Mapping Flows of Textile Waste in Sweden and an Analysis of Alternatives

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Sammandrag

Inom detta projekt har flöden av textilavfall i Sverige kartlagts och analyserats. Mycket av informationen i rapporten baseras på en litteraturstudie som utfördes i början av projektet. Det framkom att textil i första hand bör återanvändas, i andra hand materialåtervinnas och som sista alternativ förbrännas. Omvandling av textilavfall till biobränsle är inte ett rimligt alternativ till avfallsförbränning med hänsyn till den användbara energi som produceras.

Totalt skulle årligen 42 000 – 55 000 ton textilavfall kunna återanvändas och 39 050 – 50 050 ton textilavfall kunna materialåtervinnas. Årligen har 5000 – 8000 ton textilavfall en förhöjd risk för innehåll av kemikalier med farliga egenskaper. Dessa flöden förbränns i nuläget och härstammar främst från textilavfall i hushållens restavfall. Textilavfall från donationer såväl som textilavfall insamlat som brännbart material på återvinningscentraler är andra stora källor. Om textilavfallet skulle hanteras på bästa sätt ur miljösynpunkt (i första hand återanvändning, i andra hand materialåtervinning och som sista alternativ förbränning) skulle potentiellt 447 – 585 kton CO_2-ekvivalenter, 4,4 – 5,9 PJ primär energi från förnybara källor och 6,5 – 8,6 PJ primär energi från icke-förnybara källor kunna sparas. För utsläppen av växthusgaser motsvarar detta flygresor tur och retur mellan Stockholm och Bangkok för 629 000 – 824 000 människor.

Som en del i detta projekt utfördes en fallstudie i samarbete med företaget Ramboll. Med kraven Ramboll ställde skulle mellan 2900 och 5500 ton textilavfall årligen kunna användas till produktionen av akustikpaneler.

Nyckelord

Textilavfall, miljöpåverkan, avfallshantering, alternativ användning, Sverige

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Abstract

During this project, flows of textile waste in Sweden were mapped and analysed. Much of the information in the report was based on a literature review performed in the beginning of the project. It was concluded that textile waste should firstly be re-used, thereafter recycled and as a last option incinerated. Turning textile waste into biofuel is not a reasonable option compared to incineration with regard to the useful energy being produced.

In total, 42 000 – 55 000 tonnes of textile waste per year could be re-used, 39 050 – 50 050 tonnes of textile waste per year could be recycled and 5000 – 8000 tonnes of textile waste per year has an elevated risk of containing harmful chemicals. These flows are currently incinerated and originate foremost from textile waste in the residual waste. Textile waste from donations as well as textile waste collected as bulky waste at recycling centres are other large contributors. If the textile waste would be managed in the best way from an environmental point of view (firstly re-used, secondly recycled and lastly incinerated), 447 – 585 ktonnes CO_2-equivalents, 4.4 – 5.9 PJ primary energy from renewable resources and 6.5 – 8.6 PJ primary energy from non-renewable resources could potentially be saved every year. For the emissions of greenhouse gases this equals 629 000 – 823 000 persons making roundtrip flights by air between Stockholm and Bangkok.

As part of this project a case study was performed in collaboration with the company Ramboll. With the requirements Ramboll had, 2900 – 5500 tonnes of textile waste per year could be used in the production of acoustic panels.

Keywords

Textile waste, environmental impact, waste management, alternative use, Sweden

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Preface

This work is my master thesis in Environmental Engineering (Civilingenjör inom Ekosystemteknik) at LTH, Lund University. The work has been performed in Lund and Malmö during the spring semester of 2018, January to June.

Firstly, I would like to thank my partner Oscar, my parents Elisabet and Lars and my brother Jonas for all the support and encouragement during this work and the rest of my education. I would also like to thank my supervisors, Eva Leire and Charlotte Retzner at LTH and David Althoff Palm at Ramboll, for all your time and input, and Max Åhman for being my examiner. Further, a special thank you to Sanita Vukicevic and the rest of Envir AB as well as Renova for allowing me to participate in the Solid Waste Composition Study. Thank you Ladaea Rylander for the help. Another thank you goes to everyone contributing with information and support as well as to Ramboll's office in Malmö for welcoming me and letting me share your office.

Table of contents

1. Introduction 2

1.1. Background 2
1.2. Objectives 2
1.3. Delimitations 3
1.4. Methodology 3

2. Literature Review 3

2.1. About Textile 3
2.2. Legislation and Objectives 4
2.3. Flow of Textile Waste in Sweden 5
2.4. Alternative Approaches to Textile Waste Management 14
2.5. Environmental Impact of Textile 16
2.6. Harmful Chemicals in Textile 18

3. Case Study 19

3.1. Method 19
3.2. Acoustic Panels 20
3.3. E-mail/Interviews 21
3.4. Solid Waste Composition Study in Gothenburg 23

4. Results and Analysis 24

4.1. Summary of Textile Waste in Sweden Suitable for Alternative Management 24
4.2. Summary of Flows of Textile Waste in Sweden Usable for the Acoustic Panel Requested by Ramboll 30
4.3. Environmental Impact 31

5. Discussion 32

5.1. What amounts of textile waste arise in different sectors? 32
5.2. Where do flows of textile waste originate and where do they end? 33
5.3. What alternatives exist for management of textile waste? 34
5.4. Which alternative is the best from an environmental point of view? 34
5.5. What is the potential gain for the environment? 35
5.6. What amounts and flows of textile waste could potentially be used in a new product as a better alternative than the current waste management? 35
5.7. Future Studies 36

6. Conclusion 37

7. References 38

Legislation 43

Appendix 1 - Calculations 44

1. Introduction

1.1. Background

Due to the potential of reduced environmental impact and improved use of resources, many countries and organisations in the world are attempting to implement circular economies. In a circular economy, design is used to ensure that resources are used wisely. After a product's lifetime, it re-enters the circle by re-use or recycling of the material (Naturvårdsverket 2017a). Waste and its management are thus important aspects of the circular economy. Textile waste in particular is an area of recent interest in waste management in Sweden. Textile waste is present both as a focus area in Sweden's waste prevention program 2014-2017 and as an objective in the waste management plan of Sweden 2012-2017 (Naturvårdsverket 2015b; Naturvårdsverket 2012a).

The interest in textile waste is mainly due to the large environmental impact associated with the life cycle of textile and especially the production of textile. If virgin textile is replaced by re-used or recycled material, the environmental impact resulting from the production of virgin textile can be avoided. Some of the categories of environmental impact associated with textile are the uses of pesticides, water and fertilisers as well as emissions of greenhouse gases (Defra 2011). Every year, 1.6 times the water of a Swedish household and 2.5 times the CO_2 emissions of the electricity of a Swedish household (excluding electricity for heating) are needed to produce the bought textiles of an average Swede (Nielsen & Schmidt 2014). This is equal to about 64 288 L water and 300 kg CO_2-equivalents (Nielsen & Schmidt 2014).

In Sweden in 2008, 15 kg of textile was bought per person (SMED 2011). The same number for 2013 was 12.5 kg per Swede (SMED 2014). Of the bought textile in 2008, 8 kg of textile per Swede ended in the residual waste and 3 kg per Swede was donated (SMED 2011). The fate of the rest of the bought textile is unknown but could be accumulation in the households or waste management by other ways than those investigated (SMED 2011).

This project aims to investigate flows of textile waste and the potential for reduced environmental impact by changing the management of textile waste. Primary data will be taken from a literature review. A specific example is illustrated by a case study, performed in collaboration with the company Ramboll. The focus of Ramboll's project and thus the case study is on textile flows which have gone through sorting but are still incinerated.

1.2. Objectives

The aims of this project are to map and analyse flows of textile waste in Sweden in order to investigate how much textile waste can be used to reduce environmental impact. To do this several questions have been asked:

- What amounts of textile waste arise in different sectors?
- Where do flows of textile waste originate and where do they end?
- What alternatives exist for management of textile waste?
- Which alternative is the best from an environmental point of view?
- What is the potential gain for the environment?
- What amounts and flows of textile waste could potentially be used in a new product as a better alternative than the current waste management?

1.3. Delimitations

The flows studied in this project will be limited to Sweden. Textile waste considered in this project consists of clothes and home textile such as towels, curtains and cloths. Textile can also be part of furniture for example, but such applications will not be part of this project. Waste in the form of shoes will only be included when it is included in the literature. Economic and social aspects of waste management will not be considered in depth.

1.4. Methodology

In this project, a literature review has been performed. Some grey literature has also been included. This contributed with the main input of information to the project. To compensate for the gap in the literature on textile waste at recycling centres, I participated in a Solid Waste Composition Study in Gothenburg conducted by Envir AB. To include the view of a company on textile waste that could potentially be used in a new product, a case study was performed in collaboration with the company Ramboll. In the case study, flows of discarded textile from the private and public sectors were investigated through e-mail and telephone conversations. The decreased environmental impact from alternative waste management was estimated from the total flows in this project.

2. Literature Review

Firstly, background information about textile and textile waste are presented. Legislation and objectives are important as a framework for changes and will therefore follow. The current situation is represented by flows of textile waste in Sweden while alternative ways of textile waste management show possibilities for the future. Since this project focuses on environmental impact this will be presented next. Harmful chemicals in textile can be a barrier for improved management of textile waste and will thus be presented as the final part of Chapter 2.

Discussions exist about the classification of textile as waste versus as raw material for new products. In this project the term "textile waste" has been used continuously. This has not been done as a statement but to make the report easier to follow and because the discussion is ongoing. More about the problem and statements can be read in Chapter 2.2.

2.1. About Textile

Textile consists of fibres, which can be both natural and man-made (Bergner 2013). Examples of natural fibres are wool, cotton, silk and cashmere (Bergner 2013). Man-made fibre can be synthetic fibre based on products of fossil origin, such as polyester, acrylic and nylon, or synthetic fibre based on biomass, such as viscose, modal and lyocell (Bergner 2013). To make textile from raw material includes several steps. The steps vary depending on the raw material but are usually production/cultivation of raw material, spinning of thread, transforming the threads into fabric, dying and/or other treatment of fabric and production of garment (Beton et al. 2014) or other kinds of textile. Some of the techniques used to transform threads into fabric are spinning, weaving, knitting and nonwoven-techniques (Bergner 2013). Dyeing and other steps in the production may be intense in terms of water use (Defra 2011) and use of chemicals (Naturvårdsverket 2015b).

In the Nordic countries textile waste is estimated to consist of 57 % cotton, 34 % polyester, 4 % wool and 5 % other, assuming that the waste has the same composition as the textile mix sold in the countries (Schmidt, Watson, Roos, Askham & Brunn Poulsen 2016a). If work clothes and cloths as well as clothing and home textile are considered, the inflow of textile products in Sweden consists of approximately 53 % polyester, 26 % cotton, 6 % viscose, 1 % wool and 15 % other (IVA 2015).

Textile is associated with environmental impact in different categories. Which category that is most important depends on the textile and fibre as well as how and where it is produced. For example, cotton is a natural fibre but need vast amounts of water to be produced (Defra 2011). Pesticides, herbicides and fertilisers are usually used during the cultivation of the cotton (Defra 2011). Polyester is based on petroleum (Bergner 2013) which is of fossil origin. Textile made of synthetic fibres counted as plastic (such as polyester and acrylic) can release microplastic (plastic less than 1 mm) during washing, which can end in marine sediments (Browne et al. 2011).

2.2. Legislation and Objectives

Waste in the EU is regulated by laws both from the EU and the member state. The European Union waste hierarchy is found in Directive 2008/98/EC of the European parliament and the council of 19 November 2008 on waste and repealing certain Directives, Article 4. The waste hierarchy states that

> 1. *The following waste hierarchy shall apply as a priority order in waste prevention and management legislation and policy:*
>   *(a) prevention;*
>   *(b) preparing for re-use;*
>   *(c) recycling;*
>   *(d) other recovery, e.g. energy recovery; and*
>   *(e) disposal.*
>
> (Directive 2008/98/EC of the European parliament and the council of 19 November 2008 on waste and repealing certain Directives, Article 4)

The waste hierarchy has been implemented in Swedish law in the Swedish Environmental Code 15 chapter 10 § (SFS 1998:808). Combustible waste, such as textile waste, must not be landfilled in Sweden (SFS 2001:512, 9 §). The management of household waste and waste similar to household waste (which textile waste is usually a part of), including collection, is handled by the municipalities (SFS 1998:808) while other waste from the private and public sectors is the responsibility of the private and public sectors (Naturvårdsverket 2012a). Some kinds of waste, such as newspapers and packaging are part of an extended producer responsibility where the producers are responsible for the waste management, including collection (Naturvårdsverket 2017b). Textile is not one of the products included in the extended producer responsibility in Sweden. However, in France extended producer responsibility covers textile (Watson et al. 2014). Extended producer responsibility has been presented as an alternative in Sweden by the Swedish Environmental Protection Agency (Naturvårdsverket 2016).

