Master's Programme in Operations and Service Management

Effect of collection method on the quality of collected consumer end-of-life textiles and reverse logistics efficiency

A case-study of a Finnish textile collection pilot "KaMu"

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Master's Thesis
2021

Aalto-yliopisto
Aalto-universitetet
Aalto University

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Title of thesis Effect of collection method on the quality of collected consumer end-of-life textiles and reverse logistics efficiency: A case-study of a Finnish textile collection pilot "KaMu"

Programme Industrial Engineering and Management

Major Operations and Service Management

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Collaborative partner SATIN-project

Date 14.12.2021 **Number of pages** 58+2 **Language** English

Abstract

The studies and practices of collecting end-of-life textiles from consumers are typically focused on the quantity of the collected textiles and the efficiency of the collection activity. This study seeks to broaden that perspective by examining the efficiency of the textile sorting phase of the end-of-life textiles supply chain and, firstly, how or if changes in collected quality affect the sorting efficiency, and secondly, if the collected quality can be affected through the choice and implementation of the collection method.

The study was implemented as a single-case study of a Finnish consumer end-of-life textiles collection pilot "KaMu" that was contrasted to the collecting organisation, Southwestern Finland Waste Management Ltd. (LSJH's), other collection methods. LSJH has an obligation to collect and recycle consumer end-of-life textiles, which is relatively unique as most of the established textile collectors seek reusable textiles, and the results reflect this focus. The study combined results from interviews, observations, and quantitative data of the sorting activities. As a result, the quality of textiles and effort spent collecting and sorting could be compared from both the pilot and LSJH's established collection methods.

The results of the study show that the choice and implementation of collection method can have significant impact on the quality of the collected textiles which in turn was found to affect the efficiency of sorting activities. This contributes to existing literature by highlighting the need to include the quality aspect to any efficiency-based comparisons of collection methods. Particularly, the results suggest that it is possible for a collection method that is inefficient in producing collected quantity to be more efficient in producing reusable and recyclable textiles once efficiency gains in sorting activities are factored in. The studied collection pilot was found to be one such collection method.

Keywords Circular Economy, Reverse Logistics, End-of-Life Textiles, Waste Collection, Recycling

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Tekijä Henri Gröhn

Työn nimi Keräysmenetelmän vaikutus kerätyn kuluttajapoistotekstiilin laatuun ja paluuvirran tehokkuuteen: Yksittäistapaustutkimus suomalaisesta keräyspilotti ”KaMu”:sta

Koulutusohjelma Tuotantotalous

Pääaine Operaatioiden ja palveluiden johto

Vastuuopettaja/valvoja Prof. Lauri Saarinen

Työn ohjaaja(t) TkT. Riikka Kaipia

Yhteistyötaho SATIN-projekti

Päivämäärä 14.12.2021 **Sivumäärä** 58+2 **Kieli** englanti

Tiivistelmä

Kuluttajapoistotekstiilien keräysten käytännöt ja tutkimukset ovat tyypillisesti keskittyneet kerätyn tekstiilin määrään ja keräystoimintojen tehokkuuteen. Tässä työssä tätä näkökulmaa pyritään laajentamaan tutkimalla poistotekstiilien paluuvirran lajitteluvaiheen tehokkuutta ja ensiksi, kuinka kerätyn tekstiilin laadun muutokset vaikuttavat lajittelun tehokkuuteen, ja toiseksi voiko kerättyyn laatuun vaikuttaa keräysmenetelmän valinnalla ja toteutuksella.

Työ toteutettiin yksittäistapaustutkimuksena, jossa suomalaista kuluttajapoistotekstiilikeräyspilotti KaMu:a verrattiin keräyksen järjestäjän, Lounais-Suomen Jätehuolto Oy:n (LSJH) muihin keräysmenetelmiin. LSJH:lla on velvollisuus kerätä ja kierrättää kuluttajien poistotekstiileitä, mikä on suhteellisen ainutlaatuista, sillä useimmat vakiintuneet tekstiilienkerääjät hakevat uudelleenkäytettäviä tekstiileitä, ja tämä kohdennus näkyy tutkimustuloksissa. Työssä yhdistettiin tuloksia haastatteluista, havainnoinnista sekä lajittelua koskevasta kvantitatiivisesta datasta. Näiden pohjalta voitiin vertailla keräyspilotin sekä LSJH:n vakiintuneiden keräysmenetelmien välisiä eroja tekstiilien laadussa sekä keräykseen ja lajitteluun käytetyssä työmäärässä.

Tutkimuksen tulokset näyttävät, että keräysmenetelmän valinnalla ja toteutuksella voi olla merkittävä vaikutus kerättyjen tekstiilien laatuun, minkä vuorostaan löydettiin vaikuttavan lajittelutoiminnan tehokkuuteen. Työn tuoma lisä kirjallisuuteen on korostaa tekstiilien laadun merkitystä ja suositella laadun sisällyttämistä tekstiilinkeräysmenetelmien tehokkuuspohjaisiin vertailuihin. Tutkimustulokset vihjaavat erityisesti, että keräysmenetelmien olisi mahdollista olla tehottomia lajittelemattoman massan keräämisessä, mutta tehokkaampia uudelleenkäytettävien ja kierrätettävien tekstiilien keräämisessä, kunhan lajitteluvaiheen tehokkuuden kasvu lisätään tarkasteluun. Tämä toteutui tutkitussa keräyspilotissa.

Avainsanat Kiertotalous, Paluuvirta, Poistotekstiilit, Jätteiden keräys, Kierrättäminen

Contents

Preface

I would like to give thanks to my family and friends for keeping me sane, motivated, and happy throughout my years of study that are now coming to an end; to my educators and their supporting staff who have shared with me the skills and knowledge I now possess; to Nordic Innovation for funding this master's thesis through SATIN project; and to LSJH who readily gave me access to their wealth of knowledge.

Espoo, December 2021
Henri Gröhn

Abbreviations

CE	Circular Economy
GSCM	Green Supply Chain Management
KaMu	"Kauppa ja Muoti" = "Retail and Fashion", the name of LSJH's pilot textile collection program where the premises of retail and fashion businesses are used as textile collection sites.
LSJH	Lounais-Suomen Jätehuolto Oy (Southwestern Finland Waste Management Ltd.)
MMSW	Mixed Municipal Solid Waste
RL	Reverse Logistics
T&A	Textile and Apparel

1 Introduction

Pollution, the accumulation of waste and threats of resource scarcity are some of the symptoms of the world's ever-increasing consumption and production of physical goods. More specifically, they are symptoms of the currently dominant linear production methods, where almost every product is produced primarily from virgin raw materials that are extracted from the ground or from plants or from other sources. Combined with the Earth's growing population and increasing consumption, these issues are only going to get worse unless our reliance on virgin raw materials can be reduced. (Ellen MacArthur Foundation, 2017; UNEP, 2018; Manickam and Duraisamy, 2019).

One possible way of solving these problems without unduly limiting the ability of people to improve their quality of life through consumption, is to adopt Circular Economy practises throughout a product's lifecycle. These practices enable products to be used for longer and be recycled into new products, either of the same kind or another, at the end of their lives, thus reducing the need for virgin raw materials. This in turn reduces waste and the pollution caused by raw material extraction and ensures that the reserves of unextracted raw materials last longer, or in the case of growable raw materials, reduces the land, water, and fertilizer consumption of growing them. (Ellen MacArthur Foundation, 2017; UNEP, 2018; Manickam and Duraisamy, 2019).

Circular economy is already somewhat well studied and has several large-scale practical solutions for some materials such as metals, plastics, and paper. For other materials such as textiles, the practices of circular economy are at best implemented in a limited manner, as textiles are reused and resold in noteworthy quantities, but recycling efforts are only small-scale (Palm et al., 2014; Dahlbo et al., 2021; Watson, 2020). The need to develop efficient and effective collection and recycling methods is apparent especially in the EU, where the member states are obligated to have a textiles collection system capable of separately collecting more than half of discarded textiles by 2025 (Eur-Lex, 2008). Further, the Finnish lawmakers have ambitions that Finland should become one of EU's forerunners in collecting textiles by mandating that large-scale collection systems should be in place already by 2023 (YM, 2021).

In academia the circular economy of textiles has been predominantly focused on collection efforts to the exclusion of other stages of the reverse logistics supply chain and the most studied aspect of the collections has been the collected quantities (Struk, 2017; BiPRO/CRI, 2015; Ellen MacArthur Foundation, 2017; Ferronato et al., 2019; Jäämaa, 2021). In this single-case

study the focus is shifted towards the sorting of textiles and the quality, rather than quantity, of collected textiles.

In this study, the case-company seeks to recycle the textiles brought to them (R&D manager and project planner interviews). As consequence of this focus on recyclables, in this study the quality of collected textiles refers to the portion of textiles that could be recycled from the collected mass. The case company's aim to recycle affects the design of the collection methods used and as such the study's results will likely not be in line with findings from studies with a reusability focus.

1.1 Context of the study

This study is done as a single case study of a Finnish waste management company LSJH's collection pilot "KaMu". LSJH – Southwestern Finland Waste Management Ltd. – is one of Finland's 31 municipal waste management companies. The area that LSJH serves contains 17 municipalities with a combined population of around 420 000. In addition to their own textile collection efforts, LSJH serves as the focal company in a combined textile recycling effort of 29 Finnish municipal waste management companies where the other companies send their collected textiles to LSJH to be sorted and recycled. (R&D manager and project planner interviews)

KaMu collection is LSJH's newest collection pilot where LSJH places collection receptables within the premises of businesses closely related to circular economy of textiles, such as flea markets and charity organisations' second-hand shops. The idea behind the pilot is that being located indoors and in locations that are convenient for the consumers could increase the quality of collected textiles. (R&D manager and project planner interviews)

1.2 Objective of the Study

The objective of the study is to examine how placing collection sites indoors in locations close to the consumer affects the collection and sorting activities of the reverse logistics supply chain. The existing research has already shown that increasing the density of collection sites and otherwise lowering barriers to recycle increases the separation rate, which is to say the volume or mass of separately collected recyclables compared to mixed waste. (Struk, 2017; BiPRO/CRI, 2015; Ellen MacArthur Foundation, 2017; Ferronato et al., 2019; Jäämaa, 2021). The studies referenced above also note that bringing the point of collection closer to the consumer practically always translates to more work spent collecting and occasionally requires greater technological capability as well. In short, each additional piece of end-of-life textiles tends to cost more to collect than the preceding ones.

One of the main sub-objectives of this study is to find if changing the perspective from the collection activity to a larger section of the reverse logistics supply chain moderates this trade-off of higher collected amounts requiring higher unit costs. A key hypothesis is that the quality of the collected textiles could change when different collection methods are used. A further hypothesis is that an improvement in textile quality would lead to greater efficiency in the sorting phase of the reverse logistics supply chain as less effort would be spent on textiles that would be discovered to be unfit for recycling and reuse.

The main source of data for this study is Southwestern Finland Waste Management Ltd. (LSJH). Due to the inherent focus on LSJH and its KaMu collection pilot, it is only natural for this study to also provide an assessment on the efficiency of KaMu-collection for LSJH.

As such, the research questions for this study are:

1) Can the quality of collected consumer end-of-life textiles be improved through the choice and implementation of the collection method?
2) How does increased quality of collected textiles affect the sorting of textiles?
3) Is KaMu-collection an efficient part of LSJH's consumer end-of-life textiles recycling operations?

For the purposes of this study the quality of the collected textiles refers to the size of the fraction of recyclable and reusable textiles within the collected mass. Additionally, here the term efficiency is linked to the mass of recyclable and reusable textiles that result from the sorting process rather than to the mass of the input textiles.

1.3 Structure of the Study

The study is structured in a rather standard manner. In the second chapter the results of a literature review are presented including the definitions of key concepts relating to the study along with some of the most recent findings concerning textile recycling and collection of consumer end-of-life textiles. In the third chapter the methodology of the study is explained, and the fourth chapter describes LSJH and its consumer end-of-life textiles collection and sorting activities in detail. The fifth chapter presents and discusses the findings of the study while the sixth provides a concluding summary.

2 Literature review

In this chapter the results of the literature review are presented. The chapter starts with overall presentations and definitions of circular economy, reverse logistics and related terms. Afterwards, the specifics and key concepts of textiles circular economy are presented followed by descriptions of the current situation of textiles circular economy in the Nordics and Finland especially. Finally, textile reverse logistics and its unique requirements, difficulties and current methods are explored.

2.1 Circular Economy and related terminology

Circular Economy (CE) is at its core a way of designing manufacturing practices and the supply chains that surround them in a way that harms the environment as little as possible and to do so in a way that makes economic sense. The core principle of CE is the closing of the loop, also known as the transition from cradle-to-grave thinking to cradle-to-cradle thinking (Manickam and Duraisamy, 2019). What this means is that traditional, non-circular ways of manufacturing (linear economy), a product starts its lifecycle as a pool of resources (cradle) from which it is produced, serves its purpose for some time, and then ends up discarded as waste (grave) in one form or another. In circular economy, the aim is to find a way for every product to end its life as a pool of resources from which a new product can be made, either one identical to the old product or something different.

