To Reuse or to Incinerate?
A case study of the environmental impacts of two alternative waste management strategies for household textile waste in nine municipalities in northern Stockholm, Sweden

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Abstract

With an increasing human population in the world, textiles are part of current unsustainable consumption patterns. Unlike most other mass produced products available today however, textiles are often vital to satisfy human core needs, and cannot be considered superfluous. Textile materials can be problematic from an environmental perspective. Synthetics are made from non-renewable petroleum, while production natural textile materials are very resource intensive, and rely on non-renewable energy supplies.

Many reports on textiles indicate that production and use have great environmental impacts compared to waste management. On the other hand, it is in the latter phase decided whether the textile should be reused, recycled or discarded. These different material flow alternatives greatly determine overall impacts, since the possibility of avoided production through reuse and recycling is an important factor to consider.

The main goal of this report was, through the use of life cycle assessment (LCA), to evaluate the environmental impact of household textile waste management from reuse and disposal alternatives, when conducted through the activities of the Swedish waste management company SÖRAB. Two different waste management strategies/scenarios where compared: one centered around incineration of textile waste, specified as the incineration scenario, and one focused on a textile waste flow where the textiles are separated from household waste and sorted for reuse, recycling and incineration, specified as the reuse scenario. Due to the potential effects of displaced production through reuse and recycling, it was deemed important to additionally include the textile production phase besides the waste management phase in the LCA. Since the use of the textiles was considered outside of the sphere of influence of SÖRAB, this phase was excluded from the report.

Results indicate that the reuse scenario is, in all impact categories investigated, preferable to the incineration scenario. The reason for this is the displaced production in the reuse scenario thanks to the fact that textiles sorted as reuse in the waste management phase are assumed to replace virgin textiles in the use phase. Since the production phase contributes with the vast majority of the environmental impacts, avoided production affects results greatly, by lowering total impacts. For a company like SÖRAB, the easiest way currently to contribute to lowering environmental impacts would be to inform and in different ways encourage households to increase sorting of textiles for reuse, instead of it being thrown in the household waste.
Preface
This report is the last part of the Master Program in Sustainable Technology at The Royal Institute of Technology (KTH) in Stockholm. The investigation made through the report has been conducted in cooperation with the waste management company SÖRAB.

I would like to thank all the employees at SÖRAB who have been very forthcoming and helpful concerning my inquiries, and special gratitude is directed towards my supervisor at SÖRAB, Åsa Lindelöf, whose support has been of great importance.

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Abbreviations

**DWR** Durable water repellent

**LCA** Life Cycle Assessment

**LCI** Life Cycle Inventory

**LCIA** Life Cycle Impact Assessment

**FU** Functional Unit

**Eq** Equivalents
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1 Goal and Scope Definition

In this report, the Goal and Scope Definition starts with a background section consisting of parts such as Introduction, Waste prevention in the EU, Textile recycling, Textile waste management in Swedish municipalities and an introductory paragraph about the waste management company SÖRAB (section 1.1-1.5). The intent here is to lay a foundation upon which the aim and the objectives of the report can be motivated, contextualized and easily understood.

1.1 Introduction

With the current global population growth, and the increase in living standards in developing countries, there is an increased need for textiles. This is one of the core necessities for a decent living standard and cannot be overlooked. Textiles can have many areas of use, where apparel, home furnishing and industrial applications usually are considered the three main ones (Wang, 2006). Although especially textile apparel can be categorized as a core necessity for decent living, this area of use is anything but humble in scale. In Sweden alone, approximately 141 million tonnes of textiles are annually consumed (Palm, 2011). The habit of wear and tear is widespread in developed countries and further encouraged by the textile and apparel industry. When considering the increased consumption, and when including the aspect of environmental sustainability, it becomes relevant to look at the environmental impacts of the life cycle of textiles.

The fabric of a textile can consist of many different materials, which in turn can be alone or combined to form new materials with a range of useful properties. Textile materials are usually divided into two categories: natural and synthetic, where cotton and viscose are examples of the former while polyester and nylon are included in the latter category. The raw material needed for producing synthetic polymers is petroleum; a non-renewable resource with an extensive environmental impact, especially from greenhouse gas emissions. On the other hand, natural materials are renewable by definition, but the production of them usually demands non-renewable resources as energy supply (Wang, 2006). The resource demand for natural materials can also be very extensive. Cotton production, for example, is infamous for its huge water demand and the heavy use of fertilizers and pesticides (Muthu et al., 2012).

In Europe, clothing contributes to 2-10% of the environmental impacts of consumption (Tukker et al., 2006). This might seem like negligible numbers, but they are in fact a relevant contribution to the current unsustainable consumption patterns of the developed world. When the goal is to lower environmental impacts, managing the different phases of the life cycle of the textile is of importance. Although the textile production and the use phase are generally seen as the main contributors to environmental impacts (Peters et al., 2015), the waste management phase of a life cycle can be of great importance since it is here determined if a product can be reused or recycled, which could greatly affect the impacts of the other phases in a positive way from a sustainability standpoint.

1.2 Waste prevention in the EU

In the European Union waste directive (2008/98/EG), waste prevention is considered the preferable method for handling waste in general. Member states are obliged to implement a program for waste prevention, which should include targets and measures for lowering environmental impacts of waste,
amount of waste and dangerous substances in the waste. Aligning national legislation is considered relevant for adapting to the waste directive.

Waste prevention is seen as the highest step in what is defined as the waste hierarchy. The waste hierarchy is a priority order, included in the waste directive, for managing waste, with the following five steps from top to bottom: 1. prevention, 2. preparing for reuse, 3. recycling, 4. recovery (e.g. energy) and 5. disposal (e.g. landfill) (European Commission, 2016), as seen in Figure 1.

1. Waste prevention
2. Preparing for reuse
3. Recycling
4. Recovery
5. Disposal

Figure 1 EU Waste hierarchy

The further up a waste process is in the waste hierarchy, the less environmental impacts are generated. Where textiles are concerned, waste prevention refers to strategies such as making production less resource intensive and with less byproducts or production spill, or producing textile products with longer durability. The second preferable alternative is reuse of textile products, where they are collected and send to second hand outlets or as aid. These are the main two stages encouraged by the waste directive. Since the waste directive is intended to direct Swedish waste policies and legislation, it becomes relevant to look at the current situation concerning textile waste management in Sweden.

1.3 Textile recycling

If one wishes to avoid energy recovery or disposal of textiles, and if reuse is not a realistic alternative, there exists the option of recycling. What decides if this option is possible is the quality of the fiber and its origin, that is, if it is natural or synthetic. The natural, or cellulose based fibers, such as cotton, viscose, lyocell and modal, experience a decline in quality through use, washing and recycling processes. Recycling of these fibers therefore cannot produce a virgin material quality since there is a decline each time the material is recirculated. This condition is called down-cycling. Synthetic fibers such as polyester and polyamide, on the other hand, can be broken down into monomers and rebuilt to a quality equal that of a virgin product, making the state of the textile less important for deciding whether to recycle it or not. This also makes it possible to involve waste from other processes and material flows, such as PET bottles, during the production of polyester fibers.
Whether a textile is natural or synthetic determines what kind of recycling processes can be performed. Currently, recycling processes are divided into two categories: mechanical and chemical. Mechanical recycling in its simplest form can consist of tearing a fabric to shreds to be utilized as wipers or similar products, but it is also common to cut, tear and card the textiles into a smooth fiber pulp, which can be used as padding or, if a heat treatment is added to the process, insulation. Besides these techniques, which are currently available today, there also exist mechanical fiber-to-fiber recycling of cotton demin jeans without elastane, and fiber-to-fiber recycling of wool.

Chemical recycling is a process where the material is dissolved through the addition of degrading chemicals, and later rebuilt into new fibers for textile use. There are currently companies in Japan and Korea with established chemical recycling technologies which can process synthetic materials such as polyester and polyamide 6.

Mechanical or chemical recycling processes are not exclusive to either natural or synthetic fibers. Cotton, for example, can be processed through both mechanical and chemical means with available technologies today. However, since cotton is a natural fiber, both chemical and mechanical recycling will result in down-cycling to some extent.

An important factor for determining whether a material can be recycled or not, is if it is a mixed material, consisting of several different fibers. Furthermore, the amount of various fibers in the material and their percentage is also of importance. Both mechanical and chemical recycling processes can encounter difficulties when dealing with mixed fabrics. Machines might not be able to shred materials properly, and mixed materials might prove to be resilient to dissolving chemicals and hard to separate afterwards. Therefore, certain textiles in the waste flow will be unfit for recycling and needs to be removed. Manual sorting can be utilized in certain waste flows, and is today considered necessary for determining if a textile is fit for reuse, and for determining reuse quality. Currently, almost all sorting is manual, but there exist a demand for a quick and highly efficient sorting process for large flows of textiles, something that is particularly important for chemical recycling. Manual separation of pure fabrics has proven to be too imprecise, which has generated a demand for more reliable sorting processes. Technologies such as near infrared spectroscopy (NIR), radio frequency identification (RFID) and 2D bar-code labeling are under development, but are not yet out on the market (Östlund et al., 2015).

1.4 Textile waste management in Swedish municipalities
The inflow of textiles to Sweden was estimated to be about 12.5 kg/person in 2013. This should be related to the measurement of approximately eight kg/person of textiles in the household waste stream, while three kg/person were collected by aid organizations. The main part of the latter is given by private persons rather than textile business and companies (Östlund, et al., 2015).