To show the environmental work that should be done within a generation, Sweden has a generation goal (Naturvårdsverket 2012b). It states that

> *The overall goal of Swedish environmental policy is to hand over to the next generation a society in which the major environmental problems have been solved, without increasing environmental and health problems outside Sweden's borders.*
>
> (Naturvårdsverket 2012b)

In addition to the generation goal, Sweden has a number of objectives in the area of environment, including 16 environmental quality objectives (Naturvårdsverket 2012b). Of these objectives some are connected to waste. Of the environmental quality goals, the objective of reduced climate impact is connected to incineration of waste with fossil origin, emissions of greenhouse gases from landfills and other parts of the waste management system (Naturvårdsverket 2012a). Chemicals in waste and from waste management are connected to the objective of a non-toxic environment and the objective of a good built environment relate to waste management (Naturvårdsverket 2012a). The last of the mentioned objectives is the only one to have an explicit mention of waste management (Naturvårdsverket 2012a).

In Sweden's waste management plan 2012-2017, textile has a specific objective and is an area of special focus in the waste prevention program of Sweden 2014-2017 (Naturvårdsverket 2012a; Naturvårdsverket 2015b). Furthermore, at the Swedish government's order the Swedish Environmental Protection Agency has investigated possible objectives and policy instruments for textile management (Naturvårdsverket 2016).

There is an ongoing discussion of the classification of textile as waste versus as raw materials for new products/still re-usable products. The Swedish Environmental Protection Agency has in a report said that if the intention of the owner is to get rid of the item, it is to be classified as waste due to the definition of waste in the law (Naturvårdsverket 2016). Others argue that textile could be recycled and should therefore not be considered as waste but rather as a resource (IVA 2015). The Swedish Environmental Protection Agency has stated that textile left where the collector at least in part use the material for recycling should be classified as waste (Naturvårdsverket 2016). They have also stated that the interpretation as part of their report has been made since several parties have had questions and do not wish the textile to be classified as waste (Naturvårdsverket 2016). Palm et al. (2014) mentioned difficulties regarding responsibility for authorizing collection of textile for re-use as another problem.

2.3. Flow of Textile Waste in Sweden

Textile waste originates from numerous sources, including households, industries, the public sector and after donations to charities. To examine the content of waste a Solid Waste Composition Study can be conducted. During a Solid Waste Composition Study waste is collected and sorted in different fractions. The fractions are chosen beforehand to give relevant information to the project the Solid Waste Composition Study is part of (Avfall Sverige 2017b). A Solid Waste Composition Study can give information about which percentage of the weight of the tested waste that consists of textile waste.

A few studies have tried to map flows of textile in Sweden, including waste. The focus of most of these studies has been on households and charity organisations. The information presented in this chapter is mainly taken from three reports; "Kartläggning av mängder och flöden av textilavfall" by SMED 2011, "Textila strömmar och förbehandlingsmetoder för textilfiberåtervinning – En studie om förutsättningar för pilot, begränsad och fullskalig drift av Re:newcells anläggning i Vänersborg" by Brismar 2014 and "Plockanalyser av textilier i hushållens restavfall – En kartläggning av mängder och typ av kläder, hemtextilier och skor" by SMED 2016. The results of these studies presented below are on a yearly basis.

The first report "Kartläggning av mängder och flöden av textilavfall" by SMED 2011 is based on statistics of textile flow in Sweden, reports and information from businesses handling textile in different ways. Different parts of the information are collected for different years and in the complete report information is taken from the years 2000-2011, with information taken foremost from the years 2009-2011 (SMED 2011). For most of the information some amounts or shares are found and then assumed to be applicable to the rest of the country (SMED 2011).

In the second report "Textila strömmar och förbehandlingsmetoder för textilfiberåtervinning – En studie om förutsättningar för pilot, begränsad och fullskalig drift av Re:newcells anläggning i Vänersborg" by Brismar 2014 information has been collected via personal contact and statistics. The report is made with chemical recycling of cotton as a focus and homogeneous flows of cotton are therefore in focus. The share of cotton in different clothes or home textile has been calculated for some categories based on statistics (Brismar 2014). The flows are based on the information from statistics and companies and are not re-calculated to represent all of Sweden (Brismar 2014). Both this report and the report by SMED 2011 use Solid Waste Composition Studies to determine the flow of textile in the residual waste from households (SMED 2011; Brismar 2014).

The last report "Plockanalyser av textilier i hushållens restavfall – En kartläggning av mängder och typ av kläder, hemtextilier och skor" by SMED 2016 used 391 Solid Waste Composition Studies performed 2012-2014 to estimate the amount of textile waste in the residual waste. Furthermore, the authors have made an attempt to subtract residual waste from the private and public sectors from the residual waste from households. 14 Solid Waste Composition Analyses were then performed in October 2015 (SMED 2016a). These were used to estimate the state of textile (torn or intact), the fibre content of the textile and textile with an elevated risk of hazardous chemical content (SMED 2016a). As in the first report the amounts were re-calculated to represent all of Sweden (SMED 2016a).

2.3.1. Textile Waste from Households

Households can dispose of their waste either in the garbage bin or at a recycling centre. Waste disposed of in the garbage bin is called residual waste while waste disposed of at a recycling centre is called bulky waste. When textile is part of the bulky waste it is collected as combustible waste. Additionally, households may choose to donate, sell, trade or give away their textiles. Flows of textile by informal channels (for example giving to friends or family) are difficult to investigate and will not be included in this project. At some recycling centres textile waste is collected separately, either for recycling, donation/re-use or incineration (Naturvårdsverket 2016; Lunds kommun 2018; Stockholm vatten och avfall 2015). Flows of textile from households can be seen in Figure 1. According to one smaller study in Sweden more people dispose of their textile waste as bulky waste than as residual waste, 25.3 %

versus 17 % (Ekström, Gustafsson, Hjelmgren & Salomonson 2012). The fate of donated textile will be further investigated in Chapter 2.3.3. Sold and traded textile goes into a new household and will eventually become waste from that household and the choices above are then relevant again. Residual waste is normally incinerated in Sweden (SMED 2011), as is the combustible part of the bulky waste. In Sweden, textile waste from households is unlikely to be recycled (SMED 2011).

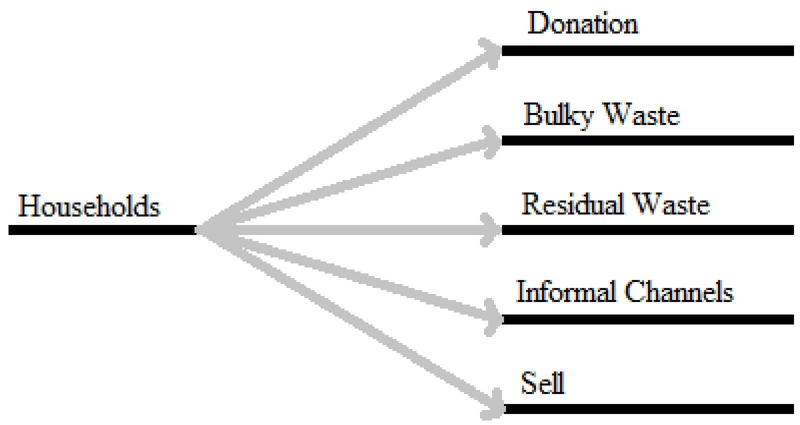

Figure 1 shows flow of textile from households.

In Sweden in 2008, approximately 26 000 tonnes, or 20 %, of the 131 800 tonnes of textile available for sale were donated (SMED 2011). In 2013, 23 630 tonnes of textile was donated from households and the private and public sectors (Brismar 2014). Table 1 shows these estimations on donations of textile from households.

The result from SMED (2011) is based on eight bigger charities, based on one year only and provided by Humana Sweden and the charity cooperation organisation Ideell Second Hand. The result from Brismar (2014) is based on interviews with nine charities with amounts taken from year 2012 or year 2013, depending on the company.

Table 1 shows different estimations on textile from households to donations.

Flow to	**Quantity (tonnes / year)**	**Source of information**	**Year of data**
Donations	26 000	SMED	2008
Donations (including from the private and public sectors)	23 630	Brismar	2012/2013

SMED (2014) estimates that 1500 tonnes of textile was sold online for re-use in Sweden 2011 and 2000 tonnes in 2013. These estimations are based on values given by Blocket and Tradera, re-calculated to include other online organisations selling textile and satisfying certain set criteria (SMED 2014). In addition to only including part of the second hand market online, the re-calculations are subject to uncertainties due to for example the "re-calculation factor" used and the limited time during which data was collected for the re-calculation (SMED 2014). Table 2 shows these estimations of textile sold online by households.

Table 2 shows different estimations on textile sold online by from households.

Flow to	**Quantity (tonnes / year)**	**Source of information**	**Year of data**
Sold online	1500	SMED	2011
Sold online	2000	SMED	2013

Most studies conducted concerning textile waste from households have focused on textile waste in the residual waste. In Sweden, the amount of textile waste in the residual waste has been estimated to 48 000 tonnes per year (SMED 2016a), 56 000 tonnes per year (SMED 2016a) or between 21 973 and 127 441 tonnes per year with a mean of 70 960 tonnes per year (SMED 2011). If all residual waste, including that from the private and public sectors, is taken into consideration the value is estimated to 72 000 tonnes (SMED 2016a). Table 3 shows these estimations of textile waste in the residual waste.

The first value (48 000 tonnes) is based on 391 Solid Waste Composition Studies from around Sweden performed during 2012-2014 and an attempt has been made to subtract residual waste from the private and public sectors from residual waste from households (SMED 2016a). An attempt has also been made to include differences in composition and amount of residual waste from for example houses and apartments in the calculations (SMED 2016a).

The result from SMED (2011) is based on Solid Waste Composition Studies from Skåne and the region around Stockholm performed during 2008-2010. The Solid Waste Composition Studies and the mean value of collected residual waste for 2008-2009 were used to calculate the minimum, maximum and mean amount of textile waste in residual waste (SMED 2011).

The value 72 000 tonnes from SMED (2016a) is based on the same 391 Solid Waste Composition Studies as mentioned above but the value is calculated with the same method as in SMED (2011) and include textile waste in residual waste from the private and public sectors. The last of the mentioned values (56 000 tonnes) represents the 72 000 tonnes but re-calculated to not include residual waste from the private and public sectors (SMED 2016a).

Table 3 shows different estimations on textile waste from households to residual waste.

Flow to	**Quantity (tonnes / year)**	**Source of information**	**Year of data**
Residual waste	48 000	SMED	2014
Residual waste	56 000	SMED	2014
Residual waste (including the private and public sectors)	72 000	SMED	2014
Residual waste (including the private and public sectors)	21 973 – 127 441 (mean 70 960)	SMED	Mean 2008-2009

Estimations of destinations of textile waste originating in households are summarized in Table 4. This summary includes results from Table 1, Table 2 and Table 3 and implies where the larger flows exist.

Table 4 shows different estimations on where textile from households ends up.

Flow to	**Quantity (tonnes / year)**	**Source of information**	**Year of data**
Donations	26 000	SMED	2008
Donations (including from the private and public sectors)	23 630	Brismar	2012/2013
Sold online	1500	SMED	2011
Sold online	2000	SMED	2013
Residual waste	48 000	SMED	2014
Residual waste	56 000	SMED	2014
Residual waste (including from the private and public sectors)	72 000	SMED	2014
Residual waste (including from the private and public sectors)	21 973 – 127 441 (mean 70 960)	SMED	Mean 2008-2009

SMED (2016a) has estimated that 41 %, or 17 800 tonnes 2015, of the textile waste in the residual waste in Sweden is not fit for re-use since it is damaged while the remaining 59 % could be re-used. The study further estimates that 42 % of the textile waste is made of mixes of fibres or fibres other than cotton while the rest is made of cotton (SMED 2016a). An estimation of 5100 tonnes of the 48 000 tonnes (around 11 %) of textile waste examined had an elevated risk of containing hazardous chemicals (SMED 2016a). These textiles have been removed before calculations of material and suitability for re-use were made (SMED 2016a). The study does however include some important uncertainties, for example only one month was used for the Solid Waste Composition Studies and only 14 Solid Waste Composition Studies were conducted (SMED 2016a).

442 000 tonnes of combustible waste per year is collected at recycling centres[1]. One Solid Waste Composition Study on bulky waste from two recycling centres in Stockholm 2012 showed a share of 4.5 % textile waste in the fractions “combustible waste” and “remaining waste” (Avfall Sverige 2013). If all textiles, including pillows, tents and other groups of textile not studied in this project, were included the share was 7.6 % (Avfall Sverige 2013). The fraction “remaining waste” used in Avfall Sverige (2013) does only represent the name of a fraction at a specific recycling centre and is not to be confused with residual waste discarded in the garbage bin by households.

In 2013, another Solid Waste Composition Study on bulky waste from the same two recycling centres in Stockholm showed a share of 5.4 % textile waste in the fractions “combustible waste” and “remaining waste” (Avfall Sverige 2013). If all textiles, including pillows, tents and other groups of textiles not studied in this project, were included the share was 8.5 % (Avfall Sverige 2013).

