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Logistical Preconditions for Economical Reuse of End-of-life Textiles

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The importance of textile recycling has long been highlighted and extensively covered in the literature. More recently, tightening waste regulations have forced household waste management organizations to seriously consider different alternatives for reducing the amount of textiles in mixed waste. To date, the high logistical costs associated with collecting, sorting and treating of end-of-life (eol) textiles has prevented the use of recycled textiles in production. The particular challenges of organizing these operations cost-effectively include small batch size, material diversity, and complex sorting and treatment processes. Finding economical alternatives for the reverse logistics of eol textiles will help companies that use recycled textile materials in large-scale production to evolve. This paper addresses the issue through mixed methods research combining a quantitative and qualitative approach. The paper is based on a case study of organizing the eol textile ecosystem in Finland. The material was obtained primarily from interviews with stakeholders and workshops. The economic impacts of different alternatives are compared using a designed cost model. Based on the study, local collection of eol textiles should be carried out at regional level using the expertise of local municipal waste companies. Centralized sorting and treatment enables adequate volumes to justify investment in automation and paves the way for economies of scale benefits.

Keywords: Reverse logistics; Textiles; Recycling; Cost model

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1 Introduction

In the developed world, most end-of-life (eol) textiles end up in municipal waste collection as mixed waste, meaning that they will end up in energy burning plants or landfills. In almost every country, charity organizations collect apparel in good condition either for sale in their own retail stores, as relief aid to e.g. areas suffering from natural disasters, or for sale in underdeveloped countries. However, a considerable share of donated eol textiles are in such poor condition that they cannot be sold to other consumers in the country of origin, and transporting them to underdeveloped countries is ethically questionable (Norris, 2015). Reusing the material from eol textiles in new products therefore makes sense and is an important tool for increasing recycling rates. From an environmental point of view, recycling textile material is important as it can take more than 20,000 liters of water to produce 1kg of cotton (Bärlocher et al., 1999), but the reuse of 1 tonne of cotton clothing only uses 2.6% of the energy required to manufacture it from virgin material (Woolridge et al., 2006).

Charity organizations compete in the second-hand clothing business, which means there are good procedures for getting users of reusable clothes. In addition, some textile items no longer fit for purpose can be reused as raw material for other products without the need for fiber-level recycling, such as cast-off hotel bedding. However, once the recycling process moves to material and fiber-level, processing costs shoot up and the cost of recycled material can quickly exceed that of the corresponding virgin material. This is because a number of problems arise with the reuse of eol textiles as raw material for new products. First, the collected textile contains several types of material that need to be separated. To make matters worse, today's apparel seldom comes in a single material but rather as mixture of materials that somehow need to be recognized and sorted. Second, eol textiles usually include built-in parts such as zips and buttons that need removing before the recycling process. Third, used textiles may have dirt that interferes with the recycling process difficul . Further issues may arise if the textile material is wet or contains mold or pests.

A further challenge related to the reuse of eol textile material in developed countries such as Western Europe and North America is that their own textile industry has largely been shifted to other continents, notably South and East Asia. Thus there is only a limited number of industrial companies that could use collected textile material locally. One option could be to transport collected textile materials to countries with a large textile industry, but that has its own problems: Countries like China have recently prohibited the import of waste material, including eol textiles (Davies and Ding, 2018), and transporting material that is relatively cheap but vulnerable to e.g. humidity to the other side of the world has its own costs and lessens the environmental benefits of recycling.

This paper examines the supply network of eol textile recycling. The aim is to find different alternatives for organizing operations within the network, because when there is enough information on available alternatives, it becomes easier to select the most functional ones and cut recycling costs to a reasonable level. Reasonable costs and an ensured supply of materials encourage the use of eol textiles as raw material for textile products as opposed to virgin material. This paper also aims to model the costs of recycled textile material, to help users evaluate their raw-material costs when planning a business related to the use of recycled textiles

2 Theoretical Background

Waste Framework Directive 2008/98/EC (European Commission, 2008) outlines how waste is defined in the European Union and how it should be treated. The Directive not only makes recommendations on the treatment of eol waste but also recommends a 'waste hierarchy' that is applicable across all member states. In the hierarchy, the primary aim is to avoid waste. The hierarchy has four waste categories in order of desirability: Reuse, recycling, other recovery, and disposal. (European Commission, 2008; Gharfalkar et al., 2015).