The goal and vision for Circular Economy is a zero-waste economy enabled by the "restorative and regenerative cycles" that allow the reutilisation of old materials. In their paper Farooque et al. (2019) define regenerative cycle as the one concerned with biological matter and recycling methods while the restorative cycle includes technical methods such as repairing, refurbishing, and remanufacturing. In addition to the above concepts and visions, the literature review by Farooque et al., (2019) identified that the idea of a triple bottom line has had a large impact in the literature on circular economy and related terms. The triple bottom line suggests that to be sustainable organisations need to consider the natural environment, society, and economic performance. Some of the concepts which were identified to actively consider all three parts of the triple bottom line included sustainable supply chain management, green supply chains, closed loop supply chains and environmental supply chains. (Farooque et al., 2019)

As circular economy is focused on creating loops to replace the traditional manufacturing, it is necessary to understand that there are two types of loops in circular economy: closed loops and open loops. Of these, closed loops refer

to resource flows where a discarded product or parts of one, are used to create an identical or equivalent product. Open loops, also known as cascading (Ellen MacArthur Foundation, 2017), refer to using the product or its parts in the creation of other products, such as using plastic bottles in the creation of synthetic fibre-based clothing. (Farooque et al., 2019)

Some of the core methods through with which companies may implement circular economy can be defined through the 3 Rs of waste management: Reduce, Reuse and Recycle (Manickam and Duraisamy, 2019). Other authors have used even more extensive lists of 4, 7 or even 10 Rs, some of which no longer relate to only the waste management possibilities of CE, but for the entirety of circular economy (Manickam and Duraisamy, 2019; Kirchherr et al.,2017). The most extensive of these being composed of 10Rs: Refuse, Rethink, Reduce, Reuse, Repair, Refurbish, Remanufacture, Repurpose, Recycle and Recover.

A closely related concept that also utilises these 3 Rs in their definition is the waste hierarchy. Waste hierarchy is simply put a list of priorities on what should be done to minimise the generation of new waste with the most effective means presented first. The most common waste hierarchy definition consists of the following five steps (Manickam and Duraisamy, 2019):

1. Reduce/avoid creation of waste
2. Reuse
3. Recycle
4. Energy recovery
5. Disposal

Of these steps, the first is usually most concerned with production processes and the design of products with the central ideas being to reduce the waste generated during production and creating a product that lasts for a long time by either being designed for endurability, repairability, or by creating timeless designs when products where changes in fashion greatly impact the likelihood of the product being discarded are concerned. The second step, reuse, simply means that a product discarded by one user, if found to still be functional, should be put to further use by another who would still appreciate it. Recycling refers to using the discarded product's materials as basis for the creation of a new product. Finally, if none of the previous steps were applicable, then at least some of the chemical energy inherent to the product should be captured which typically means being incinerated for heat or electricity. If anything remains after these steps, the remainder should be disposed of in a way that damages the environment as little as possible such as landfilling in a designated site instead of dumping to a river. (Hansen, Christopher and Verbuecheln, 2002)

While this study is inherently focused on the waste management aspects of circular economy, it must be noted that according to some authors waste management is only a fraction of what circular economy should include. For instance, McKinsey (Bismar, 2017, referenced in Manickam and Duraisamy, 2019) lists five major principles for circular economy:

- Design out waste
- Build resilience through diversity
- Rely on energy from renewables
- Think in system
- Waste Management

It should be further noted circular economy is not the only set of principles and methods that aim to create good business ecologically. Another closely related term is Green Supply Chain Management (GSCM). GSCM has been defined in a very similar fashion as CE: "Environmental supply chain management consists of the purchasing function's involvement in activities that include reduction, recycling, reuse and the substitution of materials." (Narasimhan and Carter, 1998, p. 6, referenced in Zhu and Sarkis, 2004). The differences between GSCM and CE are mainly to do with scope as GSCM takes a broader outlook in both methods to be used and in activities covered. For instance, optimizing logistics to reduce energy consumption is a valid part of GSCM and an organization that practices GSCM could also spend time ensuring that they source their materials from eco-friendly companies, both of which have inherently nothing to do with circular economy and closing the loop but are obviously green initiatives. (Zhu and Sarkis, 2004)

2.2 Reverse Logistics

What all circular economy initiatives have in common is that, by definition, they need to get the discarded products and materials from their point of origin back into circulation. This idea of taking back products or their parts and materials with the purpose of recapturing value is known as Reverse Logistics (RL) (Prajapati, Kant and Shankar, 2018; Govindan and Bouzon, 2018).

From the literature review by Prajapati, Kant and Shankar (2018) it seems clear that the overall academic outlook towards RL is that it is a beneficial and attractive business opportunity. However, not all companies face similar opportunities nor is implementing RL always simple. As a result of their literature review, Govindan and Bouzon (2018) identified an extensive list of drivers and barriers for adopting RL practices. For the drivers, they noted

that regulatory pressure is by far the most cited in academic papers with a significant margin of being mentioned nearly twice as many times (24 v 13) as the runner up -green consumerism. This is not to say that companies are only participating in CE and implementing reverse logistics due to governmental and market pressure, as the economic viability of RL was already the third most mentioned driver and the potential of gaining competitive advantage through RL was also mentioned in 7 of the articles examined.

On the barriers side Govindan and Bouzon (2018) identified that so far, the most influential barriers are of the kind that any project seeking to achieve major changes could have, but they did also identify several barriers more specific to reverse logistics. Namely, the most important barriers identified by them were lack of personnel technical skills at 22 mentions, lack of initial capital (21 mentions) and low involvement of top management (19 mentions). The most important barriers relating specifically to RL were lack of specific laws (11), low importance of RL relative to other issues (10), company policies against RL (7) and inconsistent quality [of products made from RL materials and the materials themselves] at six mentions.

Business willingness and ability to implement RL practices are, however, only one half of the picture, as successful and efficient RL implementation requires that the end-users are willing and able to participate in returning their used products to the manufacturers. From the end-user willingness perspective, it is widely accepted that for the best collection results one should provide some incentives to do so, and that returning opportunities should be convenient and close to home (Hole and Hole, 2020).

Another issue that a successful RL implementation should deal with is end-user knowledge on whether and what they should and should not recycle. The effects of these can be significant when knowledge levels are low; For instance, a textile collection pilot in Finland (Telaketju and TEM, 2020) managed to reduce the portion of undesired material collected from an initial 16% share down to 3% by distributing informative leaflets to the residences in their target area just once. On the other hand, a study by Lakhan (2014) found that in some circumstances additional effort made to inform the end-users does not improve recycling rates. The study was made in Ontario, Canada and studied the relationship between municipal recycling promotion & education budgets and the recycling rates of paper, some metals, plastic bottles, and glass and found no statistically significant relation. It should be noted however, that these studies are not directly comparable, as one result was focused on the quality and the other on the quantity of collected material.

2.3 Circular Economy of Textiles

Currently, the Textile and Apparel (T&A) industry is responsible for between 2% and 8% of the global carbon emissions according to UNEP (2018). McKinsey (2020) provides a more precise estimation of 4%. This is a somewhat high share of global emissions for an industry that counts for 2% of the global GDP (Fashion United, 2021). Of these emissions, McKinsey (2020) estimates that ~71% are caused by the production of the clothes, with the rest being attributed to retailer activities, use (20%), and disposal. Much more alarmingly, UNEP (2018) further suggests that if the T&A industry does nothing to cut their emissions and continues growing at expected rates, then by 2050 they would already account for a quarter of all carbon emissions.

Going by the waste hierarchy the first actions that should and could be done to lessen the impact would be to reduce the produced amounts and/or the amounts of material, energy, and other needs such as water used to make the clothes. Some methods that could achieve this are, for instance, to further improve the efficiency of cutting fabric, use more efficient fibre production methods or much more effectively, try to push away from fast fashion towards making products that are meant to last and be used for several years. McKinsey (2020) notes that 40% of all clothes are sold at a markdown leading them to suggest that significant gains could be made through better demand forecasting as well.

The next best thing according to the waste hierarchy is reusing. This is perhaps the best-known CE method known to consumers, as reusing means using the clothes as they are by another user. This includes such common practices as selling old clothes at a flea market, giving outgrown clothes to a younger sibling, or renting a tuxedo for an evening. Even the practice of purchasing clothes from an online retailer with no intention of keeping them, using them once or twice, and then returning them to the seller to get one's money back is technically a form of reuse - if the seller is subsequently able to sell the product again – although not a recommended one as the practice is more environmentally damaging than keeping the clothes and using them for longer. (Sandin and Peters, 2018)

As the last step in the waste hierarchy before burning for energy recovery and landfilling, it should be no surprise that recycling is usually the least utilised of circular economy activities in the T&A industry. For instance, in the Baltic nations, only 1% of end-of-life textiles are recycled domestically, compared to 13% domestic reuse, although a further 29% are exported with the purpose to either recycle or reuse elsewhere (Watson, 2020). Globally, Ellen MacArthur Foundation (2017) estimates that less than 1% of clothing is recycled in a closed loop (clothes to clothes) while 12% are recycled cascadingly

(clothes to other products). In addition, the foundation estimates that 2% of material used to produce clothing was recycled cascadingly from other industries. For instance, plastic bottles can be used in creating synthetic fibres.

The potential for textile recycling is however quite large as there are multitudes of potential use cases for recycled textiles. They could for instance be recycled back to fibres, or even polymers and monomers or pieces of the fabric could be used as-is as base for a new piece of clothing or in other purposes. Resizing and repairing clothes are also classified as a type of recycling as is using old clothes as rags or insulation material. (Sandin and Peters, 2018)

Waste hierarchy steps	Concrete actions
Reuse	Swapping, borrowing, inheriting, renting, trading
Closed-loop recycling	Fabric, fibre, polymer, oligomer or monomer recycling
Open-loop recycling (cascading)	Textiles to rags, padding or insulation; Plastic bottles to polyester fibres
Energy recovery	Textiles to heat or electricity

Table 1: A classification of CE use-cases for textiles adapted from Sandin and Peters (2018).

To provide insight into the potential effectiveness of recycling efforts one can look at the emissions produced by activities that would be substituted by the recycling effort. According to McKinsey (2020), the production of fibres is responsible for 38% of the carbon emissions of the T&A industry. This figure of 38% is as such the upper limit for the potential ecological effect of recycling clothes back to fibres if one were able to do so with no additional emissions. Meanwhile recycling as fabric has an even higher maximum effect of 52% of the T&A industry. However, one should keep in mind that these maximal effects cannot realistically be reached due to all recycling efforts consuming some energy and often requiring investments in machinery and transportation. While reusing and recycling is often beneficial for the environment, Sandin and Peters (2018) state that there is a very real possibility, that under certain conditions this may not be the case. A good example of this is a piece of clothing bought from a flea market only to be forgotten in the wardrobe and never used again, while the transportation of the item from one user to the next through the flea market consumed some energy.

A key concept in circular economy prefaced with the above examples is the replacement rate. The replacement rate is a metric that describes how likely

the sale of one product, usually reused or recycled, is to reduce the demand of another, usually one that is made from new materials. From the ecological perspective, it would be advantageous to have as high replacement rates as possible as otherwise reusing and recycling clothes that are only slightly more ecological to produce than new ones would result in increased emissions. Nørup et al. (2019) discovered through their own study and a synthesis of similar studies that the replacement rates for second-hand clothing may vary significantly between countries, with the lowest number found being 28% in Great Britain, and highest in Estonia at 75%. However, they did note that the Estonian number was not calculated in exactly the same manner as those in the other studies. But even if one were to discard that result, the highest would still be significantly higher than that of GB at a 63% replacement rate in Angola.

One last concept that has a high impact on the T&A circular economy is that of downcycling and upcycling. The terms refer to reusing or recycling products in ways that either degrade or upgrade/maintain the product's quality respectively (Manickam and Duraisamy, 2019). While some upcycling is currently possible in the form of mending tears or adding decorative elements to clothes or even creating garments from tablecloths and curtains, downcycling is currently the prevalent mode in T&A CE in Europe (Palm et al., 2014 and 2015).

2.3.1 Circular Economy of Textiles in the Nordic countries

The Nordic countries are almost entirely reliant on imports for their finished clothes and household textiles consumption. Palm et al. (2015) estimated that the domestic production only satisfied 10% of the consumption in 2012 and further estimated that this share would decline to 7% by 2015 and stay there until 2020. This they saw to be caused both by increasing imports and decreasing domestic production, with the exceptions to the latter point being Iceland and Denmark. However, the two countries combined only accounted for around 6% of the Nordic production. The imports especially were noted to having risen quite significantly by 41% between 2000-2012. However, it is also noteworthy that imports went down between 2008-2012 from 358 thousand tonnes to 316. The study emphasises that these numbers only relate to finished clothes and household textiles. For instance, Norway has notable production in other textile categories, such as fishing nets, tarpaulins, wool fibres, and synthetic textile fibres.