In both years collection of textile for re-use was available at the recycle centres in Stockholm (Avfall Sverige 2013). In 2013, collection of textile for recycling had been established at the recycling centres (Avfall Sverige 2013). The Solid Waste Composition Study in 2013 was conducted in September while that in 2012 was conducted in April (Avfall Sverige 2013). In

[1] Jenny Westin, Avfall Sverige, e-mail, 2018-04-20

both cases the fraction "combustible waste" had a considerable higher share of textile than the fraction "remaining waste" (approximately 12 % versus 4 % in 2012 and approximately 11 % versus 6 % in 2013) (Avfall Sverige 2013).

2.3.2. Textile Waste from the Private and Public Sectors

The private and public sectors have different alternatives for waste management depending on the type of waste. Leaving it as residual waste or bulky waste are alternatives if the waste is similar to that from households (Avfall Sverige 2017a). When the waste is of other types, the private and public sectors have to work with companies providing waste management services. Similar to households, the private and public sectors may donate or sell the textiles instead of disposing them as waste (Brismar 2014; SMED 2011). Flows of textile from the private and public sectors are shown in Figure 2. Commercial laundries, stores with textile products, hotels and producers of textile and products containing textile are examples of the private sector handling textile. Commercial laundries may handle textile from the public sector, such as textile from healthcare and some municipal functions, as well as textile from the private sector, such as textile from hotels and restaurants (SMED 2011; Brismar 2014).

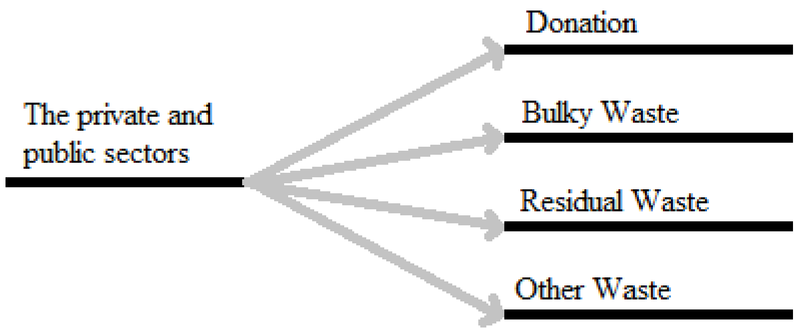

Figure 2 shows flows of textile from the private and public sectors.

Brismar (2014) has estimated the amount of textile waste from commercial laundries in Sweden going to incineration to be 165 tonnes. SMED (2011) estimated textile waste from commercial laundries in Sweden to 320 tonnes, with most textile waste going to incineration. Table 5 shows these estimations of flows of textile waste from commercial laundries to incineration.

Brismar (2014) sent out a questionnaire which was answered by seven commercial laundries. Some of the answers were from one specific commercial laundry while others were from organisations with several commercial laundries (Brismar 2014). The result from Brismar (2014) is based on these answers and therefore only represents the seven commercial laundries who contributed with information.

The result from SMED (2011) is based on information from four commercial laundries, re-calculated to represent textile waste via commercial laundries from all of Sweden's county councils. Some textile from the private sector and municipalities is included in the result from SMED (2011) but the focus is on county councils.

Table 5 shows different estimations on textile waste from commercial laundries.

Flow from	**Flow to**	**Quantity (tonnes / year)**	**Source of information**	**Year of data**
Commercial laundries	Incineration	165	Brismar	2013
Commercial laundries	Incineration (mostly)	320	SMED	2011

In 2013 around 450 tonnes of home textile and clothes were produced in Sweden (Naturvårdsverket 2016). Stores selling textile in Sweden usually do not experience high amounts of textile waste due to for instance clearance in the stores (SMED 2011) but 1210 tonnes of textile waste arise from consumer complaints of products (IVA 2015). The amount of textile waste from consumer complaints estimated by IVA (2015) is based on information from asked companies. These numbers as well as the ones from Table 5 are summarized in Table 6.

Table 6 shows different estimations on where textile from the private and public sectors ends up.

Flow from	**Flow to**	**Quantity (tonnes / year)**	**Source of information**	**Year of data**
Production in Sweden	Stores	450	Naturvårdsverket	2013
Consumer complaints of products	Waste	1210	IVA	2013
Commercial laundries	Incineration	165	Brismar	2013
Commercial laundries	Incineration (mostly)	320	SMED	2011

When looking at the amounts of production of garments and the amounts of losses in the report "Resurseffektivitet – färdvägar mot 2050" it can be seen that around 10 % of the textile is estimated to be lost in the processes of making a garment from the fabric (IVA 2015). Estimations of losses from raw product to garment range from 20 or 30 % (Carlsson 2016 in Naturvårdsverket 2016 p. 34; Tapio 2013 in Naturvårdsverket 2016 p. 34) to 50 % (IVA 2015).

Only one Solid Waste Composition Study on waste from the private and public sectors in Sweden including textile as a fraction has been found. In that study, conducted in Borås 2006, 6 % of the waste consisted of textile (Olofsson 2006). In the 11 samples taken in the study, the content of textile varied between 1 % and 13 % (Olofsson 2006). Olofsson (2006) was able to find two other Solid Waste Composition Studies to compare her result with. The two studies were one from Borås 2001 and one from Lidköping 2003 (Olofsson 2006). Furthermore, Olofsson (2006) was able to get personal information on the studies from Borås 2001 and Lidköping 2003 to make the results comparable to hers. Since the results were processed by Olofsson the information from Olofsson (2006) will be used. In both cases around 3 % of the waste from the private and public sectors consisted of textile waste (Olofsson 2006, pp.32 & 38). In 2018 at least three textile manufacturers existed in Borås (Make Works 2018).

2.3.3. Textile Donated to Charities

Textile can be donated to charities, and in more unusual cases to other organisations. Donated textile in Sweden is mainly sorted in Sweden or sent to be sorted in other European countries (Watson et al. 2016). As part of the sorting process, waste is removed from the flow, and the rest is sold, either in the country where it is sorted or in other countries, for example Eastern Europe, the Middle East, Central Asia or Africa (Watson et al. 2016). Sometimes this is done with organizations in other countries as middlemen (Watson et al. 2016). Flows of textile from donation are shown in Figure 3.

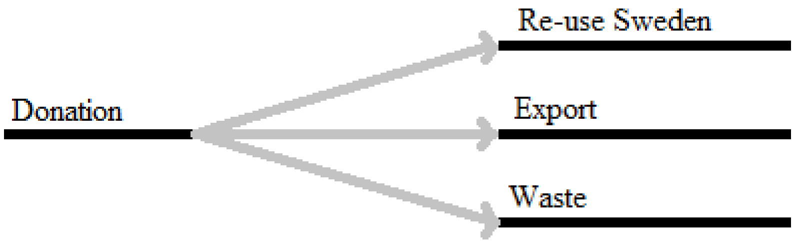

Figure 3 shows flows of textile from donation.

Total re-use from donated textile 2008 is estimated to 22 000 tonnes (Ideell Second Hand 2010, Humana Sverige 2010, Myrorna 2010 in Palm 2011, pp. 11). In 2008, 3000 tonnes of textile was estimated to be re-used in Sweden while 19 000 tonnes was exported (SMED 2011). SMED (2014) estimates that 5700 tonnes of the donated textile was re-used in Sweden 2011 and 6670 tonnes in 2013. The same study estimates that 15 900 tonnes of textile was exported and re-used abroad 2011 and 14 800 tonnes in 2013 (SMED 2014). Of the exported textiles an estimation of 7500 tonnes was not re-used 2011 (SMED 2014). The same number for 2013 was 6600 tonnes (SMED 2014). The textiles not re-used are assumed to be incinerated or recycled and partly consist of shoes and other non-textile products (SMED 2014). Table 7 summarizes these estimations of donated textile that is re-used and/or exported.

The result found in Palm (2011) is based on information from eight charities and the charity cooperation organisation Ideell Second Hand. The information from Humana Sverige in Palm (2011) is from 2009 while the rest of the information is from 2008 which is why 2008 is stated as the year of data. The result from SMED (2011) is based on information from one charity and the charity cooperation organisation Ideell Second Hand but represents amounts for eight of the bigger charities in Sweden.

Results from SMED (2014) regarding re-use in Sweden are based on information from 36 charities and are thought to represent most of the textile re-used in Sweden from donations with the exception of collections by local churches. The results of exported textile (both for re-use and not re-use) from SMED (2014) are based on statistics from SCB and information from 29 charities where the share of textile going to re-use is given by the charities or assumed based on answers from other charities.

Table 7 shows different estimations on re-used and exported textile from donations.

Flow to	Quantity (tonnes / year)	Source of information	Year of data
Re-used	22 000	Palm	2008
Re-used Sweden	3000	SMED	2008
Re-used Sweden	5700	SMED	2011
Re-used Sweden	6670	SMED	2013
Export	19 000	SMED	2008
Export (re-used)	15 900	SMED	2011
Export (re-used)	14 800	SMED	2013
Export (not re-used)	7500	SMED	2011
Export (not re-used)	6600	SMED	2013

Estimations on textile waste from donated textile in Sweden range from 1550 tonnes (Brismar 2014) to 4000 tonnes (SMED 2011). A third study estimated that 2000 tonnes textile waste from donated textile is incinerated in Sweden (Rosinski 2013 in Palm et al. 2014, pp. 53). Table 8 presents these estimations.

As above, the result from SMED (2011) is based on information from one charity and the charity cooperation organisation Ideell Second Hand but represents amounts for eight of the bigger charities in Sweden and the result from Brismar (2014) is based on interviews with nine charities with amounts taken from year 2012 or year 2013, depending on the company.

Table 8 shows different estimations on textile waste from donations.

Flow to	Quantity (tonnes / year)	Source of information	Year of data
Incineration	1550	Brismar	2012/2013
Incineration/landfill	4000	SMED	2008
Incineration	2000	Palm et al.	2013

Palm et al. (2014) estimate that between 500 and 1000 tonnes of donated textile is stolen before reaching the organisations. Only the most valuable of the stolen textiles are sold while the remaining textile waste is discarded or dumped[2]. Estimations on where the donated textile ends up are summarized in Table 9.

[2] David Althoff Palm, Ramboll, personal contact, 2018-03-20

Table 9 shows different estimations on where textile from donations ends up.

Flow to	Quantity (tonnes / year)	Source of information	Year of data
Re-used	22 000	Palm	2008
Re-used Sweden	3000	SMED	2008
Re-used Sweden	5700	SMED	2011
Re-used Sweden	6670	SMED	2013
Export	19 000	SMED	2008
Export (re-used)	15 900	SMED	2011
Export (re-used)	14 800	SMED	2013
Export (not re-used)	7500	SMED	2011
Export (not re-used)	6600	SMED	2013
Incineration	1550	Brismar	2012/2013
Incineration/landfill	4000	SMED	2008
Incineration	2000	Palm et al.	2013
Stolen	500 – 1000	Palm et al.	2013

2.4. Alternative Approaches to Textile Waste Management

Waste can be managed in several ways, though not all methods are equally desirable. As mentioned before, landfilling of combustible waste is not allowed in Sweden. It is also the least desired option according to the waste hierarchy (see Chapter 2.2). For these reasons landfilling is not discussed as an alternative for textile waste management in this report. Four other alternatives are described below.

2.4.1. Re-use

Even if one person has lost interest in a textile, the textile could in many cases still be used. This is the principal idea of re-use, to use something again for the same purpose, for example by selling or donating textile and buying second hand. Other examples include swopping (Swopshop 2018), clothes swap days (Naturskyddsföreningen 2018) and renting of textiles (Klädoteket 2017; Houdini 2018; Sabina & Friends 2018). Additionally, repairing or re-design of textile can make it possible to use the textile longer.

2.4.2. Recycling

Textile can also be recycled, which can be handled either chemically or mechanically. During chemical recycling of textile, the textile is broken down to pieces in different processes. These pieces can then be put together again and form a new textile. Different fibres go through different processes in chemical recycling; fibre made of plastic can be melted while fibre such as cotton can be dissolved (Naturvårdsverket 2015a). Mechanical recycling takes several forms, including techniques to make insulation, cloths and padding from textile waste (Naturvårdsverket 2015a). It is also possible to make new thread from textile waste through mechanical recycling, so-called fibre-to-fibre recycling (Naturvårdsverket 2015a). The fibres degrade during its lifetime (Naturvårdsverket 2015a) and several of the options for mechanical recycling mentioned in this chapter require incorporation of virgin textile (WRAP 2012). Some materials produced by mechanical recycling cannot be recycled a second time and the end product is usually down-cycled rather than recycled (Naturvårdsverket 2015a; Palm et al. 2014). When something is down-cycled it is recycled but the resulting material has lower quality than the original material. Thus, the material goes through steps of degradation rather than an endless loop of circularity.

