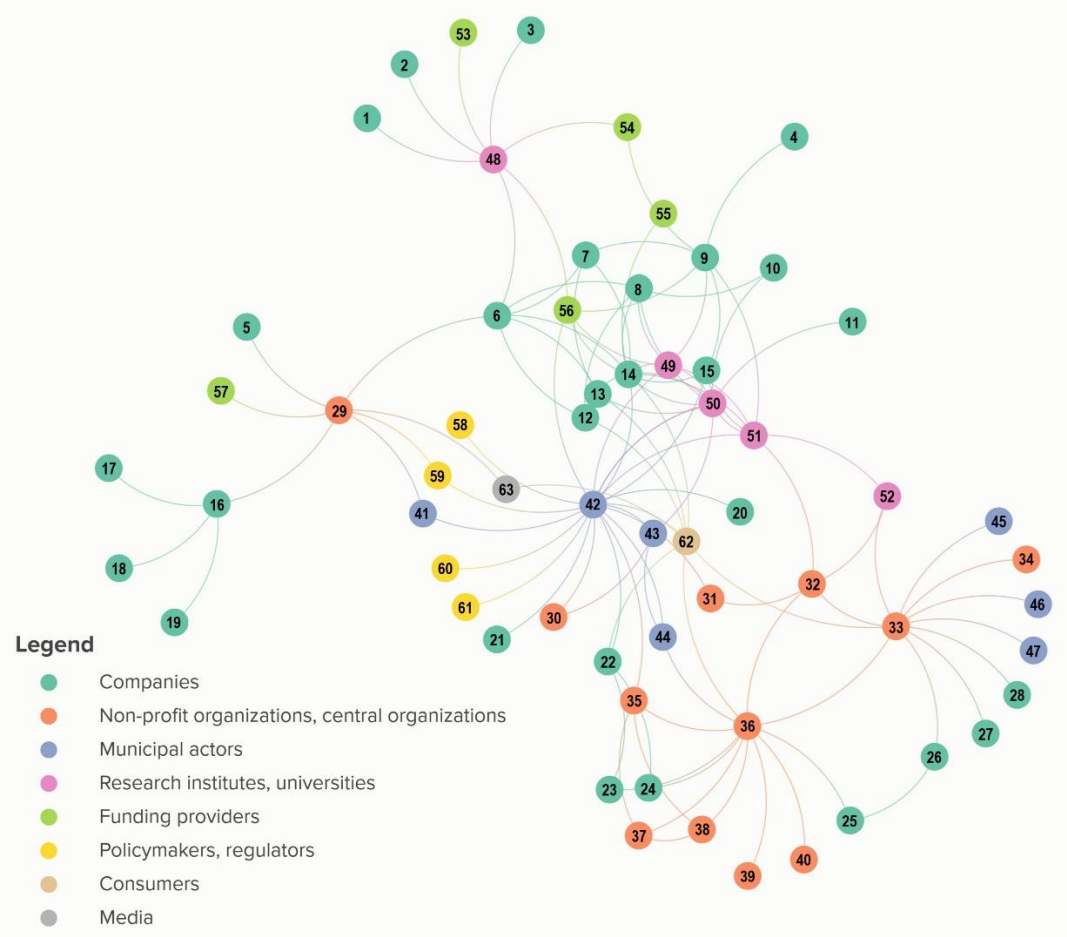

Figure 10. *Example of the composition and structure of a textile circulation ecosystem based on the actor interviews.*

Table 4. List of actors presented in figure 10.

Companies	
1	Metsä Fibre
2	Stora Enso
3	UPM
4	Textile fibre manufacturers
5	Private waste management actors
6	Companies of textile and fashion industry
7	Designers and fashion brands
8	Partner companies in research projects
9	Infinited Fiber Company
10	Soften Acoustics
11	Research commissioners
12	Finlayson
13	Vaatepuu
14	Pure Waste
15	Textile recycling actors
16	End-of-life textile utilizers from other fields of industries
17	Furniture industry
18	Shipbuilding industry
19	Automotive industry
20	Private textile collecting actors
21	Technology developers
22	Retail chains
23	S Group
24	Kesko Corporation
25	Technical textile manufacturing
26	Dafecor
27	Micro entrepreneurs
28	Culture and art productions
Non-profit organizations, central organizations	
29	Finnish Textile & Fashion
30	Turku Science Park
31	Turun Seudun TST ry
32	Texvex workshops
33	Pirkanmaan Kierrätys ja Työtoiminta ry: Nextiili textile workshop
34	Latvia-apu
35	Charitable organizations
36	UFF
37	SPR Kontti
38	Fida
39	Hope ry
40	Rinki
Municipal actors	
41	Municipal waste management actors
42	Southwest Finland Waste Management
43	City of Turku
44	Cities and municipalities
45	Schools of Tampere
46	Kindergartens of Tampere
47	Tammervoima
Research institutes, universities	
48	Aalto University
49	VTT
50	Turku University of Applied Sciences
51	Lahti University of Applied Sciences
52	Häme University of Applied Sciences
Funding providers	
53	Academy of Finland
54	European Union
55	Finnpartnership
56	Business Finland
57	Sitra
Policymakers, regulators	
58	Ministry of the Environment
59	Public administration
60	Regional Council of Southwest Finland
61	Ministry of Economic Affairs and Employment
Consumers	
62	Consumers
Media	
63	Media

5.2 Field of actors and missing links of the value chain

Even though there is a large amount of promising activity, textile circulation related research and enthusiastic and determined actors within the Finnish ecosystem of textile circulation, the ecosystem is only in the very beginning of its expansion phase and far from functioning as a full business ecosystem. When the current, national situation is reflected to the processes illustrated in the model of circular business ecosystem of textiles (chapter 3.3.1, figure 8) by Fontell & Heikkilä (2017), there are various links missing from the value chain of textile circulation. However, it is important to bear in mind that the missing links presented in this chapter are addressed based on the scenario in which the whole production chain would exist in Finland. In the case of global textile circulation co-operation, the need for certain processes on a national level would naturally differ.

Idealistically, the optimal scenario would be having the entire, closed-loop textile production chain existing in Finland. Different materials are currently shipped back and forth around the world, and a full, national production chain would certainly reduce transport and emissions. However, there is still a long way to go before fibres and textiles can circulate in Finland in a closed loop, as a large part of the industrial scale production chain is missing from Finland – at least for the time being. Creating a national, closed loop system of textile circulation is definitely not impossible, but the scale of these processes would have to be evaluated carefully, taking into consideration for example the volumes of recyclable raw material (Heikkilä, 2019; Mäki, 2019; Mäkiö; 2019; Rissanen, 2019).

Reuse-based business, especially second-hand boutiques and charitable organizations' retail stores have found a firm foothold in Finland, yet the practices and volumes are still following behind many other European countries. Multiple practitioners offer repair and maintenance services to textiles, and clothing rental and lending services are gradually becoming more common. There are also various Finnish brands that design and produce upcycled textile products from used textiles. When compared to the ecosystem model by Fontell & Heikkilä (2017), it can be stated that the different processes of textiles' reuse are relatively well represented in Finland.

Whereas post-consumer textile-based re-use business has blossomed in Finland for a good while, recycling of non-reusable post-consumer textiles is still almost non-existent. Only a handful of actors offer textile recycling services, and the recycled fibres are often utilized in downcycled applications. Firstly, a functioning textile recycling system lacks a standardized collection of textiles (Harlin, 2019). However, this is expected to change at latest when the obligation for the separate collection of textiles takes place in 2025. A

comprehensive collection would be the first step in a working textile circulation system, followed by pre-sorting and sorting, which would allow directing suitable, recyclable textile fractions to the fibre opening process. Textiles are currently collected mainly by charitable organizations, whose sorting process is based on hand-sorting and resale value rather than separating different material contents (Rissanen, 2019). However, there is no systematic, industrial-scale sorting yet either: automatic, accurate and based on raw material content (Heikkilä, 2019).

Even though the industrial-scale pre-treatment step of opening textiles mechanically into fibres is currently still missing, a pilot-scale processing plant will be established in the region of Southwest Finland. Ideally, a textile processing plant would have multiple lines for opening different textile raw material fractions, and these masses would be directly routed to reliable partners either for subsequent mechanical processing, chemical recycling or for example yarn manufacturing (Heikkilä, 2019; Ilmonen, 2019; Mäkiö, 2019). However, alongside with a full-scale fibre opening line, commercial-scale recycling solutions are lacking as well. There is only little mechanical textile recycling activity in Finland, and chemical recycling technologies are still under commercialization and require scaling up before industrial utilization (Cura, 2019; Heikkilä, 2019; Ilmonen, 2019; Käppi, 2019).

Lastly, Finland also lacks industrial scale yarn and fabric manufacturers – if closed-loop textile circulation is wished to be executed, these processes are absolutely necessary. Apart from a few woollen yarn, knitwear and linen fabric manufacturers, there is only very little basic textile production in Finland. Some smaller scale spinning and weaving businesses do exist, but there are no larger industrial actors in Finland to produce the kind of fabrics that the textile and clothing industry currently uses. Industrial textile manufacturing infrastructure has been absent from Finland for decades, apart from a few smaller actors (Alhainen, 2019; Heikkilä, 2019; Ilmonen, 2019; Mäki, 2019; Ojala, 2019). Moreover, the know-how of the manufacturing phase has largely moved to the countries where most of the textiles are currently being manufactured (Alhainen, 2019).

When compared to the ecosystem model by Fontell & Heikkilä (2017), it can be stated that the textiles' recycling path on a national level is tackling especially with the lack of yarn spinning and the scale of fabric and textile product manufacturing. Standardized textile collection, industrial-scale sorting and different recycling technologies are all currently being developed and worked on; however, having guaranteed utilizers for both the opened fibre mass and the recycled fibres would most likely give an extra boost to the development of said processes. Due to this, it is important to find more recycled fibre utilizers also from outside textile industry, and bold textile production experiments and emphasis on product development are highly encouraged (Ilmonen, 2019; Mäki, 2019).

6. TECHNOLOGIES FOR TEXTILE CIRCULATION

This chapter enlists current technologies and future's technological advances, that are considered important enabling factors for the textile circulation ecosystem's different processes. Naturally, a vast spectrum of technologies is needed for all the aspects of textile circulation and not all the necessary and existing technologies are covered here. The purpose of this chapter is to highlight certain fields of technologies and technological innovations, that the interviewed actors perceive as beneficial for the ecosystem and important targets for further research, development and investment.

Presented technologies are relevant for different processes of textile circulation and are divided into subchapters based on the function they are beneficial for. Technologies for textile collection are presented in chapter 6.1, technologies for textile sorting and material identification in subchapter 6.2, technologies for fibre recovery and processing in subchapter 6.3 and digital, textile circulation enhancing solutions in subchapter 6.4.

6.1 Technologies for textile collection

Whether post-consumer textiles are utilized via re-use or recycling, guaranteeing textiles' good quality during collection phase is crucial. Even though degraded textiles are removed during pre-sorting, the damage often happens during the collection phase: just a few contaminated pieces of textile, such as smelly or mouldy ones, are enough to ruin the whole batch of collected textiles. Due to this, minimizing moisture in the collection boxes and sealing away textile contaminants is a matter of interest for both the actors operating in the re-use market, and the actors operating in the field of textile recycling. Making the consumers aware of the reason why dirty or wet textiles should not be put in the collection bin is therefore highly important (Makkonen & Töyrynen, 2019; Mäkiö, 2019). However, the quality of collected textile fractions can also be affected with the type and placement of collection bin, emptying frequency and implemented technologies for moisture and contaminant minimization (Mäkiö, 2019).

The type of collection container has its effect on the preservation of the batch of textiles, especially in a country such as Finland, where the weather can fluctuate drastically from freezing and snowy to warm and humid. Textile collection points are currently located mainly outdoors, and condensation moisture can still accumulate in the containers, especially during warm days. Therefore, adding humidity sensors or artificially adding air circulation inside the containers could be a way to control the problem. Experiments

about different collection container type's effect on textile preservation have been carried out by Southwest Finland Waste Management and Turku University of Applied Sciences. However, the most dominant factor for receiving clean and dry textile would most likely be having the collection box located indoors, no matter the container type (Mäkiö, 2019). Consumers tend to appreciate short distances when it comes to dropping off their textiles, and therefore, examples of good textile collection points could be shopping centres or larger grocery stores. Textile drop-off in a controlled environment, with other people moving around, could also possibly decrease the amount of other waste materials ending up in the collection box. When textile sorting centres become more common, textiles could naturally be brought directly to these centres instead of collection containers. Dropping off textiles in a place, where another person is receiving and handling the textiles is also likely to increase the quality of the fraction. Emptying intervals of the containers should also be optimized to suit each collection point: this could be monitored more efficiently for example by adding some sort of a digital fill meter inside the container (Makkonen & Töyrynen, 2019; Mäkiö, 2019).

The collection phase of post-consumer textiles and technologies related to it should also be considered in terms of potential business models. Mäkiö (2019) from Turku University of Applied Sciences remarks, that one example of this could be a deposit-based textile collection bag that the customer buys once, fills up with unnecessary or worn out clothes and other textiles and returns it to the collection point. After the return, a new collection bag would be given or sent to the customer. According to estimations (Dahlbo *et al.*, 2015), one person generates an average of 13 kg of textile waste per year: this would be equal to one large collection bag, and the collection bag's size and dimensions could also be optimized in such a way, that it would fit neatly into the textile collection bin. "*The bag could come with instructions on what kind of end-of-life textile should be packed in it and how in order to guarantee the quality of the batch and the bag remaining sealed during the return. The bag could also be manufactured so, that it would isolate both the external contaminants, such as moisture, and correspondingly, possibly degraded textiles on the inside*", Mäkiö (2019) muses. A personalized code that is typed into the collection box's screen and without which the lid does not open could also be considered: if a textile collection bag was placed in a collection box enhanced with a code system, the system could automatically send the customer a new bag. Having a specific customer code could also help the customers to establish a more personal relationship to the service and recycling in general. When the contents of each bag would be sorted, the customer could for example be provided with personal feedback about the suitability of returned textiles and the customer's own textile return quota (Mäkiö, 2019).

6.2 Technologies for textile sorting and material identification

Careful sorting of post-consumer textiles is a crucial step for textile circulation, as this phase creates and defines the value for the collected textiles. The sorting process can be divided to pre-sorting and sorting itself. During pre-sorting, the textile fractions are sorted by their future use: re-use, recycling or energy recovery (Ilmonen, 2019). After pre-sorting, re-usable textiles often go through multiple other, manual sorting rounds for defining which garments and textiles match the current demand (Makkonen & Töyrynen, 2019). If pre-sorted textiles are directed to recycling, sorting itself will be based purely on the material composition. Material-based sorting is preferably automatized to as high extent as possible, enabling the processing of larger volumes. However, if a piece of textile is directed to recycling purposes, this might, too, require several sorting rounds to separate suitable fractions for each recycling process, for example based on the products' colours (Cura, 2019; Ilmonen, 2019; Mäkiö, 2019).

Relevant aspects and technologies for textile sorting and material identification are presented in subchapters 6.2.1 and 6.2.2, divided into manual pre-sorting and automated sorting and material identification.

6.2.1 Manual pre-sorting

Pre-sorting is currently done by hand, regardless whether the sorting takes place at the premises of an actor operating at reuse market or at recycling market. Manual sorting is needed for separating the products that can be resold and the products that have higher market value, such as vintage pieces and brand items, and for recognizing possible imperfections, such as discolorations, holes and stains (Käppi, 2019; Makkonen & Töyrynen, 2019). Manual inspection and sorting are necessary for identifying the textiles and garments that are intact and suitable for reuse, and it seems unlikely, that reuse-based evaluation could ever be replaced in a fully automated manner. Although the exact fibre composition cannot always be recognized, especially if the care labels have been cut off, the overall condition, feel and looks of the product and possible vintage value can be evaluated more realistically when sorting by hand. Accurate, fibre level detection is not reckoned to increase the reusable textile product's sales value significantly. Sorting and identification by hand also offers employment for many, and for example in the case of regenerative work, supports the idea of rehabilitative guidance and work training (Käppi, 2019). The technologies that would benefit the reuse and resale actors' pre-sorting processes are mainly physical and tied to basic logistics: loading docks, conveyor belts and infrastructure of the premises (Käppi, 2019; Makkonen & Töyrynen, 2019).

It is important to ensure that reusable textiles are directed back to use according to the waste hierarchy, and only a suitable flow of non-reusable textiles is directed to automated, material-based sorting and further recycling processes. Industrial textile surplus may possibly be sorted and directed to recycling based on a few random sample tests, but consumers' end-of-life textiles need to be identified garment by garment, textile item by textile item. The quality of collected textile fractions cannot be relied only to the knowledge and motivation of the consumers, and therefore, manual pre-sorting of end-of-life textiles is certainly needed. (Cura, 2019; Mäkiö, 2019). Pre-sorting is also needed in order to separate the non-reusable textile products, which would be unsuitable for further material identification for example due to complex, multi-layered structures (Heikkilä, 2019). Despite the manual nature of the pre-sorting phase, development of sorting and material identification technologies will surely have their demand when the collected textiles are no longer suitable for reuse (Käppi, 2019; Makkonen & Töyrynen, 2019).

6.2.2 Automated sorting and material identification

As volumes of collected end-of-life textiles grow, the automation of sorting and material identification becomes even more relevant. Ideally, everything happening to the non-reusable textiles after pre-sorting would be automatized: textiles would be sorted into different fractions based on their fibre composition or some other prerequisite, and either transferred to a warehouse or directly to a processing line. Developing automatic sorting is also important in economic sense, as manual sorting of textile waste would not be profitable in Finland on an industrial scale due to its work intensiveness (Mäki, 2019; Mäkiö, 2019). However, even though the sorting and identification processes themselves would be automized, these steps would obviously require human work force to monitor the process (Ilmonen, 2019).

When fibrous raw material is sold to recycling actors and other customers for further refining processes, material providers must be able to guarantee the exact fibre content. If a recycling process is really sensitive and requires for example pure cotton as a raw material, the quality needs be possible to verify (Ilmonen, 2019). Although automated machine vision is not a new technology as such, utilizing the technology for textile identification is still relatively new and challenging due to the complexity of textiles: their different surface treatments, complex knitted structures and additional elements, such as linings, buttons and zippers. Achieving completely automated sorting is certainly not impossible, but for the time being, the technology is not yet available for industrial use due to the lack of demand (Ilmonen, 2019; Mäki, 2019; Mäkiö, 2019). Currently, one of the main bottlenecks in an automated sorting process is feeding the textiles onto the sorting

line and to the recognition device in such a way, that both fast enough feeding and accurate readings can be guaranteed. Potential feeding equipment are being developed, but textiles' highly varying structures and weights pose certain challenges. Some of the textiles may be very rigid and stiff, whilst some textiles may be very slippery or bumpy – all of which complicates optimizing the mechanical grip (Cura, 2019; Heikkilä, 2019).

Textile material identification technologies themselves are already existing, at least up to a certain level: efficiency and speed can naturally be enhanced, but identification itself can be accomplished even from a tiny point in the textile. The current, hindering challenge lies on specifying what kind of material is wished to be sorted from the textile waste. It is important to decide, whether it is necessary to sort everything that can be identified from the textile stream, or if it is more reasonable to concentrate on a few exact material fractions that can be utilized in mainstream applications (Ilmonen, 2019; Mäki, 2019). Either or, developing fibre detectors into a more versatile direction is considered essential, since technologies based on character recognition and colour recognition would allow a wider range of classification criteria for the raw materials. "*Given Finland's expertise in optics and electronics and digital applications, we could be able to do a lot of things in this field – necessary and even inexpensive developments*", Harlin (2019), a founding member of Infinited Fiber Company, remarks concerning the possible future developments of material identification technologies. Nevertheless, the development of both material-based identification and other forms of identification can be considered as equally important. Many consumers cut out the care labels from their textiles due to itchiness, and the care labels might not even always contain completely accurate fibre percentages. There are billions of non-labelled textile products in the world, due to which material identification is an absolute necessity; on the other hand, newer products would certainly benefit from having for example tags, from which all the product information could be read (Alhainen, 2019; Harlin, 2019; Heikkilä, 2019).