Even though overall, the Nordic countries are on the track to increase their T&A related emissions due to fast growing consumption of new textiles there are positive trends in the population's behaviour. Most importantly, understanding on the environmental burdens of clothing is growing as has the

attention spent towards environmentally friendly clothes disposal, reduction of the amount of needlessly stored clothes and do-it-yourself activities. As one indicator, the two largest Norwegian used-textile collectors Fretex and UFF reported 15% and 5% increases in collected amounts in 2013. However, there is still room for great improvement in consumer attitudes at the time of purchase, even though the attitudes during the time of disposal are improving, as clothes are still widely regarded as disposable, mainly due to their low costs compared to the purchasing power of the population. In addition, the levels of consumer knowledge could be improved, as for instance Norwegian consumers believe that roughly 40% of their used clothes are not reusable, while the real portion was found to be 8%. (Palm et al., 2015)

Across the Nordic countries a mass of clothes roughly equivalent to 32% of the yearly supply of new clothes is separately collected. The rest is predominantly incinerated, or to a lesser extent, landfilled, while the rest is mostly accumulated. Of the separately collected amounts, charity organisations such as the Red Cross, Salvation Army and UFF account for a significant majority in every Nordic country, around 80% or more. Of the collected amounts, only a small portion is circulated within the Nordic market as some are deemed unfit for reuse and incinerated or landfilled as a result and more importantly over half of the collected textiles are exported to other countries, typically to Eastern Europe, to be sorted there. (Palm et al., 2014)

2.3.2 Circular Economy of Textiles in Finland

Like all the Nordic countries, Finland depends mostly on imports to satisfy the population's textile demands. In 2019, 67% of the net supply of new textile products was imported. In total, Finland's net supply of new textiles was 174 457 tonnes, where net supply is defined as imports + domestic supply – textile consumption of the domestic textile industry. A further 4 680 tonnes of the textiles supply were used textiles of which 1 029 tonnes were imported. (Dahlbo et al., 2021)

The target of the Finnish textile collection schemes is the "clothes and household or similar textiles" segment which makes up 62 342 tonnes of the net new textiles supply, or 11.3kg per capita. Of these textiles, 71% were clothes and the rest household textiles. Some 83% of them were consumed by households and the rest by enterprises and the public sector. (Dahlbo et al., 2021)

Of the 51 906 tonnes of clothes and household textiles consumed by households some 44%, 22 739 tonnes, were separately collected by private collectors, charities, and municipal waste companies in 2019. Of the separately collected textiles, the majority at 15 036 tonnes were exported, 3 843 tonnes were incinerated, 198 went to material recovery and the remaining

3 662 tonnes were reused domestically. In total 9 990 tonnes of used textiles from households were reused through charity organisations, flea markets and exchanges with friends and family or through online hubs, forming part of the clothes supply for the year. 40 376 tonnes were discarded as mixed municipal solid waste (MMSW) and were exclusively incinerated. (Dahlbo et al., 2021)

From the end-of-life clothes and household textiles generated by the public sector and enterprises, the majority (71%, 1 132 tonnes of 1595) went to energy recovery by incineration. Most of the rest were recycled as material recovery (26.7%, 426 tonnes) and the rest were reused or exported (29 and 6 tonnes respectively). (Dahlbo et al., 2021)

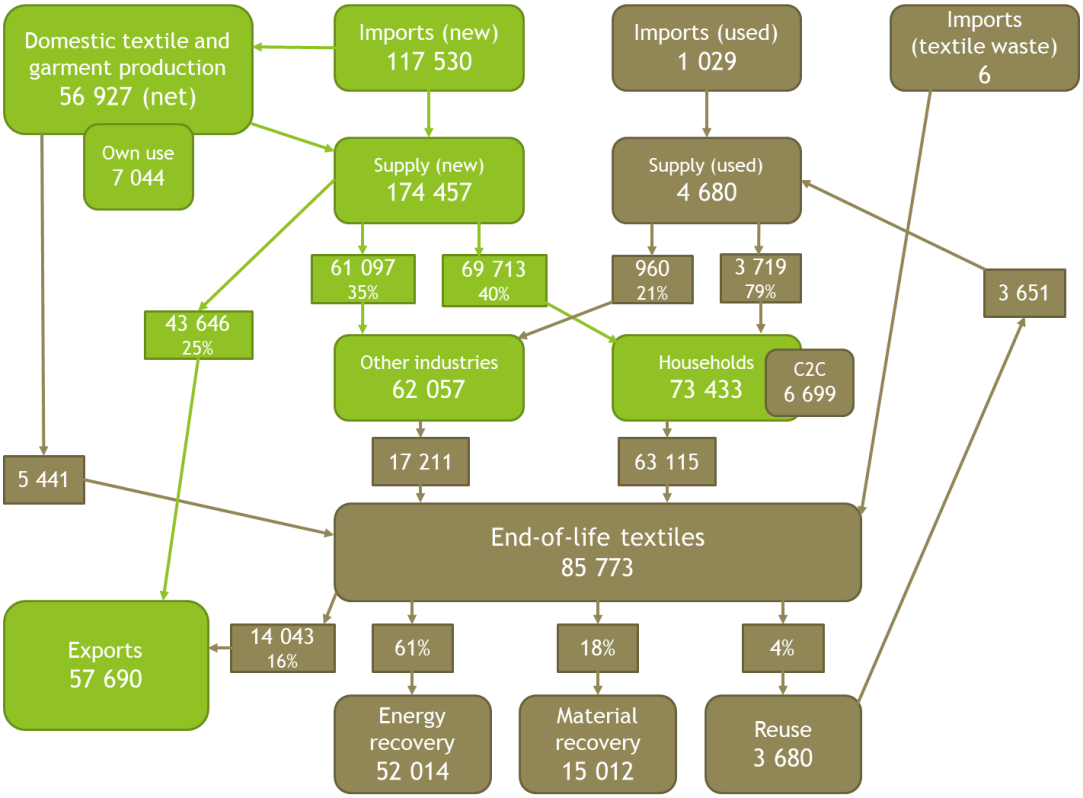

Figure 1: End-of-life textile flows in Finland in 2019, tonnes. (Dahlbo et al., 2021)

Concerning the data presented above, it should be said that the authors of the study noted that they had to estimate several of their figures and that there are "severe gaps" in the end-of-life textile information they could gather. For instance, multiple charity organisations only estimate the weight of clothes brought to them instead of weighing them while for some others the authors had to make the estimations themselves based on the organisations' economic activity. Likewise, the MMSW figures were the results of a

previous study's estimation on the composition of Finnish MMSW and another study that estimated the factor with which the weight of MMSW textiles should be multiplied to get their dry weight, as textiles in MMSW are often wet and dirty. (Dahlbo et al., 2021)

Municipal textile collection is still only a minor factor in the Finnish T&A CE by weight of collected textiles being responsible for only 213 tonnes of the nearly 23 000 tonnes separately collected across Finland in 2019. They are, however, still in very early stages of operation, having started their first collection pilots in 2016 and in 2019 the municipalities that were collecting textiles contained less than 10% of Finland's population. As result of new municipalities starting their collection efforts and small increases in collected amounts in the already active municipalities, during 2020 the municipalities managed to nearly double their total yearly collected mass (213 to 416 tonnes). Of this increase in collected mass 9 tonnes were attributed to increases in collected amounts in municipalities that were already actively collecting in 2019 while the rest (194 tonnes) were collected in new municipalities. (Dahlbo et al., 2021)

The main driving force behind municipal textile collection in Finland is the EU directive 2008/98/EC that mandates that all member states should set up separate collections for textiles by Jan 1, 2025 (Eur-Lex, 2008). However, much more pressingly recent amendments to the Finnish waste law mandate the same but already by 2023 (YM, 2021). As such, the municipal collections can be expected to increase very rapidly in the next few years with collected amounts near 2 500 tonnes by the time all municipalities have started collections if collected mass per resident stays the same as in 2019. This would make the municipal collections the third largest textile collection effort in Finland close behind the Salvation Army (2 785 tonnes in 2019) but still significantly behind UFF (14 742 tonnes in 2019) (Dahlbo et al., 2021).

The most significant impact that the municipal efforts may have on the Finnish T&A CE is, however, not their collected amounts, significant as they may soon be, but their processing method. The municipal waste management companies are committed to recycling the textiles that cannot be reused, if possible, before sending the rest to be incinerated. This has meant that already in 2019, the municipal actors were responsible for half of all recycled textiles in Finland. This has also meant that the municipal actors were able to reuse or recycle nearly half of the textiles they collected (103 of 213 tonnes) whereas the charities only reused or recycled 15% of their collected textiles, although the fate of the textiles they exported (68% of collected textiles) is unclear. (Dahlbo et al., 2021)

Another way in which the municipal actors are unique in the Finnish T&A CE ecosystem can be seen by examining the connections between different actors, as was done in a master's thesis from the Tampere University (Pohls, 2020). From the findings, it is possible to see for instance that LSJH, the focal company of the municipal textile recycling efforts, has got good connections to all types of stakeholders from the consumers and media to policymakers, businesses, and funding providers. Meanwhile, the charity organisations have good connections mainly among each other, some businesses, academia, and consumers. The unique municipal connections to policymakers and media could be especially valuable in creating an ecosystem that actively supports recycling efforts.

2.4 Textile & Apparel reverse logistics

In this chapter the unique difficulties, challenges and methodologies of T&A collection and recycling efforts are discussed. In the first subchapter the effects of weather, supervision and consumer education on collection efforts are examined. The second subchapter is focused on sorting methodologies and contrasts sorting by hand to machine aided sorting. Finally, the current state of recycling methodologies is presented in the final subchapter.

2.4.1 T&A collection

From a series of collection pilots and related studies by the Finnish Telaketju T&A CE collaboration and the Finnish Ministry of the Environment and the Ministry of Economic Affairs and Employment (Telaketju and YM, 2019; Telaketju and TEM, 2020), the two main findings were that weather, and supervision mattered greatly in their T&A collection efforts. Somewhat surprisingly, given the novelty of textile recycling, consumer education was found to have little to no effect on the collection effort over time.

The weather is particularly important to textiles as they can be easily spoiled by moisture. In the Telaketju and TEM (2020) pilot where a single collection receptable was supplied for a city block of around 40 residences, they first used a receptable that could only conveniently be emptied to the bed of a flatbed truck. This naturally left the textiles exposed which combined with a rainy February led to the spoiling of all collected textiles from that month. Combined with the observations that the used receptable was over sized for the influx of textiles and that on windy days the hatch on top of the receptable could be blown open (Project planner interview) this led to a change of receptable type to a smaller metal box with a hatch on the side that couldn't be blown open by wind and which could feasibly be emptied into other types of vehicles. Over a period of several months, this collection pilot collected a total of 207 kg of which 76% (or 85% if the ruined delivery from

February is discounted) was reusable or recyclable. (Telaketju and TEM, 2020)

In the Telaketju and YM (2019) series of studies, the textiles collected at indoor halls where staff received the textiles personally were contrasted to textiles collected from monitored sorting stations where the collection receptables were outdoors. The results showed that while the sorting and waste centres had roughly 70% of the collected mass be unsuitable for recycling and reuse, in the indoor halls with personal reception the equivalent rate was a little below 25%. The authors of the study further noted that both the ratios of spoiled and otherwise unwanted products (such as shoes or belts) were higher in the sorting stations which would suggest that moving the collection indoors safe from the weather is not the only explaining factor as that should intuitively only affect spoilage. As such, some credit was given to the personal reception of textiles. (Telaketju and YM, 2019)

For the Telaketju and YM (2019) study on the impact of consumer education they had a test set up with six districts. Two of them included mostly bungalows, two had terraced houses, and the remaining two were mostly blocks of flats. These were divided into a control and focus group with one of each district type in both. The focus group received advice and encouragement to recycle both by mail and face-to-face while the control group relied solely on the information posters on the sides of the collection boxes. The results did show that greater quality textiles were collected from the focus group with only around 34% of the collected mass being unsuitable to reuse or recycling compared to control group's 39%. However, the results did not show any improvement over time in the focus group which led the authors to question whether the increased consumer education had any true effect in this test. (Telaketju and YM, 2019)

However, a collection experiment in Rotterdam noted that a different kind of communication could increase quality as they made the colour of their collection boxes uniform and moved the collection points away from receptables meant for other types of waste to reduce consumer confusion. Another experiment near Rome confirmed that in increasing collected quantity good communications are vital as the collector was able to increase collected amount by 65% and attributed the change to new communications which transparently explained how the collected textiles are processed and how the proceeds are used. Further, long-term, and consistent communications are claimed to be the key of UFF Denmark's high collected quality where on average 80% of the collected mass consists of the desired fraction, reusable textiles. (Watson et al., 2018)

As a further example of collection pilots from abroad, a pilot experiment in Latvia by the waste management company Eco Baltia Vide, is rather impressive in scale as it managed to collect 108.5 tonnes of textiles in six months using just 20 collection containers in four different cities. The quality of collected textiles was also studied. 40% of the collected mass were estimated to have no economically feasible opportunities for reuse or recycling. Comparing the results to the Finnish pilots discussed above, the quality is high, especially so when considering that it used a relatively low-effort collection method. However, these results may not be comparable given that the different waste companies may well have different standards for what can be utilised. Of the usable portion, the majority at 37.4 tonnes was exported to be sold in developing countries, 1.2 tonnes were given to recycling and 22.5 tonnes were stored for later sale. (Watson et al., 2020)

From a set of interviews with Baltic textile collectors, Watson et al. (2020) identified several challenges and barriers to textile sorting activities. Of these perhaps the most important one was the perceived low quality of collected textiles which were further believed to be decreasing over time. A key potential reason behind this finding is that the consumers pay for the mixed municipal waste they produce according to its weight but donating textiles is free which leads to the collection boxes being treated as money-saving garbage cans for waste textiles. Other key issues identified were that the textiles collected often do not match the demand for reused textiles and that locally collected textiles often cannot compete with imported second-hand textiles nor can they typically be exported further. Finally, the collectors are suffering from a lack of storage space as most collected textiles are off-seasonal products which they cannot in turn sell forward in a long time. (Watson et al., 2020)

2.4.2 T&A sorting

After collection, the textiles will be sorted and based on the results of the sorting either reused, recycled, or sent to energy recovery or landfills. The sorting can be done by hand feeling, with wash tag information or with machine recognition. With the currently available technology, Kamppuri et al. (2019) recommend using a mix of hand-feel and machine recognition methods. The first part of their recommendation can be justified quite simply by their finding that currently an experienced sorter is much better than a machine in recognising clothes that could be resold as most machines are entirely incapable of it, while a wash tag naturally cannot convey such information either. As such, any textile recycling effort that wishes to adhere to the waste hierarchy and prefers reusing over recycling should include a hand-sorting step in their process to separate such textiles from the rest.