At the moment, cotton cannot be recycled chemically, only mechanically (Naturvårdsverket 2015a). Mechanical recycling of cotton includes turning textile into industrial wipes (Palm et al. 2014) and non-woven products such as insulation (WRAP 2012). This recycling is down-cycling, and a circular flow is thus not created (Palm et al. 2014). However, in some cases the recycled product can be recycled again (WRAP 2012). Mechanical recycling in the form of fibre-to-fibre recycling can be used for cotton fibre (WRAP 2012). The old textile is then used to produce new thread (WRAP 2012). Chemical recycling of for example cotton and viscose is in theory performed using a solvent which dissolve the fabric (Jönsson et al. 2016). Chemical recycling of cotton is under development in Sweden (Naturvårdsverket 2015a; Jönsson et al. 2016). Flows will need to be homogeneous and contain a high share of cotton or other fibre from cellulose (Brismar 2014).

Polyester can be recycled chemically as well as mechanically. Chemical recycling of polyester is done with textile containing fibres of polyester even if small amounts of other fibres are sometimes accepted (Naturvårdsverket 2015a). Chemical recycling of polyester and polyamide 6 exist (Naturvårdsverket 2015a; Jönsson et al. 2016). Chemical recycling of polyester can give products with properties almost identical to virgin fibre (WRAP 2012). Mechanical recycling of polyester includes turning the textile into stuffing (WRAP 2012).

Both chemical recycling and fibre-to-fibre recycling of textile containing more than one kind of fibre, such as mixes of cotton and polyamide or viscos and polyester, are difficult (Naturvårdsverket 2015a). Research is done to make recycling of these textiles possible (Jönsson et al. 2016). Depending on fibre types and combinations, textile with mixed fibre content can sometimes be mechanically recycled. Textile containing both wool and acrylic can for example be used as insulation (WRAP 2012). For other mixes mechanical recycling can be difficult or impossible (Beton et al. 2014). A summary of the recycling techniques that can be used for different types of fibre is presented in Table 10.

Table 10 shows recycling techniques that can be used for different fibres. Based on information from WRAP (2012) and the text above.

Fibre	**Recycling technology**
Cotton	Insulation, industrial wipes, fibre-to-fibre
Polyester	Stuffing, chemical recycling
Wool	Stuffing, carpet underlay, fibre-to-fibre
Acrylic	Stuffing, fibre-to-fibre
Nylon	Chemical recycling
Textile of mixed fibres	Insulation (wool-acrylic)

Textile waste needs to be sorted in order to find textile suitable for re-use and recycling (Naturvårdsverket 2015a). Sorting is usually done manually (Brismar 2014) even if some other sorting techniques are available and under development (Palm et al. 2014). One example of a sorting technique under development is SIPTex (IVL 2016). SIPTex is thought to be able to improve textile recycling by giving fractions based on fibre content from the sorting and enhance the managed volume of textile (IVL 2017). Manual sorting by fibre content and categories is difficult (Palm et al. 2014). Furthermore, labour costs in richer countries make manual sorting expensive (Palm et al. 2014).

2.4.3. Production of Biofuel

It has been shown that it is possible to make biofuel from cellulose-based textiles, both from textiles with pure cellulose-based fibres and textiles where cellulose-based fibre are mixed with polyester (Jeihanipour & Taherzadeh 2009; Jeihanipour, Karimi, Niklasson, & Taherzadeh 2010; Högskolan I Borås 2017). The non-cellulosic fibres in the textile, for example polyester, will become waste that should be recycled (Jeihanipour et al. 2010). Some kinds of pre-treatment leave polyester almost unchanged regarding properties (Gholamzad, Karimi & Masoomi 2014). By using pre-treatment, 171 L of methane or 256 g of ethanol has been produced from 1 kg of textile waste consisting of 60 % cotton and 40 % polyester (Hasanzadeh, Mirmohamadsadeghi & Karimi 2018).

2.4.4. Incineration

Incineration is a way of reducing waste (Avfall Sverige 2018). In Sweden it is done with energy recovering and normally both heat and electricity are produced (Avfall Sverige 2018). Combustible waste has a heat value of approximately 10.38 MJ/kg (Ahrnstein & Dahlberg 2012). Textile has a heat value of 16 MJ/kg (Morris 1996), but this varies depending on for example which fibre the material consists of and the moisture of the textile (Naturvårdsverket 2015a). Incineration of textile can give rise to problems and affect the machine negatively if threads come in contact with parts of the machine (Olofsson 2006). Textile has also been found in deliveries to incineration when it is not supposed to be there (Olofsson 2006). If the fibres are of fossil origin (for example polyester made from fossil oil) incineration of the textile will release fossil carbon dioxide (CO_2) and contribute to the anthropogenic climate change.

2.5. Environmental Impact of Textile

Textile gives rise to environmental impact during its lifetime. Most studies on textile found in the literature review focused on environmental impact in form of climate change. Therefore, most of the presented data in this chapter represent this environmental impact category although other environmental impact categories might be significant for the total environmental impact.

According to a study by Roos, Sandin, Zamani & Peters (2015), the most intense part in term of emissions of greenhouse gases of the life cycle of clothes in Sweden is the production, especially the process of turning fiber into fabric. Transport by individuals to buy clothes is another intense part in term of emissions of greenhouse gases of the life cycle of clothes while retail, washing and waste management (incineration in the study) are less intense in term of emissions of greenhouse gases. Roos et al. (2015) also show that for the life cycle of clothes in Sweden the production is the most intense part in terms of water use, especially as the study takes water scarcity in different places into account. Roos et al. (2015) present results of several other environmental impact categories but they are neither discussed in depth nor shown in different part of the life cycle and are therefore not included here. The results from Roos et al. (2015) are based on five garments and represent only clothes and not home textile. Furthermore, van der Velden, Patel & Vogtländer (2014) acknowledge that the thickness of the yarn as well as the use of best practice methods in production have non-negligible effects on the environmental impact of textile.

It has been calculated for consumption of textile in Sweden and the Nordic countries that re-use is more environmentally beneficial than recycling, which in turn is more beneficial than incineration (Palm, Harris & Ekvall 2013; Schmidt et al. 2016a). The same is true for re-use of "Swedish/Nordic textile" in other countries than Sweden and the Nordic countries (Schmidt et al. 2016a). However, Naturvårdsverket (2015a) has shown that while a number of recycling techniques decrease the environmental impact of textile waste management compared to incineration, some recycling techniques instead increase the environmental impact compared to incineration. Techniques such as chemical recycling of cotton is included in the study even though it is not yet available, and the worst climate impact is found when polyester in textile of mixed fibre is incinerated while the cotton is chemical recycled (Naturvårdsverket 2015a). For the environmentally beneficial techniques, the savings in emissions of greenhouse gases per kg of textile waste range from 0.5 to 3 kg CO_2-equivalents (Naturvårdsverket 2015a).

Schmidt et al. (2016b) have estimated that re-use of clothes in the Nordic countries saves 10 235 kg CO_2-equivalents, 61 GJ of primary energy from renewable resources and 158 GJ of primary energy from non-renewable resources per tonne discarded textile. Recycling of textile waste by turning the textile into industrial wipes saves 78 GJ of primary energy from renewable resources and 8 GJ of primary energy from non-renewable resources per tonne discarded textile but emits 343 kg CO_2-equivalents per tonne discarded textile (Schmidt et al. 2016b). Incineration of the textile waste in Sweden affect the climate with emissions of 375 kg CO_2-equivalents per tonne discarded textile but saves 18 GJ of primary energy from renewable resources and 5 GJ of primary energy from non-renewable resources per tonne discarded textile (Schmidt et al. 2016b). These results are summarized in Table 11 where negative values are savings in that environmental impact category. The discarded textile in Schmidt et al. (2016a) consists of the fibre mix found in the Nordic countries and collection and sorting is included in the study. For the textile re-used in the Nordic countries, production of virgin textile and incineration of textile waste are avoided, in the case of incineration of the textile, energy production is avoided and in the case of recycling of the textile, production of cellulose-based wipes is avoided (Schmidt et al. 2016a). When the textile is not incinerated, some transportation and waste management at the end of the textile's lifetime are included in the study (Schmidt et al. 2016a).

Table 11 shows the environmental impact per tonne discarded textile in the environmental impact categories emissions of greenhouse gases and primary energy use for different waste management alternatives. Adapted from Schmidt et al. (2016b) and Schmidt et al. (2016a).

	Climate change (excluding biogenic carbon) (kg CO_2-equivalents per tonne discarded textile)	**Primary energy from renewable resources (GJ per tonne discarded textile)**	**Primary energy from non-renewable resources (GJ per tonne discarded textile)**
Re-use Nordic countries	-10 235	-61	-158
Industrial wipes	343	-78	-8
Incineration	375	-18	-5

The environmental impact can be measured in multiple categories and the results of different waste management differ in the categories depending on the fibre and technique used. For example, avoiding incineration of polyester results in savings in greenhouse gas emissions while re-use and recycling of cotton and wool result in more savings in other environmental impact categories (Schmidt et al. 2016a). According to Youhanan (2013) production of biofuel from textile waste is not beneficial compared to incineration of the textile with energy recovery with regards to the useful energy being produced. Furthermore, some of the chemicals that can be used in processes converting textile waste into biofuels have negative environmental impact (Hasanzadeh, Mirmohamadsadeghi & Karimi 2018).

2.6. Harmful Chemicals in Textile

In textile some hazardous chemicals are known to be used. This includes for example flame retardants, some metals, colours and biocides (Jönsson et al. 2016). Hazardous chemicals can be used to fill a function in the garment or be used in the production and then stay in the textile when sold (Jönsson et al. 2016). If the chemicals are not washed away during use they may go into the recycling process (KEMI 2014; Jönsson et al. 2016) and become part of the recycled material (Naturvårdsverket 2015a; SMED 2016b; KEMI 2014) or disturb the recycling process (SMED 2016b). Another possibility is that the recycling process create harmful chemicals from non-harmful chemicals (Jönsson et al. 2016).

Studies indicate that chemical use in textile life cycle can vary from 5.51 kg chemicals per kg textile (viscose shirt) to 1.86 kg chemicals per kg textile (working trousers) or from 1.92 kg chemicals per garment (cotton jeans) to 0.61 kg chemicals per garment (cotton T-shirt) (Olsson, Posner, Roos & Wilson 2009). The values are estimations of a normal garment of the studied type and content may vary, for example flame retardants and chemicals providing anti-bacterial properties were not included in the study (Olsson et al. 2009). Textiles used in for example home textile in the private and public sectors as well as working clothes may disrupt hormones or have negative environmental properties if they contain flame retardants (SMED 2016b). Some chemicals used for colouring have or are suspected of having harmful properties (SMED 2016b). The harmful chemicals can increase the risk of cancer, cause allergic reactions or disturb the reproducing capacity of humans (SMED 2016b).

Rain clothes and skiing clothes are the groups of clothes with risk of most groups of harmful chemicals; colouring, anti-bacterial substances, chemicals providing oil- dirt- and waterproof properties as well as softeners may be used (SMED 2016b). Mittens, caps and sport clothes may contain chemicals for colouring, anti-bacterial properties as well as for oil- dirt- and waterproof properties (SMED 2016b). Outerwear may contain chemicals for colouring, oil- dirt- and waterproof properties and softeners while working clothes may contain chemicals for colouring, oil- dirt- and waterproof properties and flame retardants (SMED 2016b). All of the function mentioned can be achieved with harmful chemicals (SMED 2016b).

Harmful chemicals can leave the textile by different paths (KEMI 2014). Most of these paths include possible contact with humans via, for example, the air people breathe or contact with the skin (KEMI 2014). To decrease the risk of negative impact on humans from harmful chemicals in recycled textile, the textile might be used in some applications such as insulation (SMED 2016b). Some chemicals are harmful for the environment and they can reach the environment via, for example, washing (KEMI 2014). Harmful chemicals have also been found in clothes of organic cotton or labelled as eco (Luongo 2015).

3. Case Study

In collaboration with Ramboll, flows of textile waste that can potentially be used in a different way have been investigated. Ramboll is part of another project investigating alternative management of discarded textile, for example, using textile waste to produce acoustic panels.

The product of interest to Ramboll, and thus the focus of this case study, is an acoustic panel made of second hand textile. To be of interest to the project the second hand textile must have been sorted but initially deemed unfit for any waste treatment alternative but incineration[3]. Textile containing hazardous chemicals is not of interest in the project[4]. During this project it is assumed that the textile in the acoustic panel can be divided into two layers, one inner layer and one outer layer, and that the outer layer will be visible after installation of the panel. Textile used in the inner layer will not be subject to restrictions in colour or fibre while textile used in the outer layer will need to give a uniform impression.

Homogeneous flows of textile make it easier to know the content and characteristics of the flows. Furthermore, they decrease cost of, for example, sorting and will be preferred in this study. Larger flows decrease the need of numerous smaller flows, making them easier to handle and preferable.