Two promising identification technologies are presented below as examples of material-based identification and tag-based identification.

<u>Near infrared (NIR) spectroscopy</u>

Near infrared (NIR) spectroscopy is a non-destructive method of analysis, which identifies organic compounds based on infrared absorption. Whereas the spectrum of infrared wavelengths ranges between 780 - 40000 nm, NIR ranges between 780 - 2500 nm, right next to the range of visible light. The light of the NIR detector interacts with the examined sample and the detector measures its transmittance (the amount of light that passes

completely through the sample to the detector) and absorbance (light that is absorbed by the sample). The detector senses the light that is transmitted through the sample and converts this information into digital NIR spectrums, which enable identifying the material based on its molecular structure. Textiles consist mainly of organic molecular bonds, enabling a quick identification (Kamppuri *et al*., 2019). NIR as an identification technology is already being utilized for the automated identification of various other material streams, such as plastics during plastic recycling, but its utilization in textile identification is still a relatively fresh field of experimentation (Cura, 2019; Ilmonen, 2019).

NIR spectroscopy as a textile circulation technology is being utilized for sorting experiments at Lahti University of Applied Sciences, which has built a laboratory scale sorting line into its premises. The sorting line consists of a conveyor belt and an NIR analyzer placed on top of it. The garments or other pieces of textile are placed onto the conveyor separately and the analyzer recognizes the garments based on infrared readings, without having to physically touch the textile. The analyzer is set on a certain optimal distance, from which the textile is identified as an optical single-point surface measurement. Naturally, this causes also concern considering identification of multi-layered garments and textiles: many garments have outer layers, linings and paddings, all usually from different materials, whereas the analyzer identifies the entire textile product completely based on the material of the outer layer. This obstacle can luckily be overcome with careful, manual pre-sorting, during which the different layers of the textiles are separated to as great extent as possible (Cura, 2019).

When a piece of textile slides under the analyzer, its fibre composition is identified based on the installed material libraries. New material libraries can be created based on the material compositions that are desired to be sorted from the stream of textiles: creating new libraries requires measuring and running tens of samples per material to the system. After the samples are run to the system, they are analyzed with the analyzer software, which harmonizes the measurements with a chemometric method of the second derivative. In addition, certain tolerances can be defined for the maximum variation from the fibre optimum, and these tolerances can vary greatly depending on the utilizer of the identified and sorted fraction (Cura, 2019). For example, for some applications, such as chemical recycling, tolerances can be really strict: "*The analyzer cannot necessarily tell what is the other material mixed with for example cotton, but it can tell that there is in fact also other material mixed – this can already be crucial in some cases"*, Cura (2019) from Lahti University of Applied Sciences remarks.

The NIR spectroscopy measurement itself is fast and the speed can always be enhanced by adjustments, but the limitation of having only one piece of textile going under the

analyzer at a time still exists. On an industrial scale, this limitation can be overcome for example by having multiple analyzers or lines in parallel. After the identification, air blowers blow the identified garment off the conveyor belt to a corresponding material box. Optimizing the blow rate is crucial for having the textiles end up in their own sorting boxes instead of landing elsewhere, as the weight of sorted textiles can range between featherlight to extremely heavy. Textile feed onto the line is currently done manually to ensure that only one textile product passes under the analyzer at a time – developing an automated feeding system would naturally accelerate this part of the process. On an industrial scale, the speed of feeding textiles onto the line and sorting them would depend greatly on the quality of textile fraction: if the fraction has been pre-sorted, in best cases several times, the process would naturally be faster (Cura, 2019).

In addition to purely textile circulation related material identification, NIR spectroscopy has potential on other fields of textile material identification as well. Textile brands' incorrect information on care labels has been a hot topic for a while now, and there have been quite obvious scams concerning the real fibre content of textiles: "*A lot of scams can happen for example while ordering textile material from a subcontractor – after the initial inspection, it is easy for the subcontractors to lower their own costs by sending in mixed material that is inferior to the ordered quality*", Cura (2019) points out. Therefore, NIR spectroscopy could also be used as a nifty random sampling method for catching counterfeit textile goods (Cura, 2019).

Radio frequency identification (RFID)

Radio frequency identification (RFID) is an identification method, with which products can be identified via radio transmittance. The technology is rather simple, requiring only an RFID tag, which is encrypted with the desired information, and an RFID reader for scanning the tag wirelessly. When used for textile identification, the tag can be either embedded into the product itself during production phase or added onto the product's care label or the price tag (Cura, 2019; Kamppuri *et al*., 2019).

Some brands already use RFID tags for textile identification and improved traceability and for being able to offer necessary textile care and recycling services for their products. However, majority of current RFID tags do not endure multiple washes, which is why the tag is recommended to be removed prior to washing and stored away (Cura, 2019). On the other hand, when an RFID tag is added for example to the price tag of a consumer textile product, the recommendation serves mainly the scenario, in which the textile product is owned by only one person during its lifetime. If the textile product is donated or re-

sold for example at a thrift shop, the once-removed tag is very unlike to pass along to the new owner. Durability of the RFID tags could possibly be enhanced, but this would not be profitable, if implemented to the whole, appallingly huge stream of consumer textiles. If cheap clothing production were to decrease drastically and consumer behaviour changed into a direction, where people would be prepared to pay a little more for quality and reciprocally to buy a little less, RFID tags could also become more common (Cura, 2019; Heikkilä, 2019; Ilmonen, 2019; Kamppuri et al., 2019).

6.3 Technologies for fibre recovery and textile recycling

Recycling textiles into recycled fibres can be done in various ways depending on the fibre mixtures of the recyclable fractions. In addition, textile recycling technologies vary drastically in terms of the achieved properties of the recycled fibre. Textile recycling methods and applications for the recycled fibres are already rather functional and well known for pure material fractions, such as 100% cotton or 100% polyester. However, a significant part of all textiles and garments consists of fibre mixtures, which can in some cases create challenges for the processing and the further utilization of the recycled fibres (Ilmonen, 2019). The traditional textile recycling method, mechanical recycling, is already being utilized in Finland, but the novel chemical recycling-based innovations for cellulose based fibres are also showing great potential.

The possibilities and limitations of the conventional textile recycling method, mechanical recycling, are presented in chapter 6.3.1 and the recent development steps of cellulose-based fibres' chemical recycling in chapter 6.3.2.

6.3.1 Mechanical recycling

Mechanical recycling is certainly considered as an enabling factor for textile circulation, although there has not been any new advances to the technology itself in a good while. As the name implies, the recycling method is based on mechanically cutting, shredding or grinding textiles into a fibrous form. Mechanical recycling comes at a much lower cost and risk than for example chemical recycling, as the process can be used for processing practically any kind of textile fraction, no matter the fibre composition. In addition to being a recycling method on its own, mechanical processing also functions as a necessary pre-process for utilizing textile waste as a raw material in further recycling processes. After sorting, recyclable textiles are shredded open into a processable, fluffy fibre form, which can be utilized as such for manufacturing of nonwovens, as a raw material for further mechanical, chemical or thermal recycling or in yarn spinning (Harlin, 2019; Heikkilä, 2019; Ilmonen, 2019).

Southwest Finland Waste Management is currently establishing a pilot-scale mechanical processing plant in Finland, enabling the conversion of textile waste into fibrous raw material. In addition to the aspect of sustainable waste management, the mechanical processing of textile waste is wished to facilitate the operations of several other fibre refining actors, making co-operation with these actors an integral part of the processing plant's operations. Ideally, when the pilot-scale processing plant would be up-scaled into a full-scale refinery plant, there would already be a strong combination of committed partners on standby to utilize the processed raw material. For example, a chemical recycling actor would buy cotton for chemical recycling, some other actor would buy polyester for composite production and another actor would buy opened fibre for yarn and fabric manufacturing (Harlin, 2019; Ilmonen, 2019).

Having a reliable flow of raw material, processed mechanically into fibre form from cellulosic textile waste, would be extremely important also from a chemical recycling process's point of view. In an ideal situation, the textiles would be opened into fibre form in such a fashion, that chemical recycling actors would receive raw material that is tailored exactly for their needs. For example, if a certain cellulose chain length is optimal for the cotton that is utilized in a chemical recycling process, the raw material provider could analyse the molecular chain length of the fibres, for example by viscosity measurement and molar mass distribution, and customize it to meet the needs of the chemical recycler (Rissanen, 2019).

Mechanical recycling always shortens the fibre a bit, naturally depending on how rough the process is. The shortened fibre length affects the quality of the yarn spinning when for example cotton fibres are being spun, making it difficult to obtain a high-quality yarn. The shortened fibre length usually forces manufacturers to produce either thicker yarns or utilize the fibres for example in the production of nonwoven textiles. When compared to chemically recycled fibres, mechanically recycled fibres do have market potential and suitable applications too, but the value is usually slightly lower (Alhainen, 2019; Heikkilä, 2019; Rissanen, 2019). Nevertheless, there are reasons for the existence and use of different fibres, and for example cotton loses some of its properties during chemical recycling – it is important to keep in mind that chemical recycling of cotton does not result in cotton, but in a regenerated cellulose fibre. "*Depending on the application, mechanical recycling can result in recycled cotton with good and sufficient enough quality, and there is certainly demand and markets of their own for both recycling methods. Among other methods, mechanical recycling is an integral part of the big picture*", Alhainen (2019) from Pure Waste remarks concerning the necessity and balance between mechanical and chemical recycling (Alhainen, 2019).

Mechanical recycling also makes it easier to utilize the raw material's own colour, since the yarn does not need to be re-dyed unless a very specific, accurate colour is being sought. While chemical recycling requires much more consideration concerning the behaviour of different dyes, the colours of mechanically recycled fibres automatically correspond to the colours of the original textile products. The troublesome factor, however, is that a certain volume of certain colour must always be sorted before the batch can be utilized for textile production. Furthermore, the customers cannot be promised any exact hue, as the colours always vary slightly when sorted by colour. On the other hand, this also creates a certain value and story for the product from the customer's perspective – the garment feels more personalized, as the hue differences are part of its story (Alhainen, 2019).

6.3.2 Chemical recycling

Chemically recycled fibre innovations are certainly considered as enablers for future's textile circulation. There are chemical recycling methods for both synthetic fibres and natural cellulosic fibres, and especially the latter option is gaining more and more interest within the industry due to the achieved fibre properties, that are similar to those of cotton and viscose. According to current knowledge, chemically recycled cellulose fibres would possess high enough quality for being utilized in even more demanding consumer textile applications. Due to chemically recycled fibres' enormous market potential, commercialization of different chemical recycling technologies is expected to set the wheels turning for the utilization of textile waste. Manufacturing of chemically recycled fibres has already been tested on a pilot scale, but scaling up would require more parallel recycling lines and therefore, more investments. The commercialization of chemical recycling would enlarge the supply of recycled fibre in the market – this, in turn, would make the utilization of recycled fibres more appealing to the larger textile manufacturers, who actively search more sustainable raw material alternatives for their products (Mäki, 2019; Ojala, 2019).

As an example of the chemical recycling process of cellulosic textile waste and its potential as a recycling method, two promising chemical recycling technologies, Infinited Fiber technology and Ioncell™ technology, and their providers are presented below.

<u>Infinited Fiber technology</u>

Infinited Fiber technology is a chemical recycling technology developed by VTT's start-up company Infinited Fiber Company. In addition to being suitable for the chemical recycling of cotton, the technology can also be used for other cellulose-rich fractions such as

cardboard, agricultural waste or wood-based pulp. In the context of textile waste as raw material, the operating principle of Infinited Fiber technology is based on turning opened, fibrous textile waste into cellulose carbamate, which is dissolved and re-fiberized back into regenerated cellulose fibres, Infinited Fibers. The process can be divided into two parts: the production of cellulose carbamate and the production of the textile fibre itself. This provides significant logistical benefits, as the textile waste and fibrous raw material can be processed into liquid raw material in one location and into a textile fibre in another location. In addition, opening textile waste into raw material form always produces fine, fibrous dust, which is not suitable for example for the production of yarn or nonwovens. However, this fibrous dust can also be utilized in the chemical recycling process, as long as the fibre dust originates from a cellulosic enough fraction. The suitable raw material fraction does not necessarily need to consist of pure cotton, but nevertheless, the fraction should preferably be as rich in cotton as possible (Harlin, 2019; Infinited Fiber).

The achieved fibre can have the similar natural look and feel as cotton, and the colour uptake can be up to 30% - 40% higher. One of the technology's key advantages is that it can be applied to already existing pulp and viscose factories, resulting in smaller investments costs among various other benefits: converting a viscose production facility into a chemical recycling facility would contribute both to the utilization of textile waste and to the reduction in the usage of the hazardous carbon disulphide that is necessary for the viscose manufacturing process (Harlin, 2019; Infinited Fiber). Due to the utilization of textile waste as a raw material, the environmental impact of the Infinited Fiber manufacturing process is significantly lower than those of virgin cotton and virgin viscose. For example, up to 20 000 litres of water can be saved per one kilogram of Infinited Fibers compared to one kilogram of cotton, and 160 000 hectares of forest harvest can be avoided when compared to viscose manufacturing (Infinited Fiber).

Infinited Fiber Company is a technology licensing company, and therefore, the goal is to scale the technology up in collaboration with other actors. The production volumes are still significantly lower than what the global textile manufacturers' demand would require. Therefore, a great deal of up-scaling and investing is still required before chemical recycling will become commercially viable. The production has recently moved from the laboratory phase to a pilot phase, and a production facility, invested by Infinited Fiber Company, will be launched in Valkeakoski, Finland. The following scale of production line will be a demonstration line, but the exact location is yet to be determined – due to the selling of technology licenses, this may not be Infinited Fiber Company's own manufacturing facility (Harlin, 2019).

Ioncell™ technology

Ioncell™ technology is a chemical recycling technology developed by Aalto University's Biorefineries research group. The technology was originally developed for the needs of paper and pulp industry. However, cellulose-based textile waste was soon discovered to be suitable as a raw material, alongside with newspapers, cardboard boxes and the original raw material, wood pulp. The operating principle of Ioncell™ technology is based on grinding the raw material, mixing it with an ionic solvent and spinning the cellulose solution into fibres via dry-jet wet spinning. The technology is still on a laboratory scale, but pilot scale machinery is being built in Aalto University's premises. Achieving commercial scale for the operation depends greatly on the results gained from the pilot-scale testing. Pilot-scale machinery is naturally suitable for smaller, commercial experiments, but significant upscaling is still required for commercial profitability (Rissanen, 2019).

The fibre production itself is relatively fast: when compared to for example the production process of viscose, Ioncell™ fibre is noticeably faster to produce. The production pace of Ioncell™ fibres is comparable for example to that of lyocell fibres. The efficiency of how much fibre could be produced from a unit of textile waste depends on the properties of the cellulose. The advantage of chemical recycling, compared to mechanical recycling, lies on the upgrading effect it has on the raw material's properties. For example, the fibre strength of a cotton fibre is 30 cN/tex: when cotton waste is used as a raw material for Ioncell™ fibres, the fibre strength of produced fibres increases up to 50 cN/tex. Chemically recycled fibres can be used to make thinner yarns due to the high fibre strength, which in turn increases the market value of the fibres. Since the achieved fibre is a regenerated fibre, the fibre length of recycled fibres can be modified to suit the needs of each application. Due to this modifiability, Ioncell™ fibre can be utilized for a broad variety of yarn types, ranging from cotton-like yarns to wool-like yarns and to many others (Rissanen, 2019).

Part of the textile waste that is suitable for utilization in Ioncell™ process can also be recycled into fibres of corresponding colour, thus lessening the need for later dyeing processes. However, Rissanen (2019) from Aalto University points out, that the hue of the recycled fibres depends entirely on the dye molecule that was originally used for dyeing the raw material, textile fibres. "*Whereas some dye molecules prevent the recycling process completely, some dye molecules change their hue either drastically or fade only very little during the process, and then again some of the dye molecules remain completely unchanged throughout the recycling process*", Rissanen remarks, concluding that achieving a thorough understanding of how all the different dyes behave during the process still leaves plenty of room for research (Rissanen, 2019).

6.4 Digital solutions

In addition to the processing technologies that enable the circulation of textiles and fibres, certain digital enhancements and platforms are also expected to enable smoother processes and more accessible services. It is highly important to have digital tools to manage the vast amount of data that is related textile circulation and to utilize this data more efficiently (Heikkilä, 2019; Ilmonen, 2019; Mäki, 2019).

Examples of possible fields of development regarding digital technologies will be presented in sub-chapters 6.4.1, 6.4.2 and 6.4.3.

6.4.1 Product passport

All textile manufacturing and circulation activities involve a tremendous amount of data. A promising way for handling and utilizing said data, whilst also improving traceability, would be creating digital product passports for textile products. A product passport would contain all the relevant information about the product's life cycle and even instructions for further maintenance, re-use and recycling processes. Product passport could reveal everything the product has undergone: the fibre composition, the chemicals used to dye and manufacture the yarn, different processes and so forth. For example, after material identification, alone the acquisition of dyeing data can take a considerable amount of time – having this information ready, alongside with all the other data, would save resources significantly and speed up the recycling process (Alhainen, 2019; Cura, 2019). Ilmonen (2019) from Southwest Finland Waste Management points out, that the more openly companies and organizations can produce data and share it with others, the better circular economy will pick up pace and become a natural part of everyday activities: "*Special attention should be paid to the collection, opening up and utilization of digital data, so that the data would be available to those who need it – this holds an unimaginable amount of potential*", Ilmonen remarks.

Ideally, there would be for example an RFID tag on the seam of the textile product or elsewhere in the textile. The tag would hold the product passport information of all the materials and chemicals used in the product, with their exact percentages and origins. There have also been future visions about encoding all the information about the product into the thread itself – however, the humongous product repertoire should be again reduced in order to make the process feasible and worth developing. Currently, even the origin of virgin material cannot always be fully guaranteed: a full traceability and as accurate process data availability as possible, throughout all the process steps, would be

a truly holistic change. However, the challenge is that the same traceability should preferably apply to all the textile products, and the product passport label should be on the textile regardless of the manufacturer (Cura, 2019; Heikkilä, 2019; Ilmonen, 2019; Mäkiö, 2019). Data availability would also benefit textile circulation in terms of more reliable life-cycle assessment, LCA, calculations. It takes a lot of work and struggle to acquire enough data in order to provide a reliable LCA analysis: the tiniest bits of information are needed, all the way from growing conditions to transportation, storing conditions, chemicals and processes. Unfortunately, companies do not usually have access to all this relevant information simply due to the lack of data availability (Mäkiö, 2019).

Product passports and traceability could also facilitate of business models, in which certain products circulate in smaller-scale closed loops. In such a loop, a textile product would be used, and once depleted or no longer needed, the product would be either returned to the same specific circulation for re-use or recycled as a raw material for a new, equivalent product (Mäkiö, 2019). There are already workwear manufacturers who have a system in which the polyester clothes that have been worn for a certain period of time are melted, turned into new fibres and utilized again in the manufacturing of new work wear. This sort of material cycle is possible for a certain amount of times, after which the clothes are utilized for example in composite use. However, similar circulation loops for everyday wear are problematic, since majority of the clothing manufacturers do not have these sorts of product information management or return systems to control the circulation. Furthermore, the operations of clothing manufacturers are often more global (Heikkilä, 2019). Creating efficient loops for certain products and incorporating traceability into the production would certainly require more efforts and transparency from the manufacturers, but it could also create interesting stories for the products. For example, if the consumer would be able to know how many life cycles the material in the products has gone through, the relationship towards the product could become more personal (Mäkiö, 2019).