The main reason Kamppuri et al. (2019) do not recommend using wash tags as basis for recycling efforts is quite simply that often the tags are missing, or occasionally even plain wrong. This finding was collected from a Finnish sorting experiment Telakoulu, where nearly 10 tonnes of textiles were sorted. In this sorting experiment roughly a third of the textiles were deemed unrecyclable, while a further third was deemed recyclable but lacking a wash tag and the last third recyclable with a wash tag present. In addition, they noted that the process of finding and reading the wash tag can be rather slow.

Automated sorting is currently based on near-infrared (NIR) technology and their greatest advantage over hand-sorting is their potential for better accuracy under suitable conditions (Kamppuri et al., 2019). In a pilot experiment in Lahti University of Applied Sciences an automated sorting line known as REISKAtex® was used in an experiment to determine its recognition accuracy. When used on a low purity threshold, human test personnel tagged 8.7% of the textiles classified as pure cotton as suspect, of which a sample of 14 was taken and four were found to contain impurities. On a higher threshold setting a random sample was taken from the allegedly pure textiles and no impurities were found, but from allegedly impure textiles 5.7% were tagged as suspect and from a sample of five two were found to contain impurities. It is believed that similar levels of accuracy could be attained even with mixed fibre products such that, say 60% cotton products can be identified, although currently it is unclear how precise the identification range is. For instance, whether 98% or even 99% cotton could be reliably separated from 100% is unknown. (Kamppuri et al., 2019)

The situations where the NIR-recognition technology currently struggles are rather significant and somewhat common. The first possibility is simply a fibre-mix that has not been taught to the software yet although with sufficient time to develop these instances can be expected to disappear. The second difficulty is presented by the presence of coating materials which can significantly alter the way a fabric looks hindering recognition and on the other hand if the scanner was used to scan a portion of the textile where the coating was not present or was on the opposite side of the fabric, the textile could be flagged as pure despite not being so. A very similar situation arises when the textile consists of overlapping sheets of fabric where only the topmost can often be recognised or if the product has different fabrics in different portions of the product. In addition, too thin fabrics may not be recognised at all. But perhaps the most difficult challenge rests with elastane which is often used in very small quantities and may even be hidden within the core of the yarn. In the REISKAtex® tests it was found that a product would have to have 10% or more elastane for it to be reliably recognised. This is an especially vicious problem considering that 2%-4% elastane may already cause stoppages in mechanical recycling machines. (Kamppuri et al., 2019)

2.4.3 T&A recycling

Textiles can be recycled with three main methods that are mechanical, thermal, and chemical recycling. Of these, mechanical recycling consists of shredding a piece of fabric and opening its fibres and is an applicable method for all fibre types. Thermal recycling is essentially melting and may be done to fibres based on thermoplastics such as polyester. Finally, chemical recycling may be utilised for several fibre types, but most methods are still in a piloting stage. (Kamppuri et al., 2019)

Mechanical recycling may be used for any types of fibres and is quite noteworthily currently the only method through which cotton textiles may be recycled as cotton. It typically consists of two parts. First, the textiles are cut into smaller pieces that can be easily handled in the second phase, where specialised shredding machines tear at the pieces of fabric opening them to the fibre level. The second stage may be repeated as many times as desired to ensure that no knots or pieces of unopened fabric remain, although it has been found to be almost impossible to remove all such traces. However, one should not over do the shredding phase as each application shortens the length of fibres eventually making them unusable in the creation of new fabrics. (Kamppuri et al., 2019)

As mentioned before, thermal recycling essentially means melting a piece of suitable thermoplastic, such as fabrics or even PET-bottles, the latter of which is indeed the majority source of material for this process. The result is a molten mass that can be forced through small holes and cooled to create new fibres which can be further processed, for instance by stretching, to give them their desired properties. The main difficulties in using thermal recycling have to do with the quality of the used material that has some relatively tight tolerances. The main difficulty from a textile's perspective is that there are multiple types of fibre that are all classified as polyester which are different enough on the chemical level to require a different temperature. These difficulties may be further exacerbated by the presence of other chemicals that may have been used to change the elasticity of the original fabric, ease and speed of spinning or colouring. But even with a source of material that is known to be of only a single type and contains a homogenous mix of other chemicals there is still the chance that some of the material could have been oxidised and the resulting new functional groups could interfere with the process. Lastly, the thermal process itself changes the crystallinity of the polymers and reduces the molecule weight which limits the amount of recycling cycles that can be used. (Kamppuri et al., 2019)

Chemical recycling is currently mostly unsuitable for commercial use. While a couple methods are feasible on a laboratory scale, only the TEIJIN eco-circle system has been proven on a large scale. However, while the TEIJIN system produces polyester that is identical in quality to polyester from mineral oil, the cost of the collected polyester clothing is two to three times higher than that of mineral oil. Additionally, the system requires full control of the recycled products and does not accept all polyester products which limits its quantities and drives up collection costs. (Palm et al., 2015) Another issue is that chemical recycling of cellulose-based fibres, such as cotton, results in regenerated cellulose fibres such as rayon or lyocell and as may not be used in recycling cotton as cotton, which is significant given that several collection pilots have found that the collected textiles consist typically of 50% pure or nearly pure cotton textiles. (Kamppuri et al., 2019)

3 Research material and methods

The data used in this study is composed of two main parts: interviews with, and observation of, LSJH personnel and textile sorting data supplied by LSJH. The main purpose of the interviews and observation was to provide context for the numerical data and to produce a detailed description of the recycled textiles supply chain as such descriptions were not discovered within the existing literature and might thus be of some academic interest. The numerical data would in turn be used as the primary means of answering the research questions.

The interviews were mainly held in conjunction with a visit to the LSJH's sorting facility in Turku on the 8th of September with emailed questions being sent afterwards as new gaps in knowledge were revealed during the analysis of data and interview results. The interviews themselves were semi-structured with some questions having been prepared beforehand but for the most part the interviewees were asked to describe what they do as they see fit. In addition, the main interviewee (Project planner) gave a presentation about LSJH in general and their textile collection and sorting operations. Furthermore, the two main contacts (R&D manager and project planner) participated in designing and guiding the study from the beginning by informing what quantitative data could be made available and greatly facilitating the interviews. The interviews were further planned to be complemented by a questionnaire that was distributed by email to those involved with the textiles at LSJH, but unfortunately no responses were received.

Title	Organisation	# Conversations	Time of interviews
Project planner	LSJH	10+	June-December 2021
R&D manager	LSJH	4	June-November 2021
Service manager	LSJH	1	December 2021
Sorting Partner 2 representative	Sorting Partner 2	1	November 2021
Sorting station worker	LSJH	2	June, September 2021
Textile sorting worker	LSJH	1	September 2021
Van patrol worker	LSJH	1	September 2021

Table 2: Overview of interviews held

3.1 Numerical data description

The numerical data received from LSJH came in three files. One of which was the collection and sorting data from the entire lifespan of KaMu starting from the first collections on week 21 2021 and ending on week 41. The other files were from their sorting partners. For the larger Sorting Partner 1 the data was from the entirety of 2020 and for the smaller Sorting Partner 2 the data was from the weeks 1-39 of 2021. However, due to Sorting Partner 2 dealing with difficulties not directly related to the textile collections their dataset was discarded as incomparable with the rest. Details on how this was determined can be found in Appendix A.

The data from the sorting partners had nearly the same format with each other where they had an entry for each day which contained the information on deliveries and sorting. The delivery data consisted of two numbers: how much textiles were delivered to them by LSJH on that day and how much they themselves collected from collection boxes within or close to their own premises. The sorting numbers described the sorting activities of that day divided into four categories of spoiled, excluded, reusable and "sent to further sorting at LSJH". Excluded referred to textiles found to be against the instructions of the collection effort and as such included any belts, shoes, underwear, and all sorts of other products not recycled by LSJH. Spoiled referred to the textiles found to have hygienic risks such as mold, bugs, or strong smells. In the data from Sorting Partner 1 the reusable fraction had been split into resaleable and "other reuse" categories. Further, Sorting Partner 1 included a fraction called unrecyclable which referred to textiles that were separated in the third sorting stage and consisted of textiles that were compliant with the recycling instructions and not spoiled but had other elements, such as sequins or large plastic prints that would prevent successful recycling. All numbers were in kilograms.

The data from KaMu had mostly the same format with some tweaks. The entries in the KaMu data were not daily, but rather weekly and location-specific. As such, the KaMu data had up to 10 entries per week at the beginning and at the end of the data it had risen to up to 14 entries per week due to increases in the number of locations within the KaMu collection system. The KaMu data did not have any separate figures for collected amounts and instead only included data on the sorted fractions. The difference in data format is mainly explained by the simple fact that KaMu locations are predominantly visited only once per week on Wednesdays and the collected amounts are always sorted within the same day or the day after at the latest. Of the sorted fractions the reusable and further sorting categories were merged leaving only the categories spoiled, excluded and recyclable. In addition, the KaMu data included a section for notes for each entry which typically shortly

described the composition of the unrecyclable masses such as “bugs, coat hangers and underwear”.

Dataset	Frequency of entries	Level of detail	Time period	Source of textiles
KaMu	10-14/Week	Sorting step 1	Weeks 21-48 2021	KaMu
Sorting Partner 1	Daily	Sorting steps 1-3	Entire 2020	Other
Sorting Partner 2*	Daily	Sorting steps 1-2	Weeks 1-39 2021	Other

Table 3: Summary of the key characteristics of supplied datasets.
* Dataset not used in final analysis

3.2 Data modifications

Before starting on the analysis, the data had to be cleaned and some adjustments were made. For KaMu data this meant removing lines where only the sum of the textile fractions was presented while all the individual fractions had been left blank as such data could potentially skew any analysis on KaMu collection’s impact on collected textiles’ quality. This lack of detail was an issue with every location’s data on the first collection week (week 21), where no columns for the detailed figures were even present yet, the last collection week (week 48), and on five further entries spread throughout the rest of the dataset. In total 19 of the 230 entries in the KaMu dataset were removed.

For the other data sets the daily data was condensed into weekly data because the data was discovered to not actually being detailed on the daily level. What had been noticed was that all entries for reusable fractions were made on Thursdays in the data from Sorting Partner 2 and all entries for textiles sent to further sorting were between 200-260kgs indicating that only filled big bags of recyclable clothes were weighed. The reports for spoiled and excluded categories were predominantly listed either daily or every second day. Under these conditions, making the data weekly could help find the real level of variance in textile quality, as otherwise the variance would be abnormally high as the dataset would be full of zeroes with occasional high figures in between for several of the fractions. In addition to merging daily entries into weekly entries, the weekly entries where no textiles sent to further recycling were recorded, were further merged into the next week where such an entry had been made.

In addition to the above modifications to the data, the comparability of the datasets between each other had to be ensured. This firstly meant merging the reusable and further recycling fractions into one entry in the non-KaMu data to match the format of the KaMu dataset. In the data from Sorting Partner 1, the unrecyclable fraction was additionally merged into this figure because in the other data sets the sorting phase from which the unrecyclable textiles would originate had not been included in the data and thus the figure for unrecyclable textiles would still be hidden within the sent to further recycling fraction. As such, the figure for unrecyclable textiles was to be re-hidden in the Sorting Partner 1 data for the sake of consistency.

The second action taken to make the datasets comparable with each other was to account for the variability in the processed weekly and location specific amounts by weighing the data such that the average per-entry sorted amounts from the datasets were each equal to 1. After this weighing of data, a figure of 0.05 for the spoiled fraction for any given entry and dataset would mean that 5% of that entry's sorted mass was spoiled if the sorted quantity was perfectly average for that facility and collection site/method or a smaller percentage if more was sorted or vice versa.

The main benefit of this weighting of data was that the data could be compared across the different data sets without resorting to using weekly unweighted percentages or absolute amounts of each fraction. If absolute amounts had been used, then the fact that Sorting Partner 1 sorted nearly three times more textiles during an average week than either Sorting Partner 2 or KaMu would have influenced any analysis significantly. If percentages were used, then the weeks of low activity would have had an unreasonably high impact on the findings.