When the general aim is to reduce especially the amount of disposal waste, textile waste is one category that should be taken into consideration. Even if textiles normally represent a share of around 2.5% of all the household solid waste in Europe (e.g. Edjabou et al., 2015), it usually ends up in mixed waste; a study carried out in the Helsinki metropolitan area noted that the share of textile waste was 5.0% of all mixed household solid waste (HSY, 2013). Asaadi et al. (2017) also note poor recycling rates of eol textiles; they report that in the UK, the Nordic countries and the Netherlands, 61% of textiles end up in waste after only one cycle, and in the US the rate is as high as 85%. Textiles therefore represent a waste category that is poorly recycled and requires attention if the ambitious aims to reduce the amount of disposal waste overall are to be met. In addition, producing textile items from virgin materials is energy and resource consuming (Bärlocher et al., 1999). Increasing the share of textile recycling will help to achieve other environmental targets such as reducing CO2 emissions and use of natural resources (Woolridge et al., 2006).

Based on Waste Framework Directive 2008/98/EC (European Commission, 2008), the primary way to recycle textiles is to use them according to their original purpose, or then as a raw material for new products without additional treatment (e.g. use the material of ripped cloth for a new cloth). If this is not feasible, the three most common ways to recycle fabrics are: 1) mechanical, 2) chemical, and 3) thermal treatment.

In mechanical recycling, the textile is handled mechanically by e.g. tearing and recycled at fiber level. However, this is only suitable for products made from a single material. In chemical recycling for cellulose-based materials, the textile waste, such as cotton, is dissolved in a way that its raw materials are returned to fibers and hence a usable textile raw material. Chemical recycling varies depending on the fiber type, and synthetic fibers can be recycled via the chemical repolymerization route. Chemical treatments can be also used to separate raw materials from a textile made from different materials. Chemical treatment can also be used to some extent for dirty material. In thermal treatment, the fibers are heated and can be melt-spun again into new fibers. However, textile fibers lose some of their features during this process; thus the resulting material can be used for producing plastics but is not suitable for recycling textile material.

Jahre (1995) lays out a framework for household waste collection as a reverse channel, analyzes different waste collection and sorting alternatives by using postponement speculation concepts (Boone et al., 2007), and suggests ten different propositions related to the issue. Based on the paper by Jahre (1995), increasing the number of fractions separated by collection level leads to higher collection costs but smaller sorting costs than where the numbers of separated fractions are smaller. However, increasing the number of fractions also creates more work for the consumer and heightens the risk that the material will not be suitable, as consumers may not properly separate the fractions. Nevertheless, when the number of fractions is smaller, there is greater risk of contamination with different materials, which complicates sorting in later phases of the supply chain. (Jahre, 1995)

In summary, recycling eol textiles offers significant environmental benefits but is difficul to organize cost-effectively. Therefore, the eol textile recycling network should be considered as an entity in order to get the total costs for recycled textile material. In addition, a holistic view requires operations planning to be widely applicable and to support the general target of creating a functioning recycling ecosystem. Therefore, solutions that offer benefits locally but are problematic in a network perspective should not be adopted. (Bing et al., 2016).

3 Methodology

The paper is based on a single case study (Yin, 2013) of designing a countrywide eol textile recycling ecosystem in Finland.

The data collection methods used in the paper are literature searches and mixed methods research (Johnson et al., 2007). In mixed methods research, a researcher or team of researchers integrates qualitative and quantitative research approaches within a single study or a set of closely related studies (Johnson et al, 2007; Creswell, 2009; Bryman and Bell, 2011). The main qualitative methods used were observation of the processes, interviews and workshops, while quantitative modelling (Bertrand and Fransoo, 2002) was mainly used to employ and analyze the data obtained from qualitative sources. The actual collection of qualitative and quantitative data was mostly conducted during the same stage, thus the approach of this study is concurrent triangulation design (Castro et al., 2010). The use of mixed methods is encouraged in supply chain management (SCM) research, because SCM phenomena are often complex and dynamic (Golicic and Davis, 2012). Finding functional and cost-effective processes for collecting, sorting and handling eol textiles is just this type of SCM phenomenon, as the relevant literature is scarce and existing textile recycling systems are limited. Therefore, different methods were combined to obtain reliable answers to the research question instead of building an expensive textile recycling system that might fail.