3.1. Method

To begin the case study, information about the acoustic panel of interest to Ramboll and acoustic panels overall was gathered. Thereafter, flows of textile waste from the private and public sectors were investigated via e-mails and telephone calls. This was done since homogeneous flows of textile were preferable for a new product and the possibility of homogeneous flows was assumed to be high in textile waste from the private and public sectors. Safety clothes and other working clothes used at, for example, construction sites and in different producing industries were assumed to have a high risk of hazardous chemical content (see Chapter 2.6). For this reason, this flow of textile waste was not investigated further. Employee clothing used in retail stores, grocery stores and fast food restaurants created a possible flow of textile waste. No investigations of this flow were found and it was therefore investigated further. Several companies were contacted via e-mail in order to find out the amount of textile waste from employee clothing generated by the private sector. If no answer was given after about two weeks the company was contacted via telephone.

Flows from commercial laundries are present in other studies (see Chapter 2.3.2) but were deemed very relevant because of the possibility of large and homogeneous flows. Several commercial laundries were therefore contacted via e-mail. If requested, the companies were able to give their answers via telephone. Textile from restaurants, hotels and the public sector was assumed to go via commercial laundries. This flow was therefore not investigated further as its own flow but was assumed to be included in the investigation of commercial laundries, even though it is possible that some part of this flow does not go via commercial laundries. Finally, in order to investigate the potential flow of textile waste in the fraction ”combustible waste” (part of the bulky waste) at recycling centres, I participated in a Solid Waste Composition Study that Envir AB performed in Gothenburg.

[3] Intern documentation, Ramboll, 2018-03-07
[4] Intern communication, Ramboll, 2018-03-12

3.2. Acoustic Panels

Noise can harm and in other ways have negative impact on humans (Johansson 2002). In Sweden, a number of rules and laws regulate the level of noise at different places such as in schools, at workplaces and in residential buildings (Boverket 2017). Acoustic panels are an example of a product group that can be used to reduce the noise level in an indoor space. They exist for placement on both walls and ceilings.

Acoustic panels exist in a number of different appearances and can consist of a variety of materials. For example, the company Acoustical Solutions sell acoustic panels such as "Acoustic Fabric Wrapped Panels", "Cotton Acoustic Panels", "Foam Acoustic Panels", "Metal Acoustic Panels", "Polyester Acoustic Panels", "PVC Or Ripstop Wrapped Acoustic Panels" and "Wooden Acoustic Panels" (Acoustical Solutions 2018). The product "Cotton Acoustic Panels" is made from recycled cotton (Acoustical Solutions 2018). The company Akustikmiljö offer acoustic panels made of recycled PET (Akustikmiljö 2018), the company Rockfon® offer a product made of mineral wool and fleece (Rockfon® 2018), the company Ecophon partly uses recycled glass in some of their products (Ecophon 2018) and the companies Träullit, BAUX and Troldtekt all offer products made of a combination of wood wool and cement (Träullit 2018; BAUX 2018; Troldtekt 2018). Table 12 summarize these examples of different material used in acoustic panels.

Table 12 indicates the vast diversity of materials used in acoustic panels.

Material	**Company**
Fabric wrapped	Acoustical Solutions
Recycled cotton	Acoustical Solutions
Foam	Acoustical Solutions
Metal	Acoustical Solutions
Polyester	Acoustical Solutions
PVC or Ripstop wrapped	Acoustical Solutions
Wood	Acoustical Solutions
Recycled PET	Akustikmiljö
Mineral wool and fleece	Rockfon®
Recycled glass (partly)	Ecophon
Wood wool and cement	Träullit, BAUX and Troldtekt

Environmental Product Declarations (EPD) have been made for some of the acoustic panels mentioned above. The EPD of Troldtekt's products has been performed by an external party and includes environmental impacts from raw material to manufacturing of the panel (IBU 2014). It shows that the panels contribute to global warming with 208 kg CO_2-equivalents per tonne grey acoustic panel and 434 kg CO_2-equivalents per tonne white acoustic panel (IBU 2014). The total use of renewable primary energy resources is 8730 MJ per tonne grey acoustic panel and 8780 MJ per tonne white acoustic panel (IBU 2014). The total use of non-renewable primary energy resources is 4930 MJ per tonne grey acoustic panel and 6390 MJ per tonne white acoustic panel (IBU 2014).

An EPD verified by an external party has been made for Ecophon's product family "Gedina" (Ecophon 2015). The EPD is made for one m^2 of acoustic panel with the weight of 1326 g and include all of the life cycle (Ecophon 2015). Re-use, recovery or recycling is not included as alternative at the end of the life cycle (Ecophon 2015). To make it comparable to the other EPD described, only the product stage will be included in the results shown here. The production of the product contributes to global warming with 2.2 kg CO_2-equivalents per m^2

acoustic panel (Ecophon 2015). For the production, the total use of renewable primary energy resources is 24 MJ per m^2 acoustic panel and the total use of non-renewable primary energy resources is 51 MJ per m^2 acoustic panel (Ecophon 2015).

Several of Rockfon®'s acoustic panels are included in a self-declared EPD (Rockfon® 2016). The EPD is made for one m^2 of acoustic panel with the weight of 3.6 kg and include production of the acoustic panel from raw product to manufacturing (Rockfon® 2016). The acoustic panel contributes to global warming with 7.17 kg CO_2-equivalents per m^2 acoustic panel (Rockfon® 2016). The total use of renewable primary energy resources is 12.5 MJ per m^2 acoustic panel and the total use of non-renewable primary energy resources is 141 MJ per m^2 acoustic panel (Rockfon® 2016). Comparisons of the different acoustic panels are presented in Table 13.

Table 13 shows environmental impact for the different acoustic panels, calculations are shown in Appendix 1.

Company	**Global warming (CO_2-equivalents / tonne acoustic panel)**	**Total use of renewable primary energy resources (MJ / tonne acoustic panel)**	**Total use of non-renewable primary energy resources (MJ / tonne acoustic panel)**
Troldtekt (grey)	208	8730	4930
Troldtekt (white)	434	8780	6390
Ecophon	1660	18 100	38 500
Rockfon®	2140	3500	39 200

3.3. E-mail/Interviews

E-mails were sent to several companies, both in the area of fast food restaurants and retail/grocery stores, in this project called "employee clothing", as well as in the area of commercial laundries. The two cases are presented in different sub-chapters below.

3.3.1. Employee Clothing

A number of questions were asked in the e-mails. Two questions concerned the owner of the clothes and where they are washed to find out if the flow is managed by commercial laundries or not. A question of waste management of the textile waste was asked to find out if the textile waste was already re-used, ended in the residual waste or was managed in some other way. To identify the size of the flow, the amount of textile waste from employee clothing was asked. A question of interest in collaboration was also included for Ramboll's project.

The contacted companies were chosen with an attempt to include the bigger companies in Sweden where workers were known to wear specific working clothes representing the company. As mentioned above safety clothes and similar clothes were not investigated due to the risk of harmful chemicals. Employee clothing from work where employees come in contact with food, such as in restaurants as well as in food production, was considered a possible flow. Employee clothing from retail and grocery stores was another possible flow. Textile from healthcare are often managed by commercial laundries and since the goal of this part of the case study was to find flows of textile that might not come in contact with commercial laundries this flow was not investigated. The line of business of the investigated flow was thus focused on retail/grocery stores and restaurants. When choosing the specific companies to contact an attempt was made to choose companies where the differences within a specific trade, such as fast food restaurants focusing on hamburgers, as well as the overall differences in the sector could be investigated.

In total, ten companies were contacted. Of the companies three are organisations with several stores in retail/grocery, one is a store in retail/grocery, one is an organisation within the food production industry, three are chains of fast food restaurants focusing on hamburgers, one is an organisation with several fast food restaurants and the last one is a chain of stores selling furniture.

Most of the ten contacted companies either did not answer the e-mails or the telephone calls or answered that they were not able to contribute with information to the project. Only one company contributed with information and their response is shown in Table 14.

Table 14 shows answers from companies providing response with information.

Company	**Owner of clothes**	**Washing**	**Waste management**	**Amount**	**Interest in collaboration**
MAX	MAX (not shoes)	At workplace	Incineration	-	Theoretically yes but probably not practically

As can be seen in Table 14, no company could provide amounts of their textile waste from employee clothing. The answer provided indicated that improvement of textile waste management is possible since incineration is less preferred than re-use or recycling, both with respect to the waste hierarchy and the information in Chapter 2.5 on environmental impact.

3.3.2. Commercial Laundries

Earlier studies have shown that a flow from commercial laundries to incineration exists. To examine the existing flow, e-mails with questions were sent to several commercial laundries. One question about the fibre content of the textile waste was asked to investigate possible alternatives for waste management. Another question was asked about the size of the flows of different fibre mixes to other management alternatives than re-use. This question combined with the first one indicates the size of flows suitable for different waste management alternatives. The last question asked related to interest in collaboration.

The companies were chosen with an attempt to include bigger commercial laundries in Sweden. This was done since larger flows of textile were requested by Ramboll. Both private companies and companies associated with the public sector were contacted to include as much of the sector as possible. Eight commercial laundries were contacted and three of them answered the questions. The answers of the companies are shown in Table 15.

Table 15 shows answers from companies providing response with information.

Company	**Fibre content**	**Amount to incineration (tonnes / year)**	**Interest in collaboration**
Skånetvätt	50 % cotton, 50 % polyester	25 - 34[5]	Yes
Tvätteriet Alingsås	50 % cotton, 50 % polyester	0	-[6]
TVNo[7]	100 % cotton	1.6	Yes
	50 % cotton, 50 % polyester	4.3	
	Other mix cotton/polyester	3.5	
	50 % polyester, 50 % tencel	0.3	
	100 % polyester	0.5	

3.4. Solid Waste Composition Study in Gothenburg

Envir AB is a company in Sweden performing Solid Waste Composition Studies (Envir 2018). On the 29th of January 2018 Envir AB performed a Solid Waste Composition Study in Gothenburg in which I participated. The fraction examined was "small combustible waste" collected from two recycling centres located close to Gothenburg (Vukicevic 2018a). 1146 kg of waste was sorted (Vukicevic 2018a). In total, 17.8 % of the examined material consisted of textile (Vukicevic 2018a) such as clothes, pillows, duvets and cloths (Vukicevic 2018b). If stuffed textile was not included the share was reduced to 13.3 % of the waste (Vukicevic 2018b). Of the clothes and textile (not including stuffed textile and other textile) 40.5 kg was fit for re-use, 14.5 kg was accessories and 78 kg was fit for recycling (Vukicevic 2018b). Safety clothes as well as cloths were considered as other textile (Vukicevic 2018b).

The following days, four more Solid Waste Composition Studies on other fractions and origin of waste were conducted (Vukicevic 2018a) in which I did not participate. Some textile was found in the fractions "wood waste" and "inert waste" but the share was under 1 % in each case (Vukicevic 2018a). In the fraction "large combustible waste" 13.7 % textile waste was found and in the fraction "stuffed furniture" 11.6 % textile waste was found (Vukicevic 2018a). If the stuffed textile was not included the shares were reduced to 7.4 % (Vukicevic 2018c) and 1 % (Vukicevic 2018d) of the waste respectively. Of the clothes and textile (not including stuffed textile and other textile) found in the fraction "large combustible waste" almost all was fit for re-use (Vukicevic 2018c). In the fraction "stuffed furniture" most textile was duvets and pillows but the clothes and textile (not including stuffed textile and other textile) found was either accessories or fit for re-use (Vukicevic 2018d).

The fraction "large combustible waste" and the fraction "stuffed furniture" were from different recycling centres (Vukicevic 2018a). However, even if the names differ the same kind of waste was supposed to be sorted there (Vukicevic 2018a). The fractions were therefore assumed to be the same.

[5] Around 42 tonnes of combustible waste, including textiles, 2017 of which 60-80 % is estimated to consist of textile waste.
[6] The company has no flow to incineration, making this question irrelevant.
[7] Amounts have been calculated using information from the company.

4. Results and Analysis

In this section the flows found in the literature review and presented above in Chapter 2 as well as information from the Solid Waste Composition Study and the personal contact from Chapter 3 will be summarized to show flows of textile waste in Sweden that could be managed differently with decreased environmental impact as a result (Chapter 4.1). In order to summarize the flows and make calculations, the results are used as if they all came from the same year even though this is not the case. Flows of interest to Ramboll will be presented in Chapter 4.2. Finally, in Chapter 4.3 the environmental impact of the alternative management will be presented and analysed. For calculations see Appendix 1.

4.1. Summary of Textile Waste in Sweden Suitable for Alternative Management

Not all flows presented in Chapter 2 are relevant for an alternative management. Re-use is high in the waste hierarchy and preferable from an environmental perspective. Flows to re-use presented in Chapter 2.3 will therefore not be investigated further. At some point though, re-used textile will become waste. If this happens in Sweden it is assumed that this waste is included in the flows described earlier. If it happens in another country, it is assumed to be a part of that country's waste management and is thus not included in this project. Flows sold online are assumed to be fully re-used, as are flows to export where no information of re-use or other management was found. Flows from production and to donations are assumed to correspond to bought textile and donations from households and the private and public sectors without calculations being made to confirm this.