6.4.2 Online rental and lending services and sharing platforms

Developments in various circular, digital service platforms are considered as essential drivers for textile circulation. However, these platforms still need to be refined further for a smoother user experience, as the applications and platforms for borrowing or renting clothing and other textiles are currently not too functional. Examples of potential development targets could be an online clothing library, or even consumer-to-consumer based, online clothing borrowing (Linnemäki, 2019; Mäkiö, 2019). Naturally, there are physical premises, such as clothing libraries and rental studios, but digital enhancements

would still be needed to reach as large crowds as possible. Services should always be built on a need basis: large crowds do not necessarily favour circular services purely for the will to save the Globe, but for the need to access fashion and get something new in a relatively fast and easy manner. It is important to understand and accept what gets the crowds moving and put emphasis on making the service as easy and effortless as possible to use, allowing people to feed their attraction of novelty in a more sustainable manner (Linnemäki, 2019; Mäki, 2019).

Rental and lending services as such are mainly serving customers who really enjoy being able to visit the physical premises and who like to try on and feel the garments, browsing the availability of different products in a library-shelf manner. However, there are many potential customers who would be interested in responsible choices and borrowing garments, but for whom visiting the premises is simply not possible. Furthermore, if a customer has a specific product in mind, it would be a huge step forward to be able to ensure in advance that the desired product is actually available for rental or lending when the customer comes to pick it up (Linnemäki, 2019). There are many simple, basic models for setting up an online store; however, when it comes to creating an online lending service, finding a suitable service can be challenging. Online stores are usually designed only for selling goods and converting the existing platform to suit also sharing purposes is rather tricky and might not work very well in the end. In this case, developing a simple rental and lending application could really benefit the operations and act as a driver for the circular services (Linnemäki, 2019; Ojala, 2019).

6.4.3 Virtual fitting rooms

Virtual fitting room, based on the customers' own body shapes and measurements, would be a beneficial add for online stores, online clothing rentals and online clothing libraries. A virtual fitting option would certainly reduce the amount of mis-rented and mis-bought items, since customers would be able to try out the garments on themselves virtually before ordering. Virtual fitting would also contribute in reducing unnecessary parcel handling. Pointless packet deliveries have of course their environmental impact but picking up deliveries and returning them soon due to them not fitting is also a waste of customer's time. Linnemäki (2019) from clothing library Vaatepuu emphasizes, that renting or lending a garment should be just as easy as buying one. Therefore, a virtual fitting option, alongside other digital advances, would be a strong booster for textile circulation by bringing flexibility and punctuality to the service (Linnemäki, 2019).

7. DRIVERS AND BARRIERS OF TEXTILE CIRCULATION

This chapter enlists other factors that, alongside textile circulation technologies, accelerate or in some cases hinder the operations within textile circulation ecosystem. The examined drivers and barriers are compiled based on the actor interviews, and they are divided into six different main categories: business, organization and management, regulation, linguistics, visuality and psychology.

7.1 Business drivers and barriers

The following sub-chapters provide examples of business-related drivers and barriers that either enhance textile circulation or are considered as necessary targets of development.

7.1.1 Supply and demand

Textile circulation has managed to gain media's attention, which in turn evokes consumer interest, and as a result, creates demand for more sustainable textile products. Therefore, the more public attention the topic gains, the better business opportunities the companies involved in textile circulation have (Heikkilä, 2019). Recent positive changes in consumer behaviour act as strong drivers and provide confidence for the future, as there is a clear demand also for textile products that are manufactured from recycled fibres. Demand from empowered customers' direction encourages manufacturers to start steering their production to a more sustainable direction (Alhainen, 2019). Recycled yarn and clothing manufacturer Pure Waste has noticed this new consumer behaviour spreading among a variety of customers: "*Pure Waste's clientele includes a large number of start-ups and young companies, event organizers, student organizations and schools – "awakenings" have clearly occurred in many directions*", Alhainen (2019) remarks.

Supply and demand certainly have their impact also on the second-hand market and operations within the field of textile re-use: for example, there is currently much more demand for textile collection points compared to the collection points' actual amount and locations (Makkonen & Töyrynen, 2019). In addition, before deciding what sort of products are especially sought for the retail store selections from the flow of collected clothes and textiles, it is important to consider the dominating trends of each season and provide a selection that meets this demand. "*In order to meet consumers' interest, used clothing*

and other textiles, including vintage products, must provide a viable alternative to the trends and styles currently prevalent on the market – generally, people want to look presentative", Makkonen and Töyrynen (2019) from UFF summarize.

In terms of textile recycling, a lot of similarities are expected when compared to the recycling of plastic. When plastic collection was started in Finland and it became a part of everyday life, recycling of all the collected plastics became a notable issue due to oversupply – the same problem is likely to apply to textiles as well. As recycling of textiles is gaining more interest, effective control of material flows becomes even more crucial. It is important to define beforehand the types of recycled fibres there is truly demand for and simultaneously search for possible new ways to utilize collected textiles and different material fractions (Harlin, 2019; Mäki, 2019). There are already takers for recycled, pure cotton fraction, but as Mäki (2019) from Finnish Textile & Fashion points out, the other fibres and fibre mixtures should also be strived to utilize as wisely as possible: "*Large-scale recycling will not be profitable if cotton is the only material to be recovered*", Mäki remarks. Nevertheless, concentrating on large volumes and the most common material fractions might be the most practical approach for creating the market, at least for the start. Furthermore, there will always be problematic products, such as bulky pillows and blankets or multi-layered and heavily coated textile products: these are simply not an attractive choice to a recycler or a fibre utilizer due to the challenges they currently set for the recycling process (Cura, 2019; Mäki, 2019).

One of the important steps for Finnish textile recycling would be to search utilizers for recycled fibres – there is no point in providing a large supply of mechanically recycled, opened fibre if there is no demand for it from further recyclers or utilizers. Therefore, it would be beneficial if the pilot plant for mechanical recycling would have a spectrum of partners involved already in the beginning of its operation: chemical recycling actors, actors experimenting with yarn spinning and so forth (Cura, 2019). Furthermore, if textile waste is prepared into a raw material for chemical recycling, the price of said raw material should be scaled onto a level on which it provides a viable alternative to the utilization of virgin wood pulp (Rissanen, 2019). Demand should also be sought from outside the textile industry: it is important to involve other industries in utilizing recycled textiles and fibres as a raw material for their own products. For example, German car industry has been utilizing recycled textiles for decades due to their lowering effect on cars' weight and thus, also on the emissions. In Finland, shipbuilding industry could be a corresponding, promising alternative, as the same interests in lowering the structure's weight would most likely apply. Utilizing textile waste for applications such as composites is sometimes

considered as downcycling, depending on the properties of the manufactured composites. However, if the composites are utilized in a long-lasting product, such as a ship, the benefits would surely outweigh the mental image of downcycling (Mäki, 2019).

7.1.2 Business models

New textile circulation related business models are gradually starting to emerge through persistent experiments, and different actors are starting to offer also services alongside their traditional operations. Finland's small and fragmented population sets certain challenges in terms of services, but the consumers are slowly getting familiar with service-based businesses. Service-based business models often require a comprehensive change also from the service provider's point of view. When compared to traditional business, in which a product is simply bought and owned, it is important to accept the initial slower rate of gaining profits and possibly, a smaller number of customers in the beginning (Mäki, 2019). On the other hand, it can also be a conscious choice for an actor to exclude certain services from their operations in order to provide business opportunities for other small businesses or to cherish long partnerships with said service providers: "*Nextiili does not have its own repair or maintenance service, even though the existing machinery would provide prerequisites for it; textile maintenance services are consciously left as business opportunities for the small entrepreneurs that operate on the field*", Käppi (2019) from textile workshop Nextiili comments on their business model.

Especially digital enhancements to current business models are expected to boost textile circulation related business forward. For example, implementing e-commerce to a physical second-hand store's operation is expected to meet the consumers' needs better than by relying solely to physical premises and the traditional way of operating (Käppi, 2019). In general, more new business models are wished to be developed: sharing economy-based models, such as clothing lending services, already exist in Finland, but novel ideas and improvements are always needed to make textile circulation as efficient as possible (Cura, 2019). For example, clothing leasing companies could certainly benefit from facilitating online rental and home deliveries, and correspondingly, a home textile lending service and related applications would certainly be welcomed. The flexibility and adaptability of these services should also be developed in order to reach a wider spectrum of customers: "*Digital applications and services could also be developed to cope with exceptional situations such as business trips*", Ilmonen (2019) from Southwest Finland Waste Management suggests, "*for example, after a web loan, the ordered pieces of clothing could be delivered as a service to the hotel one will be staying in: the clothing set could include anything from conference wear to party wear or running shoes*".

7.1.3 Funding, investments and commercialization

Funding gives a boost to any action, and textile circulation is no exception to this – the importance of funding cannot be underlined enough, especially when large investments are planned. For example, the forthcoming mechanical recycling pilot plant for textiles has received funding from Ministry of Economic Affairs and Employment and all municipal waste management companies in Finland. This can be considered as an extraordinarily broad collaboration, and the high level of involvement in the implementation definitely proves the importance of the topic (Ilmonen, 2019). Multitude of other actors, such as Business Finland and Ministry of the Environment, have also been supporting various research and development projects concerning textile circulation. The search for larger private investors, such as fashion brands, has also become topical in various projects. Naturally, larger projects with a greater number of actors increase the project's credibility in the eyes of the financier: collaborative involvement of multiple actors generates trust and functions as a guarantee for plans being truly executed, from words to deeds (Alhainen, 2019; Ilmonen, 2019).

The involvement of universities and other research institutes is often beneficial for the companies that are renewing their processes. The knowledge that research institutes create helps the companies to gain a strong insight in the ways that circularity can be integrated in their operations. Correspondingly, thorough research is closely knit to the financial support that the companies are receiving. "*The research activities of universities depend greatly on how well companies are supported in their own circular economy activities, as this also enables the commissioning of studies and educating future's circular economy experts*", Mäkiö (2019) from Turku University of Applied Sciences points out. Nevertheless, universities have the chance to conduct rather continuous research even if desired results are not always achieved, as the core purpose is to educate students. Companies, however, especially smaller ones, experience more pressure while experimenting with their operations: one failed experiment may deplete the resources, and thus, the motivation completely, and there may not be another try due to the lack of time and money (Mäkiö, 2019). Start-ups are often the most willing and interested risk takers, but being able to finance research work without financial support is typically rare. External funding certainly generates courage and a feeling of security for companies to develop their operations forward. Support in the form of funding can enhance risk-taking towards more radical changes, such as switching to a completely new service model (Alhainen, 2019; Cura, 2019; Ojala, 2019).

However, investment support for circular economy activities in Finland has been experienced as insufficient, and whereas public financial instruments do support the research

phase, the commercialization phase is often less likely to receive funding (Ilmonen, 2019; Mäki, 2019). Therefore, additional funding for experimenting and scaling up successful experiments into commercial activities would be beneficial. Circular economy of textiles can be considered as a relatively fresh topic from a commercial perspective, and it may not have reached the full interest among financiers yet. Therefore, even if for example start-up ideas would not be immediately profitable, it is important that the financiers look further ahead: it is essential to ponder, what the next few years would hold in terms of profitability, rather than cutting off funding right after a rocky start (Cura, 2019).

Commercialization of process-type innovations, such as chemical textile recycling, is very capital intensive and the process can take years. In Finland, finding investors who really have interest to fund such long-term projects is challenging, and therefore, investors are sought also from abroad (Harlin, 2019). Fortunately, the global textile industry and its large fashion brands are constantly scouring for more sustainable raw material options and processes. Especially global textile and fashion giants, which are not usually perceived as responsible, have been providing significant funding for start-ups' commercialization processes (Mäki, 2019). Commercialization of certain process-type textile circulation operations can be boosted also by utilizing already existing infrastructure. For example, an existing viscose line in a factory can be converted into a chemical recycling line, thus resulting in drastic savings. "*One part of the whole essence of profitability is largely that the necessary hardware already exists*", Harlin (2019) points out, adding that some of the old factories have even come to a point, where changes are simply necessary due to environmental risks they pose – thus, making such renewal rather natural (Harlin, 2019).

The lack of funding is experienced as challenging also from non-profit organizations' point of view. Organizations' involvement in projects might be problematic at times, as many organizations might not be able to invest money into the project in advance, but gradually, as the project progresses (Mäkiö, 2019). It is also important to be realistic about the size of one's operations: for example, the amount of collected post-consumer textiles has been increasing steadily, and smaller actors in the field of re-use might have to ponder, whether it is occasionally necessary to limit their textile collection volumes. The sizes of sorting halls and retail spaces and the number of sorting workers all need to be taken in consideration, and vague logistic investments for example in textile storing can be a large add to the fixed costs, such as hall rents and waste collection fees. Investments in the future are complex, and their necessity is hard to predict due to the constantly evolving transition in the textile circulation practices (Käppi, 2019).

7.1.4 Collaboration and co-operation

Collaborative research and knowledge creation and joint projects are clearly having an accelerating effect on textile circulation, as different companies within the industry get the opportunity to network and find synergies. Coming up with ideas, new designs and development plans in collaboration with other companies and research institutes is an important factor that saves the time and resources of everybody involved. Textile circulation in Finland would certainly not have evolved as far without the collaboration of so many actors with multi-disciplinary perspectives and backgrounds. Especially smaller companies benefit from collaboration, as the desire to develop one's operations forward might not always be met with enough expertise from every necessary sector due to the lower amount of personnel (Alhainen, 2019; Ilmonen, 2019, Mäkiö, 2019). However, start-up companies' involvement in collaborative research projects can in some cases be slowed down by regulations concerning business IDs. For example, a start-up that does not yet have a business ID could not take part in an EU project: this would be contradictory especially if the project aimed to investigate a topic that would generate business opportunities for start-ups (Mäkiö, 2019).

Co-operation has been a pivotal driver for the development of textile circulation, and clear changes in attitudes are starting to occur. Various actors are gradually starting to grasp that instead of doing everything by themselves, mutual benefits can be achieved by finding partners that can do their parts of the process with even better expertise. "*Not everyone would have to build their own system from scratch, but together we could develop something more comprehensive*", Ojala (2019) from home textile brand Finlayson remarks. For example, developing new service models would be faster in collaboration with other companies, possibly resulting in multi-service platforms and applications that all the collaborated companies could benefit from. Moreover, collaboration in research institutes across research group boundaries is essential in order to examine relevant topics with a diverse, interdisciplinary approach. It would also be desirable to have more international cooperation and bring similar research groups together, rather than having everyone develop competitive solutions within national borders. If different countries combined their own experiences and fields of expertise, comparing the similarities and differences and interlinking different textile circulation related research areas would surely boost domestic textile circulation as well (Mäki, 2019; Mäkiö, 2019; Ojala, 2019).

Despite the active participation in past and currently ongoing projects, more participants for collaborative activities are constantly sought for. As mentioned in chapter 7.1.1, in addition to companies within textile industry, many other fields of industries and the um-

brella organizations of their companies are considered as potential and somewhat necessary targets of co-operation (Mäki, 2019). Especially the topic of recycled fibre utilization could be developed forward more efficiently via collaboration: for example, Lahti University of Applied Sciences has received a few commissions concerning fibre identification of end-of-life textiles, but there would definitely be capacity for many more experiments and company collaboration (Cura, 2019). Private actors, who receive end-of-life textiles from consumers but whose operations focus on the reuse market, would in turn benefit from a wider co-operation with textile recyclers. For example, a recycling actor could pick up the raw material – non-reusable textiles – from a reuse actor without charge, and correspondingly, the reuse actor would benefit from this via the elimination of textile waste's collection fees (Käppi, 2019).

7.1.5 Customer relations and feedback

Maintaining close relations to both customers and partner companies and reviewing feedback carefully are efficient drivers for textile circulation. The importance of said drivers gets highlighted especially in the operations of service-based businesses that operate closely with customers. For example, from a clothing library's point of view, fulfilling the target group's needs is the top priority, which can be guaranteed the most efficiently by constantly involving the customers in the development processes. Linnemäki (2019) from clothing library Vaatepuu notes, that customers seem to be increasingly interested in leaving feedback and making suggestions for improvement: "*There is a lot of feedback, because there is a lot of discussion with customers: they have noticed that opinions are really taken into account and concretized – customer feedback is not asked just for the habit of it*". Feedback-based concrete actions, such as providing the customers with a corresponding selection of garments they would like to wear, motivate customers to participate. The feedback about the garments durability and feel can in turn be passed forward to the designers (Linnemäki, 2019).

Conversations with the customers and designers generate a tremendous amount of data about different garments' behaviour. If shared, this kind of valuable information could possibly help brands to develop their products and own services into a more sustainable direction. Co-operation with highly customer-oriented clothing rentals and sharing services could provide valuable product feedback for example to material innovators. Many customers are curious about sustainable material innovations and generous with giving feedback about the garment selection; therefore, the customers could provide feedback about the pilot products' behaviour in action. Customers of clothing sharing services also tend to be active in social media, sharing pictures and experiences of the garments they

have borrowed and tried on – start-ups could certainly benefit from this in the form of both feedback about their innovative products and added visibility and publicity (Linnemäki, 2019).

7.2 Organizational drivers and barriers

The following sub-chapters provide examples of organization and management related drivers and barriers that either enhance textile circulation or are considered as necessary targets of development.

7.2.1 Leadership and strategic management

Strong and enthusiastic leadership is a powerful driver for building the Finnish textile circulation ecosystem: charismatic, visionary speakers get people involved and gain the community's interest more efficiently. For example, the area of Turku has been remarkably active in the field of textile circulation, and this has been owed among other things to an enthusiastic and innovative leader in local waste management (Cura, 2019). Ilmonen (2019) from Southwest Finland Waste Management agrees that their CEO and management have been one of the reasons why Southwest Finland Waste Management is currently the pioneer company in terms of piloting with the fibre opening plant and recycling of textiles: "*The CEO of LSJH has been farsighted and ready to take risks, which has enabled research and development concerning textile circulation, investments in projects and hiring of personnel around the topic*", Ilmonen summarizes.

Careful strategic management acts as a driver for research institutes' textile circulation research. In large research institutes with many education lines and research teams, administration can have a lot of influence on which topics the research is being focused on. Organizational management needs to be sufficiently aware of relevant topics in order to point out the right direction for the research areas, and therefore, active discussion between the management, research teams and possible research commissioners is crucial. Although different research institutes might collaborate on the same topic, it may be reasonable for an institute to profile on certain research themes, even if the research is conducted for the same, broader goal. Collaborations are also a strategic choice, as the management needs to consider for example the ownership of possible innovations created during the collaboration (Mäkiö, 2019).

7.2.2 Textile roadmap

Strategic roadmaps are often used for clarifying key priorities and what is needed in order to achieve a certain strategic vision. A roadmap acknowledges both the current situation and the desired goal and addresses the most crucial steps and changes that are needed for achieving the goal. Roadmaps can be used for communicating key priorities in an understandable way, making it easier for actors from different backgrounds to grasp the bigger picture. Having a clear textile roadmap would be a strong driver for textile circulation and therefore, Finnish Textile & Fashion has proposed a textile roadmap for guiding Finnish textile industry to a more sustainable direction. A textile roadmap would acknowledge all the aspects related to circular economy of textiles and highlight the matters with the largest impact and the most effective measures. Examples of such large-scale matters could be sustainable usage of textile products, facilitating new service-based business models, performing cost-effective collection of large textile volumes and encouraging different actors to utilize recycled material in their products. In addition to making communication clearer, a strategic textile roadmap can be utilized as an effective tool for guiding policymakers to take regulatory action concerning the addressed matters (Mäki, 2019).

7.2.3 Corporate culture

Certain changes in the Finnish corporate culture and attitudes are still called for in order to boost textile circulation. It would be beneficial for the companies to abandon the self-centered mentality and instead, embrace the possibilities that collaboration can offer. Even though different actors' motives might vary greatly, from matters such as climate action to a purely practical approach, working with mutual benefits in mind can help reaching these goals faster (Cura, 2019). Finnish corporate culture is prone to a mentality in which everyone is more likely to keep things as their own knowledge. Due to this, recent textile circulation related projects have strived to encourage actors to share both their troubles and successes more openly with the other actors (Mäkiö, 2019). If one comes up with something truly ground-breaking and beneficial, it would be advisable to share it with the others, at least on a more general level, as a booster towards the common goal (Linnemäki, 2019).