One of the last modifications to the data set was to change the Week-variables in the data from 2020 to values that would correctly indicate the age of the given entries. This was done simply by subtracting 53 from the week variable from the entries for 2020 data, so that the last week of 2020 was Week 0 and the first week of 2020 was Week -52.

Finally, two variables were added:

1) "KaMu" to indicate whether a given entry was from the KaMu dataset (KaMu = 1) or from the two others (KaMu = 0)
2) "Indoors" to indicate whether the textiles sorted in each entry were collected from indoors (1) or outdoors (0) locations. For simplicity's sake all entries from KaMu, except the outdoors location 14, were labelled as being indoors and all other entries as outdoors. However, this is not necessarily all that accurate as a portion of the textiles sorted in the partners' datasets came from the collection boxes in or near their

premises, some of which might have been indoors as well. This simplification was justified as being good enough for the purposes of this study because the textiles from those sources only accounted for ~10% of the sorted textiles in those locations.

3.3 Numerical data analysis methods

The analysis of the numerical data was directed towards finding the answer to the first research question of how collection method choice and implementation would affect quality of collected textiles. Specifically, how does collecting from locations that are in convenient and frequently visited indoors locations compare to collecting in specialised sorting stations that are mostly outdoors. Fortunately for the sake of this study, the data from KaMu mentioned that one of the collection sites had been atypically placed outdoors, which allowed examining the effects of shelter and other KaMu characteristics separately from each other.

To start the analysis on quality, the first set of tests aimed to verify if the textiles from KaMu differed in quality compared to the textiles from sorting stations. This was done as a set of three multiple linear regression models with the dependent variables being the weighted quantities of excluded, spoiled and recyclable textiles respectively. The explanatory variables used were KaMu and Week. Week was chosen in addition to KaMu to account for any potential increases or decreases in overall quality over time. The Indoors variable was not included in this first set of tests because LSJH's current policy is to not refuse any potential KaMu partners (Project planner interview) and thus it is unavoidable that some of them will be located outdoors whenever that happens to be the most convenient location for the partner.

The second set of tests was designed to find the effect that being located indoors would have on the quality of collected textiles. Comparing the results with the first test would allow determining which of KaMu collection's key characteristics had the larger effect. For this test only the data from KaMu was used where the textile quality from location 14 (outdoors) was compared to the rest. This time the model began with only a single explanatory variable because the outdoors location had only opened midway during the KaMu pilot and as such the effect of being outdoors ran the risk of being falsely attributed to the passage of time. The dependent variables were the same as in the first set of tests.

4 Description of LSJH and its textile reverse logistics

4.1 Overview of LSJH's separate collection activities

LSJH – Southwestern Finland Waste Management Ltd. – is owned by 17 Finnish southwestern municipalities and provides services for their around 420 thousand citizens. LSJH directly employs a staff of around 90 of which ten work at LSJH's textile sorting facility. (Project planner interview)

LSJH's separate collection efforts are currently organized around twelve monitored sorting stations where more than thirty different waste types are collected ranging from the usual paper, plastics and metal to asbestos, ink cassettes and tree stumps. All delivered loads must pass an inspection point before being allowed in, but this system relies mostly on customer self-reporting unless a cursory glance suffices to make it obvious that the load does not match the report (Sorting station employee interview).

Of these twelve stations, most collect only small to medium individual deliveries. Only the two largest at Topinoja, Turku and Korvenmäki, Salo accept deliveries larger than a fully loaded trailer or van. These two stations and two others are kept open on all weekdays and occasionally on weekends too while the remaining eight sorting stations are regularly open on only two days per week or even less frequently. (LSJH, 2021a)

The other main collection method is a network of more than 900 small unmonitored RINKI collection points spread throughout LSJH's area (KIVO, 2021). Additionally, LSJH maintains a smaller quantity of their own collection points that are not affiliated with Suomen Kiertovoima ry KIVO's RINKI-collection sites. Both collection point types do however collect only some of the higher volume waste types. These are glass, cardboard, paper, metal, and plastic packaging. However, not every point is used to collect cardboard and plastics. The collection points are regularly emptied, and the collected waste is delivered to one of the twelve stations.

In addition, LSJH has a couple of other much smaller scale collection methods such as their mobile Pop Up and Siira collection vehicles and the KaMu-collection points, but their volumes are rather small by comparison.

4.2 LSJH textile collection

The textile reverse logistics operated by LSJH are jointly funded by 29 of the 31 Finnish municipal waste management companies. By the end of 2020 five of them were actively collecting textiles and sending them to LSJH to be

processed. The total collected mass of textiles in 2020 was around 500 tonnes from all sources combined. By the end of 2021 the waste management companies have a goal of ramping up to 11 collecting waste management companies with a collected mass of 1000 tonnes. By the start of 2023 they intend to involve all 29 waste management companies and expect to reach their goal of yearly collected mass of 5 000 tonnes by the end of 2024. (Project planner interview)

LSJH's textile recycling activities have three sources of collected textiles that each function somewhat differently. Firstly, their own sorting stations – the eleven of the twelve that do collect textiles – send truckloads of unsorted textiles to be processed further in specialised facilities. It is noteworthy that, of the 900+ unmonitored collection sites that feed the sorting stations, only 5 of LSJH's own sites and 25 of the RINKI collection points accept textiles as of October 2021 (LSJH, 2021b; KIVO, 2021). In 2021, LSJH expects to collect around 184 tonnes of textiles from these sources. (Project planner and Textile sorting worker interviews).

Secondly, the other waste management companies send their loads which are otherwise identical to LSJH's own loads except that these textiles have been pre-sorted which means that spoiled textiles and items not included in the recycling effort have been taken out from the load. Due to logistics efficiency concerns these deliveries are infrequent as only full truckloads of around 2500kg are delivered. According to the agreements between LSJH and the other municipal waste management companies, each company is supposed to deliver between 0.2kg-0.5kg of pre-sorted textiles – or double that if not pre-sorted – per resident per year to LSJH where further sorting takes place. As an example, Kymenlaakson Jäte, the waste management company for the Kymenlaakso region of around 180 thousand inhabitants, started their textile collections in May 2021, but by the time of the observation visit to LSJH's sorting facility on September 8th, 2021, they had yet to make a single delivery. As per the agreement, Kymenlaakson Jäte could be expected to make at least 14 deliveries per year after a ramp-up period of undetermined length. (Project planner interview)

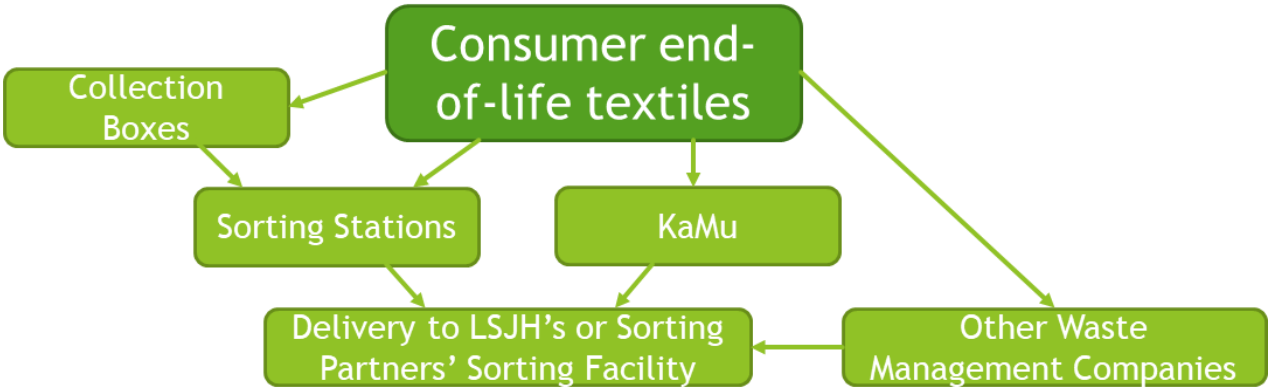

Figure 2: LSJH's three sources of consumer end-of-life textiles

4.2.1 KaMu collection system

The third source of collected textiles is the KaMu-collection. KaMu refers to retail and fashion "kauppa ja muoti" and is a collaboration between LSJH and businesses of that kind. The collaboration is rather simple in principle. If given permission, LSJH sets up a collection point within the premises of the business in the form of a textile-covered roll container with a maximum capacity of 120kg of textiles, and some printed information material. In locations with high collection rates two roll containers may be set up. In addition, LSJH keeps additional roll containers within their own facilities ready to be swapped with the filled ones for a total of two, or four, roll containers allocated to each location. Participation in the KaMu program is entirely voluntary, and no money is exchanged. The premise is that the businesses are willing to participate because they want to be involved in a green initiative - perhaps due to possible brand value gains. (Project planner interview)

Meanwhile, LSJH benefits from a collection point that is sheltered from the weather and is semi-monitored – no active monitoring is mandated by LSJH, but they believe that having staff present nearby could already be enough to increase collected quality. Most importantly for LSJH, the KaMu collection points give the residents of their area a low barrier option for recycling their textiles. The other collection sites are rather sparsely located, and so the sorting stations require that the residents make a separate trip to a location they would not otherwise visit and going through the inspection point takes its own time as well. (Project planner interview)

Once the KaMu collection point is set up LSJH visits the site once per week on Wednesdays or when the business owner requests a visit should the roll container get filled up before the regular visit. In some collection sites with low collected amounts, the business owners and LSJH may agree to only visit

when called. The emptying is currently done by a two-man patrol with a van that can fit five of the roll containers within it. When they come on site and after determining that the current roll container is filled enough to be worth taking, they exchange it with an empty one they brought with them. They also swap the textile covering, to which a recycling instructions poster is attached, from the old container to the new one as part of the process. On an average week the collections take 10 hours to complete, or 11 hours if only one person is assigned. (Service manager, and Van patrol worker interviews)

The KaMu pilot started on week 20 of 2021 and the first collections were a week later. Initially the pilot consisted of ten locations. By week 36 the pilot had expanded to 14 KaMu-locations, nine of which are in or near the city centre of Turku. Roughly one third of the 420 000 residents that LSJH serves live within 2 km from the KaMu locations.

The cluster of collection points within the city of Turku are at most 10-15 minutes' drive away from each other and LSJH's sorting facility. The other locations are between 20 and 60 minutes' drive away from the sorting facility. Furthermore, one of the locations is unlike the rest as the collection point has been placed outside. LSJH's policy of not refusing any potential KaMu-partners is a major reason behind the atypical location that goes against KaMu's central design of collecting indoors. Essentially the outdoors location is part of KaMu in name only. (Project planner interview)

Figure 3: LSJH's collection area with KaMu locations marked in red, and LSJH's sorting facility marked in blue

By week 48, the KaMu pilot had collected nearly 15.6 tonnes of textiles in total from the 14 locations. The highest collected weekly amount was reported on week 22 at 881 kg, and the lowest on week 27 at 179 kg. The collected amount is rather substantial as LSJH is expected to collect a total of 200 tonnes of textiles from their own area during 2021. (Project planner, Service manager, and Van patrol worker interviews)

4.3 LSJH textile processing

4.3.1 Before sorting

After being collected the textiles are brought into one of three facilities to be sorted. These facilities are LSJH's own and those of their two partners, referred to as Sorting Partner 1 and 2 in this study. The deliveries from LSJH's sorting stations as well as the deliveries from other waste management companies are assigned to one of them on a case-by-case basis depending on current levels of work in progress inventories. The deliveries from KaMu collection are all brought to LSJH's own facility for simplicity's sake and to ensure

good quality of data collection. For the majority of KaMu sites the LSJH facility is within 10-15 minutes' drive away, making it an alright choice logistically even though for some the Sorting Partners' facilities are even closer. (Project planner interview)

LSJH themselves does not accept deliveries of textiles that have not yet been pre-sorted barring the exceptions of KaMu and the textiles brought directly to the sorting facility by consumers. Additionally, the smaller Sorting Partner 2 only pre-sorts the textiles and checks for reusability, leaving later sorting stages to either LSJH or Sorting Partner 1. (Project planner interview)

The textiles from each individual consumer are expected to be sealed within garbage bags or equivalent as instructed and these bags are in turn brought within large storage bags that can each hold up to 280kg of textiles but normally hold between 200-250kg. Once the delivery has arrived on site, the first step after unloading is weighing each individual big bag before moving them into storage. From storage they are moved next to the sorting tables where the workers can start the sorting process. The inbound inventory is currently managed on a last in first out basis at the LSJH facility. There is one exception, however, as the KaMu textiles are sorted first even if another delivery of big bags came while they were still being sorted because they want to keep the quantity of the roll containers down to a minimum as they require space even when empty. (Project planner and Textile sorting worker interviews)

The adoption of the last in first out inventory management is mostly due to LSJH being nearly overwhelmed by the size of the inbound inventory. The forklift responsible for moving the big bags around currently does not have the space to manoeuvre needed to enable other inventory management policies without considerable effort. However, the root cause of the situation was not a lack of sorting capacity as the situation at the time of this observation on September 8th, 2021, was that the recycling facility was yet to fully open and the recycling capacity was as such lower than the sorting capacity, while the demand for recycled fibres was even lower. As the inbound inventory at the recycling facility was also rapidly approaching capacity, increasing the sorting capacity would only have resulted in moving textile bags from the sorting facility's inbound to outbound inventory, from one side of the hall to the other. (Project planner and Textile sorting worker interviews)