Some of the flows presented in Chapter 2 are relevant for an alternative management. As seen in Chapter 2.5 and in the waste hierarchy, incineration is the least favoured alternative of the alternatives presented in this project. Flows to incineration, direct as well as via residual waste and bulky waste, have therefore been included in the flows that could be managed better from an environmental point of view. All the waste from commercial laundries found by SMED (2011) is assumed to go to incineration even if it is stated that only most of it goes to incineration. The end management of flows to waste or export not re-used is difficult to know, so it is assumed that these flows are incinerated and they are therefore also included. Likewise, the fate of the stolen flow is hard to know and since the estimations of amounts as well as the percentage going to re-use are unknown, this flow will not be investigated further here.

The remaining flows presented in Table 4, Table 6 and Table 9 are summarized and presented in Table 16. Theses flows represent flows of interest for improved waste management found in the literature review. In the calculations below values have been chosen to represent the different sectors. These values are also presented in Table 16. As the information on flows presented in Chapter 2 are amounts per year, so are the results.

Table 16 shows a summary of textile waste flows suitable for alternative management, summarized from Table 4, Table 6 and Table 9. It further shows the values used as representations of the different sectors in the calculations.

Flow from	**Flow to**	**Quantity (tonnes / year)**	**Source of information**	**Year of data**
Households	Residual waste	48 000	SMED	2014
Households	Residual waste	56 000	SMED	2014
Households, the private and public sectors	Residual waste	72 000	SMED	2014
Households, the private and public sectors	Residual waste	21 973 – 127 441 (mean 70 960)	SMED	Mean 2008-2009
Value used in calculations		48 000 – 72 000		
Donations	Export (not re-used)	7500	SMED	2011
Donations	Export (not re-used)	6600	SMED	2013
Donations	Incineration	1550	Brismar	2012/2013
Donations	Incineration/landfill	4000	SMED	2008
Donations	Incineration	2000	Palm et al.	2013
Value used in calculations		8150 – 11 500		
Consumer complaints of products	Waste	1210	IVA	2013
Commercial laundries	Incineration	165	Brismar	2013
Commercial laundries	Incineration (mostly)	320	SMED	2011
Value used in calculations		1375 – 1530		

4.1.1. Textile Waste in Residual Waste from Households

Households discard between 22 000 and 127 000 tonnes of textile waste as residual waste yearly, as seen in Table 16. If the maximum and minimum values from SMED (2016a) are not taken into consideration, the amount becomes between 48 000 and 72 000 tonnes. SMED (2016a) found that around 11 % of the textile waste has an elevated risk of containing hazardous chemicals. This means that between 5000 and 8000 tonnes of textile waste has an elevated risk of containing hazardous chemicals. If this flow is not taken into consideration for alternative management, between 43 000 and 64 000 tonnes of textile waste is left. Assuming that 41 % of the textile waste cannot be re-used, as found by SMED (2016a), between 18 000 and 26 000 tonnes of textile waste in the residual waste is not fit for re-use while between 25 000 and 38 000 tonnes of textile waste is fit for re-use.

Analysis

The result from SMED (2016a) where attempts have been made to subtract residual waste from the private and public sectors from residual waste from households might be the most reliable data for waste from households. The result from SMED (2016a) is based on considerably more Solid Waste Composition Studies than the result from SMED (2011). In SMED (2011) areas with high population are represented to a higher degree than in Sweden overall which might also affect the results. The Solid Waste Composition Studies used by SMED (2016a) are from all over Sweden. However, neither of the reports have taken variation during the year (as for example if people clean out their wardrobe for summer) into consideration.

The results from SMED (2016a) and SMED (2011) where no attempt was made to subtract residual waste from the private and public sectors from residual waste from households might give a more complete picture of the textile waste in residual waste overall, since it is possible that the private and public sectors also dispose of textile in the residual waste. However, the method used during Solid Waste Composition Studies does not take this into consideration and it is possible that the share of textile in residual waste differs between households and the private and public sectors. Even so, if the residual waste from the private and public sectors is subtracted without further investigation, a possible flow of textile waste is lost.

4.1.2. Textile Waste from Donations and the Private and Public Sectors

Between 1550 and 4000 tonnes of donated textile is incinerated or landfilled in Sweden while another 6600 to 7500 tonnes of exported donated textile is not re-used, as seen in Table 16. Here it is assumed that none of these flows can be re-used but that all of the flows can still be managed better from an environmental point of view, even if it in reality might already be partly recycled or be non-textile (in the case of export not re-used). Assuming that all consumer complaints of products is a result of faulty products not fit for re-use, this flow is also available for changed management other than re-use. The flow of textile waste from commercial laundries to incineration is showed to be between 165 and 320 tonnes in Table 16. It is assumed that this flow is not fit for re-use even though re-use might be possible with, for example, lower standards. This means that in total, between 10 000 and 13 000 tonnes of textile waste from donations and the private and public sectors is available for alternative management that do not include re-use.

It is possible that textile waste is included in waste from the private and public sectors that is not similar to household waste. This was supposed to be a part of the mapping of the textile flows. Olofsson (2006) found 6 % textile waste among the waste from the private and public sectors. Olofsson (2006) also showed that two other reports had results which estimated the same number to 3 %. One of these results, as well as Olofsson's (2006), was based on waste from Borås. Since textile manufacturers exist in Borås it is possible that some or most of the textile waste originates from textile production. The possibility of results not representing the Swedish average as well as the age of the study makes any calculations based on it uncertain. Therefore, no conclusions will be drawn on this area.

Analysis

The results from SMED (2014) on exported donated textile not re-used are based on information from a number of organisations. The variations in amounts are due to the different years of data collection. When it comes to the amounts of donated textile incinerated or landfilled in Sweden reported by SMED (2011) and Brismar (2014) the amounts vary even though almost the exact same organisations provided information. This might be a result of the fact that the studies were conducted during different years. The result from Palm et al. (2014) is based on contact with one person, making its reliability uncertain since it is difficult to know if that person has full knowledge of the entire flow of donated textile to incineration in Sweden.

The commercial laundries contacted by Brismar (2014) and SMED (2011) are partly overlapping. It is unclear if the commercial laundries contacted by Brismar (2014) and SMED (2011) service the same kind of clients (such as hospitals or restaurants). It is therefore possible that the results from Brismar (2014) and SMED (2011) should not be interpreted as the maximum and minimum value (as in this rapport) but rather be summarized to show the true amount. SMED (2011) has attempted to re-calculate their result to represent textile waste from all of Sweden's county councils which might make a summary of the values precarious. Either way, few commercial laundries have contributed with information to the studies and the results from Brismar (2014) and SMED (2011) are therefore likely to be lower than the true value.

4.1.3. Textile Waste from Production

If the 10 % losses from the process of making a garment from fabric found by IVA (2015) are accurate for the textile production in Sweden, Sweden's production of 450 tonnes of textile will give rise to about 50 tonnes of textile waste in form of fabric. This is unlikely to be textile fit for re-use but might be recycled. The current waste management of this flow is unknown but assumed to be incineration since Olofsson (2006) reported textile going to incineration.

4.1.4. Textile Waste in Bulky Waste at Recycling Centers

Of the results from Avfall Sverige (2013), the value of 4.5 % in 2012 and the value of 5.4 % in 2013 align best with the textile categories examined in this project. The values are from both "combustible waste" and "remaining waste" at recycling centres. In both cases the total share of textiles was higher for "combustible waste" and the presented values are thus lower than if the fraction "combustible waste" would have been examined separately.

Of the results from Vukicevic (2018a), textile not including stuffed textile aligns best with the purpose of this project. The shares of textile in the fractions were then 13.3 % of the small combustible waste, 7.4 % of the large combustible waste and 1 % of the stuffed furniture. The part of the textiles not fit for re-use found by Vukicevic (2018a) varied significantly from almost none to around 65 %. The composition of textile products also varied significantly.

The mean value of the five values from Avfall Sverige (2013) and Vukicevic (2018a) is 6.3 %. By using this and the 442 000 tonnes of combustible waste, a flow of about 28 000 tonnes of textile waste in the combustible waste at recycling centres can be estimated. Since the share of re-useable/recyclable textile varied significantly in the different fractions during the Solid Waste Composition Studies in Gothenburg it is difficult to know how much of the textile that can be re-used or recycled. As a first estimation it is assumed that 60 % of the textile is fit for re-use while the rest is fit for recycling. The estimation is based on the results from SMED (2016a) on textile waste in the residual waste but it is still an estimation without extensive support.

With the assumptions made, around 17 000 tonnes of textile is available for re-use in the combustible waste at recycling centres and another 11 000 tonnes of textile is available for recycling. It is likely that these flows also contain textile with a risk of hazardous chemical content but since no information on this has been found, no calculations are made on the subject.

Analysis
This result is lower than most estimations of textile waste in residual waste but might be reasonable since SMED (2011) estimate that about half of the bought textile ends up in the residual waste. The result is counter to the information from Ekström et al. (2012) that more people dispose of their textile waste as bulky waste than as residual waste (assuming that every person disposes of the same amount of textile waste). However, the study by Ekström et al. (2012) is a small one and might therefore not give a complete picture.

The results on the share of textile waste in the different fractions reported from Avfall Sverige (2013) and Vukicevic (2018a) vary significantly, from 1 % to 13.3 %. This means that the amount of textile waste varies from 4420 to 58 786 tonnes, indicating the uncertainties of the result and the difficulties of making a good estimation.

As mentioned, the estimation on the share that could be re-used or recycled is highly uncertain. For a better estimation, more Solid Waste Composition Studies need to be conducted with focus on if the textile is damaged or not.

4.1.5. Summary
The results from Chapter 4.1.1 to Chapter 4.1.4 on flows with potential for an alternative waste management are presented in Table 17 and Table 18. Table 17 shows flows that could be re-used while Table 18 shows flows that could potentially be managed in an alternative way, for example recycled, but not re-used. The mean value for textile that could be re-used and managed in an alternative way, not including re-use, in the different sectors are shown in Figure 4 and Figure 5 respectively. Summarizing all results, 42 – 55 ktonnes of textile waste per year is available for re-use, 39 – 50 ktonne of textile waste per year is available for alternative waste management not including re-use and between 5 and 8 ktonnes of textile waste per year has an elevated risk of containing harmful chemicals.

Table 17 shows amounts of textile waste that could be re-used.

Sector	**Minimum (tonnes / year)**	**Maximum (tonnes / year)**
Residual waste from households	25 000	38 000
Textile waste from donations and the private and public sectors	-	-
Textile waste from production	-	-
Bulky waste at recycling centres	17 000	17 000
Summary	**42 000**	**55 000**

Table 18 shows amounts of textile waste that could potentially be managed in an alternative way, for example recycled, but not re-used.

Sector	**Minimum (tonnes / year)**	**Maximum (tonnes / year)**
Residual waste from households	18 000	26 000
Textile waste from donations and the private and public sectors	10 000	13 000
Textile waste from production	50	50
Bulky waste at recycling centres	11 000	11 000
Summary	**39 050**	**50 050**

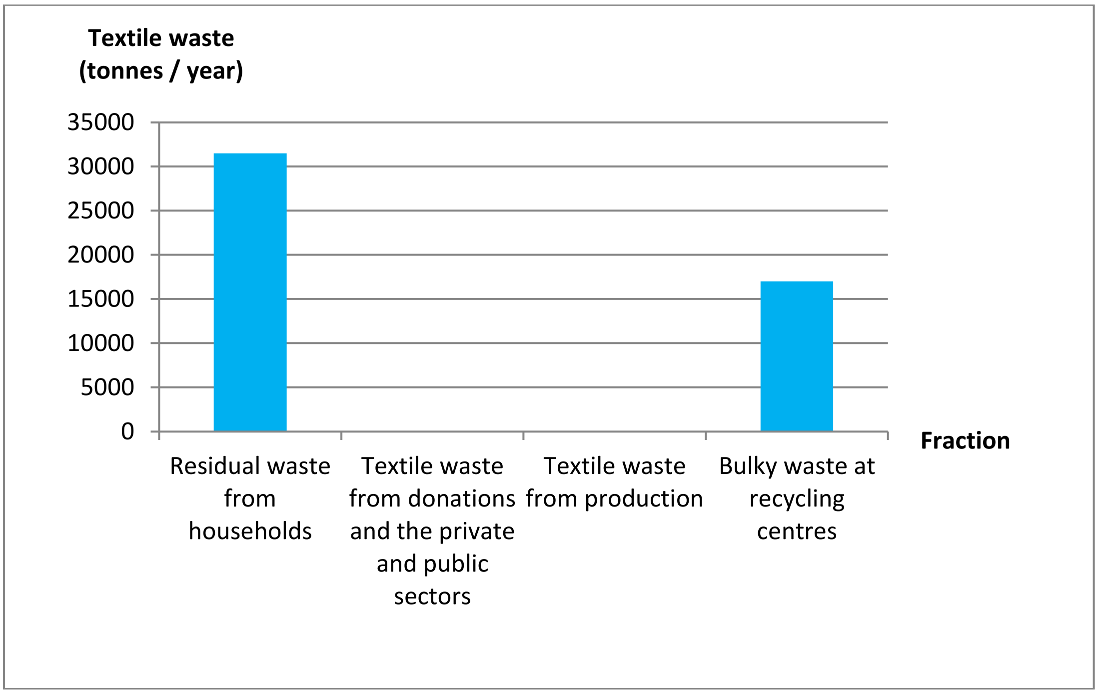

Figure 4 shows amounts of textile waste in the different sectors that could be re-used. The mean values of minimum and maximum is used.