In a survey conducted by IVL, the Swedish environmental institute, Swedish municipalities were interviewed concerning their collection of used textiles. Results show that at least some sort of collection of textiles exists in all but one of the investigated municipalities, but the extent of the collection or the means of it differs. Approximately 15 percent of the municipalities organize their own collection, which
in all cases takes place at recycling centers. In some municipalities in the latter category, these textiles are sent to incineration, while in others the textiles are sent to reuse or to recycling.

In almost all municipalities there are other organizations present which collect used textiles. Aid organizations such as Myrorna, Swedish Red Cross, Emmaus and Human Bridge are examples of stakeholders involved, but there are also cases of local aid organizations which manage collection of used textiles. The textile collection situation in Sweden is complex since there is no coherent system in place for all municipalities concerning the allocation of the collection. A municipality can organize its own collection with or without an aid organization present which is also collecting, or the latter can handle all of the collection with or without an established agreement with the municipality, which in many cases does not have a separate collection of its own in place. Consequently, there are currently many local arrangements established.

About a fifth of the municipalities have some sort of signed agreement with a waste collecting organization. More common, however, is unofficial arrangements, where municipalities provide organizations with space for textile waste collection at recycling centers. Two thirds of the municipalities have a system like this in place, while about 43 percent also allows collection of textiles at recycling stations. A third of the municipalities state that waste collecting organizations manage collection of other waste besides textiles.

The reasons for the confused situation are several. There are currently no relevant national regulations concerning how textile waste collection should be handled, and the responsibilities between different stakeholders are unclear. Many municipalities claim that they try to cooperate with NGOs whenever possible, but textile waste collection has not been much prioritized, and the general impression seem to be that there is a lack of professional and reliable actors available (Palm, Danielsson, & Elander, 2015).

1.4.1 Textile waste collection by NGOs and aid organizations
In 2008, the eight largest aid organizations in Sweden\(^1\) collected about 26,000 tonnes of textiles, which is equivalent to approximately three kg of textiles per person and year. A common procedure for handling these textile flows is to first separate reuse from unusable. Textiles that are considered qualitative enough are separated and send to second hand outlets in Sweden. If the textiles are not seen as up to this standard, but still considered useable, they are collected as aid or sold and exported to a second hand market abroad.

Of the 26,000 tonnes that were collected in 2008 by aid organizations, approximately 73 percent were sorted as reuse for aid or export, 11 percent were resold in Swedish outlets and 15 percent were sent to incineration or landfiling (Carlsson et al., 2011). Although this data only describes a single year, it can still give an estimation of sorted fractions, even though the data will fluctuate from year to year.

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\(^1\) Myrorna, Erikshjälpen, Röda Korset, Läkarmissionen, PMU Intertrade, Stockholms stadsmmission, Humana Sverige and Emmaus Björkå.
1.4.2 Recycling of textiles in Sweden

Although there are established mechanical recycling techniques, there is little to no infrastructure for this kind of treatment domestically in Sweden. Most textile waste is sent to incineration due to inefficient collection of consumer textiles and sorting of household waste (Östlund et al., 2015), but there are exceptions to this, where some Swedish municipalities state that they have textile waste flows directed towards recycling through cooperation with a third party operator. This is always down-cycling processes such as wiper or insulation production, and the processes are taking place abroad (Palm, Danielsson, & Elander, 2015). Directing waste flows abroad is currently the only realistic alternative for textile recycling handled by municipalities in Sweden. Large sorting facilities are absent, and textile flows are not big enough for efficient material recycling in the country (Östlund et al., 2015).

1.5 Information about SÖRAB

A common way to organize waste management in Sweden is through municipality owned companies. One such company is SÖRAB. Founded in 1978, SÖRAB is a regional company which is owned by the following ten municipalities in Stockholm County: Danderyd, Järfälla, Lidingö, Sollentuna, Solna, Stockholm, Sundbyberg, Täby, Upplands Väsby and Vallentuna. The primary objective of the company is to collect and manage household waste flows originating from the aforementioned municipalities, with the exception of Stockholm municipality, which has a separate waste management infrastructure and waste management plan. In addition to household waste flows, SÖRAB also receives operational waste from regional companies. SÖRAB manages six recycling centers and waste management sites spread throughout the owning municipalities. These are: Hagby, Smedby, Löt, Görväln, Kvarnkullen and Stockby. (SÖRAB, n. d.).

![Figure 2 Placement of recycling centers in relation to own municipalities](image)

SÖRAB has been ISO 14001 certified since 1998, and works continuously with environmental issues. Every year the environmental aspects of the company are identified and evaluated. With the help of the
company’s environmental policy, and together with the identified aspects of note, environmental goals are established. The two environmental goals that can be directly connected to the textile waste management of the company are:

- Lower emissions of greenhouse gasses during the period 2013-2016.
- Ascend the waste hierarchy established through the EU waste directive (2008/98/EG) (SÖRAB, n.d.).

This report aims towards providing SÖRAB with valuable information concerning how to work towards reaching the environmental goals in relation to textile waste management, while at the same time strives to investigate and analyze textile production and waste management from an academic perspective, dealing with environmental impacts in general.

1.6 Aim and objectives

Research question: What are the changes in environmental impacts associated with by increasing reuse rates through altered material flows, in connection to SÖRABs textile waste management?

The aim of this master thesis is to evaluate the environmental impact of household textile waste management from reuse and disposal alternatives when conducted through the activities of the Swedish waste management company SÖRAB. The intent is to identify a better strategy for handling such waste by the company, and to assess such strategy from an overall perspective. To reach this goal, the following objectives are necessary:

The quantification of environmental impact from current production, collection, transportation and waste treatment of textiles in relation to SÖRAB, and to estimate the contribution to environmental impacts for the specified parts of the life cycle;

The identification and investigation of alternative textile flow paths within SÖRABs sphere of influence and the estimation of their environmental impacts; and

The assessment of changes in environmental impacts when textile flows are altered from current to alternative flow paths.

1.7 Method: LCA

The tool adopted for achieving objectives is Life Cycle Assessment (LCA), which will be applied to the life cycle of a specified household textile, a T-shirt. A LCA is used to determine the environmental impact of the life cycle of product or a service, and can cover either the whole life span of a product, from the raw material extraction and the production of the product through the use phase and all the way to the waste management (cradle to grave), or can be directed towards different phases of the life cycle (cradle to gate, gate to gate, gate to grave etc.). Several environmental impacts are included, where perhaps the most common one is global warming potential (GWP), but others are commonly included too such as acidification and ozone layer depletion (Bauman & Tillman, 2004).

LCA is normally conducted through several stages. Firstly, the purpose of the LCA, the product of interest and the system boundaries are defined in the goal and scope definition stage. Subsequently, the life
cycle model is created and impact data, such as emissions output and resource use, is collected and accounted for – this is life cycle inventory (LCI). A Life Cycle Assessment (LCIA) phase follows, where the emissions and resource use is related to different environmental problems through classification and characterization. This analysis is quantitative. Finally it is possible to put the measured impacts on the same scale through what is called normalization and weighting. This can be done in order to get a clearer picture of the scale of the environmental impacts if the impact assessment is very extensive and difficult to grasp (Bauman & Tillman, 2004).

1.8 Previous studies
There are a couple of reports where environmental impacts of Swedish textile consumption have been analyzed. A thorough LCA of textile management in Sweden is done by Strand (2015), who, with the use of data from Statistics Sweden for 2000-2013, maps textile flows for 25 different household textile products. Specific environmental impacts are modeled over three years; 2000, 2007 and 2013. Strand’s study covers the entire life cycle of the textiles.

Palm, Harris and Ekvall (2013) have, through IVL, the Swedish Environmental Institute, published a LCA study on Swedish textile consumption. In this LCA, the impacts from textile use have been excluded, while the textile materials included are limited to three. In the waste management phase, the authors compare energy recovery, reuse and recycling through an impact perspective.

A report conducted by the European Commission and the Joint Research Centre investigated the possibilities of environmental improvement of textile management in the 27 EU member states by using a LCA approach. The production, use, transport and waste management phases were investigated and compared through environmental impacts (Beton, et al., 2014).

Finally, in a study by Roos et al, (2015), five textile garments (jeans, T-shirt, dress, jacket and hospital uniform) are analyzed through a complete LCA, covering the entire life cycle. An aspect that differentiates this study from the others is that it also includes the use phase transport when estimating environmental impacts.

1.9 Systems analyzed
This report will be a comparative scenario LCA, where two different waste management systems are compared. The previous textile waste management system handled by SÖRAB was based on incineration. Here, containers for textile waste were present at the recycling centers, but the textiles collected there were exclusively sent to incineration. This is a system that is a common practice in many municipalities in Sweden today, and in this report it will be defined as the incineration waste management phase.

The waste management company SÖRAB has recently introduced is a system where a part of the household textile waste stream can be separated from the normal household waste stream through sorting at recycling centers. This separated textile waste stream is managed by a third party contractor.
who processes the textiles through sorting for reuse, recycling and incineration. This currently established system will be defined as the **reuse waste management phase**.

Both phases described above will be gate-to-grave systems, but this report will also include a cradle-to-gate phase, which will be defined as the **production phase**. Included here will be the upstream production of materials used for the textile fabric and the production of the textile product through the different processes involved. The production, incineration and reuse phases will be compared through their respective environmental impacts.

An additional process included is the transportation from the production phase to the use phase. This will be defined as the production-to-outlet transportation.

The production phase together with the production-to-outlet transportation and the incineration phase will form the **incineration scenario**, while the production phase together with the production to outlet transportation and the reuse phase will define the **reuse scenario**. Consequently, the production phase and the transportation will be the same in both scenarios, but the actual environmental impacts of the phase might differ depending on whether production can be avoided through reuse of textiles in the reuse scenario.