The literature search examined all kinds of electronic material related to eol textile recycling (scientific papers, research and project reports and other articles). In addition, figures on the costs, speed and capabilities of related technological solutions were sought by probing the web pages of equipment manufacturers and organizations running used textile collection pilots, among others. The search used keywords such as 'textile recycling' and 'used textile collection'. It emerged that there is very little literature on the logistics of organizing eol textile recycling. As the technology related to sorting and reusing textiles is still in its infancy, the technological questions lean heavily on the current literature.

The authors visited three plants that use recycled textile as a raw material for new products: two in France and one in Estonia. The visits gave an idea of the criteria required by eol textile raw material to make it eligible. The authors also visited two textile sorting centers: one in Germany and one in Estonia. In the semi-automated eol textile sorting center in Germany, human workers do the actual sorting but conveyor belts move the material. In the Estonian sorting center, which is run by a charity organization, human workers do all the sorting manually. These visits provided information on the costs and speed of different sorting systems.

Interviews with ten representatives from six organizations provided information on current processes and figures that could help design an eol textile recycling system, as well as expert input on various aspects of the recycling. The organizations were a charity organization collecting funding by selling used textiles, two regional house-hold waste management companies, an environmental service company, the Finnish Solid Waste Association, and an agent selling equipment for recycled textile material handling and treatment. The interviewees worked as logistics managers or experts in textile recycling. The organizations were also involved in projects related to eol textile recycling and gave valuable insight into their experiences. The interviews were semi-structured, with prepared questions intended not only to obtain specific answers and figures, but also to lead open discussions on the organizations' viewpoints and activities.

Stakeholders related to eol textile recycling were also invited to a workshop. The 18 participants included representatives of a regional waste management company, two charity organizations that collect funding by selling used textiles, two universities, a research institute, an organization representing textile and fashion commerce, the Finnish Solid Waste Association, and four organizations that sort used textiles and/or use them as raw material for new products. The purpose of the workshop was to evaluate different scenarios designed for organizing eol textile recycling in Finland and to estimate the related figures.

The first version of a process model for eol recycling was developed based on the literature research, then further elaborated based on the process observations, interviews and workshop. The process model worked as a basis for the cost model, which was designed to give numerical values for different options and scenarios for organizing eol textile recycling in Finland and to respond to research questions. The cost model was built using activity-based costing (Cooper and Kaplan, 1991) and typical components of investment cost-profit analysis (Drury, 2015). The model consists of the following process phases:

1) Collection of eol textile material. The potential volumes of recyclable textile waste were based on figures from Statistics Finland. The organization of eol textile collection was planned together with experts from a regional

household waste management organization. To get cost figures related to textile collection, the authors interviewed the representatives of another regional household waste management organization, which was running an eol textile collection pilot. In addition, the clothes-collection manager of a charity organization shared insight on how they have organized their countrywide used-clothes collection in Finland. Different eol textile collection alternatives and the related costs were discussed in a workshop.

2) Sorting of eol textiles. Different alternatives for organizing the sorting of eol textiles were discussed in interviews and a workshop. The cost model enables comparison of the following alternatives: First, the collected textile material is sorted in the regional collection centers of regional household waste management organizations. Second, the textile material is perhaps quickly presorted in these centers, but most of it is transported to centralized sorting that deals with all the textile material collected in Finland. The cost model also enables comparison of the costs of manual, automation-assisted, and fully automated sorting with different parameters.

3) Treatment of sorted textiles. Based on previous studies related to the content of eol textile material, the model gives the amounts of different textile raw materials (e.g. cotton, polyester etc.). The model then offers different alternatives for treating the sorted material in such a way that it can be used as raw material for new products. In addition, the cost model calculates all the costs of the selected previous process phases to offer production costs per kilogram for usable textile raw material.

The designed cost model was validated by presenting the cost model to Finnish eol textile related stakeholder organizations and asking for their expert feedback on the credibility of the figures.