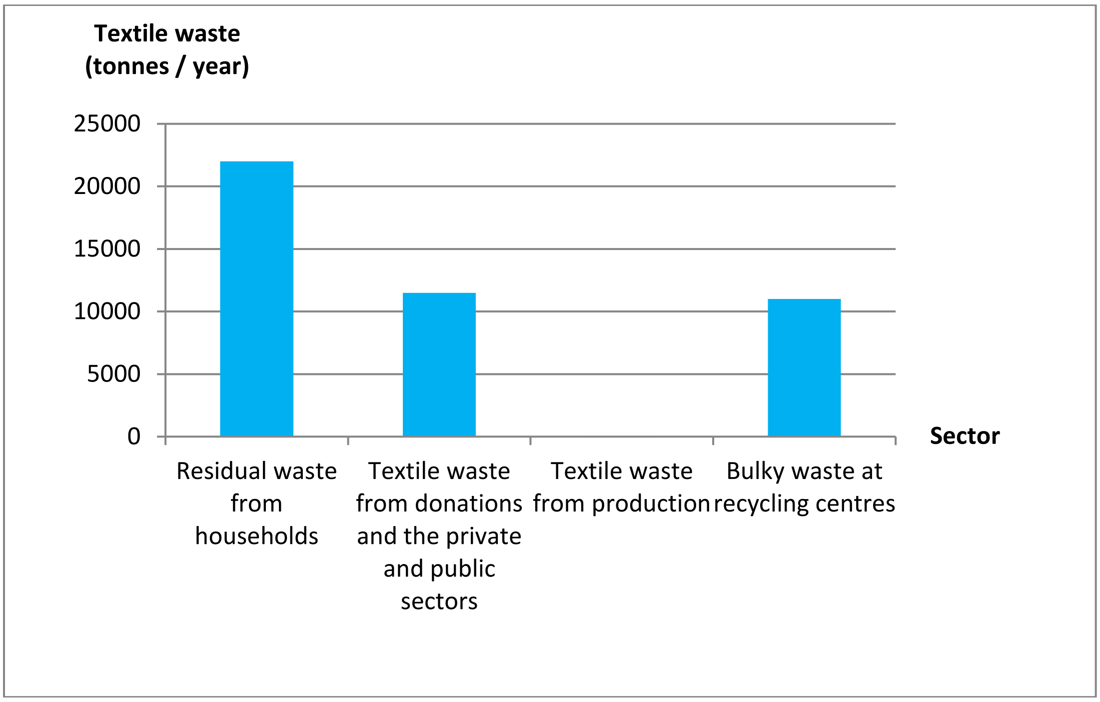

Figure 5 shows amounts of textile waste in the different sectors that could potentially be managed in an alternative way, for example recycled. The mean values of minimum and maximum is used.

4.2. Summary of Flows of Textile Waste in Sweden Usable for the Acoustic Panel Requested by Ramboll

Ramboll's project is currently on-going and thus the demands on the textile are not complete or very specific and might be subject to changes. Furthermore, it has not been decided what amounts or flows of textile waste are needed to make the production of the acoustic panels reasonable. No conclusions can thus be drawn from the results of the contact with companies presented in Chapter 3.3.

If only textile that have been sorted and found unsuitable for re-use and recycling is included (as requested by Ramboll) the flows become much smaller than in the summary in Chapter 4.1.5. The flows to residual waste and bulky waste are not included in this section since they have not been sorted and therefore are not of interest to Ramboll's project. The flow that is exported but not re-used is probably sorted but since this happens outside of Sweden the flow is not included in this section. It might be possible to import the flow or make arrangements for it to be brought back to Sweden after the sorting, but this is not investigated further in this project.

The flow most certain to have gone through sorting is the flow to incineration from donations. This flow was in Chapter 4.1.2 shown to be between 1550 and 4000 tonnes. It is not clear if textile waste from consumer complaints of products or textile waste from commercial laundries have been deemed unsuitable for re-use/recycling but assuming that is the case, another 1375 – 1530 tonnes of textile waste is available for the production of a new product. In total this means that between 2900 and 5500 tonnes of textile waste from Sweden per year could be used in the acoustic panels. Of this flow 2800 – 5200 tonnes of the textile is not homogeneous and could only be used for the inner layer of the acoustic panels. The textile waste from commercial laundries might be homogeneous and could then be used as the outer layer of the acoustic panes. However, the flow from commercial laundries is less than 350 tonnes even in the best case scenario.

4.3. Environmental Impact

Almost all the textile waste from Chapter 4.1.5 can be used in a better way with respect to the environment. A large amount of the textile found in the residual waste and the bulky waste has potential for re-use, the best management for produced textile with respect to the environment as well as the waste hierarchy. Another large amount is suitable for alternative management not including re-use, such as recycling. Finally, a smaller part of the found textile waste might not be suitable for re-use or recycling because of an elevated risk of hazardous chemicals in the textile. However, in this project it is assumed that this textile can also be recycled. A theoretical calculation is made below for all of the groups. The results are summarized in Table 19.

By using the results from Schmidt et al. (2016b) seen in Table 11 it has been calculated that emissions of 11 tonne CO_2-equivalents, 43 GJ primary energy from renewable resources and 153 GJ primary energy from non-renewable resources per tonne of discarded textile can be avoided if textile is re-used in the Nordic countries instead of incinerated in Sweden. If textile is recycled by being turned into industrial wipes instead of incinerated in Sweden, 32 kg CO_2-equivalents, 60 GJ primary energy from renewable resources and 3 GJ primary energy from non-renewable resources per tonne of discarded textile is avoided.

If all re-usable textile waste would be re-used, 446 – 584 ktonne CO_2-equivalents could be avoided. If all recyclable textile waste would be recycled by turning it into industrial wipes, 1250 – 1600 tonnes CO_2-equivalents could be avoided. If the textile waste with an elevated risk of containing harmful chemicals would also be recycled by turning the textile into industrial wipes another 160 – 256 tonnes CO_2-equivalents could be avoided. In total, 447 – 585 ktonnes CO_2-equivalents could be saved every year. The same amount of carbon dioxide is released by 629 000 – 823 000 roundtrips by air between Stockholm (Sweden) and Bangkok (Thailand)[8]. Savings in primary energy from renewable and non-renewable resources are shown in Table 19.

Table 19 shows potential savings by changing the waste management from incineration to re-use and recycling.

	Climate change (excluding biogenic carbon) (ktonne CO_2-equivalents / year)	**Primary energy from renewable resources (PJ / year)**	**Primary energy from non-renewable resources (PJ / year)**
Textile waste re-used	446 – 584	1.8 – 2.4	6.4 – 8.4
Textile waste turned into industrial wipes	1. 25 – 1.60	2.3 – 3.0	0.1 – 0.2
Textile waste with an elevated risk of harmful chemicals turned into industrial wipes	0.16 – 0.26	0.3 – 0.5	0.015 – 0.024
Summary	**447 – 585**	**4.4 – 5.9**	**6.5 – 8.6**

[8] Calculated by assuming that one roundtrip by air between Stockholm (ARN) and Bangkok (BKK) emits 711 kg CO_2/passenger as stated on https://www.icao.int/environmental-protection/CarbonOffset/Pages/default.aspx

Analysis

A product can be made with the goal of replacing another product or solving a problem. To calculate the changed environmental impact of this product or solution the replaced alternative needs to be considered. Re-use of textile is environmentally beneficial if it replaces virgin textile production and its associated environmental impact. If the re-use does not replace any virgin textile production the environmental benefit is lost. If it is assumed that the textile replaces virgin textile, the best alternative from an environmental point of view would be to re-use the textile. However, at some point this is not possible due to the condition of the textile. Assuming the textile is still in a condition where all the remaining stages of waste management are possible, it has been shown in Chapter 2.5 that recycling is more beneficial than incineration. The composition of the textile will affect which recycling techniques that are possible. According to both Naturvårdsverket (2015a) and Palm et al. (2014) down-cycling is often the result of mechanical recycling and circularity is not achieved.

The results are based on environmental impact reported by from Schmidt et al. (2016b) which is based on life cycle assessments. The result of a life cycle assessment depends on assumptions made during the assessment and the calculated results in this report should therefore be viewed as approximate.

5. Discussion

The discussion will follow the different objectives stated in the beginning. In the end, a discussion on future studies will be included.

5.1. What amounts of textile waste arise in different sectors?

The summarized result on textile waste in the different sectors together with the flow to export abroad is in the same order of magnitude as the sold textile in Sweden 2008 reported by SMED (2011), indicating that most significant flows of textile waste are included in this report. However, given the numerous possible sources of error as well as the huge differences in estimated numbers (such as the interval 21 973 – 127 441 tonnes textile waste in residual waste from households reported by SMED (2011)), it is possible that some significant flow of textile waste has been overseen during this project.

Some of the flows reported, such as flows through informal channels, are hard to estimate and were therefore not investigated. They might be important but as long as they follow the other flows mapped when discarded, the waste management alternatives in the results in Chapter 4 are still relevant. At least one uninvestigated flow, however, does not follow the waste management presented in this report as indicated by personal contact with David Althoff Palm (see Chapter 2.3.3). Further work might then need to be done to decrease negative environmental impact from the current management. This could be true for more flows.

All data from the literature review are at least four years old at the time of writing (2018). Newer data would be more relevant for the current situation. The studies used in this report have been produced to answer specific objectives and continuous data from several years are hardly found. One exception is the results reported by SMED (2014), where data were examined from two years. To follow trends, data from a number of years need to be taken into consideration. The fact that the studies have had different objectives and used different methods make comparison between the results hard and precarious.

Since data from Brismar (2014), SMED (2011), IVA (2015), Palm (2011), SMED (2014) and Palm et al. (2014) are partly based on information from organisations it is also relevant to consider if the knowledge of the organisations is complete and covers the entire sector. For example, IVA (2015) report that 1210 tonnes of textile waste arise from consumer complaints of products, based on information from companies. To represent the entire sector, the companies providing the information must have knowledge of consumer complaints in other companies than their own.

The results on bulky waste at recycling centres presented in Chapter 4.1.4 include uncertainties since they are based on few Solid Waste Composition Studies. The Solid Waste Composition Studies were conducted in Sweden's major cities which could further affect the results. Additionally, it is possible that the results, especially in Gothenburg in January, reflect habits at that time of year; for example, if people clear out their wardrobe for the holiday sales or dispose of unwanted Christmas gifts. If this is the case, the result does not represent the average share of textile waste discarded in the bulky waste during a year.

The literature review indicates that the knowledge of textile waste in some sectors is higher than in others. Textile waste from households via residual waste and donated textile have been the focus of several reports while textile waste from the private and public sectors is considerably less studied. This is especially true for the total amounts. Even in the areas where studies have been conducted, differences in amounts exist. This might be a consequence of the different years studied but might also indicate that the area would benefit from more research and better data and statistics. As showed by SMED (2016a), the method of calculation also contributes to differences in results.

5.2. Where do flows of textile waste originate and where do they end?

A number of flows are presented in this report but it is possible that textile waste originates from more sectors, and other parts of the investigated sectors, than presented. Furthermore, it is possible that the textile waste ends in other areas than the ones presented. Some textile waste might, for example, be dumped. However, the fact that the results agree with the amount of textile sold indicates that most relevant flows have been included.

Considering employee clothing, it is possible that the textile waste investigated is discarded in the residual waste at the workplace or in employees' homes. In that case the waste is possibly included in the flows from the literature review.

Results from the study by Ekström et al. (2012) suggested that more textile waste is likely found in the bulky waste than the residual waste (assuming that every person disposes of the same amount of textile waste), but this was not the result found in this project. Neither the study by Ekström et al. (2012) nor this project was extensive enough to draw a complete picture of the situation. The study by Ekström et al. (2012) was a small one. On the other hand, the Solid Waste Composition Studies used in this project were few. To get a complete picture of the situation and confirm if more textile is discarded as residual waste or as bulky waste, more studies should be done. If people discard torn textile in the residual waste and discard greater amounts of textile from, for example, a more extensive cleaning of a wardrobe in the bulky waste, the flow of textile waste to residual waste might be more uniform than the flow of textile waste to bulky waste. This might be the reason for the large interval in the share of textile found in combustible waste in Chapter 4.1.4.

5.3. What alternatives exist for management of textile waste?

Attempts have been made to include all alternatives for waste management possible for textile waste in Sweden in Chapter 2.4. However, some of the presented alternatives are unlikely for textile waste in Sweden and other alternatives than those presented might exist or be under development. For example, textile waste with an elevated risk of containing harmful chemicals might be unusable for recycling even if this alternative is used for calculation of the results of this project.