In the future LSJH wishes to get their inventories back down to a manageable size and transition back to a first in first out system. This wish is mostly rooted in the reality that mold or other contaminants in the textiles could in time develop and spread to others ruining the textiles which could be avoided with a timely processing lead time. During the observation visit a bit of

gallows humour could be overheard where the workers suggested tossing lit matches on the older half of the inbound textiles inventory "as that's what's going to be done to them anyhow." (Project planner and Textile sorting worker interviews)

4.3.2 Sorting

Eventually, the textiles will be brough from the inbound inventory to the sorting tables. The whole sorting process can be done all at once by one person, but LSJH recommends that their sorting partners arrange their sorting process along a series of four steps with four or more stations along the way. They see that this setup would significantly reduce the amount of things a single person needs to pay attention to at once which in turn speeds up the process. However, LSJH themselves and one of the partner facilities have been forced to do their sorting within single stations due to a lack of space. LSJH's own workers have enough expertise with the process that they no longer struggle too much with their single stations system. However, their partners deal with very high levels of churn and as such their workers do not have the time to get to the same expertise levels. (Project planner and Textile sorting worker interviews)

The first of the four sorting steps is known as pre-sorting. It is the same sorting step that the other waste management companies need to do before sending their deliveries to be sorted by LSJH and their partners. It consists of separating dirty or otherwise unsanitary products as well as products that go against the recycling instructions from the rest. Textile products that are not included in the recycling effort are underwear, socks, pillows, blankets, padding, carpets, belts, bags, and shoes. (Project planner interview)

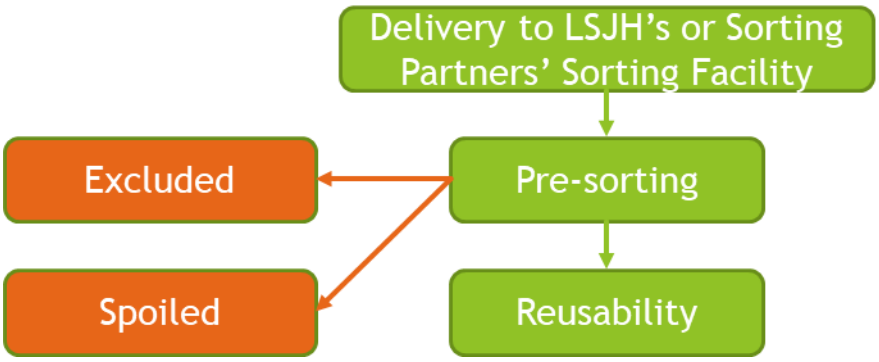

Figure 4: LSJH's textile sorting step 1: Pre-sorting

The second sorting step is to check for reusability. In this stage textiles that do not have visible wear and tear and which could potentially be resold as-they-are are separated from the rest. Technically these textiles go against

the instructions of this recycling effort as all information leaflets contain a strong recommendation to give such textiles to charity collections or to sell them directly on a flea market. But as the people keep bringing such textiles to LSJH, they have decided to relent a bit by selling them forward themselves instead of sending these textiles to be recycled as that would go against the waste hierarchy. The recommendations to give these textiles to the charities have nevertheless been kept in all informational material. (Project planner interview)

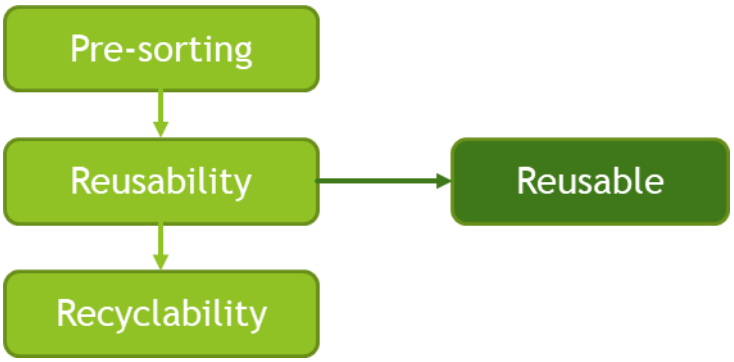

Figure 5: LSJH's textile sorting step 2: Reusability

The third step of sorting is the check for recyclability. At this stage the textiles are inspected for the presence of materials that might prevent the textile from being recycled properly or would result in the fibres containing too many impurities. For instance, rain-proof coatings, patches of leather, or large plastic prints could prevent the textile from being torn to fibres, while sequins could be small enough to slip through the shredding process, but the resulting impurities could still cause issues for the manufacturers that use the recycled fibres. (Project planner interview)

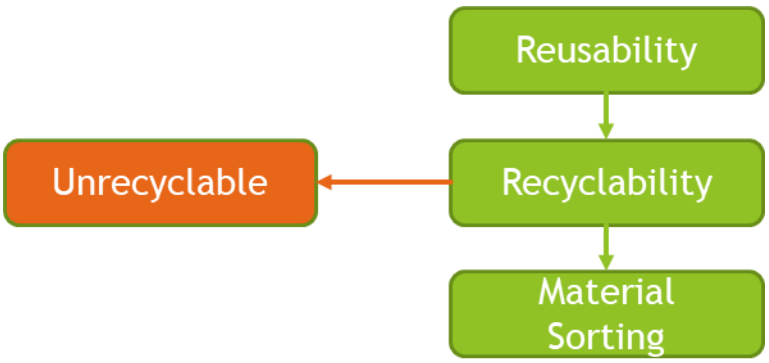

Figure 6: LSJH's textile sorting step 3: Recyclability

By the fourth step the textiles have been verified to be recyclable. At this stage the textiles are sorted by the type of their fibres. This is done in two steps, although occasionally just one suffices. The first step is to sort them by

hand into five general categories that are: cellulose, wool, denim, synthetic, and mixed fibres. Other textile types can be separated from these should a customer wish so. For example, during the observation visit in early September LSJH was additionally separating net curtains and light-coloured cellulose to be delivered to specific customers. Another example is that denim used to be just a part of the cellulose segment, as they are mostly cotton, but as customer demand for denim was consistent, it was eventually separated into its own segment. (Project planner interview)

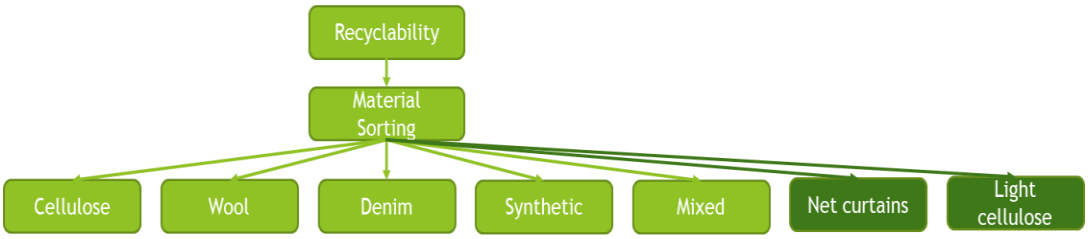

Figure 7: LSJH's textile sorting step 4a: Rough Material Sorting

The second step of the fourth stage is not necessarily always done, but when it is, it is used to separate the previously only roughly divided textile segments into further segments with the help of a near-infrared optical scanner and recognition software. As the scanning process takes some 8-12 seconds per piece of cloth, the scans are only made if current customers need high purity fibres and want to have the quality verified. By comparison, during the observation visit to LSJH's sorting facility, there was an opportunity to observe one of the sorting workers for around four minutes without distractions while waiting for the next stage of the guided tour to begin. In this time, the worker did not go above the 10 second mark per piece of cloth unless the cloth in question had plenty of buttons, studs, or other hard pieces for them to cut away. As LSJH had organised their stations around doing every step at once (apart from pre-sorting that is done elsewhere), using the scanner as part of the process would have – according to this very, very small sample size – roughly doubled the time spent sorting. (Project planner interview)

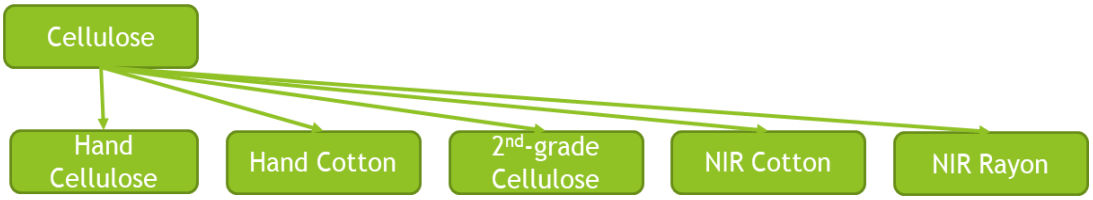

Figure 8: LSJH's textile sorting step 4b: Detailed Material Sorting (for Cellulose textiles)

The reason why the scanner is used at all, instead of reading the information from a wash tag, is that often the tag may be worn beyond readability, entirely missing, contain wrong information, and often locating and reading it takes nearly as long as simply using the scanner. When the scanner is used, it can recognise a limited selection of fibre types and mixes depending on what types the software has been taught to recognise. As of September 2021, the textile types the scanner could recognise were 100% cotton, 100% rayon, 100% polyester, 100% polyamide, 100% wool, and 65%/35% polyester/cotton. If the scanner is used on a piece of cloth that it fails to recognise, it is labelled as 2nd grade cellulose/wool/synthetic/mixed to distinguish the fabric from un-scanned textiles which are labelled simply as cellulose/... or hand-cellulose/... The scanner is not used to further segment denim textiles or the special textile types requested by the customers given that the scanner has not yet learned to recognise any textiles belonging to those categories. LSJH also rents the scanning devices and lets other companies bring their textiles to LSJH to be scanned. (Project planner interview)

4.3.3 After sorting

After sorting, the loads are weighed again, and the follow-up depends on the segment in question. The textiles, and possibly non-textile products, that were deemed unfit to be reused or recycled will go to energy recovery by incineration. Meanwhile, the textiles fit to be resold will be sent to a second-hand shop that occupies a portion of the hall that LSJH's own sorting activities are handled in. (Project planner interview)

The recyclable textiles will eventually be taken to LSJH's textile recycling pilot plant in Paimio. Before that however, the most common types of textiles, such as 2nd grade cellulose, are baled to help reduce the required storage space both through condensing the textile mass and making it easier to stack on top of each other. The less common textile types are instead packed into big bags. (Project planner interview)

After the potential baling process, the recyclable textiles are put into the outbound inventory to wait delivery to LSJH's recycling plant in Paimio. No interviews went into much detail on the further processes as by then it was evidently clear that no difference caused by the KaMu-collection could have much if any impact beyond the sorting phase. In any case, LSJH currently only recycles mechanically which is to say that the textiles are first cut into small pieces in a guillotine machine before being fed into a shredding machine that opens the pieces into fibres. LSJH currently does not bleach the resulting fibres or otherwise treat them, so afterwards they are simply packed and delivered to the customers. (Project planner interview)

4.4 Summary

As the focal company of Finnish municipal textile recycling efforts, LSJH manages a significant network of partnerships. Below is a table where they are presented according to which steps of the recycling effort they participate in. In total LSJH has partnered with 28 other municipal waste management companies, two sorting partners and 14 KaMu partners. Not shown in the table are logistics companies to whom LSJH has outsourced the tasks of collecting and delivering unsorted textiles from LSJH's sorting stations to the sorting partners.

Activity	LSJH	Waste m. companies	Sorting partner 1	Sorting partner 2	KaMu partners
Collection	YES	10/28	YES*	YES*	NO*
Pre-sorting	YES**	YES	YES	YES	NO
Reusability	YES	NO	YES	YES	NO
Recyclability	YES	NO	YES	NO	NO
Material	YES	NO	YES	NO	NO
Recycling	YES	NO	NO	NO	NO

YES* - These partners collect textiles, but only from a single collection point per partner

YES** - LSJH pre-sorts only KaMu textiles and textiles from a single collection box within the sorting facility's premises

NO* - KaMu partners do not collect the textiles, but their permission is needed for LSJH to collect from their premises

Table 4: Overview of LSJH's textile recycling partnerships and the stages of textile recycling process they are active in as of December 2021

Presented below is a visual summary of LSJH's consumer end-of-life textiles reverse logistics that were described in detail in the preceding chapters. Presented in it are the four sorting steps and the textile flows that originate from each step along with eventual use-cases of either energy recovery, sale, and recycling. To reduce clutter, the weighing steps are not pictured but they would be situated firstly before pre-sorting and secondly before the eventual use-cases.