**Figure 3** Simple scenario flowchart

### 1.10 System boundaries
The systems in this LCA will consist of all of the phases in the life cycle of a textile with one important exception, the use phase. This phase, which mainly includes repeated washing and drying of textiles, will be excluded on the basis that it is independent from the waste management phase. The company SÖRAB has no influence on how textiles are handled or of the textile flows during the use phase, and therefore it will be considered irrelevant. Data on the use phase of textiles in Sweden can be accessed through Strand, who has a more in depth analysis of this phase (Strand, 2015). In addition, the handling of textiles in outlets, and the transportation from outlets to consumer residences will not be included, as this will be considered as part of the use phase.

Similarly, the textile production phase cannot be considered to be within the sphere of direct influence of the waste management stakeholders, but its inclusion is considered relevant for estimating the potential benefits of reusing textiles through displaced production. The question of whether environmental impacts can be lowered through reuse can only be answered if the displaced production phase is included in the analysis. According to Engelhardt, 2010, China is the biggest producer of textile fibers in the world. Consequently, for simplification reasons, the production, including the sub processes and the production of the materials for the fabric, will be placed in China in this LCA.
The modeled system excluded waste collection; it starts where textiles enter SÖRABs recycling centers in Sweden, through facility processing and transportation to third-party sorting, recycling and/or incineration in The Netherlands and Poland.

**Figure 4** Incineration scenario flowchart
1.11 Functional unit
The functional unit in this report is one kg of household textile waste. It will be defined as clothing, cloth and beddings. Textile waste from households can consist of many other products; but, for simplification purposes, it will be narrowed down to the categories mentioned above. In the textile production
process, the textile flows will be treated as materials used for T-shirt production, and energy demands will be adjusted according to these specifications. During the production phase, the functional unit will be defined as one kg of produced textile, which will be the equivalent of the textile waste in the two scenarios.

In the reuse scenario, the waste flow of one kg of textile waste will be seen as separated from normal household waste. Though textiles often end up in the latter waste flow, since it is a common occurrence to throw textiles there, such textiles will not be included. The reason for this is that in this scenario, there exists a waste flow that deals specifically with textile waste, and it is on this waste stream that focus of the LCA is directed since the purpose is to investigate this specific waste management stream.

1.12 Impact categories
Five different impact categories have been chosen to be included in this report. Their inclusion has been determined primarily through their common use in similar LCA reports, but also due to requests made by the waste management company SÖRAB. The five included impact categories are: Global warming potential (GWP), eutrophication, acidification, human toxicity and terrestrial eco-toxicity. In addition, the two resource use categories water and energy will also be included to provide additional inputs concerning impacts and sustainability.

To quantify the different impact categories, the impact assessment method CML 2001 will be used (GaBi, n.d). The choice is motivated by its common use both globally and by KTH. Below a description of the different impact categories is presented:

1.12.1 Resource use: Water
The resource water is considered an overarching term for all anthropogenic water uses. A resource use is in this case defined as an input into a system or a process. The most common way this is manifested is as a withdrawal of water. A resource such as water can in a system be used in several different ways. In GaBi, freshwater use is divided into consumptive or degradative water use. The former involves freshwater losses through evaporation, evapotranspiration, binding of water in products and the release of freshwater into the sea. Degradative water use on the other hand, describes water which, although it is returned to the system, is affected by quality alterations through different kinds of pollution. It is therefore important to realize the difference between this kind of water use and the former definition of consumption of water when the goal is to interpret data and to calculate water footprints. A note of worth is that no consideration is taken to rainwater consumption, since this kind of water is assumed to have no environmental impact (Gabi, 2014).

1.12.2 Resource use: Energy
Energy use in this report is defined as total energy input per functional unit. It included renewable and non-renewable resources and is presented in MJ.
1.12.3 Global warming
Global warming potential (GWP) is used as the characterization factor for Global Warming. GWP refers to the impact greenhouse gasses have on the climate relative to CO₂, which primarily means increased average global temperatures. It is calculated through converting LCI data to kg CO₂ equivalents. Emissions consist primarily of CO₂, but included is also substances such as methane (CH₄), chlorofluorocarbons (CFCs), hydro-chlorofluorocarbons (HCFCs) and nitrogen dioxides (N₂O). GWPs can be defined for different time frames, such as 50, 100 or 500 years potentials (EPA, 2006). In this report, CML 2001 (GWP 100 year) will be used due to its common practice.

1.12.4 Eutrophication
The phenomenon of eutrophication involves the high concentration buildup of nutrients, mainly phosphates and nitrates, in bodies of water. This usually leads to excessive growth of algae, which eventually changes the biotopes affected severely through decrease in oxygen, release of toxins, and in some cases the raising of lakes and river beds, which in the long run convert the area to land (Lawrence, Jackson, & Jackson, 1998). Eutrophication is calculated through the conversion of LCI data to phosphate (PO₄) equivalents, and besides phosphates and nitrates eutrophication emissions usually involves Nitrogen oxides (NO) and dioxides (NO₂) and ammonia (NH₄) (EPA, 2006).

1.12.5 Acidification
Acidification describes the process when acidic substances such as Sulphur dioxides and nitrogen oxides are released into the environment, primarily through atmospheric emissions such as the burning of fossil fuels. These substances can persist in the atmosphere for several days, and can thereby be transported thousands of kilometers, making acidification both a local and a regional issue. During this time, the emitted substances undergo chemical transformation into sulphuric and nitric acids, which leads to a significant change in the chemical disposition of soil and/or water in the area affected, a process that can severely affect ecosystems (European Environment Agency, 2016).

Acidification can be estimated through the conversion of LCI data to hydrogen (H⁺) ion equivalents, through acidification potentials. In the report, this will be indicated as SO2 equivalents. Other than the mentioned substances ammonia, hydrochloric acids (HCL) and hydrofluoric acids (HF) are also considered relevant contributors to acidification (EPA, 2006).

1.12.6 Human toxicity
The human toxicity impact category relates to the effect of toxic substances on human health. Such intake can be conducted through fluids, solids or air. In LCAs, this can be categorized through the human toxicity potential, which conveys the health effects from exposure of a substance (Krewitt et al., 2002). This toxicity potential is measured as kg 1,4-dichlorobenzene equivalents.

1.12.7 Terrestrial eco-toxicity
Terrestrial eco-toxicity describes the impact of toxic substances from emissions through air, soil and water on terrestrial ecosystems, where animal and plants are affected in different ways through different media. Eco-toxicity potential describes fate, exposure and effects of toxic substances, and as with human toxicity, terrestrial eco-toxicity is also measured as kg 1,4 dichlorobenzene equivalents (Garrett & Collins, 2009).
1.13 Handling of co-production
A life cycle of a product will usually contain several different processes, and life cycles of different products could be intertwined in different ways. Furthermore, several of the processes can potentially generate more than one product or flow (multi output) which will generate impacts which are important to consider. A process could also have many different inputs (multi input), making tracing the source of impacts more complicated. It makes it relevant to decide whether specific processes or co-products should be included in the investigated life cycle system, and this is where allocation may be needed. Examples of different methods of allocation are partitioning and economic allocation. If one wishes to avoid allocation, system expansion is an approach often used (Bauman & Tillman, 2004).

The software used in this specific LCA, GaBi, employs several databases that have been economically allocated, but, generally, the intent is to avoid complex allocation when possible through system expansion. System expansion, also known as substitution, will be applied in both scenarios modeled. The textile waste contains energy which is released when incineration occurs, meaning both energy and heat can be recovered and allow for alleviation of other processes where these resources are generated.

An additional multifunctional issue is related to recycling of textiles. In this report, recycling of textiles will be assumed to lead to the production of industry rags, or wipers.
2 Life cycle inventory analysis
The life cycle inventory analysis includes an account of all the data needed to conduct an LCA of the relevant topic. Relevant numbers for processes and respective sources are presented, and a more detailed presentation of the textile flow of the scenarios is accounted for.

2.1 Energy Consumption
The consumption of energy is based on data from GaBi and the Ecoinvent database. The electricity mix of Sweden, The Netherlands and China is used in the report to determine environmental impacts of phases and processes. Figure 6 displays the electricity mix of China and is based on data from 2005. Figure 7 presents Swedish power distribution data from 2000, while Figure 8 is an account of the data for The Netherlands, and refers to 2004 conditions.

![Figure 6 Electricity mix – China – 2005](image-url)
Figure 7 Electricity mix – Sweden – 2000

Figure 8 Electricity mix – Netherlands – 2004
2.2 Textile waste composition
In order to determine the avoided burdens associated to displacing clothing production, one needs to define the material content and the corresponding fractions of the textile household waste in Sweden. A kilogram of textile waste will consist of fabrics made from different materials. The displaced by waste therefore includes cultivation and production of the different fabrics. It is therefore of importance to define the relevant fractions.

Finding specific data for this is problematic. Information concerning textile waste content on an international level is scarce, and there are hardly any studies performed on this topic which could be easily transferable to Swedish conditions. Youhanan (2013) accounts for a report made by Bartle and Haner (2009), where fiber content in end-of-life apparel from Europe has been analyzed through use of solvents. This survey, however, has a limited time span of a season, making it hard to draw any conclusions concerning long term waste content, and the extrapolation to Swedish conditions is questionable at best (Youhanan, 2013). Furthermore, the report by Bartle and Haner is currently not attainable, and therefore the use of data from it becomes precarious since it has to be considered a second hand source.