4 Case Findings

4.1 Background Information

In Finland, consumers and institutional households discarded around 71 million kilograms of textiles in 2012. It is estimated that around 77% (54.7 million kilograms) of these textiles ended up as municipal waste and roughly 23% (16.4 million kilograms) was passed to charity organizations. Around 20% of the textiles received by charity organizations ended up as municipal waste. (Dahlbo et al., 2017). Given that there are around 5.4 million inhabitants in Finland, this means that 10.6 kilograms per capita of eol textiles ended up as municipal waste and thus in landfills or as part of energy production. Even though 58.5 tons of eol textiles is not a large share of the total 1,800 tons of municipal waste that ended up in landfills and energy production in 2012 (Statistics Finland, 2018), there is increasing pressure to improve the reuse of textile material; eol textiles are poorly suited to energy production and almost all landfill sites in Finland have been closed since 2012 (Statistics Finland, 2018).

Municipalities representing over 95% of the Finnish population have joined their waste management under 33 municipal bodies or similar organizations. These 33 organizations are members of the Finnish Solid Waste Association. The association shares the latest information on the effects of new regulations and best practices concerning e.g. separately collected material collection. Depending on the organization, private companies or entrepreneurs can handle different tasks such as waste collection, treatment or energy production. Especially smaller organizations also cooperate in certain areas of waste treatment, such as collection of certain separately collected materials, or they have common treatment or waste burning plants.

4.2 Recommendations for Eol Textile Collection and Sorting Operations in Finland

Based on the expert interviews and workshops, the collection and sorting of eol textiles should be organized as follows in Finland:

Cooperation is desirable between charity organizations that collect reusable clothes and regional municipal waste collectors that collect eol textiles primarily for material recycling. The waste hierarchy model encourages the reuse of textiles by processing these as little as possible (Gharfalkar et al., 2015). Thus used textile collection processes by charity organizations should be encouraged to separate reusable textiles from other textile material. To minimize contamination of reusable material with other eol textile material, the best option would be for reusable textile material to be collected by charity organizations and other eol textile material by regional house-hold waste management organizations. In practice, consumers would deliver their eol textiles to specially allocated containers situated in recycling centers, where other waste categories are also collected separately. Neighboring regional household waste management organizations could of course cooperate and have joint facilities for eol textile handling, but the concluding idea was that every organization would first transport their collected textile material to their own handling center.

There are several alternatives for defining the role of a regional handling center and thus how its operations should be organized. The alternatives are either to sort the collected textiles locally in a handling center or pack them tightly in full trucks for transport to centralized handling. The benefits of local handling include a reduced need for transportation and local availability of the sorted raw material. The challenges of this alternative are that because textile volumes are small, manual sorting might be the only alternative if investments in automation are not economically justified. The benefits of centralized handling are bigger volumes that e.g. make investments in automation more economically feasible, but the transport costs are higher.

Based on the experiences of charity organizations with textile collection and of regional household waste management organizations with eol textile collection pilots, textile collection faces a number of challenges that affect the sorting process. To begin with, most consumers do not have the expertise to sort clothes as reusable or non-reusable.

This makes cooperation between charity and household waste management organizations important. Charity organizations already deliver unwanted textiles to waste management organizations. In the future, most of that material will be passed on to textile recycling and only a small non-recyclable portion will end up as mixed waste. Consumers also hand over reusable clothes to eol textile collection by waste management organizations. Stakeholders in current eol textile collection pilots are therefore interested in studying the content of collected textiles to determine whether it makes sense to sort through them manually to separate reusable clothes before contamination happens in later process phases.

Another challenge related to collection is the presence of harmful content among collected textile material such as moldy, wet or oily clothes. This should be separated out as early as possible to avoid spoilage of a larger batch of textiles. During the workshop, the experts from stakeholder organizations proposed the following for eol textiles: generally, they were in favor of centralized sorting, which makes automation economically viable. However, they suggested that workers of e.g. charity organizations would manually presort textiles at regional sorting centers by separating out both reusable clothes and harmful material. If the quantity of reusable clothes is reasonable, their value will offset the costs of presorting. And if the sorters manage to separate out harmful material, the sorting organizations may get some rewards, as this presorting will smoother phases later in the process.