Businesses might often feel insecure about confidentiality – about what and to whom they can talk to. However, open discussion is precisely what is currently needed: for example, in the case of patent plans, it would be good to communicate clearly and openly about one's intentions without the surmise that the idea will only get stolen (Mäkiö, 2019). Opening one's operations to other actors, sharing thoughts and networking can lead to

great benefits and new partnerships, facilitating the creation of a strong, thriving ecosystem. Although increased efforts for openness and collaboration are still needed, there has already been a promising amount of positive development – different actors are clearly starting to grasp that one does not always have to try and do everything alone (Cura, 2019; Harlin, 2019; Linnemäki, 2019; Mäkiö, 2019).

7.2.4 Innovation culture

Open-mindedness is a powerful driving force, which has boosted textile circulation onwards from the very beginning. For example, when UFF was founded, Finnish second-hand market consisted more or less of flea market sales: UFF was the first notable actor in Finland to start collecting used clothing, and the manager at that time developed the necessary sorting lines himself (Makkonen & Töyrynen, 2019). Similar innovation culture has also been a strong part of Nextiili workshop's early operations. In the founding phase, the concept of rehabilitative work, combined with textile sorting and utilization of used textiles, was a new concept in Finland. Moreover, as textiles' reuse and recycling were extremely marginal fields in a business sense, their importance had to be explained thoroughly and justified multiple times (Käppi, 2019).

When a new business idea enters the textile industry, old principles for running a textile company are always challenged. Especially young and ideological staff might often base their operations on curiosity and self-learning – developing by trying and doing, rather than accepting the old norms (Alhainen, 2019; Ojala, 2019). "*When there is no deep-rooted belief that something is not possible, one can rather focus on thinking about why something would not be possible, and develop a solution for it*", Alhainen (2019) muses. In general, universities have a strong innovation culture, too, which reflects to circular economy of textiles being a stimulating field of research, from circular fashion and design education to new material innovations (Cura, 2019; Rissanen, 2019).

7.2.5 Education

The education of textile technology has been run down in several Finnish universities, but now, providing students with as thorough knowledge of textile technology as possible would certainly be beneficial for the rising ecosystem. Fortunately, education concerning sustainable manufacturing of textiles can be incorporated for example to the studies of fashion and wearable design or into circular economy studies in general. It is essential that the principles of circular design are incorporated into the designers' education: designing not just the one life, but preferably several lives for the product (Alhainen, 2019; Cura, 2019; Harlin, 2019). Cura (2019) emphasizes the importance of educating students

about thorough design: "*The students are being encouraged to consider how material choices, such as adding certain coatings and finishing chemicals affect the recyclability, and how modular solutions can ease the recycling processes*". For example, students might get to experiment with smart textiles, which usually contain electronics that either prevent or slow down the future recycling phase. Students need to be able to acknowledge that inconsiderate choices made early on in the design process tend to accumulate towards the end of the product's life and complicate recycling processes (Cura, 2019).

Students will be the ones to create the solutions in the future, making it extremely important for them to have as broad basis of knowledge and experience about the behaviour of textiles as possible (Mäkiö, 2019). Fashion and design students usually have the chance to experiment with creating products from commercially available recycled fabrics. However, having a better access also to recycled yarn would provide the students with a broader understanding about the behaviour of different recycled fibres and their effects on garment manufacturing. Nevertheless, it is still rather challenging to acquire yarns made from recycled fibres - especially chemically recycled ones - for educational purposes due to the low production volumes, and therefore, high prices (Cura, 2019).

7.2.6 Communication and guidance

Open communication is one of the prime drivers for textile circulation. Increasing communication internally within the facility, for example between different research teams, is likely to push textile circulation related research a little further. As different research teams push separate projects forward, it is only natural that not everyone knows everything about different ongoing projects. Considering the vast number of employees in larger research organizations, it is important to deal with internal communication in a coordinated way (Cura, 2019; Heikkilä, 2019; Mäki, 2019; Mäkiö, 2019). Open external communication between different textile circulation consortiums would also be beneficial, especially since the Finnish textile industry and the amount of actors in the field of textile circulation are still quite compact. Cross-consortium discussion about the ways the research could be executed more effectively together could benefit said projects' shared aims to build and promote Finnish ecosystem of textile circulation (Cura, 2019). In addition, academic credibility within the research community, resulting from active research and several research publications, can also be considered as an efficient booster for active communication. If the results of a project can be backed up with a credible research point of view, this can boost collaboration also on an international level (Mäkiö, 2019).

Textiles' production chains are often global, and therefore, it is important to communicate the company's values to the international partners and to make sure, that the partners are willing to act by the same principles – the country of manufacture can be very different in terms of culture, legislation and operating principles (Alhainen, 2019). Even if textiles were designed in a sustainable manner in a certain country, it is pointless if the values and principles are not communicated well enough to the raw material suppliers and to the production part of the value chain (Harlin, 2019). Furthermore, it is important, that the communication reaches to all parts of the production chain, not just the adjacent processes (Cura, 2019). In best case, communicating clearly the benefits of circularity and sustainable textile production can have a major positive impact on the local industry and on the communities around production premises (Alhainen, 2019).

Intertwined with external communication, educating the consumers is also an important aspect in terms of enhancing the fluency of textile circulation. For example, giving the consumers clearer instructions on what kind of textiles are exactly being wished to receive in different collection boxes could improve the quality of the collected fractions. This, in turn, would save resources during preliminary sorting (Cura, 2019; Makkonen & Töyrynen, 2019). It is necessary to provide consumers with guidance, but honesty and transparency of communication are equally important. "*If a garment is completely unusable, it is essential to not to sustain the illusion that everything can always be utilized – realism is only healthy in these cases*", Käppi (2019) from textile workshop Nextiili remarks on providing the customers with feedback about the donated garments. Nonetheless, when the obligation for separate collection of textiles comes into action, it is crucial to communicate to the consumers that the collected textiles are truly aimed to be reused and recycled to as large extent as possible. Many people might even still have the idea that collected textiles are dumped to landfills, even though this practice was banned in Finland already in 2016. These kinds of misunderstandings should also be dealt with via clear and extensive communication (Cura, 2019; Makkonen & Töyrynen, 2019).

7.3 Regulatory drivers and barriers

The following sub-chapters provide examples of regulation-related drivers and barriers that either enhance textile circulation or are considered as necessary targets of development.

7.3.1 Obligation for the separate collection of textiles

The obligation for the separate collection of textiles is predicted to set the wheels in motion and increase the utilization of recycled fibres in textile products. Therefore, it can be

considered as a major driver for textile circulation. The forthcoming obligation for providing the collection of textiles is beneficial especially from a recycling actors' point of view, as it is expected to increase the flow of collected textiles, which can be utilized as a raw material in the recycling process. Even though the implementation of separate collection is certainly on the way, the full content of this obligation is still unknown: timetable for the implementation, the extent of the obligation and the recycling and utilization rates will all be determined at broader EU level (Harlin, 2019; Mäkiö, 2019).

However, the huge number of different types of textiles on the market will certainly have its impact on the recycling processes of the collected, non-reusable textiles. If EU sets the obliged recycling rate high, achieving the target will be extremely challenging. In a worst-case scenario, the recycling process itself can transform into a more energy and resource wasting act than not recycling, if even the most complicated fibre cocktails and layered textiles need to be recycled. Thus, it is essential to contemplate what sustainable recycling truly is and determine the boundaries and recycling rates in a realistic manner (Heikkilä, 2019; Mäkiö, 2019). When it comes to the separate collection of textiles and the steps following it, Harlin (2019) from Infinited Fiber underlines the importance of careful planning: "*In this case, too, things should be thought thoroughly through beforehand*", Harlin remarks, "*things can easily escalate into a situation in which a law is created, obliging to collect textile, and only after mountains of textiles have been collected, everybody starts wondering what should actually be done with the textile mass*". The value chain of future's textile collection and further utilization should be planned in such a way, that it can start in clear phases and be executed by following common practices. If the collection is executed in various different ways, it can easily trigger severe confusion and misunderstandings, which spread quickly especially among the consumers (Harlin, 2019; Rissanen, 2019).

7.3.2 Waste status

The interpretation of waste and the bureaucracy it imposes on the actors can be a hindrance to textile circulation, especially in terms of the utilization of non-reusable end-of-life textiles. Instead of the regarding the collected fraction as waste, it would be beneficial to find a way to collect end-of-life textiles as raw material. Currently the risk is that if end-of-life textiles are circulated through multiple different collection and sorting points and there is not enough data about the processes the textiles have gone through, the textiles might no longer be utilizable in their full potential. The circulation system should be constructed in such a way, that the collectable textiles could be easily recovered for both reuse and raw material purposes – getting rid of the end-of-life textiles' waste status

would certainly make this easier for everyone. For example, the waste status could be given to the textiles during pre-sorting process, based on the realistic condition of each individual textile (Alhainen, 2019; Cura, 2019; Harlin, 2019; Mäki, 2019; Mäkiö, 2019).

Even when collected separately, discarded, non-reusable textiles are currently a type of municipal waste, which in turn can be collected only by waste management operators. The process of actors registering themselves as waste management operators is not really a problem, but as Mäki (2019) from Finnish Textile & Fashion points out, the difficulties originate from waste management companies being rather strictly regulated in Finland. "*Currently, the legislation regulating circular economy is mainly based on waste law – this creates a clear conflict considering that one of circular economy's core aims is to prevent material streams' from turning into waste*", Mäki (2019) remarks. Therefore, more individualized evaluations for the waste status of different material fractions, based on the possible risk they impose on the environment or on human health, would be beneficial. This would provide a smoother operating ground for end-of-life textiles' handlers and recyclers, cancelling in some cases the need to register as a waste management operator (Alhainen, 2019; Mäki, 2019).

7.3.3 Regulative differences between public and private sectors

The involvement of public sector, such as municipal waste management actors, is often common when discarded material streams are being dealt with. However, there are certain limiting regulations which create their own challenges for operating on the market. For example, if a municipal waste management actor wishes to process non-reusable end-of-life textiles into recycled raw material, there are regulations regarding how much market activity and commercial co-operation the municipal actor can have. When a product, such as the mechanically opened fibre mass, is sold to private actors, the share of this activity may represent only a certain percentage of the public sector actor's total turnover. Remaining within the percentage limit can be challenging, especially if the actor has interests in providing multiple different products. If the percentage of market-based activities were to fluctuate or to be reduced, valuable co-operation with private actors would become significantly more difficult, or even impossible (Ilmonen, 2019).

Especially in Finland, with long distances and small population, it would be beneficial to gather large textile waste volumes together for utilization. The larger streams are currently dispersed, originating from various commercial and municipal sources. However, municipal actors that handle end-of-life textiles have limits also concerning the volumes of textiles that can be received from private actors, making the unification of commercial

and municipal textile waste streams extremely challenging. Municipal waste management companies' core purpose is to collect and treat residents' waste – including textiles – and therefore, they should not provide services to private companies. For example, a municipal waste management actor should not receive textile waste from retail chains, private entrepreneurs that collect textile for reuse purposes, private laundry services or from workwear manufacturers – even though these sources would contribute significantly to the overall volume of collected textiles. Therefore, the regulations should be refined in a way, that would allow smoother co-operation possibilities between the private and municipal sectors (Heikkilä, 2019; Ilmonen, 2019).

7.3.4 Taxation

Taxation can be considered as an effective tool for promoting more sustainable choices, among both the textile industry's actors and the consumers. Taxation-based means of influencing could be implemented as tax reliefs, such as lower value-added tax (VAT) for more sustainable materials and services, or correspondingly, as a higher VAT on unjustified use of virgin raw materials. In essence, taxation can be used to either promote circular economy or hinder linear economy – although, the exact outcomes of taxation-related decisions can be hard to predict in full detail beforehand (Heikkilä, 2019; Ilmonen, 2019; Mäkiö, 2019).

It is essential to encourage consumers to buy higher quality products and care for them accordingly: this would be in line with the waste hierarchy's highest priority of extending the product's life span and reducing the generation of waste. However, if buying a new product costs less than repairing an old one, the consumer will most likely buy a new one – even if the repair would not require huge procedures. Work is quite expensive and heavily taxed in Finland, and naturally, expertise always has its price. If product-as-a-service based models and repair and maintenance services, such as mending and cleaning, would be subject to a lower VAT, the repair work might be more profitable and more attractive of a choice for the consumer (Ilmonen, 2019; Mäkiö, 2019).

Necessary developments within the recycling market could also be facilitated better with the aid of taxation. As long as virgin textile fibres and completely new products are as cheap as they currently are, recycled fibres are less likely to compete (Ilmonen, 2019). High prices of more sustainable products are reflected also on consumers' choices. Often at the time of purchase only the price of the product is considered without proportioning it to the number of times the product will be used or the product's sustainability (Mäki, 2019). As Linnemäki (2019) notes on the price of circular products and services: "*No matter how conscious the consumer is, the high cost of circular economy embracing*

products definitely does not encourage the consumer to make responsible choices in normal everyday life". Tax reliefs for companies and non-profit organizations that are engaged in promoting circular economy could possibly be reflected as lower prices, thus making circular economy-based products and services more desirable. Such a holistic change should originate from a higher, regulative level – mere encouragement and goodwill are rarely enough (Käppi, 2019; Linnemäki, 2019; Makkonen & Töyrynen, 2019).

7.3.5 Material standardization and safety

It is important to develop material standardization in such a way, that would enable informing recycled material content in textile products' care labels. Whereas the current labelling standard does oblige to inform the fibre names and their percentages, it does not recognize such a material as *recycled fibre*. Product's care label must always contain the material composition, but describing the exact recycled fibre content is extremely challenging, as non-standardized information should not be placed on the label. Fibre standardization is an issue that concerns the whole Europe and is being worked on at EU level. It would be beneficial to reach a consensus on standardization issues well before textile recycling and utilization of recycled fibres in products kicks off properly (Harlin, 2019; Heikkilä, 2019). Standardization of recycled fibres or other clear classification method would be beneficial also for textile recycling and recycled fibres' market, facilitating more reliable trading. Raw material should always be obtained with a certainty of the raw material's origin, quality and handling and storing circumstances. Therefore, there should be standardized grades for the raw material's purity and content. In addition, if larger quantities of raw material are purchased, the quality grades should preferably be the same for every supplier from a defined region, regardless from whom the raw material is purchased from. A separate marketplace for the recyclable raw material would be beneficial for such activities: a platform with an appropriate supply of classified, quality-controlled raw material (Harlin, 2019).

When recycled fibres are utilized in garments and household textiles, raw material controls based on mandatory tests and standards could provide a peace of mind for the both brands and the consumers (Ojala, 2019). Product safety can be at risk if end-of-life textiles contain chemical residues, such as finishing agents: typically, there are limits for the concentrations of these chemicals and they should not come in contact with the skin. The quantities of chemicals in post-consumer textiles have been studied for example in Telaketju projects, but so far, the concentrations have been extremely small. If a single piece of textile contains low concentrations of harmful substances and is accidentally directed for recycling, the concentration of these substances will very quickly become

irrelevant in terms of safety, as the single textile product is mixed with tons of other textiles. Naturally, the situation should be constantly monitored and guaranteeing consumers' safety is always essential (Cura, 2019; Ilmonen, 2019; Heikkilä, 2019). It is also important to make sure that handling of end-of-life textiles does not pose risks to the handlers. For example, textile dust, that gets generated during the handling of end-of-life textiles or during recycling as the textile structure disintegrates, can in some cases cause respiratory irritation if appropriate protection is not available. Additionally, the collected textiles can occasionally contain molds or other contaminants, that have occurred for example due to excess moisture or if something completely unsuitable for collection has been thrown into the collection box (Heikkilä, 2019). Providing gloves and masks to the handlers of end-of-life textiles are therefore reasonable, precautionary measures.

When it comes to chemical legislation and safety, a product made from recycled material must be just as safe as a product made from virgin material. However, if this condition is met, there should be no need to scrutinize end-of-life textiles beyond normal safety measures and tests. Healthy caution is always reasonable, but it should not be assumed, that used products or recycled materials automatically contain something suspicious. Most of the harmful textile chemicals get worn off from consumer textiles during domestic wash and use by the product's first holder. Therefore, if end-of-life textile batches are inspected separately and more thoroughly, this should be based on a defined risk, such as a suspicion of harmful chemical compounds. Legislation concerning waste is already rather stringent and the mental image of recycled material still contains preconceptions of dirt and impurities – an unnecessary, exaggerated chemical scrutiny will most likely only aggravate the situation and hinder textile circulation (Mäki, 2019; Mäkiö, 2019). The importance of the availability of transparent information becomes once more highlighted: if, for example, the end-of-life textile has been used as in an environment where paints and solvents have been used, this should be informed during collection in order to guarantee appropriate measures and the safety of the handlers (Alhainen, 2019; Cura, 2019).

However, if it is known that certain end-of-life textiles have been treated with functional finishing chemicals, it is also advisable to approach the chemical content with an open mind. For example, public space textiles are treated with flame retardants and these chemicals rarely get entirely worn off before the end of the textile's first life. In such cases, one could consider where end-of-life textiles with certain chemical properties could be utilized instead of only demonizing the chemical content. Furniture upholstery, for example, is not in direct contact with the skin, and if chemically treated end-of-life textiles were to be utilized in such an application, possible chemical residues would not pose threat to human health (Cura, 2019; Mäki, 2019). "*It is a Finnish basic sin to approach things*

through negativity, even though a solution-oriented approach could take us so much further", Mäki (2019) points out concerning the matter. However, the concentrations of the finishing chemicals depend greatly on where the textiles have been used: chemically treated wearable textiles, such as workwear, are washed significantly more often than for example curtains and furniture covers of public areas. In addition, the affinity and durability of a finishing chemical depends also on the method of application. If a finishing treatment has been applied on the surface of the textile, it wears off faster in normal use than with a finishing method, in which the chemicals have been applied already on the fibres themselves. Therefore, if recycled fibres with flame retardant properties were to be utilized as raw material for applications, in which flame retardation is required, it would be important to ensure, that the raw material's chemical concentration would still be adequate for said purposes (Cura, 2019).

There is room for development also regarding the standardization of end-of-life textile-based raw materials when it comes to the needs of other industries. For example, the construction industry utilizes precisely certain types of standardized textile materials that have been proven to be functioning in their application. As a consequence, even if a recycled textile alternative would be just as valid and suitable for the same purposes, the construction industry is more likely to choose the traditional virgin alternative due to the lack of sufficient research and standardization of recycled textile alternatives. However, textiles used for construction purposes are generally required to last for decades in their application, which complicates the testing process that the recycled material needs to go through. The end-of-life textiles' suitability tests would also require long time intervals in order to obtain reliable enough data on material behaviour (Mäki, 2019; Mäkiö, 2019).

7.3.6 Circular design and life cycle control

Innovative design and advances in textile technology have enabled the manufacturing of various, advanced textile products. However, the same things that give the textile product technical properties can make its recycling more difficult. Therefore, it is essential that recyclability of the products is taken into consideration already during the design process (Mäki, 2019). Even though textile-to-textile recycling is often not the most sensible solution for the most high-tech garments and textile products, it generally functions as a good basis for the design process (Heikkilä, 2019). Whenever feasible, products should be designed in such a way, that after initial use they are still either reusable in the original purpose or another purpose, or recyclable. Ideally, the textile product's whole life cycle and all the process steps involved in it would be designed in advance. This planning would include both the first life and the possible following lives, depending of course on

the product and its properties. Predicting the product's behavior is also important. For example, if a certain spot in a garment is expected or known to wear out first, product's life could be extended by adding detachable reinforcements to this spot. The product could come with necessary gear for minor repairs, such as snippets of the same thread or yarn used in the product – this way the consumer would also be involved in extending the life cycle of the product (Alhainen, 2019).