5.4. Which alternative is the best from an environmental point of view?

The literature review showed several different results on environmental impact reported for different fibres, textiles and managements. The differing assumptions made in every case as well as other uncertainties make it problematic to state one alternative that is the best from an environmental point of view, especially in the lower stages of the waste hierarchy. Usually, re-use is the best alternative but if the textile cannot fill its basic purpose, as for example keeping heat, re-use is not a suitable option. Re-use that does not replace consumption of new textile is another example of an alternative which is not environmentally beneficial. The elevated risk of content of harmful chemicals in some textile is another situation where it is more problematic to decide the best alternative.

The environmental impact of the production of acoustic panels also varies, as can be seen by the results reported by IBU (2014), Ecophon (2015) and Rockfon® (2016) and summarized in Table 13. It shows that a range of results of environmental impact exist and motivates the importance of including the product replaced by a new product in the analysis of witch alternative benefits the environment the most. Table 13 only shows results from production but to make a complete analysis of the best alternative, the entire life cycle needs to be included.

There is a risk of new, unused textile being discarded as waste. If this is recycled instead of re-used, some of the potential environmental gain is lost. However, a functioning sorting process should eliminate this problem by sending textile to re-use before recycling. Economic and social aspects have not been included in this project but could be important for the choice of management alternative as well as for the amounts of textile consumed and discarded of.

The amounts of chemicals reported by Olsson et al. (2009) include both harmful chemicals and other chemicals. It is thus important to differentiate between chemicals with different properties. If smaller amounts of harmful chemicals and less harmful chemicals would be used in the production of textile, re-use and recycling of the textile would be easier since the risk of contamination of harmful chemicals would decrease. Some harmful chemicals, such as flame retardants, can be important for the user of the textile, such as firefighters. Those chemicals might be more difficult to remove from the production if no acceptable alternative exist. As it is now, the best alternative for textile with an elevated risk of containing harmful chemicals might be incineration even if the results of this report include recycling of textile with an elevated risk of containing harmful chemicals.

SMED (2016b) mentioned that textile used in application such as insulation might decrease the risk of negative impact on humans from harmful chemicals in recycled textile. Textile containing chemicals which are harmful when they come in contact with the skin but not air might then be used in acoustic panels mounted out of reach without a risk of negative impact on humans. If this is possible, a group of textile waste with difficult properties might be used in a circular way without causing harm to humans or affecting recycling processes negatively.

5.5. What is the potential gain for the environment?

The savings in greenhouse gases reported by Schmidt et al. (2016a; 2016b) and used for the calculations in Chapter 4.3 differ from the savings reported by Naturvårdsverket (2015a). The results from Schmidt et al. (2016b) were used since the results from Naturvårdsverket (2015a) give numbers on savings only when recycling is beneficial, even though they report that some recycling techniques are not environmentally beneficial. If the results from Naturvårdsverket (2015a) had included numbers on savings for all recycling techniques, an average value could have been used to give a better estimation. The potential gain for the environment thus depends on the techniques used for recycling. The environmental gain also relies on which products are replaced and the environmental impact associated with that product. To decrease the environmental impact, a decrease in consumption without need must also take place.

In order to decrease the environmental impact, the recycled material or the textile for re-use must be wanted by someone. This was one of the reasons to include the case study with Ramboll, to give the view of a company. In a new product, harmful chemicals are usually unwanted. However, it might be difficult to know if a textile contains harmful chemicals. Safety clothes used during construction can include flame retardants with harmful properties but are easy to recognize and remove from the flow if sorting is done. Other kinds of textile can be more difficult to sort since it is unclear if they contain harmful chemicals.

5.6. What amounts and flows of textile waste could potentially be used in a new product as a better alternative than the current waste management?

Two large flows of textile waste found in this project are in the residual waste and the bulky waste. To change the management of these flows, people need to change their habits and choose to donate the textile to charities, sell/give it to companies who recycle, re-use, or use some other solution to improve the management of the textile. This is a problematic situation but work is being done by several organisations to find a solution.

For the acoustic panel in this project, flows of textile waste that have not been sorted are not of interest. Flows from donations, commercial laundries and consumer complaint are the possible flows identified. Textile waste from commercial laundries might be homogeneous while the other flows are unlikely to be homogeneous. If a product is to be developed it must be decided if this is a problem. For the acoustic panels, questions might include if the different fibres give different acoustic properties and if the machines included in the process can handle differences in, for example, thickness and strength of the textile. In the future, improved sorting might make the problems of non-homogeneous flows easier to handle.

Sorting can also be difficult due to other problems. For example, according to SMED (2016b) some chemicals used for colouring might be harmful. Other chemicals used for colouring might not be harmful, making separation difficult without information on the content. This might present a large problem since harmful chemicals are usually unwanted and many new products are subject to restrictions regarding content. Sorting is made more difficult since textile from different sectors can have been subjected to different conditions during its lifetime. Textile waste from commercial laundries has probably been washed many times, decreasing the risk of harmful chemicals. Textile waste from healthcare is most likely subjected to extra restrictions regarding the chemical content and should therefore have a low risk of harmful chemical content, especially if it has been washed many times. Online sale from countries outside of the EU might increase the risk of unwanted chemicals in the textile. On the other hand, textile sold in Sweden should follow Swedish regulation and the problem might therefore be non-existing.

5.7. Future Studies

More Solid Waste Composition Studies on combustible waste at recycling centres with a focus on textile waste would give a better estimation on the share of textile waste in this fraction. Avfall Sverige, a Swedish waste management association, is currently working on a project with Solid Waste Composition Studies on combustible waste, plastic waste, wood waste and metal waste at recycling centres[9] with results being published autumn 2018[10]. This information is highly relevant since the current research on the subject is insufficient. Studies concerning if the textile waste is torn or not is also needed. This is true for textile waste in residual waste as well.

Further information on waste from the private and public sectors is needed to show a complete picture of the situation. Continuous data and statistics would improve the knowledge of investigated flows and thereby the knowledge of people's behaviour. With this said, studies can only give information; improvements in actions and habits are also needed.

[9] Johan Hultén, IVL, e-mail, 2018-01-23
[10] Johan Hultén, IVL, e-mail, 2018-01-22

6. Conclusion

Households discard between 48 000 and 72 000 tonnes of textile waste as residual waste and another 28 000 tonnes of textile waste at recycling centres every year. The private and public sectors as well as donations give rise to between 10 000 and 13 000 tonnes of textile waste per year and the textile production in Sweden yields 50 tonnes of textile waste per year. Most of this is incinerated.

With the requirements Ramboll had between 2900 and 5500 tonnes of textile waste per year could be used in the production of acoustic panels, mostly in an inner layer. This textile waste is the flows from donations, commercial laundries and consumer complaints of products. The rest of the textile waste is not of interest to Ramboll's project since it is not sorted.

Textile waste can be recycled, used for production of biofuel, re-used or incinerated. It can also be landfilled, but considering laws and the waste hierarchy, this option is not included in this report. From an environmental point of view, the best is to follow the waste hierarchy with textile being re-used firstly, recycled secondly and incinerated lastly. Compared to incineration, production of biofuel from textile waste is not a reasonable option with regard to the useful energy being produced.

If all textile waste was managed in the best way possible, between 447 – 585 ktonnes CO_2-equivalents, 4.4 – 5.9 PJ primary energy from renewable resources and 6.5 – 8.6 PJ primary energy from non-renewable resources could potentially be saved every year. The changed textile waste management would save the same amount of greenhouse gas as 629 000 – 823 000 persons deciding not to make a roundtrip between Stockholm and Bangkok by air.

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Appendix 1 - Calculations

Share of fibre (Chapter 2.1)
New sale: 122 210 tonnes
Cotton products: 31 408 tonnes
Polyester products: 64 405 tonnes
Viscose products: 7088 tonnes
Wool products: 1344 tonnes
Other products: 17 965 tonnes
(IVA 2015 p. 28)

Cotton: 31 408 tonnes / 122 210 tonnes ≈ 0.26
Polyester: 64 405 tonnes / 122 210 tonnes ≈ 0.53
Viscose: 7088 tonnes / 122 210 tonnes ≈ 0.06
Wool: 1344 tonnes / 122 210 tonnes ≈ 0.01
Other: 17 965 tonnes / 122 210 tonnes ≈ 0.15

Environmental impact per tonne for acoustic panels (Chapter 3.2)
Ecophon
1 m^2 of acoustic panel with the weight of 1326 g
Global warming: 2.2 kg CO_2-equivalents / m^2 acoustic panel
Total use of renewable primary energy resources: 24 MJ / m^2 acoustic panel
Total use of non-renewable primary energy resources: 51 MJ / m^2 acoustic panel
(Ecophon 2015)

Global warming: (2.2 kg CO_2-equivalents / m^2 acoustic panel) / (1326 g acoustic panel / m^2 acoustic panel) * (1 000 000 g acoustic panel / tonne acoustic panel) ≈ 1660 kg CO_2-equivalents / tonne acoustic panel

Total use of renewable primary energy resources: (24 MJ / m^2 acoustic panel) / (1326 g acoustic panel / m^2 acoustic panel) * (1 000 000 g acoustic panel / tonne acoustic panel) ≈ 18 100 MJ / tonne acoustic panel

Total use of non-renewable primary energy resources: (51 MJ / m^2 acoustic panel) / (1326 g acoustic panel / m^2 acoustic panel) * (1 000 000 g acoustic panel / tonne acoustic panel) ≈ 38 500 MJ / tonne acoustic panel

Rockfon®
1 m^2 of acoustic panel with the weight of 3.6 kg
Global warming: 7.17 kg CO_2-equivalents / m^2 acoustic panel
Total use of renewable primary energy resources: 12.5 MJ / m^2 acoustic panel
Total use of non-renewable primary energy resources: 141 MJ / m^2 acoustic panel
(Rockfon® 2016).

Global warming: (7.17 kg CO_2-equivalents / m^2 acoustic panel) / (3.6 kg acoustic panel / m^2 acoustic panel) * (1000 kg acoustic panel / tonne acoustic panel) ≈ 2140 kg CO_2-equivalents / tonne acoustic panel

Total use of renewable primary energy resources: (12.5 MJ / m^2 acoustic panel) / (3.6 kg acoustic panel / m^2 acoustic panel) * (1000 kg acoustic panel / tonne acoustic panel) ≈ 3500 MJ / tonne acoustic panel

Total use of non-renewable primary energy resources: (141 MJ / m^2 acoustic panel) / (3.6 kg acoustic panel / m^2 acoustic panel) * (1000 kg acoustic panel / tonne acoustic panel) ≈ 39 200 MJ / tonne acoustic panel

Share not fit for re-use of residual waste (Chapter 4.1.1)
41 % not fit for re-use (SMED 2016a)
43 000 – 64 000 tonnes of textile waste
0.41 * 43 000 tonnes ≈ 18 000 tonnes
0.41 * 64 000 tonnes ≈ 26 000 tonnes

Share fit for re-use of residual waste (Chapter 4.1.1)
59 % fit for re-use (SMED 2016a)
43 000 – 64 000 tonnes of textile waste
0.59 * 43 000 tonnes ≈ 25 000 tonnes
0.59 * 64 000 tonnes ≈ 38 000 tonnes

Minimum and maximum of flows not suitable for re-use from donations and the private and public sectors (Chapter 4.1.2)
Minimum:
Business laundries: 165 tonnes
Consumer complaints of products: 1210 tonnes
Donations (incinerated/landfilled Sweden): 1550 tonnes
Donated (export, not re-used): 6600 tonnes
Sum minimum ≈ 10 000 tonnes

Maximum:
Business laundries: 320 tonnes
Consumer complaints of products: 1210 tonnes
Donations (incinerated/landfilled Sweden): 4000 tonnes
Donated (export, not re-used): 7500 tonnes
Sum maximum ≈ 13 000 tonnes

Losses from production in Sweden (Chapter 4.1.3)
450 tonnes = 90 %
1 % = 450 tonnes / 90 = 5 tonnes
Losses = 10 % = 5 tonnes * 10 = 50 tonnes

Mean value share textile in combustible waste at recycling centres (Chapter 4.1.4)
(4.5 + 5.4 + 13.3 + 7.4 + 1) / 5 ≈ 6.3

Re-use compared to incineration in Sweden (Chapter 4.3)
Climate change (kg CO_2-equivalents): (-10 235) – 375 = (-10 610)
Primary energy from renewable resources (GJ): (-61) – (-18) = (-43)
Primary energy from non-renewable resources (GJ): (-158) – (-5) = (-153)

Recycling by turning textile into industrial wipes compared to incineration in Sweden (Chapter 4.3)

Climate change (kg CO_2-equivalents): 343 – 375 = (-32)
Primary energy from renewable resources (GJ): (-78) – (-18) = (-60)
Primary energy from non-renewable resources (GJ): (-8) – (-5) = (-3)