4.3 Treatment of Sorted Textile Material

Depending on how the sorting is organized, other operations may be needed before or after sorting. In general, any treatment raises costs and is preferably avoided. However, some treatment is needed depending on the material and the needs of users:

1) Components, such as zips and buttons, must be removed.

2) The fibers must be opened and cut up into relatively small pieces.

3) The textile material may need washing depending on the need of the end-user. However, this raises the costs of the material, as drying requires both space and energy.

4.4 Cost Estimations for Organizing Eol Textile Recycling in Finland

Based on the cost model, it seems that sorting of textiles is the most expensive phase of eol textile recycling, if mechanical recycling is used. Another expensive phase is collection of materials. The operations of regional handling centers incur costs, but these are much smaller than the costs of collection and sorting. Textile material treatment can also be expensive, but these costs depend on the required treatment. Transport costs of packed collected textiles between regional handling centers and centralized sorting represent only a small share of the total costs of recycling.

The purpose of the cost model created during the research is to get an estimation of the costs per kilogram of recycled ready-for-use textile material in Finland. This cost has several uncertainties, but based on the research, the following estimations can be offered:

Some estimations for eol textile collection can be made based on the experiences of charity organizations, and on discussions during the workshop. The authors estimate that adding eol textile collection containers to existing recycling centers (one collection place per 10,000 inhabitants on average) could during the first phase enable collection of some 40% of potential eol textile that currently goes to mixed waste. This would entail annual collection costs of around two million Euro, derived from the estimated costs of refuse trucks and containers.

The authors also estimate that with cooperation between regional household waste management companies, the number of local handling centers could be roughly equivalent to the number of administrative regions in Finland (18). If the annual costs of a single local handling center are around 50,000 Euro, the total costs would be of the order of one million Euro. This would include the costs of presorting, if charity organizations are willing to this without substantial costs and the amount of harmful content remains small.

The costs of transport between regional handling centers and centralized sorting can be estimated fairly accurately if textile volumes and the place of sorting are known. Currently, the regional household waste management organization in Southwest Finland has the most advanced plans to build eol textile sorting and treatment facilities. If centralized sorting is situated in Turku, the weighted average transport distance between regional handling centers and centralized sorting will be around 270 km and the transport costs around 300,000 Euro.

The costs of centralized sorting vary widely depending on the sorting methods and technologies used. The most cost-efficien way to handle sorting would be to use automation as much as possible. Based on the experiences of charity organizations' manual sorting efficiencies the authors estimate that manual sorting would cost around 4.5 million Euro annually. The figure is roughly the same whether manual sorting is centralized or decentralized, but in decentralized manual sorting, presorting may not be needed. The second alternative, automatic-assisted sorting, would double the effectiveness of one sorter but incur additional costs over manual sorting to make up around three million Euro annually. For the third alternative, different technological solutions exist for automated sorting, but given the limited number of automated sorting lines in production use it is difficul to estimate the performance. Also, since the technology is still young, the performance will probably improve and the costs drop significantly in the near future. Based on the figures from an advanced European technology provider, the authors estimate that the annual costs of automated sorting would be around two million Euro.

The costs of treatment will depend on the treatment needs. If the purpose is to use mechanical recycling, adding a cutting machine to the end of automated sorting lines would be a relatively small cost. There are also technological solutions for removing non-textile material from textiles. However, other treatments like washing will increase treatment costs. For chemical recycling the costs are substantially higher than for mechanical recycling, but using chemical treatment allows the use of mixed and somewhat dirty materials that could not be used after mechanical treatment. Thus the output volumes of chemical recycling could be higher than with mechanical recycling — depending of course on the content of the processed textile material.

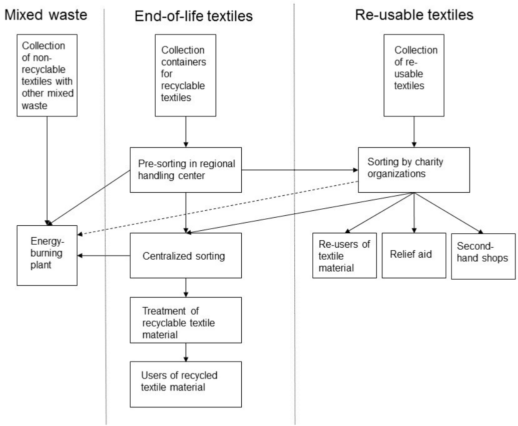

Figure 1: Suggested process for organizing reuse and recycling of excess textiles of households.