Even though avoiding unnecessary fibre mixes and complicated layers results in cleaner fractions for recycling, guaranteeing the usefulness of a textile product should be one of the key focus points during the design process. Textile products cannot be considered as high-quality products, if they are unsuitable for their intended use or will not be used for a long period of time due to them being uncomfortable. Fibre blends are necessary for achieving certain properties: for example, in order to provide both comfort and strength in work clothes, mixture of cotton and polyester is often quite justifiable. However, it is equally important to understand when a certain property, such as adding elastane to an already stretchy, knitted garment, is not required. Multi-layered products, such as clothing for cold weather, are often designed with a clear purpose in mind. In such cases, the aspect of circular design can be applied by designing the products in a way that allows attaching the different material layers to each other for example with buttons or zippers, making therefore the sorting and recycling processes easier (Heikkilä, 2019). The ease of disassembling a product is a factor that can be beneficial also from an economic point of view: as a rule of thumb, if a product is easy to disassemble, it is often also easy to assemble, which in turn saves time and resources (Harlin, 2019).

Whether the product's circularity and design process should be regulated more is a challenging question, that has also been discussed at EU level. For example, an index, which would evaluate the responsibility or circularity of a product, has been proposed: the index would include several different aspects, such as recycled material content, recyclability, adaptability and ease of care. However, as the index would be a combination of multiple elements that would be counted together, the practical implementation of such regulation could be quite challenging (Harlin, 2019; Heikkilä, 2019). Quality criteria based on the utilization of existing standards has also been suggested. Naturally, durability of a product is affected greatly by how and in which circumstances it is used, but the manufacturer could guarantee by standards that the product meets certain criteria, for example in terms of abrasion resistance (Harlin, 2019; Mäki, 2019).

If product design and production were to be subjected to regulative intervention, it is necessary to define clear limits for the circumstances in which it would be sensible.

Strictly regulated design process and regulatory sanctions on product design can become rather problematic, since the same recyclability or maintainability properties do not apply to all products. In principle, nobody deliberately wants to design low-quality products, and the designer alone cannot be expected to know every specific detail about the future life cycle of the designed product. Therefore, it is important that there are experts from multiple disciplines involved in the design phase. In order to utilize the full potential that the product can have during its life cycles, there is a strong need for interdisciplinary approach to circular life-cycle planning – this requires a great deal of input for example from universities and companies (Alhainen, 2019; Mäkiö, 2019).

Producer responsibility – companies' obligation to handle the waste management of products they have manufactured after discarding – is also in use for certain waste fractions and products in certain countries in order to guarantee controlled life cycle for the products. However, it has not been considered as a particularly effective solution for textile circulation due to the textile industry's globality. Furthermore, it is always more desirable to try to achieve common practices on a more voluntary basis, rather than through a forced way, such as an obliged producer responsibility. If an individual textile manufacturer thinks that control over the product's life cycle adds value to their products, this can act as an alluring selling point on the market, leading the rest of the manufacturers to gradually follow the example voluntarily (Heikkilä, 2019; Mäkiö, 2019).

7.3.7 Controlled import and export

Textiles are one of the major imported product groups, and if the circularity of textiles were to be regulated more strictly, this would naturally affect imports too (Harlin, 2019). In addition to the new, low-quality garments and textiles that are imported to Europe, there are also large quantities of imported second-hand products that may not meet the European product safety requirements (Mäki, 2019). If certain quality criteria were required to be met before textiles are brought into Europe, this could decrease the number of low-quality products entering the market – naturally, the same criteria would apply to the products manufactured in Europe. Ideally, if the Europe decided to simply not allow the import of any textiles that do not meet certain quality criteria and hold sufficient product details, the countries of production would most likely change their ways to meet the criteria, as there would be no other way to export the products. In practice, however, the execution would be a much more complicated process (Harlin, 2019; Heikkilä, 2019).

Export of low-quality textiles especially to countries with lower income has been an explosive topic recently, locating in a gray area in terms of legislation. For example, if tex-

tiles are collected for reuse purposes and not all of them are sorted and sold, the remaining surplus fraction is still classified as reusable – regardless of the quality (Mäkiö, 2019). If the non-reusable textiles are not separated from the surplus and directed to either recycling purposes or for energy recovery, and if the surplus is sold on the global market, low-quality textiles and garments can accidentally end up around the world as export textiles (Käppi, 2019). Therefore, it could be beneficial also in this sense, if the product or waste status was granted in Finland at the time of the sorting itself, not beforehand. This could reduce significantly the amount of textile waste that is exported uncontrollably abroad, as the import of textile waste is banned in several countries (Mäkiö, 2019).

7.3.8 Traceability, privacy and brand protection

Digital advances and identification tags are expected to enhance the traceability of textiles, but due to the same reasons, the boundaries of business confidentiality and privacy need to be considered. For example, it is important to define the level of included detail about the product's life cycle and the spectrum of people who will have access to the data. On one hand, full traceability would facilitate better control over the life cycles of the products, but on the other hand, having all the data available for everyone interested could also allow competitors to find out trade secrets. Furthermore, textiles go through a long production chain, and it should be determined carefully, when and where would the information be embedded into the garment. The origin of a textile product is currently determined by the place where the garment is sewn; if the origin would be changed into the place where the material was produced, one would have to consider the larger scale effects on matters such as free trade and custom benefits (Mäki, 2019; Mäkiö, 2019).

Traceability and the rights of the brands are also worth pondering when it comes to brand protection and trademark products. Some high fashion brands have been known to go to the extremes of grinding, shredding or burning their unsold garments in order to protect the brand and to prevent anybody from selling their products elsewhere with a run-down price – such practices are naturally far from those favoured in a circular economy. However, utilizing end-of-life textiles that have been produced by well-known brands leaves room for questions regarding brand protection. For example, if patterned end-of-life textiles, that clearly originate from a specific brand, are upcycled into new products and the signature patterns or fabrics of the original brand can be recognized, the question of ownership is at hand. Therefore, it would be important to define clearly whether the upcycling actor can do business with such products or not (Heikkilä, 2019).

7.4 Linguistic drivers and barriers

The following sub-chapters provide examples of linguistic drivers and barriers that either enhance textile circulation or are considered as necessary targets of development.

7.4.1 Terminology and common vocabulary

Language is a fundamental element, and the importance of correct terms and vocabulary cannot be overemphasized, applying to both consumers and actors within the field of textile circulation. A certain loudness concerning common terminology is desirable, as the right or wrong use of terms can easily fluctuate the direction of textile circulation, either for better or for worse (Mäkiö, 2019). It is essential that different actors within the industry act as messengers concerning what the circular economy of textiles really entails. It should be made clear that in addition to recycling, circular economy also involves important aspects such as careful and optimized product design, maintenance, reuse and various services – in fact, in a circular economy, recycling comes as the last resort after the textile products can no longer be reused. The media has also an important role as a conveyor of information from the actors to the consumers, and therefore, it is important to clarify the meaning of different terms to journalists and interviewers (Alhainen, 2019; Heikkilä, 2019; Ilmonen, 2019; Mäki, 2019).

The correct terms are starting to be relatively familiar to the actors within textile industry, but there is still room for improvement. If actors of textile industry use fragmented terminology when communicating about their operations either to the actors outside the industry or to the consumers, this especially may provoke confusion and misunderstandings (Makkonen & Töyrynen, 2019; Mäki, 2019). It is not enough if correct terminology simply exists, but it is important to ensure that all the actors within the field commit to the common vocabulary (Mäkiö, 2019). Even if an actor personally disagrees with a certain, agreed-upon term, it is important to communicate to the general public using the common terminology (Mäki, 2019). Not everyone is a circular economy expert, and one cannot insist that everybody always knows all the right terms for everything. Naturally, occasional mistakes do happen to everybody, but cultivating the right terms tends to take hold eventually (Alhainen, 2019; Ojala, 2019). Using correct terminology in expert communication, such as reports and publications, is essential, but clarifying the vocabulary also internally among the employees can make a huge difference on the cohesiveness of the actor's overall communication (Heikkilä, 2019; Käppi, 2019).

Whilst also using terms in a consistent way, it is important to simplify the message enough in order to guarantee it getting through (Rissanen, 2019). If possible, it may also

be useful to use a memorable, illustrative example to support the information. Even if a researcher uses exact terms in scientific publications, the core message needs be expressed clearly enough for example to the media, which in turn informs the consumer. An orthodox vocabulary does not necessarily speak much to the average consumer, and there needs to be a balance between sticking to the right terms, and at the same time, making the message understandable (Heikkilä, 2019; Ojala, 2019). "*In essence, it is important for the actors themselves to be aware of these differences and understand that the same terms do not always bear the same meaning for different people*", Heikkilä (2019) from research institute VTT remarks concerning vocabulary differences. Moreover, it is advisable to examine the terminology critically every now and then and ponder what kind of perceptions and mental images do the different terms evoke among consumers (Alhainen, 2019).

The word "*recycling*", in particular, is currently an all-encompassing everyday word, that can cover anything from actual material recovery to taking one's old textiles to the collection box or selling them at a flea market. This generates a lot of misunderstandings and complicates textile circulation related communication, as the distinction between reuse and recycling is an essential and influential factor when it comes to circular economy (Ilmonen, 2019; Käppi, 2019; Makkonen & Töyrynen, 2019). In addition, whereas the term "*end-of-life textile*" is either in use or at least understood among the actors in the field of textile circulation, its meaning may be confusing and unclear to most consumers. When the separate collection of textiles comes into action, it would be worthwhile to provide clear descriptions for what kind of textile fraction is wished to be donated in which box (Cura, 2019; Heikkilä, 2019). Moreover, additional confusion may be caused also by differences in recycling technologies and the way these technologies are addressed in discussion. For example, even though the recycling of synthetic fibres is, from a certain point of view, plastic recycling, the terms mechanical recycling, chemical recycling and thermal recycling mean two different things in the contexts of plastic recycling and textile recycling (Heikkilä, 2019).

When different terms are thrown around in discussion, it is important to specify what is meant with a certain term. For example, the adjective "*responsible*" is often used to describe garments that have been manufactured in a sustainable manner from both ecological and ethical points of view. However, the practical content and boundaries of the word may vary greatly depending on one's inner values. "*The term can mean a multitude of different things to different people and therefore, it could be a smart basis for the designer and manufacturer to define more precisely what aspects of responsibility are actualized in each product – this would be more realistic than just stating that a product*

is responsible", Linnemäki (2019) points out. In addition to the variations in perception, responsibility – alongside with sustainability and circular economy – can be considered as a trend word. As a consequence, regardless of the important content, constant repetition of a trend word tends to start annoying people. It is important to try to find a way to keep such terms as positive as possible, for example by accompanying the term with a more elaborate explanation of how the term is actualized in practice (Linnemäki, 2019).

7.4.2 Discourse

General discussion about climate change and textile industry's impact on it have certainly made people more interested in their own role as conscious consumers. The increased amount of discussion around textile circulation has clearly activated consumers, leading for example to increased amounts of customers visiting second-hand clothing stores – this, in turn, has facilitated expansions within the textile reuse market (Makkonen & Töyrynen, 2019). In order to push textile circulation forward, it is crucial to feed the civic interest sufficiently and keep up the discussion. A multitude of public speeches, lectures and workshops are required in order to spread the information and keep the topic on the surface. Making people aware of the circularity of textiles is a slow process, but the direction is certainly positive. It is already trendy to be interested in the subject and join the discussion about textile industry's sustainability issues (Harlin, 2019).

In order for the discussion to remain open and constructive within the textile circulation ecosystem, the quality of discourse must be such that all actors can join and feel involved. Different actors can have extremely varying backgrounds, and it is important that everybody has an opportunity to be equally involved, stay on track, and understand the discussion. As mentioned, the use of correct terminology is important – however, if a topic is discussed in too fancy of a manner and with too complex of a vocabulary, some of the involved actors may even end up thinking that the topic does not concern them (Mäkiö, 2019).

7.5 Visual drivers and barriers

The following sub-chapters provide examples of visual drivers and barriers that either enhance textile circulation or are considered as necessary targets of development.

7.5.1 Visual term and process clarification

Visual factors are usually closely linked to linguistic factors and to general understanding, whatever the topic may be. Thus, visualization is a necessary and accelerating factor for

communicating matters related to textile circulation. Circular economy as a concept and its various possibilities are vast and complex topics to condense into an effective verbal explanation. Therefore, explaining these matters either through images and other visual cues or, in the best case, as a combination of verbal and visual explanation, is often more effective. Furthermore, as mentioned in chapter 7.4.1, the increasing repetition of the trend words and terms such as "*circular economy*" can be experienced as annoying – it is only positive if the repeated verbal version can be accompanied with an effective visualization (Ojala, 2019; Mäkiö, 2019).

Naturally, there are differences in the ways people learn and perceive things: some people want to see data and accurate information, whereas for some, technical details don't necessarily spark interest towards the topic. An effective way to overcome such differences is to provide both specific details and something tangible for people to reflect upon, for example via videos or infographics (Alhainen, 2019; Cura, 2019). Images are helpful for internalizing new information, due to which it is essential to visualize for example research results whenever possible (Heikkilä, 2019; Ilmonen, 2019).

When discussing a topic such as textile circulation, which involves multiple different types of activities and technologies, pictures can be used to clarify the processes and technical details. This way, everyone is provided with an equal opportunity for understanding at least the basics of the matter at hand. Mäkiö (2019) points out, that actors with very different types of operating fields might not immediately notice any connections between their activities, but they can be made aware of these linkages through graphs and images: "*By displaying images, actors have the opportunity to elucidate their processes to other actors whilst keeping trivia-based business secrets safe, yet still delivering a strong message and creating an open atmosphere between them*", Mäkiö explains. For example, in the case of Telaketju co-operation network, a cogwheel pattern that illustrates and clarifies the processes and sub-processes that are needed for the textile circulation to function as an entity has been a driver for actor involvement. When actors have located themselves onto those parts of the cogwheel figure, within which they see themselves operating in – either currently or in the future – different linkages within the ecosystem have become highlighted and cleared up. "*When an actor locates itself on a certain part of the value chain and another actor is noticed to have located itself on an adjacent part, it is quite organic to start wondering if there would be synergies and whether this could facilitate some sort of collaboration*", Mäkiö remarks.

7.5.2 Concretization

Visualization acts as an excellent tool for concretizing textile circulation related material flows, that otherwise would seem intangible and too distant to grasp. Especially when it comes to large quantities, the sense of quantity tends to get blurred rather easily. Therefore, it is worthwhile to visualize the large numbers related to resources and material flows. For example, if the average amount of textiles that one person throws away annually – not to mention the roaring volumes of industrial material streams – is announced only in kilograms, creating a concrete mental image of the amount can be challenging (Alhainen, 2019; Cura, 2019; Mäki, 2019). However, no matter how clearly the impacts of linear textile production and possibilities of textile circulation are visualized, this has only little impact if only the already conscious consumers take the time to view the images and videos – the real challenge lies in reaching the people who are not so interested in the topic to begin with (Mäki, 2019). In some cases, providing concrete, visual examples can trigger annoyance and even guilt among the consumers; the goal of visual concretization, however, is not to accuse, but to function as a realistic awakening call (Heikkilä, 2019).

A simple yet efficient way to concretize the impacts of personal choices would be providing a natural resource consumption counter for the consumers and business partners, accompanied with corresponding visualization. Such counters could even be developed in co-operation with different actors in order to create as accurate counter and as comparable information as possible (Linnemäki, 2019). For example, water saving can be used as a concrete example when it comes to utilization of recycled materials: achieved savings in water usage become relevant especially when it comes to cotton, which has an enormous water footprint. Even though masses in kilograms can be hard to grasp, a litre of water can be pictured rather accurately. Therefore, the huge amounts of water that can be saved by choosing a recycled product can be internalized better (Alhainen, 2019). Along the same lines, tangible and concrete examples can be provided by utilizing familiar units: "*Circular economy has been demonstrated for example by showing concretely how many PET bottles have been utilized for one mat made out of recycled polyester*", Ojala (2019) describes.

Lastly, when it comes to innovative technologies for producing more sustainable fibres and materials, it is essential to have concrete, visual examples of possible products to show off the material's practical potential (Harlin, 2019). For example, it would be beneficial to have more yarn spinning experiments in order to showcase, what kind of yarns can actually be produced from the recycled fibres that have been manufactured by using

end-of-life textiles – this would surely be of interest for the recycled fibres' potential utilizers (Cura, 2019).

7.5.3 Symbols as guidance

Good infographics and memorable symbols have tremendous power and exploiting symbols should go hand-in-hand with the data in order to reach as many people as possible. For example, a garment's care label could contain symbols for recyclability, thus guiding the consumers and actors concerning the steps to take when the garment is being discarded (Cura, 2019; Rissanen, 2019). However, such guideline symbols should be somewhat universal: "*The symbols should be simple and universal, and it should be taken into consideration that textiles are being exported to multiple different countries with different levels of recycling readiness – the symbols cannot really be designed as certain kind for one country and a different kind for another country, since the same textiles or clothes are being sold all around the world*", Rissanen (2019) explains.

Unique symbols could also be utilized for guiding the consumers to return their reusable and non-reusable textiles to correct collection boxes. For example, clear logos for intact, clean or worn-out textiles could be added to the boxes to inform the consumers on the qualities that the donated textiles should have (Heikkilä, 2019). Since the practical meanings of reuse and recycling can be challenging to grasp terminologically, symbols could be helpful for clarifying the meanings for the consumers. Naturally, the fractions would still go through pre-sorting after collection, but improvements in the quality of collected fractions would save time and resources during the sorting (Makkonen & Töyrynen, 2019).

7.5.4 Aesthetics

Textiles and garments that are made from recycled material tend to cause certain kinds of stereotyped mental images among the consumers. Fortunately, this preconception of the traditional *eco-fashion* look is gradually starting to fade. Fashion has always been based on aesthetics, varying styles and self-expression: when textile products are manufactured from recycled fibres, it is a huge stimulus for textile circulation, if the products represent varying styles (Mäki, 2019; Rissanen, 2019). There are already plenty of possible options for the models, colours and textures for garments made from recycled fibres, serving a significantly wider spectrum of different tastes. Therefore, it would be beneficial to get rid of the mentality that choosing a more sustainable product, with for example recycled fibre content, needs to be done solely as a climate action. Ecological fashion covers nowadays both unique and wild creations and ordinary everyday clothes,

and a more sustainable product can be chosen also as a visually attractive option (Linnemäki, 2019; Rissanen, 2019). Even though the core aim is to move away from linear economy and towards circularity, the ideology should not be poured aggressively on the consumers. Instead, textile circulation should be introduced in a supportive and inspiring manner, for example via events such as art camps, exhibitions, workshops and fashion shows. It is important to show the consumers what really can be achieved with more sustainable material choices and by supporting responsible brands (Ilmonen, 2019; Linnemäki, 2019).

Aesthetics and visuality are also a remarkably strong part of marketing and social media. In general, consumers rarely read articles and research results from start to finish due to the busy lifestyles. Therefore, a concise message with a memorable and attractive visualization of the topic are essential. Social media, too, is nowadays more or less revolving around aesthetics and image sharing. For example, Instagram as a picture service has a gigantic influence on consumers, as images are usually the first things to catch the consumers' attention. Often, only if the image is considered as appealing or thought-provoking, the text captions are read, and the picture and message are possibly shared with others (Ilmonen, 2019; Linnemäki, 2019).

Aesthetics act as a driving force also for the reuse market of textiles. Companies operating on the field of reuse are steadily disassembling the stereotype that reuse-based business consists only of small-scale flea market operations. A fresh, updated image is found to be an appealing factor for the customers of second-hand stores: "*A couple of years ago, UFF got new logos and the whole brand was freshened up with a more up-to-date look. This new, more attractive look was noticed to please the customers and increase the number of customers and the amount of sales in UFF's retail stores*", Makkonen and Töyrynen (2019) from UFF comment on the organization's previous makeover. Obviously, a huge part of second-hand store's attractiveness is based also on its selection – in other words, the aesthetics of the textiles that people bring to the collection points. However, people's judgement on whether a garment is aesthetically pleasing or not is highly subjective and often blurred by sentimental value. People donate a lot of clean and vendible, even trendy garments but also a lot of intact and clean, yet ugly and old-fashioned garments, that have no sales value despite of them being practically reusable. People's criteria for the aesthetics of clothing vary drastically, causing the quality and looks of the donated textiles vary correspondingly (Heikkilä, 2019; Makkonen & Töyrynen, 2019). Whereas one person might think that a completely worn out and shabby garment is still reusable by someone else, the other person might think that a

minor flaw in a good quality garment makes it completely unusable, even though its looks would actually be perfectly appreciated by someone else (Heikkilä, 2019).