Since no specific data can be found on material composition of Swedish textile household waste, alternative data needs to be measured. An LCA study of Swedish textile consumption made by Strand (2015), presents an alternative approach to the problem. With data from Statistics Sweden, compiled from 2000-2013, Strand makes an estimation of the fiber content of clothing and household textiles for the accumulated net consumption between these years. In this case, the consumption is related to the import, production and export of textile goods. Strand divides this consumption into end goods categories such as fabrics, yarn, household, clothing, other textiles and other fibers, and chooses to focus on the two dominant groups, clothing and household, which together amounts to 68 percent of total content. The fibers of these two groups are broken down into three categories, man-made, natural and unspecific fibers, which make up 49 percent, 41 percent and ten percent, respectively. The unspecified fiber category is proportionally allocated into the other two categories. In man-made fibers the following materials are included: nylon, polyester, synthetic, viscose, polyethylene, regenerated fiber and unspecified man-made fiber. The breakdown of the category natural fibers includes: cotton, wool, coco, other plants and unspecified natural fibers. To define a manageable amount of textile materials to work with, Strand allocates the smallest material fractions and the unspecified fractions into the five major categories cotton, polyester, nylon, wool and viscose (figure 4). Due to the small amount of the allocated fractions, this should not be considered an issue, with one exception: unspecified man-made fibers. This specific category consists of 46 percent of the category man-made fibers, which makes allocation problematic since it increases uncertainty of the final results (Strand, 2015). In the cradle to grave LCA used by Strand, these five materials make up the final fiber classification of Swedish textile consumption.

Since there is currently no superior alternative at hand, these categories and their respective amounts will be applied in this report. To make them valid however, certain assumptions need to be made. First, it has to be assumed that the textiles produced are consumed the same year, and that this is true for all accounted materials. The lifetime of different products and materials must therefore be considered to be the same, although this is not the case, since certain materials and products will be more durable and
last considerably longer than others. The assumptions results in a consistent flow throughout the system; material fractions entering are also material fractions leaving.

![Figure 9 Fiber classification for textile consumption and waste content](image)

### 2.3 Textiles: Virgin material production

In the production process of textile manufacturing, the cultivation of crops needed to produce certain materials will be included. Below is presented what processes are included within the chosen boundaries for each textile.

#### 2.3.1 Cotton fiber

In this LCI, cotton fiber production refers to cultivation of cotton and the process of generating the fiber. The cultivation includes sowing, fertilizing, spraying, irrigation, plowing, harrowing and harvesting. In the ginning process baling is also included. Additionally added is operation of vehicles and transportation of the cotton within the process. The data is taken from Ecoinvent and refers to Chinese conditions as defined in the database.

#### 2.3.2 Polyester

Production of polyester, a material procured from oil resources, is defined here as fleece production of polyethylene terephthalate, and the information for this process is provided by the Ecoinvent database. Data available is an average of European production standards, which is utilized in the report, since no equivalent data is available about Chinese production.
2.3.3 Wool
The production of wool is considered to take place in China, but specific information for the process in the region is unavailable. Instead, conditions for US production will be applied, since it is available in the Ecoinvent database, which is used in this case.

Wool is a co-product of “sheep”, which is estimated to generate 4.2kg wool/sheep and year. In the software Gabi economic allocation with a factor of 64.9% to wool is applied. Additional byproducts from production of sheep are not considered.

2.3.4 Viscose
Viscose can originally be obtained from cellulose or cotton. The actual conversion process is conducted through chemical processes. The data for viscose production is taken from Ecoinvent and is based on a global average. Since viscose production is a multi-output process additional substances such as sodium sulphate and sulphuric acid are extracted. Economic allocation is provided by the software Gabi to handle this.

2.3.5 Nylon
Similar to polyester - and also procurable from oil - data on production of nylon 66 (or polyamide 6.6) is based on a European average. The information is taken from Ecoinvent but originates from European plastics industry (PlasticsEurope) Eco-profiles.

2.4 Textile Product Manufacturing
In this life cycle inventory, the textile product manufacturing is divided into four parts, excluding the cultivation or the production of the raw materials. These are 1) yarn spinning, 2) fabric manufacturing, 3) wet processing and finally 4) textile production. The resources used and emissions of these different processes differ, but they are all assumed to be using power from the Chinese electricity grid, as defined by Ecoinvent. Details for each process are presented below.

During different production phases of fabrics and textile products, waste of different kinds are generated. This waste may be sent to landfills, recycled or used as secondary materials (Muthu S. S., Li, Hu, & Ze, 2012). Due to lack of information about specifics concerning waste generation in this process stage, this factor will not be included in the LCA.

2.4.1 Yarn Spinning
An average spinning process typically includes sub-processes such as opening, carding, stretching, roving and spinning (Laursen et al., 2007). The energy demand of the spinning process differs on whether the yarn is combed or carded. Another important factor for energy demand is the mass density of the yarn (Koç & Kaplan, 2007). Data from Koç and Kaplan concerning energy consumption for yarns with different density in both knitting and weaving processes are used by Strand to calculate a total average of 3.21 kWh/kg textile for these processes (Strand, 2015). In this report, Strand’s method of obtaining an average for energy demand of spinning is applied, and therefore, the same value will be used.

Concerning material losses during spinning data differs between different materials. According to Baydar, Ciliz and Mammadov, the textile losses averages at ten percent for cotton production (Baydar,
Ciliz, & Mammadov, 2015). The same figure is reached by Strand as an average for textiles in general, through comparing data from different articles. Therefore, in this report, material losses during spinning will be set at ten percent.

2.4.2 Fabric Manufacturing
The process of manufacturing a fabric can be performed through several methods, such as weaving, knitting and production of nonwovens. Knitting is normally done through the use of a single machine to convert yarn to grey fabric, while weaving is performed through several preparatory processes such as winding, warping and sizing (Muthu S. S., 2014). For simplification purposes, weaving will be chosen in this report as the method of choice for fabric manufacturing.

Data on energy demand for the weaving process differs between different report. Muthu accounts for several data from different reports, and therefore an average of Muthus numbers and data from Koc and Cincik (2010) is used to calculate an average of 16.363 MJ/kg of textile. Koç & Çinçik also specify that 9.85 kJ/kg thermal energy is used (Koç & Çinçik, 2010). Since no other data concerning this have been found, these figures will be applied.

Data on fabric loss during weaving is taken from Blackburn and Payne (2004), who state that typical mass loss for weaving differs between 3-8 percent. In this report, an average mass loss will be set at five percent.

2.4.3 Wet Processing
In wet processing there are, in addition to, several sub-processes, three main stages: fabric preparation or pre-treatment, coloring (dyeing) and finishing (Baydar, Ciliz, & Mammadov, 2015). The bleaching and dyeing process demands considerable amounts of chemicals, and both the bleaching and the process of washing the cloth after dyeing are water intensive. Baydar et al. (2015) state that hydrogen peroxide is a common bleaching chemical, and estimate the usage to 0.118 kg/kg textile for cotton t-shirt production. Data for hydrogen peroxide production is taken from Econivent database. Roos et al. (2015) present additional data on chemicals included and the respective amounts, in the process of dyeing black and green T-shirts. These chemicals include sequestering, antifoaming and penetration agents, a base, formic acid, lubricant and soda, for which data can be found in the Ecoinvent database. Roos et al. (2015) also include a durable water repellent (DWR) agent, and black, yellow and blue dyestuff. For these substances, there are not equivalents in the version of GaBi used in this LCA, and they are therefore not included. The data for chemical amounts per kg of textile in the wet process used by Roos et al. (2015) is presented in Table 1.
In total, dyeing for the wet process is set to 0.95 kg/kg textile and water use is approximated to be 150 L/kg textile. These figures will be used in this report to represent the wet processing. When considering the complex process of dyeing, there are several methods which can be applied. In this report direct dyeing will be chosen since it is a common process which can be applied to several textiles other than cotton (Teonline, n.d.).

The material losses during wet processing are estimated by Blackburn and Payne to be between 3-10 percent (Blackburn & Payne, 2004). In this report, an average will be set at 6.5 percent loss.

2.4.4 Textile Production
For simplification purposes, the produced textile of choice will be a T-shirt. In this report, the production of the garment will be defined as a cutting and sewing process. As such, the only environmental concern of note will be the energy consumption of machinery and the loss of fabric during the process. Data are taken from Baydar et al. (2015) where it is stated that average energy consumption is estimated at 2 MJ/kg of textile produced and where the loss of fabric is estimated to be ten percent.

2.5 Production-to-outlet transportation
It is estimated that 92 percent of textile imports are transported by ship (Beton et al., 2014). Since precise data for Swedish imports is challenging to find, and for simplification reasons, it will be assumed that 100 percent of imports are transported by sea. Transportation from production to use phase is defined as an oceanic container ship with a 27,500 deadweight tonnes payload capacity. The resource demanded at this stage is fuel oil, and environmental impact is based on shipping of one kg of goods. Data is taken from PE International. The distance traveled is set to 23,224 km, which is based on the sea route distance, estimated between the port of Shanghai and the port of Gothenburg (Ports.com, n.d.).

Also included in transportation between production and use phase is transportation from Swedish import harbor to outlet. The distance is set as an average of 100 km. Vehicle data is based on a 14-20 tonnage truck with a payload of 11.4 ton. Furthermore, diesel production will also be included. Data is taken from PE International. This transportation will be defined as production-to-outlet transportation.