In summary, depending especially on the quality and volumes of collected material but also on the availability and costs of technological solutions for sorting textile material, the cost of usable recycled fiber raw material will be between 0.7–1.3 Euro/kg if mechanical recycling is used. Figure 1 shows the suggested process for organizing the reuse and recycling of excess textiles from households.

5 Conclusions

When considering the creation of an eol textile ecosystem from an SCM perspective, the most obvious challenge is to similarly create demand and enable an adequate supply of raw material. There is currently a limited demand for recycled textile material that might be more expensive than the corresponding virgin material. On the other hand, if an organization decides to invest in production using recycled textile material on a large scale, supply will quickly become a problem.

Therefore, by involving stakeholders such as raw material collectors, potential end-users and technology developers in joint development projects, the ecosystem has better possibilities to evolve. One essential precondition for ecosystem development is cost-effective logistics, which requires information about the costs and volumes of raw material when the recycling system is in production use. The developed cost model aims to contribute to this challenge.

Based on the results of the study, it seems possible to produce recycled textile raw material at a reasonable cost. However, achieving this requires the latest automation technologies and willingness on the part of consumers to spend some time separating their old textiles from other waste and taking them to collection containers. Once the ecosystem is in use, however, the processes involved will be further developed and the technology become cheaper.

For an SCM point of view, the organization of sorting is a key issue. Based on the study, two-phased sorting was recommended as follows: First, presorting where usable clothes and harmful material are separated from other eol textile material. Second, actual sorting where different textile materials are separated based on their material into 10–20 different fractions. Even if this kind of sorting was seen as the most workable, it is not the most effective. The best alternative would be automated sorting without presorting. The main motivation for presorting is that the collected material probably includes harmful content, which should be separated out as early as possible. When eol textile is collected using containers in unmanned sorting stations, it is difficul to avoid this kind of harmful content. However, if the collection system could be different, for example by getting apparel stores to organize the collection of used textile material, the amount of harmful content would probably remain minimal. If separating reusable textile becomes the only reason for presorting, it could be arranged to be more focused. Different collection methods and places most likely comprise different shares of reusable textiles. Presorting could then be focused on places where the share of reusable textiles is large. Where the amount and quality of reusable textiles are low, it is probably environmentally and ethically more sustainable to recycle these textiles as new raw material than to try to separate potentially reusable textiles and find users for those textiles in developing countries.

The study presented here has the following limitations: First, the figures are based on approximations using the best available information, as to our knowledge large-scale eol textile collection and a recycling ecosystem have not yet been developed. In addition, especially the figures related to collection rates and the share of non-recyclable textiles are only estimations based on expert opinions, eol textile pilot tests and recycling of other types of material such as plastics. Therefore, the presented cost estimations have a fairly wide margin of error. Second, the results of the paper are not fully generalizable to other countries, as there are big differences within a single country. For example, people living in the countryside and in metropolitan areas use different types of clothes, which affects the composition and quantity of the collected material. Collection costs are also higher in sparsely populated communities. Because some figures of the cost model are based on experiences from local pilot experiments, the figures could have been different if the pilot has been carried out elsewhere. Therefore, before generalizing the results to other countries, the circumstances in Finland need to be considered first.

Related to almost every other waste category, appropriate management of textile waste requires further division of different types of processes. Depending on the textile item it may end up for reuse, recycling or as energy waste. Usually the reverse logistics process for separately collected waste categories has two destinations: If the collected batch meets the standards, it is passed on to recycling; if not, it is sent to energy waste or for disposal depending on the material type. In contrast, the reverse logistics process for items like wooden pallets has two options: either the pallet will be eligible for reuse (some fixing can be done if needed) or it will become energy waste. Thus the conducted research related to eol textile processes can offer novel viewpoints for diversifying reverse processes of other waste and recyclable item categories.