7.6 Psychological drivers and barriers

The following sub-chapters provide examples of psychological drivers and barriers that either enhance textile circulation or are considered as necessary targets of development.

7.6.1 Awareness and sense of righteousness

News about the state of the Globe and climate change concerns have pushed actors to contemplate what kind of future they want to create for the textile industry. A strong commitment to change the textile industry and its traditional practices to a more sustainable direction can be recognized among various actors. Such desire to act for a common good can function as a strong driver for a company's involvement in textile circulation. Constantly evolving technologies and growing public awareness of the industry's effects on the environment encourage companies to develop their processes and promote more sustainable and responsible ways of operating (Alhainen, 2019; Käppi, 2019; Ojala, 2019). "*The responsibility point of view is a strong psychologic factor as itself – implementing circular economy and trying to act for the Globe is simply the right thing to do*", Ojala (2019) from Finlayson points out, adding: "*It is tricky for one company to save the whole Globe, but if only there are things that a company can have an impact on with its own actions, these things should be addressed*". Moreover, working for an employer with strong ethical and ecological values is clearly important to an increasing number of employees (Alhainen, 2019). There are motivated textile design students who are clearly well aware of the field's sustainability issues and workers who enter the textile industry especially with the sustainability aspect in mind (Harlin, 2019).

For the last couple of years, consumers have been, if not prepared, at least aware that that the textile industry cannot continue for long as it currently does. News about textile industry's sustainability issues and the importance of conscious choices have most likely reached everybody by now – whether these news have been accepted and integrated into everyday choices or not, is a whole other thing. It takes time for the consumers to start taking everyday actions for what they feel is right, but a transition is certainly in the air, led by already conscious and determined individuals (Alhainen, 2019; Linnemäki, 2019). For example, just like city bikes have gained popularity instead of owning a car, owning enormous piles of clothes is not an absolute necessity anymore and lending garments can gradually be seen as a viable option (Linnemäki, 2019).

Sense of righteousness can be regarded as an accelerating factor also on the reuse market. The aspects of charity and climate work seem to be essential for consumers, resulting in increased volumes of donated textiles. The amount of donated textiles can be used as a directional indicator that people generally wish to act for the common good (Käppi, 2019; Makkonen & Töyrynen, 2019). "*Naturally, some people also just want to get rid of the clothes they don't need, and the volumes of donated textiles do follow a certain seasonal rhythm, peaking especially at the time of spring and autumn cleanings*", Makkonen and Töyrynen (2019) from UFF point out. Nonetheless, climate awareness and will to support charitable work can still be considered as important, positive drivers. "*People seem to be genuinely interested in what happens to the textiles, how the collection is arranged and what are the practical impacts of their actions*", Makkonen and Töyrynen (2019) conclude.

7.6.2 External pressure and consumers' expectations

Public opinion is a weighty factor, and businesses all the way from smaller manufacturers to the world's leading fashion giants are clearly starting to notice, that now, if ever, is the time to think and act for the sustainability of their operations. Sustainability is a hot topic, and brands really must start thinking about issues such as the textile waste they generate and the life cycle of their products (Harlin, 2019; Rissanen, 2019). "*Surely, no company wants to ruin their image by being the one actor who is no longer interested in the fate of their products once they leave the store*", Rissanen (2019) from Aalto University remarks. In essence, the cause for all textile circulation related action originates from the public discussion that NGOs have sparked up concerning the injustices within linear textile industry. This publicity has created external pressure for the actors, which in turn has led to multiple developments within the field of textile circulation. On the other hand, heated public discussion often tends to lead to some misunderstandings alongside the constructive critique, but in general, things would not be moving forward as much without the public pressure (Harlin, 2019). The increased community pressure can also have an effect on the consumers themselves: if one feels that everybody else is environmentally aware and acting for the cause, the urge to also act on one's own part might become stronger (Makkonen & Töyrynen, 2019; Mäki, 2019).

In some cases, actual external pressure is not being experienced, but actions take place as a response to consumers' and business partners' expectations and wishes. Encouraging examples and feedback from conscious customers provide inspiration and added confidence for the actors to strive towards more responsible practices. For example,

when experiments concerning the collection and recycling of textiles were started in Finland, the consumers gave enthusiastic feedback and expressed their expectations concerning the matter. Therefore, consumers' expectations act as a driving force for research and encourage different actors to develop their ideas and projects further. When consumers are involved to the research and discussion and their expectations are listened carefully, the actual root of the problem can often be found faster (Alhainen, 2019; Heikkilä, 2019; Mäkiö, 2019; Ojala, 2019).

7.6.3 Consumer behaviour

Consumers have an essential role in the ecosystem of textile circulation, both as demanders of circular economy solutions and as providers of products and raw material, end-of-life textiles. In order to encourage changes in consumer behaviour, involvement to textile circulation should be made as convenient as possible for the consumers. For example, a lack of textile collection points can cause a lack of motivation concerning textile donations, especially in sparsely populated areas (Cura, 2019; Harlin, 2019). In addition, if multiple trips to different locations are required in order to drop off the household recyclables, including the textiles, this will probably not motivate consumers to participate either (Makkonen & Töyrynen, 2019). Rather than only blaming the consumers for not making sustainable choices, it is crucial to make the involvement as effortless as possible and offer the consumers a chance to be part of the solution. If people think that their own actions are meaningless and nobody acts on anything, nothing is also likely to happen. Therefore, emphasizing the importance of individual choices is highly important and can be really empowering for the consumer (Heikkilä, 2019).

It is essential to take forward the message, that one can still enjoy clothes and wear a wide variety of them, even though they were produced and acquired in harmony with circular economy-based practices. People’s inbuilt attraction for novelty can also be met with carefully designed and responsible garments, and the contents of one’s wardrobe can change sustainably even every week for example via shared wardrobes. In addition, using sharing services functions as a great way for the consumers to find out, whether a certain product is truly pleasing and a reasonable choice to purchase as their own (Heikkilä, 2019; Linnemäki, 2019). Focusing also on the adaptability of clothing provides tremendous opportunities and an inspiring playing field for the designers. Having a large number of different garments with different looks could be replaced with fewer garments, which could be customized into different purposes and positions, and perked up for example by turning the garment other way around or by switching detachable decorations (Heikkilä, 2019).

It is important to patiently guide consumers away from the mentality of throwaway culture and careless consumption and towards circular economy practices. Currently, the low price of fast fashion allures consumers, leading easily to unnecessary inspiration shopping. As a result, fast-wearing and low-quality products are being purchased instead of high-quality, durable and long-lasting products. Moreover, consumers have become so accustomed to the quickly changing fast fashion trends that they might not exactly know what the cornerstones of their own personal styles are or which materials to favour, which also leads to reckless purchasing decisions (Heikkilä, 2019; Linnemäki, 2019). Heikkilä (2019) highlights the importance of taking time to figure out what is really needed and then searching and finding exactly the right product for one's needs: "*If one buys garments for a real need and not for other reasons, and goes from quantity to quality, the clothing will surely satisfy the needs of the user*", Heikkilä remarks, adding: "*When one finds the right product for oneself and values and appreciates it – albeit due to a higher price – one also takes good care of the product and really uses it*".

Even though the progress is slow, an increasing number of consumers are growing more and more aware of how to care for their clothing, the properties of different materials and how to separate bad and good quality. Furthermore, second-hand garments have become more appreciated and even matters of pride: now, it is even trendy to wear old gems, and some vintage designs may even cost more than a new product. Nevertheless, changes in attitudes are still needed and there are myths that should be eliminated. For example, many people still have the impression that a reused or a recycled product is inevitably of lower quality than a new product or a product made of virgin materials (Ilmonen, 2019; Linnemäki, 2019; Mäki, 2019).

7.6.4 Trust and transparency

Trust and transparency can be acknowledged as some of the key drivers for guaranteeing the functionality of the textile circulation ecosystem. Getting to know other actors, working together and sharing knowledge are all essential elements that both generate trust and guide actors in finding their own valuable place in the ecosystem. One must dare to share information across the value chain, trusting that others will not simply exploit this knowledge, but knowledge will bring value to everybody evenly – all the while trusting that the information that others are sharing is also accurate and sincere (Cura, 2019; Heikkilä, 2019; Ilmonen, 2019; Mäkiö, 2019). As Ilmonen (2019) points out: "*Everyone gives something, and everyone gets something. The goal is to move toward sustainability, fairness and collaboration - this requires everyone's trust and courage to jump into the unknown*". After all, the ecosystem of textile circulation is constantly evolving,

and many actors are struggling with similar problems. When different actors start learning things together, trust in mutual doing is important, and can in best cases prevent pointless bureaucracy (Heikkilä, 2019; Mäkiö, 2019). "*Trust is really essential in building new types of ecosystems such as this: if there is an opportunity to build the ecosystem voluntarily and in an atmosphere of trust and good team spirit, it will also reduce the need for policy action and regulatory interference*", Heikkilä (2019) points out.

For a mutual trust to form, it is essential to invest time in meeting ecosystem partners face-to-face every now and then, rather than discussing only via email threads and web meetings. If people are not connected in any other way apart from electronic communication, deep-rooted trust on each other is less likely to form (Linnemäki, 2019; Mäkiö, 2019). Permanence of actors is also a valuable aspect in trust-building. If actors are constantly going back and forth with their participation interests, or if the workers of certain projects are constantly changing, personal relationships – and therefore, also trust – must often be re-built from scratch (Mäkiö, 2019). Visiting different workshops and production facilities together and discussing and innovating around the same table does not only provide the actors with a mutual understanding of the current situation, but also with a certain guarantee of the other actors' commitment to a project or to a shared goal (Heikkilä, 2019; Mäkiö, 2019). For example, if an actor is never involved in mutual meetings and events, suspicions might occur about the actor being a free-rider on other's hard work (Mäkiö, 2019).

In general, Finland has a good atmosphere of trust and it is usually relatively easy to rely on another person's word (Mäki, 2019; Rissanen, 2019). However, doubts tend to emerge rather rapidly when people are facing new things. For example, separate collection's effect on the textile streams of the reuse market and clothing rentals' effect on designer's product sales have all initially sparked up questions and mild concern. Eventually, these concerns and differences in opinions have been managed to resolve by gathering together and discussing in a transparent manner. Disagreements and suspicions cannot ever be completely avoided in large ecosystems, and trust on the other actor's word, on solving problematic situations together and on transparent information is paramount in such cases (Heikkilä, 2019; Linnemäki, 2019). "*Transparency within the industry would certainly boost textile circulation and help actors to understand their own role in the ecosystem and their magnitude in a bigger picture*", Käppi (2019) from Nextiili workshop agrees, suggesting also: "*for example, it would be interesting to know more accurate numbers on what kind of textile streams are flowing in Finland and to where, how much end-of-life textiles are different end-of-life textile collecting actors importing abroad, and so forth.*"

The atmosphere of trust is regarded as sufficient on consumers' side, even though there will probably always be some healthy doubt about different actors' operations, despite the general trust. The more openly matters related to responsibility and textile circulation are being communicated, the more customers also question, inquire and become interested (Ojala, 2019). Transparency about the collected textiles, different processes and worker's working conditions is essential, and will certainly reduce cynical suspicions. However, there are also a lot of misconceptions about the whole field, especially concerning the fate of collected textiles. For example, if there is media coverage of textile waste being dumped into developing countries, or an uproar about mountains of textiles being incinerated, this may aggravate a climate of mistrust for years to come (Makkonen & Töyrynen, 2019; Mäki, 2019). On the other hand, it is important to be honest and transparent and inform the consumers about the actual volumes of collected textiles that are currently being recycled or incinerated (Rissanen, 2019). The importance of terminology becomes once again highlighted in such a situation: "*If an actor misuses the terms and for example sloppily says that the collected textile fraction is directed to recycling, when in reality most parts of it would end up in incineration, this would most certainly cause suspicion and frustration among the consumers*", Mäki (2019) from Finnish Textile & Fashion notes.

7.6.5 Common goal

A common, clear goal is an important driver for textile circulation. When it comes to the foundations of the Finnish textile circulation ecosystem, everything has started with individual actors wanting to do something good together and to make things right within the textile industry. It is essential to determine a common goal and keep repeating it every now and then: this way, the progress towards the goal can be observed better and the involved actors will stay motivated. A multi-actor, collaborative approach is a win-win solution for achieving the goal, as co-operation is usually helping everybody to reach both their own personal goals and the larger common goal faster (Linnemäki, 2019; Mäkiö, 2019). "*It is also beneficial to create clear boundaries for the goal and the process towards it, so that those involved would misstep to side-paths as little as possible*", Mäkiö (2019) points out, adding: "*Although, valuable things may sometimes be found also from the side-paths, even if they would not serve the original purpose*".

In general, it is usually beneficial to go through all the possible future scenarios beforehand in order to internalize the aim of a common project better. After going through the possible outcomes for the project, the most reasonable end-scenario should be selected collectively as the common goal. This scenario can then be considered as the basis for

all research and action, unless something unexpected occurs, urging to change the aimed end-scenario and the current approach. After defining the common goal, it is necessary to determine together what steps are needed for this scenario to actualize and whether the steps are viable or not. Setting a goal and evaluating the progress together every now and then is also a way of identifying Finland's strengths and position on a global level: as the field of textile circulation evolves globally and knowledge about the matter increases, the goals of national projects might also shift correspondingly (Mäkiö, 2019).

Trying, doing and repeating the same things over and over again is often not very motivating, unless one has a clear overall picture of the goal and a larger purpose to act for. Even if an actor’s own part in the ecosystem would not seem to be the most exciting thing in the world, it should be observed as a necessary piece in a bigger, functioning entity. One should try to find an inner balance with the thought that nobody alone can be responsible of everything that a sustainability transition requires, and it usually takes more than one actor to solve all the problems. However, it is equally important to realize that one’s own contribution can influence others, causing a snowball effect which in turn brings everybody gradually closer to the goal (Cura, 2019).

8. SUMMARY OF RESULTS AND DISCUSSION

The key points risen from the results are summarized and discussed in this chapter. The chapter is divided into three sections that reflect each of the three research questions: sub-chapter 8.1 discusses the composition and structure of the ecosystem and activities within it, sub-chapter 8.2 analyses the compiled textile circulation technologies and chapter 8.3 examines other drivers and barriers that affect Finnish textile circulation.

8.1 Ecosystem composition and structure

This study provided a view on the composition and the status of current Finnish textile circulation ecosystem by visualizing the linkages between different actors. As stated earlier, the visualization (chapter 5.1, figure 10) was created based on the actor interviews as an example of the actor types currently present in the ecosystem. Based on the results, it can be stated that the textile circulation ecosystem consists of actors with highly varying operating fields. Even though the ecosystem visualization was created based on a relatively small amount of actors, the composition already included a large variety of actors: companies, different industries, various universities and research institutes, central organizations, non-profit organizations, municipal actors from various fields, ministries and councils, funding providers, media and consumers. Naturally, the results of this ecosystem inspection provided only a surface scratch on the ecosystem's realistic interlinkages and do not reflect textile circulation's ecosystem structure within whole Finland. Nevertheless, figure 10 provides a good example of the vast spectrum of parties, different interactions and linkages that are needed to enable the operations of different actors – even in a small-scale ecosystem inspection such as the one provided by this study. Textile circulation related activities are currently geographically centered in the large cities of Finland. when the bigger scheme of domestic textile circulation clarifies, it will be important to find a way to involve also smaller cities and northern areas. Even though Finland is a small country in terms of textile industry, this can also be considered as an advantage rather than as a disadvantage: smaller amount of actors can lower the bar for extensive co-operation and mutual practices.

Figure 10 shows that universities and other research institutes are working in close collaboration with each other and with different companies. In addition, certain actors, such as Southwest Finland Waste Management, Turku University of Applied Sciences and VTT clearly have a lot of interaction with different actors in the inspected ecosystem.

Albeit, it must be acknowledged that majority of the interviewees have been involved in Telaketju textile research projects with varying intensities, which obviously affects the shown linkages and the types and amounts of addressed textile circulation related stakeholders. If the ecosystem visualization was created based on a larger sample of interviewed actors from more varying fields of textile circulation, the composition and structure of the visualization would probably change drastically, becoming much more complex and consequently, more realistic. Furthermore, as some of the actors shown in the figure are in fact groups of actors or even whole fields of industries, the illustrated ecosystem structure is a distorted version of the structure that the same sample of interviewees would realistically form. In addition, the figure focuses mainly on the linkages between the interviewed actors and their stakeholders and does not illustrate the possible linkages that different stakeholders might have between each other. Moreover, the provided ecosystem structure and the illustrated linkages between the actors do not inform about quality of the interactions: whether the interaction includes for example knowledge sharing or business activities. With a larger sample of interviewed actors and a more definite, qualitative focus on their interactions, the dynamics within the ecosystem would also become more truthful and explicit, enabling a more extensive ecosystem analysis.

Taking into the consideration the mentioned aspects, it can be argued that careful methodology is truly essential when ecosystems are being explored. Ecosystem's boundaries can be difficult to determine, and the structure of the ecosystem can change radically based on the focus areas of the inspection. For example, in this study, the topic of textile circulation was approached especially with textile circulation's technological processes and technology development in mind, and majority of the interviewed actors were involved in handling or processing textile streams or doing research concerning the topic. The chosen approach surely affected the results of the inspection, for example in terms of the addressed stakeholders. Moreover, as the interview data of this study was mainly based on the answers of individual interviewees, this might also be reflected in the results: another interviewee from the same company or organization might perceive the actor's role in the ecosystem in a slightly varying way. It is also essential to take into consideration that many actors in the ecosystem may have multiple roles. For example, ministries may act as regulators within the ecosystem, but they also have an important role as funders for research projects and other commissions. Naturally, this kind of overlapping in terms of ecosystem roles needs to be taken into consideration when the ecosystem dynamics and the qualities of the different interlinkages are being examined further. Seconding the study by Phillips & Ritala (2019), when an ecosystem is being studied, it would be beneficial to approach the ecosystem not just from one perspective, but

by taking into consideration various affecting aspects: ecosystem's boundaries, hierarchies and relationships within the ecosystem and the ecosystem dynamics.

In addition to creating an example of the composition and structure of the textile circulation ecosystem, the operations within the studied ecosystem were examined in further detail. The status of national textile circulation was evaluated in chapter 5.2 in relation to the ecosystem model by Fontell & Heikkilä (chapter 3.3.1, figure 8). The missing textile circulation related activities were addressed based on a scenario, in which the full value chain of textile circulation, including at least a medium-scale, closed loop textile recycling system, would be based in Finland. The results indicated, that the activities within the Finnish textile circulation ecosystem are currently largely focused on technology research and development, raw material processing and operations within the re-use market. However, if textiles were to be produced in Finland in a closed loop system, several important parts of the textile circulation's value chain would still be missing – parts, such as yarn and fabric manufacturing, that have disappeared from Finland a good while ago alongside with large-scale textile industry. Therefore, now that the textile circulation ecosystem is being developed and enhanced, it is topical to ponder which parts of the value chain should remain in Finland and on what scale, and which parts would be reasonable to execute in co-operation with global partners. It is important to evaluate realistically Finland's strengths and resources, and correspondingly, the strengths and resources of the possible co-operative countries. For example, co-operation within Baltic Sea region and the rest of the Nordics has been considered as a promising option, and networking events are being organized to promote the matter (Heikkilä, 2019). Especially the countries that are relatively close to Finland would provide a sensible co-operation possibility, reducing the need to transport raw materials around the world. The longer the transport distances become, the lower overall benefits are naturally achieved from the textile circulation processes.