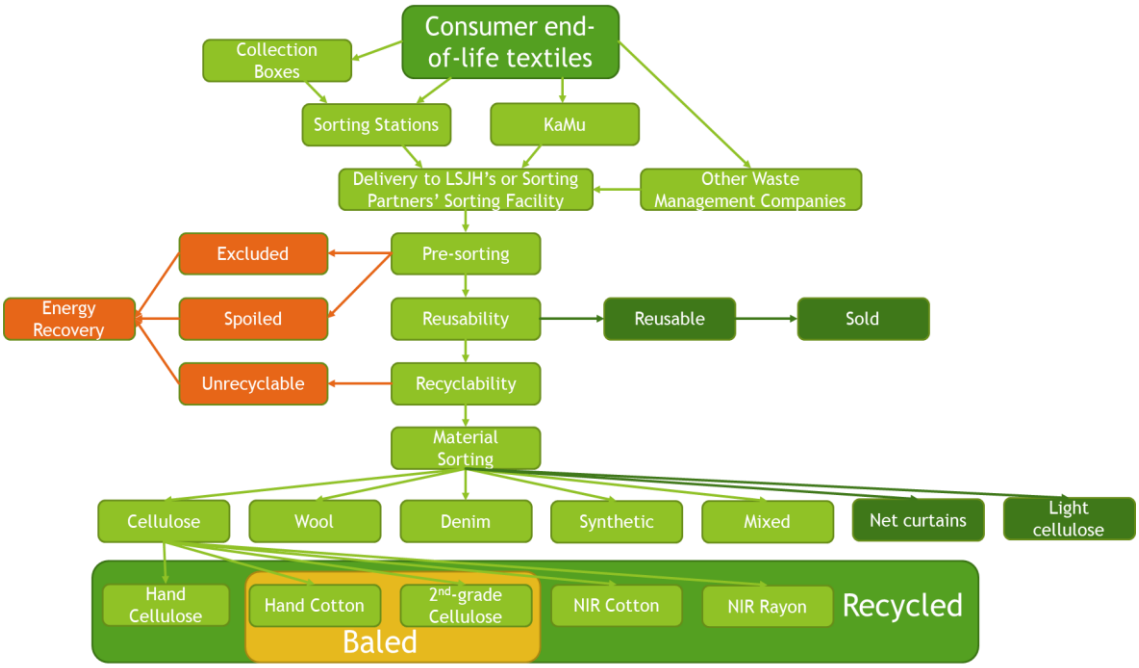

Figure 9: LSJH's consumer end-of-life textiles reverse logistics as of September 2021

5 Answering research questions and discussion

5.1 First research question

The first research question: "Can the quality of collected consumer end-of-life textiles be improved through choice and implementation of collection methods?" can be answered through the analysis of the numerical data which showed that the KaMu collection significantly overperforms LSJH's established centralised sorting station collection method in quality of collected textiles. Overall, the share of recyclable textiles in the collected mass from KaMu was nearly 28 percentage-points higher compared to the established collection system.

In the first regression model the finding is that KaMu collection has resulted in a significantly better quality than LSJH's other collection methods and that the findings are statistically significant as well according to the student's-t tests. A finding of especial interest is that the KaMu collection reduces the quantities of both unwanted fractions. While the model started with a second explanatory variable Week, it was removed from the final model once its effects were discovered to be statistically insignificant.

1. KaMu vs others	Recyclables	Spoiled	Excluded
Others	53.7%***	36.4%***	9.9%***
KaMu	+27.8pp***	-23.0pp***	-4.9pp***

*** statistically significant $p<0.001$

Table 5: Shares of recyclables in total collected textile mass, comparing KaMu to other sources

In the second test, the single outdoors KaMu location was compared with the indoors locations. Here, perhaps due to the smaller amount of data, the results are not as statistically significant. Only the finding that being indoors more than halves the amount of spoiled textiles is found to be significant. This means that slightly over half of the perceived quality gains of KaMu should be attributed to other factors than being sheltered. These factors might include being targeted to pro-recycling consumers given the placement within flea markets and charity shops, being in a location closer to the consumers, and being in a semi-monitored environment.

2. Indoors vs outdoors KaMu	Recyclables	Spoiled	Excluded
Outdoors	69.5%***	25.2%***	5.3%***
Indoors	+13.7pp()	-13.2pp**	-0.5pp()

() not statistically significant p >0.1
** statistically significant p<0.01
*** statistically significant p<0.001

Table 6: Shares of recyclables in total collected textile mass, comparing Outdoors KaMu locations to Indoors KaMu locations

5.2 Second research question

The second question: "How does increased quality of collected textiles affect the sorting of textiles?" can be answered through the results of the interviews. Here the results indicate that the efficiency of the sorting process increases but the magnitude of the increase in efficiency depends on the characteristics of the sorting process and organisation. The reason behind this increased efficiency was that, as expected, reducing the quantity of unrecyclable textiles reduces the time and effort spent separating recyclable and reusable textiles from the unusable ones in the sorting process. No effects that would reduce the efficiency were discovered in the interviews, but a few factors that moderate the magnitude of the positive effect were identified. (Textile sorting worker and project planner interviews)

The main moderating factor for the increase in efficiency is how many stages and workstations are included in the sorting process. LSJH encourages their sorting partners to organise their sorting process into four distinct steps if they have the means to do so as they have found that methodology to be more efficient than processing all sorting steps in one go. In this methodology however, the first step, where spoiled and excluded items are separated from the rest sees very little changes in the time it takes to process a given mass of input textiles, but an increased quantity of textiles passes through the stage without any actions being taken on them which increases the workload of all following steps in the sorting process. Increase in input quality also increases the amount of redundant work in this system as, for instance, the very next step where textiles are checked for reusability will also implicitly confirm each textile passing through that stage as not spoiled or excluded. This redundant work is what moderates the magnitude of increase in efficiency. In a single stage process, as used by LSJH themselves due to spatial limits, no redundant work is present and as such the efficiency increase from higher quality input textiles is greater.

At a sufficiently high level of quality the single stage process is the most efficient – think of a situation where all textiles are fit to be recycled, but not reusable, for instance – and that according to LSJH the multiple-stage process is more efficient for the textile masses they collect through their established collection methods. What is not yet clear is what threshold textile quality must be reached before the single-stage process becomes more efficient, and if KaMu collection might have already surpassed it.

Overall, the efficiency of both sorting systems that were compared above does rise with increased input quality, as in this study efficiency was linked to the quantity of reusable and recyclable textiles produced in the sorting process compared to the effort spent. From this perspective the workload per piece of textile for the steps 2-4 remains the same while less time is spent in the first step whether the steps are processed separately or not.

A secondary moderating factor is the availability of experienced sorting personnel. Pre-sorting is suitable work for inexperienced sorters given that any person fit to work could be expected to be able to identify with ease the presence of moisture, bugs, and strong smells in a piece of textile as well being able to identify if a given product is included in a very short list of accepted textiles or not. For the other sorting steps greater expertise is needed. As such, when the quality of textiles increases, the demand for experienced sorters increases as well and if the demand cannot be met then the speed of sorting is greatly impacted. As an extreme example, Appendix A mentioned that during Sorting Partner 2's worst period of labour shortage and churn they had a streak of three weeks during which the weekly sorted quantity was lower than half the average daily sorting capacity of a single sorter at LSJH, who are typically highly experienced.

5.3 Third research question

As for the last research question: "Is KaMu-collection an efficient part of LSJH's consumer end-of-life textiles recycling operations?" the answer relies rather heavily on inferences and estimations from the interviews and observations made during the on-site visit. The key figure is that based on the data analysis the textiles collected through KaMu contain 52% (27.8pp) more reusable and recyclable clothes than those collected from the sorting stations. As such, KaMu collection should not require more than 52% more labour to collect and sort the textiles to be an efficient addition to LSJH's operations.

The first estimation is how much time is spent collecting the KaMu textiles. Based on the interviews the two-man patrol that collects the textiles spends ten hours per week collecting the KaMu textiles. However, LSJH has noted that the second person in the van patrol, although necessary for most

of the patrol's work, is not needed for collecting textiles and as such they have begun trying to find other work for one of the van patrol's members during textile collection runs. On those weeks where other work has successfully been found, the now one-man patrol takes a slightly longer time at around eleven hours to collect the KaMu textiles. (Service manager and Van patrol worker interviews)

The second estimation is how much time is spent sorting the textiles from KaMu and from the other sources. For these purposes LSJH's Project planner supplied an estimate that to sort the already pre-sorted textiles from other sources the workers at LSJH's own sorting facility have a capacity of 300kg/worker/day. As they could not provide an estimate on pre-sorting speed, due to LSJH pre-sorting only very limited quantities, pre-sorting was estimated to be as fast as the average of the three other sorting steps at 900kg/worker/day. As the average weekly collected quantity from KaMu is ~560kg of which 81.5% passes pre-sorting, the weekly collection requires 2.1 workdays to sort. To produce the same amount of textiles that successfully pass pre-sorting (456.4 kg), a total of 850 kg of textiles from the other sources need to be pre-sorted. As such, recycling textiles from the other sources to produce the same amount of reusable and recyclable textiles as from one week of KaMu collection requires 2.5 days to sort. (Textile sorting worker and project planner interviews)

The third estimate is how much time is spent delivering the textiles from other sources. A single shipment contains roughly 2500 kg, or enough to produce as much reusable and recyclable textiles as three weeks of KaMu collection. Using the five largest sorting stations and LSJH's own sorting facility as the basis for a travel time estimate, the typical delivery of textiles from sorting stations requires 28 minutes' drive (one-way) and some additional time to load and unload. If it took three minutes per big bag to load, unload and weigh (done immediately as part of unloading) then delivering a load of textiles equivalent to one week of KaMu collections requires 0.1 workdays. The five largest sorting stations were used as the basis of the estimate as jointly they directly receive some 100 tonnes of the 108 tonnes brought directly to the 11 sorting stations that accept textiles and are all relatively close to LSJH's sorting facility which makes the comparison fairer given that most KaMu locations are also relatively close to the sorting facility. (Project planner interview).

The fourth estimate is how much work is spent to collect from the 30 collection boxes that supplement the sorting station collection. Some 76 tonnes are expected to be collected from them during 2021 and they are emptied weekly (average 1.46 tonnes per week). As these collections are for the most part outsourced, no estimate on the labour spent was given and as such needs

to be constructed from scratch. For simplicity's sake, they are estimated to be emptied within one workday, which would make the routing of the collection run three times more efficient than that of KaMu collection even if the collection boxes were as close to each other as the KaMu locations, which they are not. As this day of labour would result in collecting a mass of textiles with a recyclable and reusable content equivalent to 1.72 weeks of KaMu collection and makes up 41% of textiles not collected through KaMu, the labour spent collecting from the unmonitored collection boxes would add 0.2 workdays to the effort spent collecting textiles per each 850 kg of textiles collected from non-KaMu sources.

The last of the significant estimates is how much labour is spent collecting from the sorting stations given that those sites are monitored. However, this is by far the hardest estimate to get correct as the sorting stations are used for collecting dozens of other recyclable materials and thus the share of attention spent towards textiles would have to be estimated for an accurate result. But making such an estimate would be hard even with full access to all data collected by LSJH so yet again a much simpler estimate of there being the equivalent of one worker working full time exclusively on monitoring the incoming shipments of textiles which also corresponds roughly with 1.0 workdays per each 850 kg of collected textiles (equivalent to one week of KaMu collection in reusable and recyclable content).

As such, the overall estimation on the efficiency of the KaMu collection was based on the four following figures: It would take roughly 1.5 workdays to collect and deliver a weekly batch of KaMu textiles, and it would take a further 2.1 workdays to sort them. To produce the same amount of reusable and recyclable textiles from other sources, it would take 1.2 days to collect and monitor, 0.1 workdays to deliver, and 2.4 workdays to sort. As such, the KaMu collection produces the same amount of reusable and recyclable textiles as 3.7 workdays spent collecting and sorting textiles from the other sources while requiring 3.6 workdays of labour.

Based on the estimates, KaMu is better than the established collection methods, but by a narrow enough margin that the finding could easily be caused by inaccuracies in the estimates. However, the KaMu collection still contains some sources of inefficiency caused by the relatively small scale of the pilot. For instance, many of the KaMu partners open their stores at 11am or later causing the early hours of the van patrol's workday to be spent idling or driving along severely suboptimal collection routes which could easily be solved by separating the collections among more days so that mornings need not be used, but that would increase the complexity of managing the van patrol for little gain (Service manager interview). When these remaining sources of inefficiency are resolved, KaMu collection will certainly be an

efficient addition to LSJH's consumer end-of-life textiles reverse logistics even if the estimates were found to be wildly inaccurate.

5.4 Significance of results

The study's main result is that the quality of collected consumer end-of-life textiles can be improved through choice and implementation of collection method which in turn improves the efficiency of sorting. This result builds upon the previous academic results, which recommended collection solutions based on collected quantity and the efficiency of collection efforts (Struk, 2017; BiPRO/CRI, 2015; Ellen MacArthur Foundation, 2017; Ferronato et al., 2019; Jäämaa, 2021), by pointing out the need to include quality into the consideration given its ability to impact the overall efficiency of the collection solution. The quality aspect might well cause changes in the recommended collection methods or reinforce the previous suggestions.

Particularly, the master's thesis by Jäämaa (2021) recommended a semi-centralised collection system, more specifically a neighbourhood-based one, for Finland in all but the most sparsely populated regions where centralised methods would be suitable. As in the other studies, the recommendation was based on the finding that collected quantity increases with the density of collection points, but after some threshold the marginal gains become too low to be worth the effort.