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References

Asaadi, S., M. Hummel, S. Hellsten, T. Härkäsalmi, Y. Ma, A. Michud, and H. Sixta (2016). “Renewable High-Performance Fibers from the Chemical Recycling of Cotton Waste Utilizing an Ionic Liquid”. In: *ChemSusChem* 9.22, pp. 3250–3258.

Bärlocher, C., R. Holland, and B. Guija (1999). “The impact of cotton on freshwater resources and ecosystems: A preliminary synthesis”. In: *WWF Background Paper*.

Bing, X., J. M. Bloemhof, T. R. P. Ramos, A. P. Barbosa-Povoa, C. Y. Wong, and J. G. van der Vorst (2016). “Research challenges in municipal solid waste logistics management”. In: *Waste management* 48, pp. 584–592.

Boone, C. A., C. W. Craighead, and J. B. Hanna (2007). “Postponement: an evolving supply chain concept”. In: *International Journal of Physical Distribution & Logistics Management* 37.8, pp. 594–611.

Bryman, A. and E. Bell (2011). *Business research methods*. Oxford University Press, USA.

Castro, F. G., J. G. Kellison, S. J. Boyd, and A. Kopak (2010). “A methodology for conducting integrative mixed methods research and data analyses”. In: *Journal of mixed methods research* 4.4, pp. 342–360.

Commission, E. et al. (2008). “Directive 2008/98/EC of the european parliament and of the council of 19 november 2008 on waste and repealing certain directives (waste framework directive)”. In: *LexUriServ. do*.

Cooper, R. and R. S. Kaplan (1991). “Profit priorities from activity-based costing”. In: *Harvard business review* 69.3, pp. 130–135.

Creswell, J. W. (2009). *Research design: Qualitative, quantitative, and mixed methods approaches*. Sage publications.

Dahlbo, H., K. Aalto, H. Eskelinen, and H. Salmenperä (2017). “Increasing textile circulation & Consequences and requirements”. In: *Sustainable Production and Consumption* 9, pp. 44–57.

Davis, B. and L. Ding (2018). “China’s waste import ban upends global recycling industry”. In:

DRURY, C. M. (2015). *Management and cost accounting*. Andover.

Edjabou, M. E., M. B. Jensen, R. Götze, K. Pivnenko, C. Petersen, C. Scheutz, and T. F. Astrup (2015). “Municipal solid waste composition: Sampling methodology, statistical analyses, and case study evaluation”. In: *Waste Management* 36, pp. 12–23.

Finland, O. S. of (2018). “Municipal waste 2016”. In:

Gharfalkar, M., C. Campbell, Z. Ali, G. Hillier, et al. (2015). “Analysis of waste hierarchy in the European waste directive 2008/98/EC”. In: *Waste management* 39, pp. 305–313.

Golicic, S. L. and D. F. Davis (2012). “Implementing mixed methods research in supply chain management”. In: *International Journal of Physical Distribution & Logistics Management* 42.8/9, pp. 726–741.

Jahre, M. (1995). “Household waste collection as a reverse channel: A theoretical perspective”. In: *International Journal of Physical Distribution & Logistics Management* 25.2, pp. 39–55.

Johnson, R. B., A. J. Onwuegbuzie, and L. A. Turner (2007). “Toward a definition of mixed methods research”. In: *Journal of mixed methods research* 1.2, pp. 112–133.

Norris, L. (2015). “The limits of ethicality in international markets: Imported second-hand clothing in India”. In: *Geoforum* 67, pp. 183–193.

Pulkkinen, S. and S. Sinisalo (2012). “Quality and quantity of household mixed solid waste in the Helsinki metropolitan area 2012”. In: *Helsinki Region Environmental Services Authority, Finland*.

Will M. Bertrand, J. and J. C. Fransoo (2002). “Operations management research methodologies using quantitative modeling”. In: *International Journal of Operations & Production Management* 22.2, pp. 241–264.
Woolridge, A. C., G. D. Ward, P. S. Phillips, M. Collins, and S. Gandy (2006). “Life cycle assessment for reuse/recycling of donated waste textiles compared to use of virgin material: An UK energy saving perspective”. In: *Resources, conservation and recycling* 46.1, pp. 94–103.
Yin, R. K. (2013). *Case study research and applications: Design and methods*. Sage publications.