For simplification purposes, all road based transportation in the LCA will be modeled as empty return trips.
2.6 Reuse scenario waste management phase

2.6.1 SÖRAB recycling center

There are six recycling centers associated to SÖRAB, located in: Löt, Smedby, Hagby, Görväln, Kvarnkullen and Stockby, where textile household waste is brought by consumers and put into containers. These containers are partially managed and organized by staff on site. Once per week the content of the containers is collected, either by SÖRAB or by the non-profit organization Human Bridge. At all recycling centers except Löt and Kvarnkullen, there are specific containers, besides the normal containers for textile waste, labeled as Human Bridge containers, where consumers can throw textiles considered fit for reuse. Textiles put in these containers stationed at Hagby and Smedby are transported to a sorting facility in Vallentuna. This textile flow amounts to approximately 5.9 percent of total amount of textiles collected at SÖRAB’s recycling centers. The rest of the textiles, 94.1 percent, are sent to a textile gathering hub in Rosersberg. At Rosersberg the textiles are repacked and loaded for transportation to another facility in Dordrecht, Netherlands, while textiles at Vallentuna are sorted for reuse and transported to second-hand outlets in Sweden or sent to be distributed as aid. Not accounted for in this scenario are textiles disposed of in the general household waste stream (Rosinski, 2016).
In 2015, 1 027 704 kg of textiles were collected through the textile waste stream at the six facilities (Rosinski, 2016). This is only an insignificant amount of the total waste stream that is treated at SÖRAB, where for instance the recycling center of Hagby alone handled more than 277,000 tons of waste in 2015 (SÖRAB, 2015). The energy demand for waste processing at SÖRABs facilities is related to electricity and heating requirement of buildings, use of working equipment, waste crushing and leachate cleansing procedures. With the goal of determining energy usage per kilogram of household textile waste, and given that the energy intensive processes of waste crushing and leachate cleansing are independent from this specific waste, data for textile waste management energy demand will be taken from the facility of Görväln. This facility has no waste crushing or leachate cleansing processes connected to it. Average numbers for energy use per functional unit will therefore be more accurate for textiles than if non related energy intensive processes were included. In the case of the recycling center of Görväln, the average energy demand for 2012-2015 is 25,631 kWh per year, and waste processed during the same
period amount to 8491 tonnes per year. This result in approximately 3.0185 kWh per tonnes of waste processed.

2.6.2 Transportation
After the textiles have been collected from the recycling centers, the responsibility for them is taken over by the aid organization Human Bridge. The textiles are now transported to sorting facilities. Only about 5.9 percent is taken to the facility in Vallentuna, while the rest of the textile waste is transported all the way to a facility owned by the company Gebotex in Dordrecht, Netherlands. In this facility some textiles are sorted as recycling, and these are transported to a facility in Poland where they are turned into wipers. Where this facility is located is unclear, so for simplification purposes it will be assumed that the facility will be located in Poznan. The textiles are being transported by trucks, and in the case of the transportation from Rosersberg to Dordrecht, transportation includes the use of ferries.

Vehicle data for transportation from Hagby and Smedby to Vallentuna is based on a 14-20 tonnage truck with a payload of 11.4 ton. Vehicle data for transportation from SÖRAB recycling centers to Rosersberg is based on a 7.5-12 tonnage truck with a payload of 5 ton. Data for the extensive transportation from Rosersberg to Dordrecht in Netherlands and from Dordrecht to Poznan in Poland is based on data for a 20-26 tonnage truck with a payload of 17.3 ton. Data for ferry transportation is based on data for a coast going roll on-roll off (roro)-ship with a 1200-10 000 deadweight tonnes payload capacity, and with EU-15 light oil fuel. Fuel data for all truck transportation is based on EU-15 diesel estimations. Data for all transportation and fuel is taken from PE International.

Information concerning distances between SÖRABs recycling centers and Rosersberg, between Rosersberg and Dordrecht and ferry distances is based on estimations by Ascue (Ascue, 2015). Distances between Hagby and Vallentuna, Smedby and Vallentuna, Vallentuna and Högdalen incineration facility and finally Dordrecht and Poznan is estimated with the help of Google maps.

2.6.3 Netherlands sorting facility
The facility in Dordrecht, Netherlands, is owned by the company Gebotex and has the capacity to deal with at least 90 tonnes of textiles per day. The company buys textiles from several European collecting companies which often work together with charity organizations, but they also get textiles directly from the latter. The textiles are sorted into five different qualities, where the finest quality textiles are sold to Russia or Eastern Europe, and where other textiles are shipped to Africa, Middle East or South America. Textiles not considered good enough for reuse are sent to recycling companies and turned into industry cleaning rags or shredded into fibers for use in mattresses and carpet underlays. Textiles too dirty or unfit for even these processes are sent to incineration (Gebotex, 2015).

In this study, environmental impact will be derived from energy use of the facility, which in turn is linked to data for Netherlands energy mix taken from Ecoinvent. Energy use for 2015 was determined to be 285,823 kWh. Total amount of textiles handled at the facility the same year was estimated to 22,860,000 kg. (Bes, 2016) This leads to an average of 0.1688 kWh/kg textile. In this report all textiles flowing through Gebotex facility will be considered household textile waste for simplification purposes, although in reality one can also find products like footwear and toys in the flow (Gebotex, 2015).
Data for textiles sent to incineration will be based on the same parameters as those for Swedish conditions and equal to those in the incineration scenario. Data for incineration is taken from PE International and transportation to incineration facilities is set to 50 km and made by a 14-20 tonnage truck with a payload of 11.4 tonnes.

In the Gebotex facility the textiles are sorted into categories reuse, wipers, recycling and waste (incineration). For textiles sent from SÖRAB, the fractions are as follows: reuse 67.68%, recycling 18.16%, wipers 6.99% and waste 7.18% (Gebotex, 2014). For simplification purposes, the category recycling will be allocated into the other categories, and the distribution used in the LCA is presented in Table 2.

Table 2 Distribution of sorted textiles in Gebotex facility after allocation

<table>
<thead>
<tr>
<th>Category</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reuse</td>
<td>73.73%</td>
</tr>
<tr>
<td>Wipers</td>
<td>13.04%</td>
</tr>
<tr>
<td>Waste</td>
<td>13.73%</td>
</tr>
</tbody>
</table>

2.6.4 Dutch energy recovery
Due to the fact that textiles are being sent to incineration in the Netherlands, there will be displaced energy and heat. The energy is connected to the Dutch energy mix, and will affect the energy consumption of the system to some extent. In GaBi, this displaced energy will be included in the overall energy consumption of Dutch processes in the reuse scenario, and will therefore not be displayed separately in the LCIA. Since between 40 and 50 percent of Dutch energy consumption can be derived to natural gas (Eurostat, 2015) (Government.nl, n.d.), it will be assumed in this LCA that heat produced will be from this energy source. This will be represented in GaBi as the process heat, natural gas, at boiler >100kW.

2.6.5 Recycling
Although recycling textiles, as they are defined by the company Gebotex, is allocated into other categories, the category wipers is a process where old textiles are recycled into industry wipers. This process will be included in the LCA.

Woolridge et al. (2006) investigate what energy credit can be gained by replacing paper wipers with recycled textile equivalents. The production of one kg of paper wipers demands approximately 20 kWh of energy, while the production of one kg of cloth wipers needs only 1.697 kWh. This means that there is an energy saving of 18.303 kWh per kg of replaced paper wiper, granted that one kg of recycled material can directly replace one kg of paper wiper. The energy saving gained through this assumption will be used to take into account the replaced paper wipers in the system. For simplification purposes it will also be assumed that the energy saved is related to the country where the sorting of the textiles takes place. This is due to lack of information of where the relevant paper wiper production is situated. Such inquiries are considered to be beyond the scope of this LCA.
2.6.6 Vallentuna Sorting Facility
Unlike the Gebotex facility in Dordrecht, the facility in Vallentuna is significantly smaller. While the Netherlands facility in 2015 handled around 22,860 tonnes of textiles, the numbers for Vallentuna was reported to be 258,689 kg (Zackrisson, 2016). At current date, there exists no large scale sorting facility in Sweden on par with the one in Dordrecht; Human Bridge together with Boer Group in Netherlands have plans to start a large-scale textile sorting facility in Sweden in the second quarter of 2016 (Human Bridge, 2016) (Rosinski, 2016).

The Vallentuna facility is not private; it is organized by the municipality as an employment project for people with long sick leaves. There is however a strong cooperation with Human Bridge, which transport textiles to the facility every Monday for sorting. The facility also has its own weekly collection procedures where textile charity containers in Vallentuna and neighboring municipalities are collected and transported to the facility, and there are also textiles coming in from recycling centers other than those owned by SÖRAB. In 2015, Human Bridge transported 60,142 kg of textiles to the facility in Vallentuna (Rosinski, 2016). This amounts to approximately 23 percent of all the textiles handled there that year. Only 6395 kg, or approximately 2.5 percent, of the total amount of textiles in 2015 were sorted as waste for incineration. Distance for transportation of textiles to Högdalen incineration plant is estimated to be 44 km, where transportation is performed by a 14-20 tonnage truck with a payload of 11.4 tonnes. Data for transportation and incineration is taken from PE International.

The rest of the textile flows, 97.5 percent, were deemed fit for reuse. Amounts sorted for recycling are currently so insignificant they will be treated as non-existent for calculation purposes in this report. Energy demand for the building was in 2015 measured to reach 67,500 kWh (Högberg, 2016). This covers all areas, include those not used specifically for textile sorting. For simplification purposes in this report, the whole building will be considered part of the textile sorting activities. Energy use is therefore set to be 0.261 kWh per kg of sorted textile, and is set as Swedish energy mix as defined by PE International.

The high amount of reuse textiles in the Vallentuna textile flow are likely due to the facility’s own collection of textiles from charity containers, where consumers put textiles they consider fit for reuse. One can therefore draw no conclusions concerning the reuse rate of textile flows from SÖRAB’s recycling centers from these numbers.