Based on the concept for a business ecosystem's life cycle (Moore, 1993), it can be argued that the Finnish ecosystem of textile circulation is currently at the end of its birth stage and preparing to start its expansion stage. The emphasis within the ecosystem has been especially on extensive textile circulation related research and mapping new business opportunities: discovering how post-consumer textiles can be collected and processed, what are the products and services that can be offered to customers, and how can these alternatives compete with the current, linear textile market. As it is typical for an ecosystem's birth stage, the actors of the ecosystem have laid the foundation for expansion with new innovations, such as chemical recycling and identification technologies. As the ecosystem keeps evolving and novel innovations become commercialized,

these technologies and new services will start to compete even more eagerly with the conventional practices of the textile industry, facilitating further expansion of the textile circulation ecosystem.

8.2 Technologies for textile circulation

The technologies presented in chapter 6 were compiled in order to provide an overview of the technologies that are currently considered as enablers for national textile circulation. The addressed technologies are essential for a wide variety of textile circulation processes, varying from textile collection and textile material identification to fibre recovery and recycling. In addition, certain digital solutions were highlighted as technological drivers that would benefit current textile circulation activities.

It is essential to guarantee that the collected post-consumer textiles remain in pristine condition after the donation. If the textiles get spoiled during the collection, all the following processes and further circulation technologies will become pointless. Functioning collection has its impact both on the re-use and recycling markets: moldy, wet or smelly garments and textiles possess hardly any sales value, and heavily contaminated textile waste cannot be considered as suitable raw material for textile recycling either. Donated textiles form larger textile batches, which remain in the collection point for a certain amount of time before the fraction is directed to pre-sorting. As mentioned, even small amounts of spoiled textiles or excess humidity can contaminate the whole batch if the contact occurs for too long. Therefore, if the textile collection points are located outdoors, the technologies related to the preservation of textiles, such as moisture meters or tightly sealed, standardized collection bags, could show great potential. Such technologies could both prevent large-scale losses in raw material volumes and result in fresh, clean and more attractive garments with a better re-sale value. If the textile collection boxes or other drop-off points are located indoors in a relatively controlled environment, the risk of humidity related textile spoilage would most likely decrease. However, a collection system that utilizes standardized, certain-sized collection bags could still be beneficial for example in terms of storing and other logistics.

The results concerning textile sorting and material identification – but also the requirements for the following processes – highlight the importance of a careful and manual pre-sorting process. Even if automated identification methods were developed in such a way that more accurate and selective identification methods could be provided, it is highly unlikely that the identification process will ever become sophisticated enough to be able to separate the reusable textiles and garments automatically. Detecting value-adding

factors such as vintage character and brands, and correspondingly, value-lowering factors such as discolorations, holes and strong odours all require human perception and evaluation. In addition, manual pre-sorting enables pre-treating the textiles for sorting itself by separating different material layers and un-processable objects, such as zippers and buttons. When it comes to the textile products that are yet to be produced, it is highly encouraged to focus on farsighted product design, which can accelerate the future's sorting and separation processes for example via ease of disassembling.

Apart from the importance of manual pre-sorting, developing the sorting process to function as automatically as possible would be of great importance. With an automated, material-based sorting process, sorting higher volumes of textiles would become more feasible in an economic sense. In practice, both feeding the textile products onto the sorting line and identifying the textiles' material compositions should be automized. Both NIR spectroscopy and RFID tags can be considered as promising identification technologies for the sorting process. NIR as an identification technology is already being utilized on an industrial scale for the material identification of other recyclable fractions, such as plastics. However, utilizing the technology for textile identification purposes is still a relatively novel application. If NIR identification is upscaled for the needs of industrial scale textile sorting, it is necessary to build accurate material libraries for the analyzers, based on the textile fibres and fibre compositions that are wished to be recycled and the necessary identification accuracies. Ultimately, the fluency of the sorting process and the direction into which identification technologies will be developed is highly dependent on the materials that are desired to be sorted from the textile stream – determining this will require decision-making from both textile product manufacturers and textile recycling actors. After the manufacturers have determined what kind of textile products are wished to be produced from recycled fibres, and what are the properties required from said products, raw material providers and recycling actors can optimize their own processes to meet these requirements.

In terms of different fibre recovery and textile recycling methods, the results support the statement that there is a clear need for both mechanical recycling and chemical recycling of cellulosic fibres in the textile circulation ecosystem. Different chemical recycling technologies that are currently being developed in Finland, such as Ioncell™ technology and Infinited Fiber technology, can result in fibre properties, such as strength and colour uptake, that become even enhanced compared to the original cellulosic fibres. Therefore, chemical recycling is praised – rightfully so – as one of the key enablers for textile recycling's future. Nevertheless, since non-reusable textiles needs to be opened into fibre form before they can be utilized as raw material for example in a chemical recycling

process, there will certainly be long-term demand for mechanical recycling processes as well. Furthermore, whereas the chemical recycling methods set certain requirements for the purity of the cellulosic raw material, mechanical recycling as a further processing method is more forgiving and enables the recycling of various sorts of fibre mixtures. In addition to providing fibrous raw material for chemical recycling, mechanical recycling is also a perfectly viable method for producing raw material for nonwoven and yarn manufacturing. Therefore, mechanical recycling's position as a recycling method should not be underrated. It should also be borne in mind, that the results of this study addressed only a limited amount of textile recycling methods. There are also chemical and thermal recycling methods for example for synthetic fibres, and their importance as recycling methods is by no means disregarded. However, as these recycling methods were not addressed during the interviews as currently relevant technologies for the national textile circulation, they were not be discussed in further detail in this study.

Lastly, digitalization is unstoppably revolutionizing various industries and the results clearly support the argument that textile industry is no exception to this. Developing digital solutions further is expected to serve both the commercial actors and the consumers. For example, online rental and lending platforms would make circular economy-based services more effortless to use and more accessible to a wider spectrum of customers, making lending or renting textiles more alluring as an option. Also, adding virtual fitting options to online clothing libraries and online stores would provide the customer with a more personalized online lending or purchasing experience. Furthermore, virtual fitting option would result in lower environmental burden caused by unnecessary parcel handling – all the while saving both the customer's and the commercial actor's time and resources.

In addition to the convenience related benefits, digital solutions can be used to monitor products' life cycles more accurately. Textiles go through a lengthy chain of processes during their life cycles and managing all the data involved in these processes contains a huge amount of untouched potential. Creating digital product passports for textile products would not only make the products' life cycles more transparent, but it could also make their later processing easier. Theoretically, a product passport would reduce the need for material-based identification, as all the necessary data would travel with the textile and could be read from its identifier, such as an RFID tag. However, in practice, both the material-based identification and digital traceability enabling solutions need to be developed and utilized hand-in-hand, as the textile streams still consist mainly of untagged products and will continue to do so for a long time to come.

Even though the discussed technologies provide varying examples of the technological advances that are needed in the field of textile circulation, it can be noticed that the results are related only to certain technological processes. For example, yarn and fabric manufacturing are important parts of a textile product's manufacturing process, yet they were not being addressed in the results. It remains unclear, whether the reason for this is the confined number of interviewees or the lack of yarn and fabric manufacturing on a national level – or, if yarn and fabric manufacturing processes have evolved to such extent, that no additional technological aspects need to be taken into consideration when for example recycled fibres are being utilized. Based on the results, it can be concluded that the most crucial technologies for the different parts of the value chain more or less exist already. In order to implement the addressed technologies into industrial textile circulation purposes, the focus should be now on upscaling these technologies and developing automation. As the textile circulation ecosystem continues to expand, upscaling different sorting and recycling technologies is needed in order to answer the raw material demands of the textile industry and to create a noteworthy competitor for the utilization of virgin fibres.

8.3 Drivers and barriers of textile circulation

The set of different drivers and barriers, addressed in chapter 7, provided an extensive insight on the factors that, alongside technological advances, accelerate the activities within the textile circulation ecosystem. Respectively, some of the results were acknowledged as hindrances and obstacles that still need to be overcome before the ecosystem can reach its full potential.

A compiling summary of the most relevant drivers and barriers that affect the Finnish ecosystem of textile circulation is presented in table 5. Even though technological advances act also as drivers for textile circulation, the technological aspects were already addressed in detail in chapter 8.2. Therefore, this summary enlists only the other main categories addressed in this chapter: business, organization, regulation, linguistics, visuality and psychology. Some of the addressed drives and barriers are related to the current status of the ecosystem, while some of the addressed factors, such as the recycling percentages defined by EU, are related to future scenarios and future's decision-making. However, it is important to bear in mind that the drivers and barriers are summarized based on the compiled answers of 12 different actors. Therefore, the results in their entirety may not reflect the absolute truth for every actor. Depending on the actor and their specific backgrounds and points of view, the effect of a certain driver or barrier may be experienced as quite contradictory compared to the effects addressed in this study.

Table 5. Summary of the drivers and barriers of national textile circulation.

Business	
Drivers	Barriers
Conscious consumers' demand for more sustainable products	Possible initial oversupply of recycled fibres due to the lack of utilizers
Utilizers for opened textile fibres also from outside the textile industry	Low price of virgin textile fibres (recycled fibres less likely to compete)
External funding (e.g. fashion giants funding innovative start-ups)	Long distances and fragmented population complicating service provisioning
Utilizing existing infrastructure for new process-type innovations	Service provider's initially slower rate of gaining profits
Credibility for funding by taking part in larger multi-actor research projects	Lack of funding for novel innovations' commercialization phase
Companies' process renewal in co-operation with research institutes	Lack of funding for non-profit organizations
Collaborative projects (combining expertise and finding synergies)	Small companies' low chances for experimenting (lack of resources)
International co-operation (companies, research institutes, projects)	Costs and practicalities of recycling bulky textile products (storing, processing)
Developing digital platforms and services in co-operation with other actors	
Digital enhancements (e.g. e-commerce, online lending with home deliveries)	
Second-hand garment selections reflecting prevalent trends	
Close customer relations and actions based on customer feedback	
Organization & management	
Drivers	Barriers
Enthusiastic leadership and visionary speakers	Finnish, withdrawn corporate culture
Aware administration (strategic choice of research topics and projects)	Companies' uncertainties about what information can be shared and with whom
Textile roadmap as a guide towards a sustainable textile industry	Lack of textile technology education in Finland
Innovation culture and curious, ideological staff	
Circular economy education and textile design education	
Cross-consortium communication, communication between research groups	
Clear communication throughout the global production chain	
Transparent communication between actors and realistic consumer guidance	
Regulation	
Drivers	Barriers
Obligation for the separate collection of textiles (EU level)	Giving the waste status to collected textiles prior to sorting
Implementing the separate collection in clear phases with common practices	Current circular economy legislation (mainly based on waste law)
Feasible recycling percentages (EU level)	Low co-operation possibilities between public and private sectors
Standardized quality grades for opened textile raw material (purity, content)	Current labelling standard (difficulties in marking recycled fibre content)
Circularity-favouring taxation (e.g. lower VAT for services or recycled content)	Challenges in creating globally uniform quality grades for textile raw material
Designing multiple life cycles for textile products	Standardizing recycled textile fibres for the needs of other industries
Circularity index for textile products	Preconceptions concerning end-of-life textiles' chemical residues
Risk-based inspection of end-of-life textiles' chemical content	Challenges of regulating circular product design (differences in e.g. recyclability)
Solution-oriented approach to chemical content (finding suitable applications)	Durability of textile products highly dependent on the user
Quality criteria for textile products (less low-quality imports and exports)	Challenges in balancing full traceability and business secrets
Linguistics	
Drivers	Barriers
Common terminology	Annoyance due to the repetition of sustainability related trend words
Media's correct terminology usage	Differences in perceiving certain terms (e.g. recycling)
Elaborating the full spectrum of circular economy - not just recycling	Using too complex terminology in a general discussion
Elaborating the practical meaning of trend words (e.g. responsibility)	
Critical evaluation of terms and the mental images they evoke	
Reinforcing verbal communication with visual communication	
Active discussion (media coverage, workshops, seminars, public speeches)	
Visuality	
Drivers	Barriers
Clarifying technical processes with visuals (e.g. videos, infographs)	Creating unified symbols for the global market
Utilizing visuals to reach people who are not interested in technical details	Stereotypes of eco-fashion
Concretization of large amounts (e.g. saved natural resources)	Judgement of donated clothes' looks being blurred by sentimental value
Symbols as guidance (e.g. symbols for circularity or recyclability)	Without interesting visuals infomation is less likely to be read and shared
Sustainable garments that vary in styles, colours and destined occasions	
Second-hand stores' and clothing libraries' fresh looks	
Picture sharing-based social media (e.g. sharing photos of second hand finds)	
Psychology	
Drivers	Barriers
Awareness of the textile industry's sustainability issues	Preconceptions concerning recycled materials and used products
Company's strong values attracting motivated employees	Consumers who are not personally interested in sustainability
Charity aspect for consumers' clothing donations	Consumers' suspicions concerning the fate of collected textiles
External pressure and demands for sustainability, peer pressure	Heated public discussion causing misunderstandings
Empowering consumers and highlighting the importance of personal choices	Mistrust caused by greenwashing
Feeding people's attraction for novelty (clothing libraries, adaptable products)	
Trust on other actors and project partners	
Meeting project partners face-to-face, shared workshops and field trips	
Common goal in a project	

The business drivers and barriers identified in this research varied from supply and demand to business models, funding and commercialization, highlighting strongly the importance of collaboration and interactive customer relations. Supply and demand act as some of the core building blocks for the textile circulation ecosystem, facilitating the utilization of textile waste in the form of recycled fibres. There is currently a clear demand for steering the textile industry towards both ecologically and socially sustainable direction, which in turn boosts for example the development of innovative textile recycling technologies. However, as textile recycling becomes more common, it is crucial to find utilizers for the recycled fibres, both from within and outside the textile industry. While there is surely will to develop technologies and take one's operations into a cleaner direction, the funds to do so are not usually as abundant. Companies – start-ups particularly – are often dependent on external funding, which is usually granted mainly for the initial research work. However, commercialization is the crucial phase, during which more sustainable alternatives usually start competing with the conventional, linear alternatives. Now that textile circulation as a research topic is on the rise, it would be important that the funding would be directed to support also the commercialization phase of textile circulation related innovative technologies and services.

There has been a lot of collaborative projects within the inspected ecosystem, which has definitely benefitted the involved actors. Due to previously mentioned funding issues, especially the smaller companies do not often have enough resources to do all the necessary research and experiments alone – nor does one actor alone usually have enough knowledge about all the aspects that would be needed in order to develop their operations to a more sustainable direction. Shared projects enable brainstorming, distribution of knowledge and networking, and in best cases, synergies can be found even with actors that one would not immediately perceive as possible co-operation partners. Developing new business models or executing service-provisioning could also be more fruitful in co-operation with other actors, benefitting from different actors' varying fields of expertise.

Organizational factors, such as strong and open-minded leadership and innovative corporate culture are also identified as drivers that can truly take textile circulation forward. In addition, since the amount of actors involved in national textile circulation activities can be considered rather limited, it is important to unify the knowledge created during different textile research projects. Co-operation and open communication between different consortiums and research groups could reduce the amount of unnecessary, overlapping research and produce a wider spectrum of knowledge. Albeit it can be stated that these factors are rather generic positive drivers for any industry, the importance of

innovative spirit becomes especially highlighted as the ecosystem of textile circulation is starting its expansion. For example, establishing a pilot plant for mechanical textile recycling and thus, investing in Finnish textile industry, takes certain guts, given the situation that a large portion of industrial textile operations have been absent from Finland for a long time now. As the Finnish textile industry started to flee to countries with lower production costs, technological textile education also started to become run down in Finnish universities. Even though textile technology as a study option would not revive, it is important that education concerning the circularity of textiles and garments is incorporated strongly to the still existing, textile related study lines.

The addressed regulatory drivers were identified as strong means, that could accelerate the transition towards a more circular textile industry. The obligation for providing a separate collection for textiles is expected to enable a steadier flow of raw material for its utilizers, while the possible standardization and common quality criteria for recycled fibres would guarantee the recycling actors a more homogenous, high-quality stream of raw material. Certain regulatory drivers, such as the obligation for the separate collection and possible standardization of recycled fibres will be decided upon and executed at EU level, and therefore, future operations in Finland rely highly on these decisions. Even though regulatory decisions can direct operations to a more sustainable direction, the outcomes of each decision should be thought through well in advance. For example, if the obligatory recycling percentage is set too high at EU level, and textile products that are simply not suitable for current recycling processes are forced to be recycled, the regulation can easily backfire by causing the process to consume more resources than it would save. Regulations concerning chemical safety can also hinder textile circulation – albeit, the concerns about the chemical content of textiles are arguably well justified. Naturally, the safety of the workers that handle end-of-life textiles and recycled fibres needs to be guaranteed, and the textile product itself always needs to be safe for the consumer to use, whether the product is manufactured from virgin fibres or from recycled fibres. It will require careful balancing to guarantee the product safety for the consumers in a reasonable, risk-based manner, while also avoiding preconception-based and stigmatizing chemical content scrutiny of end-of-life textiles.

When it comes to regulatory matters at national level, the results indicate that Finnish textile circulation is tackling with certain bureaucratic hindrances. For example, waste status is currently given to collected textiles based on the purpose in which they have been collected, regardless of the actual quality of the textiles. If the status was determined during the pre-sorting process, the status would more likely reflect the actual content of each batch and bureaucratic obstacles concerning waste management could be

avoided. In addition, co-operation possibilities between the public and the private sectors were experienced as insufficient due to the current legislation. The limits concerning the volumes of textiles that municipal waste management actors can collect from private actors are regulated rather strictly, and therefore, unifying commercial and municipal textile waste streams into a larger and more profitable stream can be extremely challenging.

It can also be debated, whether legislation should intervene with product design or not. On one hand, certain requirements for the circularity of products would certainly affect for example the later recyclability positively, but on the other hand, the range of different textile products is humongous and creating unified requirements is therefore challenging. Due to the varying properties and applications of textile products, all the same aspects of circularity cannot usually be realized in different products. Therefore, it would be more beneficial to encourage circular design by moving towards circularity-favouring taxation. Circularity-favouring taxation would surely encourage the textile manufacturers to pay attention to the circular design and to produce more transparent information about all the aspects of circularity and sustainability that are actualized in each product. The products that can be proven to be designed and produced according to the principles of circularity and sustainability could be subject to tax reliefs, whereas the taxes for fast fashion and an unjustified use of virgin materials could correspondingly be higher. In addition, circular services, such as clothing lending and maintenance and repair, would most probably increase their attractiveness among the consumers if the prices of these services were to become lowered with taxation-based means.

The results indicate that linguistic drivers, such as active conversation and usage of uniform terminology, also have a strong accelerating impact on textile circulation. Correspondingly, if different terms are used misleadingly and in a mixed manner, this can be considered as a strong barrier that may have its effect on consumers' opinions for a long time to come. For example, if certain textiles are directed to incineration due to their unrecyclability, it is important to communicate this to the consumers transparently and understandably, instead of using vague terms and expressions that might leave the consumer with the assumption that said textiles are being recycled. *Recycling* as a term also sets certain challenges, as it clearly means a different thing to most consumers compared to the actors operating in the field of textile circulation. It is important to understand that these terminological differences exist, and accept, that it would probably be a time-consuming process to make the consumers stop using the term recycling in the context of clothing donations or flea market sales. Therefore, it would be beneficial to elaborate what is meant with the term recycling every time when recycling-related matters are be-

ing communicated to the media and the consumers. It could also be beneficial to question and survey every now and then, what mental images do different terms evoke among people: even though a certain term would be agreed upon in expert communication, using it in general communication can even become a hindrance, if the term provokes negative associations among consumers.

Visual elements, such as utilizing illustrations and infographics for process clarification, using symbols for guidance and concretizing the amounts of natural resources are all drivers for communicating textile circulation related matters in a tangible way. Communication relies nowadays more and more to visuality and image sharing, and therefore, actors in the field of textile circulation are encouraged to answer to this trend. As the results indicate, when textile circulation related activities are being communicated, it is advisable to enhance even seemingly clear messages with effective visuals. For example, when the separate collection of textiles comes into action, it would be advisable to inform consumers about the different collectable fractions by adding both verbal and visual instructions to the collection boxes.