This study's results show that at least the KaMu implementation of a semi-centralised collection method outperforms the centralised sorting station collection method in quality of textiles which helps mitigate the collection efficiency losses of increasing collection point density. Therefore, given that Jäämaa's thesis (2021) found semi-centralised methods as being worth the effort in Finland even without considering the quality of collected textiles, the recommendation that semi-centralised collection methods should be favoured over centralised methods is reinforced. Perhaps the recommendation could even be extended to the sparsely populated regions where Jäämaa (2021) recommended centralised collection methods.

The results of this study do not, however, support an extensive further decentralisation of the collection system compared to Jäämaa's (2021) recommendation given that an already high share of ~82% of collected textiles from KaMu were reusable or recyclable. Even if further quality gains were attainable with a more decentralised collection method the effect of it would likely remain too small to offset the losses in collection efficiency. For instance, one should note that the KaMu collection points were not as densely located, even within the city of Turku, as they would be in Jäämaa's (2021) recommended neighbourhood-based collection system, and as such any even denser

collection methods would have greatly increased logistics needs for an at most ~22% (18pp) increase in quality.

Further, this study continues the literature on LSJH's previous collection pilots (Telaketju and TEM, 2020; Telaketju and YM, 2019). Comparing the results of this study and the previous studies, it seems that KaMu might well be LSJH's most successful collection pilot by quality so far, although the results of the studies might not be directly comparable due to reasons described below.

Of all the collection methods studied in the Telaketju and YM (2019) study, only one collection method came close to the level of quality witnessed in KaMu at 77% reusable or recyclable. However, this collection method was rather labour intensive as the collected textiles were received and inspected personally by the staff at the collection point. Furthermore, the sorting station collection was also studied in the report and the share of recyclable and reusable textiles was only around 30% which is markedly worse than the ~50% reusable and recyclable fraction from the same collection method observed in the 2020 dataset used in this study. As no recent changes to the sorting station collection method came up in the interviews, it is likely that consumer education or changes in inventory handling or sorting methodology might have caused changes in quality between this and the older study.

In the Telaketju and TEM (2020) study, a neighbourhood collection box was found to produce roughly equivalent quality as KaMu at either 76% or 85% reusable and recyclable content depending on whether a single collection in February, which got spoiled by weather during the collection event, would be discarded from the results or not. However, the entire experiment resulted in only 207 kg of collected textiles and as such the results are not entirely reliable.

5.5 Study limitations

Perhaps the most important limitation of this study is that the effect that KaMu collection had on the quantity of collected textiles could not be estimated. The quantity of textiles collected by LSJH went up by around 30 t in 2021, but only 15.6 t were collected through KaMu. As such, there were very likely other reasons for the increase besides KaMu – increased media attention due to the opening of LSJH's recycling facility was mentioned as one factor by the Project planner – which hide the true effect KaMu had on quantity. Existing research suggests that bringing the collection closer to the consumers, as is the case with KaMu, would have a positive effect on collected quantity (Struk, 2017; BiPRO/CRI, 2015; Ellen MacArthur Foundation, 2017; Ferronato et al., 2019; Jäämaa, 2021), but this effect could not be

verified in this study. Consequently, the link to existing research is not as strong as it might have been.

Another important set of limitations for this study is that the datasets that were compared to each other were firstly from different time periods, and secondly from different organisations. The first issue is perhaps not critically important given that the linear regression analysis did not detect any statistically significant change in quality over time in the 2020 dataset, but that does not necessarily mean that there was none in 2021. The second issue was however immediately pointed out as a possibly major source of analysis result inaccuracy by LSJH's own personnel (R&D manager and Project planner interviews) despite all sorting locations adhering to the same set of sorting and reporting instructions.

Finally, most of the estimations that were used to approximate the efficiency of KaMu were rudimentary at best and would have greatly benefited from additional information that just was not available. In addition, some other estimates, while smaller in effect, could have provided further accuracy to the analysis, such as how much time is spent managing KaMu partnerships.

5.6 Suggestions for practice and research

Based on the findings of the study, the main practical suggestion is that LSJH should continue building up their KaMu collection system and work towards increasing its efficiency as it was clear that the system has significant potential. A major improvement in efficiency could be achieved through outsourcing the collection, as LSJH has already planned to do as soon as possible. On the more experimental side, LSJH should potentially route a part of the KaMu textiles to be sorted at the sorting partners so that the true effect that KaMu has on quality could be more accurately estimated.

Further, given the positive value that KaMu has presented to LSJH, it would be greatly beneficial for LSJH to spread their knowledge on setting up such collection systems to the other Finnish waste management companies who already provide LSJH with more than two thirds of the textiles they process. After all, they are all supposed to start their collections by the start of 2023 at the latest which leaves them little enough time to experiment themselves.

On the academic side, the main suggestion is that any future studies of textile collection methods should include the quality aspect and sorting process in their considerations as it may have great impact on any feasibility and efficiency estimations. More specifically, differences in quality may even lead

to discoveries that some collection methods previously thought to exchange efficiency for greater collected quantity would in fact have a greater overall efficiency once sorting activities are included in the analysis.

Another further research topic would be to examine what characteristics of the KaMu collection were mostly responsible for the increase in quality. While the effect of being located indoors was already separated in this study, other potential causes were still lumped together. Namely, most of the collection points were in flea markets or charities' second-hand shops which could be assumed to have customers with already good disposition towards recycling and reuse. Another potential cause is the collection points' central locations which could make it convenient for the consumer to drop-off smaller quantities at a time which in turn could reduce the burden of adhering to the recycling guidelines. A third potential cause is the monitoring the owner, staff, and other customers at the shop provide. Creating, or identifying, collection pilots which differ along these characteristics would allow identifying the most important components that make successful collection methods.

6 Conclusions

The objective of the study was to examine how placing collection sites indoors in locations close to the consumer affects the collection and sorting activities of the reverse logistics supply chain. The study was implemented as a single case study of LSJH and its KaMu collection pilot. The study drew its data from interviews, observations and numerical data supplied by LSJH. The numerical data was used in two sets of linear regression analyses that were used to generate the study's first main result and contribute to the third while the interviews and observations contributed towards the rest of the study, including a detailed description of LSJH's collection and sorting activities.

The first of the study's main results is the finding that the quality of collected textiles can be affected very substantially through the choice and implementation of collection method. The KaMu collection pilot was discovered to produce roughly 50% more recyclable textiles from the same collected mass than from LSJH's established collection methods. The existing literature (Struk, 2017; BiPRO/CRI, 2015; Ellen MacArthur Foundation, 2017; Ferronato et al., 2019; Jäämaa, 2021) suggests that implementing collection methods with more densely placed collection points, such as KaMu in comparison to LSJH's established methods, should also provide an increase in collected quantity, but this effect could not be verified nor disproved in this study.

The second result confirmed the expectation that an increase in quality of collected textiles increases the efficiency of the sorting phase of reverse logistics. While this result was not unexpected, together with the first finding it contributes to existing research by pointing out the possibility that some collection methods previously thought to be too inefficient, when only collected quantity and effort spent collecting were measured, could in fact be viable or even better than alternative collection methods once potential efficiency gains in the sorting phase are included in the analysis.

The third result of the study is that the KaMu collection was estimated to be more efficient in producing reusable and recyclable textiles despite the increased effort spent in the collection phase and the inefficiencies of the pilot implementation. However, the inaccuracies in the estimate are potentially more than large enough, and the margin of increased efficiency so slight, that with more accurate estimates the result might even be reversed. In any case, the KaMu collection was seen to hold such great potential, that expansion of the system both within LSJH and without is recommended. Building on the suggestions of previous research (Jäämaa, 2021) this study reinforces the recommendation that collection systems in Finland should be semi-centralised.

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Interviews

All interviewees are a part of LSJH unless otherwise noted, and all interviews were conducted on September 8, 2021, unless otherwise noted.

Project planner (interviewed more than ten times between June-December 2021)
R&D manager (interviewed four times between June-December 2021)
Service manager (interviewed in December 2021)
Sorting Partner 2 representative (interviewed in November 2021)
Sorting station worker (interviewed in June and again in September 2021)
Textile sorting worker
Van patrol worker

A. Difficulties at Sorting Partner 2

As mentioned in chapter 3.3, Sorting Partner 2 was discovered to have had a significant decrease in their textile quality in late Spring 2021. This deterioration was discovered as part of tests designed to determine whether KaMu collection provided LSJH with a new source of textiles, or merely a rerouting of textiles that would have been collected with the established methods. By then KaMu had been confirmed to produce higher quality textiles and the idea was to see if the start of KaMu collection led to a decrease in textiles collected from other sources which would indicate a rerouting effect. The test results indicated a significant correlation with the start date of KaMu collection and the deterioration of quality at partner 2. To verify the results a representative of partner 2 was interviewed to identify, or confirm a lack of, other explanatory factors. Based on a short interview by email there are three reasons why this finding was very likely only a coincidence and the deterioration was unrelated to KaMu.

The first reason is that, unlike LSJH, partner 2 has managed to keep on operating on a first-in-first-out basis as intended despite a build-up in the inbound inventory. According to the interview, in mid-November partner 2 had an inbound inventory of "around two full shipments" which is roughly equivalent to 5 000 kg. (Sorting partner 2 representative interview) Combining these two pieces of information and the information from the dataset, any effects that the start of KaMu collection might have had on the textile quality at partner 2 should have become visible some 9-10 weeks later. Given this information the correlation with lower levels of quality at partner 2 and KaMu collection being active was no longer statistically significant. It is noteworthy that the inventory situation has worsened significantly during 2021, as partner 2 begun the year with only 1 500 kg of inbound inventory which was less than two weeks' worth of activity with the sorting capacity they showed between January and March.

The second reason is perhaps the most influential. Sorting partner 2 has had some significant shortages in labour, yet they are still required to keep sorting textiles to make room for further shipments. During their worst period of labour shortages their weekly sorting capacity fell short of reaching half the daily capacity of a single sorter at LSJH for three weeks in a row. This combination of labour shortage and sorting obligations has resulted in them cleaning inventories and sorting "with a heavy hand". (Sorting partner 2 representative interview) While not directly admitted by the representative, it sounds very likely that some potentially significant amounts of recyclable clothes were lost due to this labour shortage. This is also the main reason why the data from partner 2 was excluded as based on the impressions from the visit to the LSJH facility, the sorting of the KaMu textiles is still done with

the precision and thoroughness one would expect from a system that does not suffer from labour shortage. As such, the data from partner 2 was found to be incomparable to the KaMu data.

The third reason mentioned in the interview was the increased levels of moisture and mold found in the textiles (Sorting Partner 2 representative interview). This is not surprising given that summer and fall are the rainy seasons in Finland. But given the magnitude of the deterioration in quality, it sounds somewhat unlikely to be the main reason. Below is a chart of the reported shares of recycled, excluded, and spoiled fractions at the two sorting partners. The fitted trend lines show a rapid deterioration in quality at partner two starting around April although the excluded fraction was growing for almost the entirety of the period covered by the dataset from partner 2. From the chart it can also be seen that the two partners likely had slightly different reporting customs as the share of excluded textiles starts higher at partner 2 than it ever was at partner 1, but the spoiled fraction starts at an equivalently lower level.

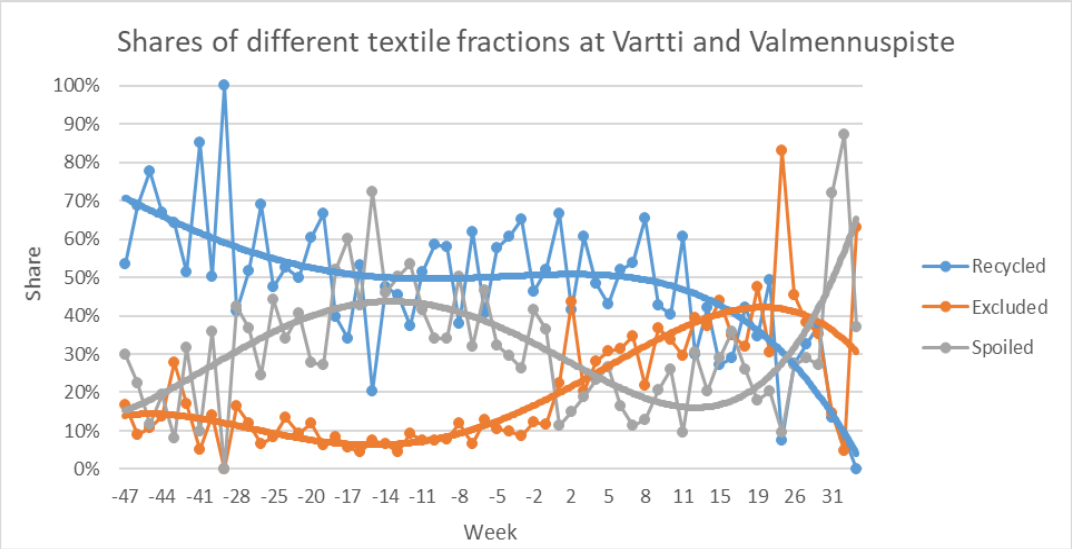

Figure 10: Shares of different textile fractions at the two sorting partners. Data from Weeks -52-0 from partner 1, 1-39 from partner 2