2.6.7 Högdalen incineration plant
Incineration of the textile waste is taking place in Högdalen waste incineration and thermal power plant. Thanks to the incineration process, energy and heat will be recovered. In this LCA, the energy recovered will be included in the Swedish energy consumption in the scenario, and therefore not be displayed as a separate process.

The displaced heat will be associated with heat production from burning of softwood chips from forest, which is a process available in GaBi through the Ecoinvent database. This choice of process is motivated by its similarities with the new combined heat and power plant in the area of Värtan in Stockholm. This new energy and heat generating power plant is planned to take care of residue from the Swedish wood industry such as wood chips, bark, branches and twigs. It will deliver 750 GWh of electricity and 1700
GWh of heat to the Stockholm region annually, and is estimated to launch in 2016 (Fortum, 2015). In the reuse scenario, a small amount of incineration takes place due to textiles from Vallentuna sorting facility, meaning that there will be some displaced heat from Värtan. However, since most of the textile waste flow now is directed towards sorting and transportation abroad, there will be a significant loss of energy and heat due to decreased incineration, resulting in increased electricity production from Swedish power grid and increased heat generation from the heat plant in Värtan.

2.7 Incineration scenario waste management phase

2.7.1 SÖRAB recycling center
In the incineration scenario, calculations concerning energy use of SÖRABs recycling facilities will include the processes waste crushing and leachate cleansing. Calculations will be conducted with data from the largest recycling center, Hagby, where these procedures are used for waste flows to incineration or landfiling. When comparing waste flows in 2015 of 277,531 tonnes with the energy consumption the same year one can estimate that total energy use per kilogram of waste flowing through the facility is 5.83 kWh/ton.

Direct environmental impacts from waste crushing and leachate cleansing will be disregarded in this report. This is due to lack of data on impacts and on how they should be allocated to textiles. Furthermore, textiles only make up an insignificant amount of total waste processes at Hagby; approximately 424 tonnes of a total of 277,531 tonnes in 2015, which is 0.15% of mass total. Although it is unclear how much of this mass that flows through waste crushing and leachate cleansing, the data indicate that the potential impacts from textiles in connection to these processes can be disregarded.

2.7.2 Transportation
Transportation in the incineration scenario is estimated between Hagby and Högdalen and based on data from Ascue (Ascue, 2015). Numbers concerning truck transportation are based on data for a 14-20 tonnage truck with a payload of 11.4 tonnes, and is taken from GaBi international.

2.7.3 Högdalen incineration plant
Incineration of the textile waste is taking place in Högdalen waste incineration and thermal power plant. As explained in 2.6.7, this will be modelled as if energy and heat recovered during the incineration will result in displacements in the Swedish power grid and in the heat power plant in Värtan.
3 Life cycle impact assessment
The life cycle impact assessment consists of an exposition of the results of the LCA. Specifically, this is accounted for as quantified numbers for the included impact categories: global warming, resource use (water, energy), eutrophication, acidification, human toxicity and eco-toxicity. The data will be presented in diagrams for easy interpretation, but the actual numbers can also be accessed through tables 5-11 in the appendix.

3.1 CO2 eq emissions
In the incineration scenario waste management phase, approximately 1.78 kg of CO2 equivalents is emitted per kilogram of textile waste. In Figure 12, different processes in the incineration scenario are shown. There it can be seen that the dominant source of emissions is the textile incineration process, which stands for almost all of the total impact. In this scenario, there is a insignificant displacement of Swedish heat and energy production.

Conversely, in the reuse scenario waste management phase, global warming is estimated at -0.944 kg CO2 equivalents per functional unit. As displayed in Figure 12, the source of this negative value is related the Dutch energy production, to which energy is displaced through the textile wiper recycling process. Although only about 12 percent of the total textile waste stream is directed towards recycling, it is still enough to affect total emissions to such extent that more emissions are prevented than actually released from this scenario. There are two main sources of emissions. The major contributor is international truck transportation, followed by the incineration processes.

The textile production phase has associated emissions of 30.5 kg CO2 equivalents per FU. Figure 13 describes how these emissions are divided between the different production processes within the phase. The largest source of emissions originates from energy demand of fabric and product production, where the energy is produced through the Chinese power grid. About 71 percent of total emissions are due to the Chinese energy production needed for these processes, where the biggest individual source of emissions is the wet processing stage, which accounts for almost a third of the total emissions. The largest material production contributor is wool, with 11.7 percent. This is significant since wool in this case only takes up three percent of the materials used to produce one kg of textile.

The international production-to-outlet transportation emits 0.322 kg CO2 equivalents per FU.

When comparing the two different waste management phases, it is clear that by changing from incineration to reuse, the GHG emissions are dramatically altered. However, when including the production stage in the life cycle analysis and when looking at a scenario as a whole, the impacts from the waste management phases contribute very little to total impacts.
Figure 12 Global warming Potential for the incineration scenario waste management phase and the reuse scenario waste management phase [unit: kg phase [CO2 equivalents/kg textile waste (FU)]

Figure 13 Global warming potential for the different processes in the textile production phase [unit: kg CO2 equivalents/kg produced textile (FU)]
3.2 Water use

The amount of water needed to process the textile waste is presented in Figure 14 for the two waste management phases. In the incineration scenario waste management phase, there is a return of -0.118 l of water when processing one kg of textile waste. This is thanks to displaced heat and energy production connected to incineration of textile waste. In the reuse scenario waste management phase, there is actually a significant return of -26.54 liters of water for the system. As being the case with the GHG emissions, this is due to the saved energy through the textile wiper recycling process. The most water intensive process in the scenario is the Swedish energy production, with 2.56 liters per kg textile waste, which is insignificant relative to the savings from avoided energy savings, which is 30.1 liters per kg of functional unit.

In the production stage, a staggering amount of 5353.2 liters of water is used to produce one kg of textile. The main source of water consumption is related to cotton production, which alone accounts for 76.9 percent of production stage water use, or 4114.8 liters in total. Cotton stands for 42 percent of the total composition of the textile material in this study. The second biggest source of water use is energy production, which demands 679.9 liters per kg of produced textile, or 12.7 percent. Ground water is the major source of water in the production phase, and over 3000 liters is extracted from aquifers. River water is the second largest source of water, where approximately 1000 liters are withdrawn. The water consumption in the production-to-outlet transportation is negligible in comparison, with only 3.3 ml/water per kg functional unit.

When comparing the water use in the two different waste management phases, it is clear that the water return in the reuse scenario is much higher. However, when coupled with the production phase, it results in a staggering amount of water use for the entire scenario.

Table 3 Water type Production stage

<table>
<thead>
<tr>
<th>Water type</th>
<th>l/kg produced textile</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ground water</td>
<td>3076.6</td>
</tr>
<tr>
<td>Lake water</td>
<td>1.7</td>
</tr>
<tr>
<td>River water</td>
<td>1136.3</td>
</tr>
<tr>
<td>Sea water</td>
<td>6</td>
</tr>
<tr>
<td>Surface water</td>
<td>0.00012</td>
</tr>
<tr>
<td>Water (unspecified)</td>
<td>1098.8</td>
</tr>
<tr>
<td>Total</td>
<td>5319.4</td>
</tr>
</tbody>
</table>
Figure 14 Water use in the Incineration scenario waste management phase and the Reuse scenario Waste management phase [unit: liter/ kg textile waste (FU)]

Figure 15 Water use for the different processes in the production phase [unit: liter/ kg produced textile (FU)]. *Includes energy need related to fabric manufacturing, yarn spinning, wet processing and T-shirt production, and also impacts from dyeing.
3.3 Energy use

In both the textile waste management phases, there is a return of energy. In the incineration textile waste management phase, -1.48 MJ is returned per functional unit thanks to displaced heat and energy from textile incineration. In the reuse scenario waste management phase, there is a return of -15.56 MJ per FU. As seen in Figure 16, energy is mainly needed for diesel fuel production and for facilities in Sweden. The energy use is however counterweighted by the energy savings from recycled wipers, which alone returns -24.8 MJ per FU.

In the production phase, a total of 426, 64 MJ is needed to produce one kg of textile. As seen in Figure 17, most of the energy, 67.1 percent, is needed in textile and product manufacturing. The second biggest contributor, Polyester production, is far behind with 11.7 percent of total energy demand.

Figure 16 Energy use in the Incineration scenario waste management phase and the Reuse scenario Waste management phase [unit: MJ/ kg textile waste (FU)]
3.4 Eutrophication potential

The eutrophication potential in the incineration scenario waste management phase amounts to 0.154 g of phosphate equivalents per FU. The major contributing factor is the incineration process. On its own it emits 0.363 g of phosphate equivalents, 95.1 percent of total contributing emissions.

In the reuse scenario waste management phase total phosphate equivalents are 0.431 g per FU. The biggest contributing processes here are the international truck transportation, which stands for 59.3 percent of contributing emissions, and the production of additional heat needed due to losses from lowered incineration which contributes 28.8% percent.

The production phase accounts an eutrophication impact of 45.7 g of phosphate equivalents per FU. The largest contributing process in this phase is wool production, with 38.5 percent, despite the small fraction of wool in the total amount of textile material. Cotton production is second with 29.1 percent of total phase contribution. The third major contributing factor is Chinese energy production needed for the textile production stages, where 22.1 percent of emissions are accounted for.

International production-to-outlet transportation emits in total 0.989 g phosphate equivalents per kg FU.