The power of aesthetics as a visual driver should not be underestimated either. Awareness about textile industry's sustainability issues does not need to be the only reason for the consumer to choose a more sustainable option: it is essential to provide the consumers with a sufficient enough range of aesthetically pleasing, sustainable alternatives that range in styles, colours and occasions, from everyday clothing to unique occasion wear. It is important to encourage the consumers to understand, that enjoying fashion and a wide spectrum of garments is possible also while favouring sustainably manufactured garments and circular services, such as clothing libraries. Dissolving the often-stereotyped mental image about eco-fashion and recycled textile materials is also crucial. For this to succeed, more examples are needed for example of the types of products that can actually be produced by using recycled fibres – tangible examples and complete pieces of clothing feed the public's attention better than pictures of innovative fibres and yarns.

People's built-in values and ways of perceiving things affect all decision-making and action. Therefore, the importance of psychological factors can be considered significant for the developing textile circulation ecosystem. The results indicate that textile industry's sustainability issues, as enlightened in chapter 2, are clearly of concern for both the actors within textile industry and the consumers. In the context of sustainable development, the 12th sustainable development goal, "*Responsible consumption and production*", can arguably be considered as the key goal for textile circulation and a take-home message in terms of the actualization of the rest of the SDGs. Changes in both consumption and

production patterns of textile goods are required equally for enabling socially sustainable production and operating within the planetary boundaries. Open discussion about these sustainability issues creates external pressure for textile companies and peer pressure for consumers, thus accelerating the transition towards a more sustainable textile industry. Even though signs of increased awareness can already be noticed among the consumers, the results indicate that motivating consumers and highlighting the importance of individual choices is now more crucial than ever. The transition from fast fashion and mindless consumption towards slow fashion and circular services will not be a quick journey, and it is important to find a way to reach and involve also those consumers, who do not possess personal interest in the textile industry's sustainability issues. The same transition requires efforts, determination and co-operation also from the current and future actors of the national textile circulation ecosystem. Allowing the ecosystem to evolve on a solid base of trust, transparent operations and mutual knowledge-sharing is essential for creating an effective textile circulation system that functions as a natural part of the textile industry.

It can be noticed from the results, that it is often hard to separate only one specific driver that would push the process forward alone – often a simultaneous contribution of multiple drivers is needed. For example, even though the existence of a specific, novel technology can be a strong driver as itself, the help of business-related drivers, such as funding and actor collaboration, is probably needed for the technology to become commercialized. Correspondingly, a strong innovation culture is usually required for the technology to become developed in the first place, and the search for funding is often accompanied with visionary public speeches and effective visual examples of the technology's potential. Naturally, the necessary drivers and driver combinations and the relevancy and magnitude of different barriers can vary drastically between different actors, depending on their role in the ecosystem. In addition, it can be rather tricky to classify a driver or a barrier only under a certain category. For example, while internal and external communication were classified in this study as essential organizational factors, they could also be analysed from a linguistic and visual points of view. Addedly, circular design, which was observed here primarily from a regulatory point of view, could be placed just as well under the main categories of technology and business due to easier processing and resource related savings. This, again, proves the complexity of the factors that need to be taken into consideration when a textile circulation system is being created, underlining the need for an interdisciplinary approach and expertise.

Due to the large amount of varying-themed drivers and barriers and their interdependencies, it is rather difficult to point out only certain drivers and barriers that would be the

most dominant ones for textile circulation. It can be claimed, that all the presented drivers are necessary for different parts of textile circulation ecosystem, either separately or as combinations. Nevertheless, the importance of regulatory drivers and overcoming regulatory barriers becomes highlighted as a sort of igniting force for all the action. Once the regulatory hindrances that affect different actors' operations would be overcome, the operations could be enhanced further with the aid of the other addressed driver categories. In addition, when the drivers are examined from a consumer perspective, the importance of product safety, pricing, aesthetics and other matters that shape consumer behaviour become emphasized. Garments and household textiles are an essential part of everyday life and self-expression, and literally close to the consumers all the time – therefore, it is important to have a thorough understanding of the factors that affect and shape the consumer's relationship towards textile products.

While some of the examined drivers and barriers were purely exclusive for textile industry and textile circulation related activities, it can be argued that a large part of the identified drivers could benefit other fields of industries as well. For example, factors such as research and commercialization funding, collaboration, innovative corporate culture and strong leadership can be considered as essential drivers that would most likely be beneficial for all rising business ecosystems. Moreover, material safety, circular design and circularity-favouring taxation are issues that are surely relevant also for other manufacturing industries that are trying to transform their operations to a more circular direction. Therefore, the addressed factors can be considered relevant also for other evolving ecosystems and other industries, that are commencing their transition towards circularity.

The results correlate strongly to a report by European Environment Agency, published in late 2019. The report discusses textiles' role in Europe's circular economy agenda and illustrates a model of circular textile systems, highlighting the importance of circular business models, policy options, education and behavioural change and the ways these aspects correlate to different parts of a textile product's life cycle. Multiple drivers that were examined in this study were addressed in the report as well – eco-design guidelines, enhanced traceability and investment support for start-ups to mention a few (European Environment Agency, 2019). The resemblance of the results indicates that both Finland and other European countries are wrestling with similar issues in terms of textile circulation. However, the similarities in the suggested drivers indicate also that there are synergies concerning the desired actions and outcomes. This could possibly facilitate closer international co-operation, as multiple European countries are clearly determined to strive towards a common goal with unified means.

9. CONCLUSION

9.1 Conclusions and implications

The aim of study was to inspect the current status of Finnish ecosystem of textile circulation and to achieve a comprehensive understanding of different factors that either benefit or hinder national textile circulation. The study was executed primarily based on actor interviews with the purpose of gaining as realistic and up-to-date information as possible. A closer look was taken at the actor types of the studied ecosystem and at current and promising technologies that enable different textile circulation related processes. Furthermore, various drivers and barriers, that either accelerate or hinder the transition from a linear textile industry to a circular one, were explored.

The first research question, concerning the structure and composition of Finland's current textile circulation ecosystem and the activities within it, was answered with an illustrative example of the ecosystem and its actor types (figure 10). In addition, the current activities within the ecosystem and missing links from the field of actors were discussed in relation to a textile circulation-depicting ecosystem model (figure 8) by Fontell & Heikkilä (2017). The compiled ecosystem figure provided a good example of the connections and actor types occurring in the national textile circulation ecosystem and a realistic overview of the activities at national level. In the context of closed-loop textile circulation, multiple necessary process steps from textile products' production chain are currently lacking from Finland. Therefore, in order to create a truly sustainable textile circulation system, the question remains, which industrial processes are reasonable to execute within Finland and which ones abroad in global co-operation. It is important to examine thoroughly each country's strengths and prerequisites for executing different processes and base the possible co-operation on mutual benefits and environmentally reasonable logistics. Nevertheless, it can be stated that Finland's technological know-how, pilot plant plans for mechanical recycling and motivated, innovative actors working with the topic could possibly facilitate even closed-loop national textile circulation, at least on a smaller scale.

Seconding the study by Phillips & Ritala (2019), it can be stated that even rising ecosystems are in fact complex structures, boundaries of which can be hard to define. For example, if another industry's contribution is needed for one industry's activities to kick off, the boundary for the studied ecosystem can quickly become vague. Since the examination of an ecosystem can be executed in numerous ways with different focal points and

different boundaries, the outcome of each examination is bound to provide slightly varying results, even for the same ecosystem. Despite the small sample of interviewed actors, this study provided a practical example of ecosystem research and a directional glimpse on some of the core actors and activities within the national ecosystem of textile circulation at the time of the data gathering. However, since the original objective was to study the whole ecosystem in Finland, the first research question can therefore be considered only partially answered.

Technological advances can be considered as strong enabling factors for manufacturing industries such as the textile industry. Therefore, the second research question focused on necessary and promising technologies for national textile circulation. The addressed technologies varied in terms of processes they are needed for and ranged from physical processing and measuring to enhancing operations with digital solutions. It can be concluded, that for most parts, the necessary technologies for textile circulation exist already, either in the context of textile processing or in the context of processing other material streams. At this point, it is time to focus on up-scaling innovative laboratory-scale and pilot-scale technologies and boosting the performance of existing technologies, for example via more efficient automation. However, especially in terms of digital technologies and data management, there is still a vast field of development areas and possibilities to explore. It is acknowledged that the technologies examined in this study do not cover the whole spectrum of technologies that are available or necessary for a fully inclusive textile circulation ecosystem. Nevertheless, the second research question can be considered to be answered sufficiently, as the research question was aimed to address the current situation in Finland rather than textile circulation in its entirety.

In addition to the technological approach, several other driver and barrier types were explored in order to answer the final research question and to map out current drivers and barriers of national textile circulation. A multitude of drivers and barriers were addressed from the fields of business, organization and management, regulation, linguistics, visuality and psychology. The recognized drivers varied from highly process-specific and strictly textile circulation related factors to more generic factors, such as open corporate culture and trust. The more generic drivers would certainly be beneficial for other fields of industries as well – regardless whether circularity is being implemented into the conventional operations or not. Additionally, certain barriers that set obstacles for textile circulation in Finland, such as strict regulations concerning waste management, were also highlighted in the results. Given the vast spectrum of recognized drivers and barriers, the third and final research question can be considered as fully answered.

Even though a certain driver, such as a recycling technology, can act as a strong driving force as itself, it is quite rare that only one factor alone catalyses progress – usually a joint reaction of multiple drivers is needed. For example, even though novel technologies and technological advances are core drivers for manufacturing industries, they are not enough as such. A new technology is very unlikely to be implemented and commercialized without sufficient funding and investments, or without innovative visionaries, who persistently keep on developing the technologies and pushing the ideas forward. Although all the discussed drivers have their own accelerative roles to play, it is especially important to recognize the bottlenecks of textile circulation and highlight the necessary drivers that aid in overcoming these barriers.

Textile collection can be pointed out as one of the crucial phases of textile circulation: if textiles get spoiled during the collection phase, or if contaminated textiles ruin the rest of the batch, also the following technological processes become irrelevant. Therefore, it is important to plan the collection phase carefully in order to guarantee as high-quality batches of reusable products and raw material for recycling as possible. Since the textiles' separate collection system is yet to be implemented, it would be advisable to consider taking into use the discussed technologies for the collection phase. Optimizing the collection point locations and other textiles' drop-off practicalities and providing extensive visual and verbal consumer guidance well beforehand is also highly recommended.

Accurate, material-based identification is absolutely essential for reliable textile recycling, especially in the case of older, non-tagged textile products. However, focusing on the digitalization of the newer products' product information is equally crucial and an enabler for better traceability. Data creation and utilization can be highlighted as a strong textile circulation driver: for example, curating detailed, digital product passports for textile products could benefit drastically the technological processes of textile circulation, as all the necessary data would be stored and accessible for the needs of each process. In addition to making further processes of maintenance, reuse and recycling easier, traceable and accessible data about the product's life cycle can also create trust between the actors involved in the production chain and strengthen the partnership. Communicating the product's origins and production steps to the consumers is also beneficial and can even create additional value for the product from consumer's point of view. Therefore, it is advisable that the actors involved in the supply chain of textiles invest in data creation, handling and sharing – it is important to insist on receiving transparent data from all the earlier process steps and to pass this valuable data further along in the supply chain.

As the results strongly verify, developing a functioning textile recycling system is crucial for saving resources and for guaranteeing fibre feedstock for both open-loop and closed-

loop recycling purposes. Nevertheless, it is equally important to focus on the very beginning, circular design: optimizing material usage, extending textiles' life cycles with reasonable, durable material choices and maintainability, and creating simple disassembly solutions for the more complicated and layered textile products. When a textile product's life cycle is thought through already during the design process, many forthcoming problems can be prevented, and the product's true level of sustainability can be observed more realistically. It can be stated that embracing interdisciplinary knowhow during the design process is necessary for creating as sustainable of a life cycle for the textile product as possible. Therefore, implementing the aspect of circularity not only to textile design education, but also into various other fields of studies, is highly advisable.

What makes textile industry different from many other fields of industries that are turning circular, is how central of a part the consumers play. Consumers both create the demand for more sustainable textile products and supply reusable products and recyclable raw material in the form of end-of-life textiles. However, even if all the end-of-life textiles could miraculously be reused and recycled, textile industry's transition towards sustainability cannot truly commence until larger crowds start reshaping their relationship towards textiles. To achieve such attitudinal and behavioural changes, it is important that the industry's different actors keep the topic on the surface and utilize both strong visual communication and consistent and understandable verbal communication for conveying the message. Motivating consumers with the environmental and social benefits that can be achieved with circular choices is certainly necessary. However, it is also essential that manufacturers, service providers and actors in the field of textile reuse involve the consumers as part of the solution and listen closely to their feedback and wishes. When the looks and properties of more sustainable and pre-owned products offer viable alternatives to fast fashion, and when services are easy and alluring to use, the preconceptions about eco-fashion and sustainable choices are likely to fade faster. Naturally, it would be desirable that regulators would also come halfway with said mission: both the producers and the consumers could be guided away from fast fashion and towards circular products and services for example with the aid of circularity-favouring taxation.

Regulatory matters are expected to have a significant role to play in catalysing Finnish textile circulation, but for certain parts, current regulations are experienced as a clear hindrance. End-of-life textiles are in general a relatively harmless type of material stream, which does not pose imminent threat to either human or environmental wellbeing. Therefore, it would be recommendable to re-evaluate the current regulations concerning the collected textiles' waste status. The results indicate, that loosening up the regulations

concerning collected textiles' waste status, and rather, perceiving collected textiles primarily as products and raw material, would generate a more feasible operating environment for the actors within the Finnish textile circulation ecosystem. The waste status should not a fall on the textiles automatically prior to sorting, but as a result of manual inspection or as a risk-based decision. In addition, it is important that end-of-life textiles can be collected as efficiently as possible from their varying sources. Therefore, it would be advisable to refine regulations also in such a way, that would enable smoother co-operation between public and private sectors in terms of textile collection.

While regulation can be used as an effective tool to steer actors towards circularity, circular actions that are ignited more organically with mutual brainstorming and collaboration are always more preferable. It is warmly recommended that companies of all sizes take actively part in research projects and the related events instead of tackling with possible problems and obstacles alone. Considering that there are currently multiple ongoing research projects that involve textile circulation, open cross-consortium communication and communication between different research groups is also highly advisable. This way, unnecessary clashes in research and experimenting can be avoided, and in the best case, different actors can learn from each other's efforts and create necessary knowledge more efficiently. It is important that Finnish textile circulation is perceived as an ecosystem rather than as a scattered group of actors: when actors with different backgrounds understand their role in the bigger system and the wide spectrum of know-how is shared transparently with others, mutual benefits can be gained. Trust between actors and working together towards the common goal of circularity are the key building blocks for a sturdy textile circulation ecosystem and a more sustainable textile industry.

9.2 Limitations and future research

Although this study provided a practical example of ecosystem research and resulted in a wide compilation of textile circulation drivers and barriers, certain limitations applied especially to the determined ecosystem boundaries and research methodology. If circular economy of textiles is approached in a truly holistic way, all the different aspects of circular economy should be included in the ecosystem inspection. For example, novel bio-based material solutions are beneficial for the industry as alternatives for the current, conventional fibres, but in this study, the scope was narrowed down to the conventional textile fibres and the fibres achieved from the conventional fibres' recycling processes. As a result, the study excluded active actors that operate as raw material providers for the needs of the future's textile industry. Furthermore, leather and fur industry are a close neighbour to textile and garment industry, but these parts were also excluded from this

study in order to keep the scope manageable. Moreover, international stakeholders were also excluded from this ecosystem study, although Finnish textile circulation's future will most probably hold also international co-operation. As already stated in chapter 9.1, setting the boundaries for an ecosystem inspection can be quite challenging, and the gained research results naturally reflect the choices that are made concerning these boundaries.

As the number of interviewees was limited due to timely reasons, it can be assumed that the whole spectrum of involved actors, technologies and drivers or barriers was not addressed in the primary data. Even though the interviews provided valuable information on the ecosystem and its drivers and barriers, interviewing a representative from each field or process of textile circulation would surely provide an even more valid overview on such a large industry and the possible obstacles within it. It must also be pointed out that the same interview template was used as a core for all the interviews. The results could have been even more specific, if the interview template had been personalized to reflect each interviewed actor's own field of operations. Moreover, since actor interviews were the primary data source for this study, this is naturally reflected in the results. For example, the ecosystem depicted in figure 10 presents only those actors and actor groups that were mentioned during the interviews, while the addressed technologies might not cover the whole variety of technologies that are utilized in national textile circulation.

Although said limitations affected the variety of results in this study, the compiled ecosystem visualization and the identified drivers and barriers provided a handy steppingstone for further research. For example, since the ecosystem visualization of this study was created only based on the interview data, the same visualization could be enhanced and bulked up by adding more textile circulation actors, based on all the available data sources. When textile circulation ecosystem is examined in the future, it could also be beneficial to divide the study at first into smaller sections – for example into the reuse market and the recycling market – and then try combining the data into a bigger entity. It could also be beneficial to explore other fields of industries separately, highlighting those actors that could possibly utilize recycled textile fibres, and see, how these actors could be connected better to the ecosystem of textile circulation. The ecosystem visualization could also be refined further by elaborating the connections between different actors: whether the connections are remarkably active or only passive and whether the connections are based on business or on knowledge sharing and mutual projects.

Finland's role in global textile circulation would also provide an interesting field of future research. Mapping each country's strengths, limitations and readiness for different textile circulation processes could help to determine, how the value chain of textile circulation

should be spread globally in order to create as sustainable textile circulation system as possible. Such examination could also help to direct possible co-operation inquiries to partner countries in a more coordinated manner. Lastly, studying the linguistic and visual aspects of textile circulation would provide a useful field of further research. Sustainable textile circulation practices need to be intertwined into a natural part of everyday life and operations with careful communication. It is important that the communication reaches consumers in an understandable way and emphasizes the need for action but does not guiltify the consumers or turn circularity into just another annoying trend word. Therefore, it could be beneficial do study what kind of mental images do different terms and visuals evoke in different people: this could help to determine what should be communicated, to whom, and how.

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APPENDIX A: INTERVIEW QUESTIONS

This appendix contains the interview question set that was used for the actor interviews of this study.

Interview question set

Role in the textile circulation ecosystem

1. *Description of Your company's / organization's operations and its role in the textile circulation ecosystem. How is circular economy implemented in Your textile circulation operations?*

Stakeholders

2. *Which stakeholders are essential for Your textile circulation operations?*
3. *Are there specific fields in the Finnish textile circulation ecosystem that lack actors, or is a certain field or function missing completely?*

Technologies of textile circulation

4. *Which technologies (process, device, digital solution, etc.) enable textile circulation in Your operations? What is the level of maturity of these technologies (experimental, commercial, etc.)?*
5. *Which technologies, if not yet applied, would accelerate Your textile circulation operations? Which developments are still needed for these technologies?*

Law and regulations

6. *Are there any regulative barriers that decelerate Your circular economy operations?*
7. *What kind of changes are needed for the laws and regulations in order to improve the execution of circular economy operations on your field?*

Other accelerative and decelerative factors

8. *Apart from the previously mentioned, are there any other factors that have noticeably accelerated (or could accelerate in the future) Your textile circulation operations? What about decelerative factors?*

a. *Business catalysts: e.g. business models, commercialization practices, investments, supply and demand incentives, customer references, service based models, collaboration with startups or large companies …*

b. *Organizational catalysts: e.g. strategic management, leadership, change management, innovation culture …*

c. *Linguistic catalysts: e.g. terms and vocabulary, strong discussion …*

d. *Visual catalysts: figures and images, art …*

e. *Psychological catalysts: acting for common good, trust between stakeholders, curiosity, external pressure …*