In total, the production phase is the largest source of phosphate equivalents related to eutrophication. The reuse scenario waste management phase has more than double the impact of the incineration scenario waste management phase in terms of released emissions, but both waste management phases

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*Figure 17 Energy use for the different processes in the production phase [unit: MJ/kg produced textile (FU)]. *Includes energy need related to fabric manufacturing, yarn spinning, wet processing and T-shirt production, and also impacts from dyeing.*
and the international product-to-outlet transportation are on a very low level compared to the production phase.

![Figure 18: Eutrophication potential in the Incineration scenario waste management phase and the Reuse scenario waste management phase](image1)

**Figure 18** Eutrophication potential in the Incineration scenario waste management phase and the Reuse scenario Waste management phase [unit: g phosphate equivalent/ kg textile waste (FU)]

![Figure 19: Eutrophication potential related to the different processes in the production phase](image2)

**Figure 19** Eutrophication potential related to the different processes in the production phase [unit: g phosphate equivalent/ kg produced textile (FU)]. *Includes energy need related to fabric manufacturing, yarn spinning, wet processing and T-shirt production, and also impacts from dyeing.*
3.5 Acidification potential

When looking at the two different scenario waste management phases in relation to acidification potential, it can be observed that the incineration scenario waste management phase stands for the least amount of emissions: 1.1g of SO2 equivalents per functional unit. The main contributor is the textile incineration process, with 95.0 percent of total emissions from contributing processes. Thanks to incineration, there are heat and energy displaced, as seen in Figure 20.Error! Reference source not found.

In the reuse scenario waste management phase, the emissions are estimated to be 1.83g SO2 equivalents per FU, which is higher than the amount of the incineration scenario. Here, 57.4 percent of the emissions come from the international truck transportation. The second largest source of emissions is from the increased heat production from wood chips incineration to compensate for lowered textile incineration. In the study, this accounts for 26.5 percent of total emissions. Thanks to the production of recycled textiles to wipers, some emissions are allocated, which lowers total emissions count in the scenario.

The textile production phase is estimated to release 312g of SO2 equivalents per kg of produced textile. The main contributor is Chinese energy production for the different processes, which accounts for 65.6 percent, or 205g of SO2 equivalents as shown in Figure 21. From wool production 17.1 percent of emissions are derived, and cotton production contributes with almost 10 percent. All of the specified individual processes in the production phase exceed the total amounts of emissions in the two waste management phases, and overall, the SO2 equivalents emissions in the production phase far exceed those of the other phases. It should also be noted that the international production-to-outlet transportation topples both waste management phases with 10.6g SO2 equivalents per FU, though it still dwindles in comparison to the production phase.
**Figure 20** Acidification potential in the Incineration scenario waste management phase and the Reuse scenario Waste management phase [unit: g SO2 equivalent/ kg textile waste (FU)]

**Figure 21** Acidification potential related to the different processes in the production phase [unit: g SO2 equivalent/ kg produced textile (FU)]. *Includes energy need related to fabric manufacturing, yarn spinning, wet processing and T-shirt production, and also impacts from dyeing.
3.6 Human toxicity potential

The human toxicity potential is measured in DCB (1,4 dichlorobenzene) equivalents per FU. In the incineration scenario waste management phase, there is a return of -52.8g DCB equivalents per FU, thanks to displaced heat and energy production, as seen in Figure 22. In the reuse scenario waste management phase, total emissions instead account for -48.3g of DCB per FU, which is slightly less. Like the results in other impact categories, this is due to the energy saving from the cloth wiper recycling process. The main source of toxicity in the scenario can be traced to heat production from wood chips incineration, which stands for 68.21 percent of the contributing emissions, followed by the truck transportation, which stands for 15.3 percent of contributing emissions.

The production phase delivers 8,41kg of DCB equivalents per FU. slightly above 60 percent of the emission can be traced to the energy production for the fabric and textile product output, but it is also worth to note that wool production stands for 14.4 percent of total emissions in the phase, and cotton production contributes with 9.4 percent as the third major impact source.

The international production-to-outlet transportation has a significantly higher emissions count than the two waste management phases, with 7.4 g of DCB equivalents per kg of transported textile. The vast majority of these emissions can be traced to the maritime shipping process.

When comparing the two waste management phases, the maritime shipping and the production phase, the dominance of the latter when looking at the human toxicity potential is apparent.

![Figure 22 Human toxicity potential in the Incineration scenario waste management phase and the Reuse scenario Waste management phase [unit: g DCB equivalent/ kg textile waste (FU)]]
3.7 Terrestrial eco-toxicity potential

Like human toxicity, the terrestrial eco-toxicity is measured by DCB equivalents. For the incineration waste management phase, this is -3.07 g DCB equivalents per FU. This can be traced to the avoided heat production related to textile incineration. The significance of heat production in the two waste management phases is further made clear when looking at the reuse scenario waste management phase, where heat produced through wood chips incineration stands for 96.2 percent of the total emissions for the contributing processes, as is the reason why total emissions for this phase reach 2.37g DCB equivalents per functional unit.

However, as with all other included impact categories in this report, the textile production phase is the overwhelming contributor, and account for 0.50kg of DCB equivalents per FU. Within the production phase, it is cotton production which is the major source of impact, and it dominates all other processes with 86.73 percent of the total emissions. An interesting note here is that wool production, usually a major contributor to different impacts, in this case has a negative contribution. It lowers total impact with 18.9g of DCB equivalents.
**Figure 24** Eco toxicity potential in the Incineration scenario waste management phase and the Reuse scenario Waste management phase [unit: g DCB equivalent/ kg textile waste (FU)]

**Figure 25** Eco toxicity potential related to the different processes in the production phase [unit: g DCB equivalent/ kg produced textile (FU)]. *Includes energy need related to fabric manufacturing, yarn spinning, wet processing and T-shirt production, and also impacts from dyeing.*
3.8 Summary of scenario totals

The lifecycle of the incineration scenario as it is simulated in GaBi is illustrated in Figure 26, while the corresponding simulation for the Reuse scenario is shown in Figure 27. Although the use phase is present in the flowcharts, it is only a placeholder and not included in the actual simulation, as defined earlier.
The environmental impacts of the two total scenarios are shown in Table 4. Additionally included in this table are calculations for the reuse scenario where impacts from transportation of reuse textiles back to the included municipalities are accounted for. When studying the results, there is a clear disparity between the two scenarios, where the Reuse scenario has between a third and a fourth of the impacts generated by the Incineration scenario.

**Table 4** Total impacts of the included scenarios per FU

<table>
<thead>
<tr>
<th></th>
<th>Incineration scenario</th>
<th>Reuse scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td>GHG</td>
<td>32,181 kg CO₂ eq/FU</td>
<td>8,591 kg CO₂ eq/FU</td>
</tr>
<tr>
<td>Water use</td>
<td>5351,8 l/FU</td>
<td>1609,1 l/FU</td>
</tr>
<tr>
<td>Energy use</td>
<td>423,45 MJ/FU</td>
<td>118,22 MJ/FU</td>
</tr>
<tr>
<td>Eutrophication</td>
<td>0,04679 kg phosphate eq/FU</td>
<td>0,015 kg phosphate eq/FU</td>
</tr>
<tr>
<td>Acidification</td>
<td>0,32387 kg SO₂-eq/FU</td>
<td>0,1022 kg SO₂-eq/FU</td>
</tr>
<tr>
<td>Human toxicity</td>
<td>8,3669 kg DCB eq/FU</td>
<td>2,534 kg DCB eq/FU</td>
</tr>
<tr>
<td>Eco-toxicity</td>
<td>0,49595 kg DCB eq/FU</td>
<td>0,1549 kg DCB eq/FU</td>
</tr>
</tbody>
</table>
4 Discussion
In this section, the results presented in the LCIA will be analyzed and discussed. This will include a section concerning uncertainty factors, where potential deficiencies in the report which could affect results will be commented on. The discussion will end with a paragraph regarding further research related to the report.

4.1 Uncertainty factors

4.1.1 Electricity mix accuracy
The electricity mixes used in this LCA can be considered slightly dated. The question is to what extent this increases the inaccuracy of the data provided by GaBi. The Swedish energy mix is dominated by hydro power and nuclear power, and this has been the case for decades. The exact percentage of each type of energy production can differ slightly depending on the source. As such, it is precarious to focus too much on specific numbers. The dominance of the two main energy sources has remained the same for decades, and their respective share of the production follows the same pattern (Swedish Energy Agency, 2015). Therefore the data for the Swedish energy mix for 2000 should still hold today. Similar can be said about the Dutch energy mix (International Energy Agency, 2014). The accuracy of Chinese power mix on the other hand, is somewhat more complicated. Currently there is an expansion of renewable energy in China, meaning that production shares could be a bit different than 2005. However, the dominance of the coal is still great, and the extent of it can be seen as an indication of that the data from the Ecoinvent database used in this report still holds up, although the accuracy is lowered by this fact.

4.1.2 Production phase uncertainties
In this report, for simplification purposes, the focus has been on Chinese textile production, specifically on T-shirts. With this in mind, there is of course a discrepancy between actual imports of textiles from countries other than China, such as India and Bangladesh, where conditions for production can be different compared to China. Though the choice for focusing on China used in this report is valid, it is still important to take this difference into consideration when analyzing the LCIA.

To focus on T-shirt production specifically can also be considered a factor that lowers accuracy of impact data, since T-shirts can only be considered a small part of textile production. The choice for using production data for T-shirts is a matter of data availability and the limited scope of this LCA. The effects of this could indicate an underestimation of energy need from sewing and cutting processes, since most clothing today (e.g. pants, jackets, shirts, and dresses) can be seen as containing more fabrics and with more complex stitching.

The material mix of the fabric in this report should be seen as an unrealistic simulation of textile fabric production, since no fabric contains all the included materials, and not all of them, such as wool, could be considered common in the production of T-shirts. As with many other aspects in the LCA, these processes needed to be simplified to create a working model. The result is a less accurate estimation of impacts.
In this LCA, the dying process – part of the wet processing – is also a source of inaccuracy, partially because of the lack of data on dyeing colors and DWR’s, and partially because the use of polycarboxylate as surfactant in the process. This substance might be too concentrated. Although the impact of the dyeing is small in comparison to other processes in the production phase, this could still mean a less accurate model.

4.1.3 Waste management phase uncertainties

In the waste management phase, incineration also means avoided heat production, and vice versa. In the case of incineration in Sweden, as stated in the LCA, the heat production is being represented by the heat and power plant in Värtan. This could be seen as an aspect adding uncertainty to the data, since this plant is very new and therefore not representative of heat production in general in Stockholm. Although one could argue that it still is a valid simulation, there is no way in this report to show that altered incineration in Högdalen incineration plant in fact correlates to a change in heat production in Värtan. It has to be assumed, and therefore the uncertainty factor is increased.

Another assumption that adds uncertainty is the Gebotex facility allocation, where it is assumed that the entire recycled textile fraction is turned into wipers. As stated in the report, this is a simplification, since there is also production of insulation from recycled textiles. Due to insufficient data from the company concerning its waste handling and of the recycled textiles insulation process, the assumption that all of the recycled fraction go to wiper production had to be made, even though it is unclear if all of the textiles in the recycling fraction can be recycled through the mechanical process used to create industry wipers. This leads to added uncertainty.

There is an additional factor that adds uncertainty to the recycling process: the location of the avoided production of virgin material wipers. In the LCIA, it is clearly shown that the avoided production greatly affects the environmental impacts in the reuse scenario waste management phase. It is assumed that this avoided production is taking place in The Netherlands, but since it is unclear if this is the case, the process could just as likely be situated in another country. This could mean that the impacts could be greater, if the process took place in a country like Poland with significant shares of coal power, or smaller, if the process was situated in a country like Sweden or Norway with a big share of hydro power in the power grid.

4.1.4 Reuse scenario closed system uncertainty

In Figure 27, the textile flows of the reuse scenario are shown. As the model is currently structured, the system is defined as a closed one in relation to the textiles. This means that in the affected municipalities, the textiles are taken to recycling centers, where they are further transported and sorted in Sweden and Netherlands, and then transported back to the same municipalities and reintroduced into the use phase, and the circle begins anew. In reality, this is highly inaccurate due to several reasons, and therefore problematic.

The model describes the waste management system deployed by SÖRAB in the affected municipalities. Since there is no unified system established in Sweden for textile waste management, this system is only directly applicable for said municipalities. An obvious problem in this case is that the probability, that the textiles sorted for reuse should be sent back to the same municipalities and households to where they
were discarded, is highly unlikely, even in the case where textiles are actually sorted in facilities within the municipalities in question. In an ideal situation, as the one the model describes, this could be true, but in reality, currently it is not. In the case these reuse textiles even return to Sweden, they could end up anywhere, and the next time they flow through the waste management phase there is a possibility that it is in a municipality where incineration is the only available alternative. Furthermore, a considerable amount of the textiles defined as reuse by the company Gebotex, is actually sent as aid, and where these textiles eventually end up when spent is way beyond the scope of this study.

Additionally, another problem with this reuse model is that it assumes that the textile fibers are indestructible, and can flow through the system indefinitely. Although synthetic fibers such as polyester can be broken down into monomers and reattached, natural fibers such as cotton are always degraded through use and waste handling, and cannot with current technology be repaired. It might be the case that these textiles can only go through the use phase twice before they have to be discarded or recycled at best. In any case, there is no data for this variable the current model. Even if the assumption is made that the system is closed in the sense that all the reuse textiles are returned to the use phase and the succeeding waste management phase, the degradation of the fabric means that the reuse rate will be lower since more textiles will be sorted as recycling or waste for incineration. Consequently, if the reuse flow is lower, so will the displaced production be. In reality, the impacts from the production phase in the reuse scenario would be higher than shown in the model, due to a higher amount of virgin textile products flowing into the textile loop.

4.2 General discussion
When comparing the incineration scenario waste management phase with the reuse scenario equivalent from a gate-to-grave perspective, it becomes apparent that the reuse waste management phase has the least environmental impacts. However, in the impact categories eutrophication, acidification and terrestrial eco-toxicity potential, the opposite is true. In the incineration scenario waste management phase, the key process affecting impacts is the incineration of textiles. On one hand, the incineration process itself emits harmful emissions, but at the same time, thanks to incineration, much energy and heat becomes displaced. Especially the displaced heat affects the overall impact in a positive way in several of the impact categories, and when it comes to toxicity potential, this results in a return of emissions for the phase. The resource use (water and energy) is insignificantly affected though, as are GHG emissions, where the incineration process has a very dominant contribution within the phase. The displaced heat production in this case is related to incineration of softwood chips, which explains why human and eco-toxicity potential is significantly lowered thanks to the avoided burning of this resource.

In the reuse scenario waste management phase, the process Dutch energy production is often affecting impacts the most. The displaced energy consumption thanks to recycled wipers, replacing production of virgin material wipers, is the sole reason for this. The other significant process is the international truck transportation, which should be considered the main contribution process to environmental impacts in almost all impact categories. From this, one can conclude that it is of importance to consider the transportation distance when dealing with textile waste. However, what could be of even greater
significance is how the textile waste is handled at its destination. As shown in the LCA, even a small fraction of recycled textiles can greatly affect the results, given that the recycling process is more energy efficient than virgin product production. This can potentially trump the importance of transport distance, meaning that choosing a facility close to home for textile waste management could be a more impact heavy alternative that actually sending the waste further abroad. So, when deciding where to send textiles, it could be valuable to investigate how textiles not fit for any kind of reuse are handled more specifically.

Comparing the two scenario waste management phases has its use, but when looking at contributing impacts, the dominance of the production phase is total. Whether it is due to the energy production for the different textile production processes, or the textile material production for materials such as cotton or wool, the impact of this phase is always much higher than the waste management phases or the international production-to-outlet transportation. If the ambition is to lower environmental impacts connected to textile waste management, it is imperative to consider the production phase.

The methods for lowering impacts are naturally different depending on where the stakeholder is in the life cycle of the textile. If looking at the waste hierarchy ladder described by Figure 1, waste prevention is the natural strategy in the production and the use phase, where more efficient production of better quality fabrics and clothing, and a more responsible use through less resource and detergent intensive washing, can be valid methods of making a sturdier textile with a longer life cycle. For the waste management phase however, the second step on the ladder, the reuse strategy, could be as high as a stakeholder can reach. So to reach it is of great importance.

In this LCA study, and in other similar studies of textile waste management, it is indicated that the production phase is the most impact intensive. If it is assumed that a reused textile can directly replace an equal textile which is newly produced, and that this is done regardless of whether the textile is sent to second hand outlets or used as aid, then the gain from increasing reuse rates cannot be overstated. This means, that though the waste management phase has small impacts through its internal processes, the direction of the textile flows in this phase will have great consequences for the total impact of the textile life cycle. If a waste management stakeholder wishes to lower environmental impacts related to the textile life cycle, increasing reuse rates of the textile waste flows should be the top priority. The benefits of increased recycling and the importance of choosing a specific recycling process has been shown and should not be overlooked, but compared to what can be saved by avoiding virgin textile production, it is of lesser importance in the short term. With this in mind, the data results in this report can be said to strengthen the validity of the waste hierarchy priority order (figure 1), since the results indicate that environmental impacts are lowered the further up the hierarchy ladder one reaches.

Consequently, this leads to the conclusion that the reuse scenario is always preferable to the incineration scenario, since so much can be gained in all impact categories by displacing the virgin textile material production. The performance of the individual waste management phases matters little when included in the total life cycle of the textile. This conclusion should be seen as valid even when considering the impreciseness of the current reuse scenario model. Since the dominance of the
production phase is so complete when it comes to impacts, every measure towards lowering virgin material production matters, making the reuse scenario the preferable alternative in all cases. Currently, in Sweden, eight kg of textile per person is being thrown each year in the household waste flow, which means it is incinerated. By lowering these amounts through changed waste flows, where more textiles are being taken care of by aid organizations or companies focusing on second hand textiles, there is much to be gained from an environmental sustainability perspective. To increase reuse rates, hardly any extra infrastructure is needed if the focus is directed on these specific textiles. Instead, it is consumer awareness that ought to be developed. For a company like SÖRAB, which already has a system in place where textiles are being sent to sorting for reuse and recycling, the aim should initially be to inform the consumer of the possibility and the environmental benefits of tossing their used textiles, regardless of the quality, in the household textile container instead of throwing it in the household waste bin or in containers for incineration at recycling centers. Much can therefore theoretically be done to improve environmental performance by SÖRAB or companies with similar textile reuse infrastructure in relation to textiles, not by investing in more expensive infrastructure, but rather by participating in information campaigns concerning the benefits of increased textile reuse. Other than this, the aim should be to strive towards making sure the sorting of the waste is handled by a contractor that can set reuse rates at the highest possible level. This will be more important than transport distance and recycling rates. However, if the choice stands between two alternatives with similar reuse rates, recycling becomes the second priority to focus on, since it can have an effect on environmental performance through displaced impacts.

4.3 Further improvement and research
There are several aspects within the report that could be further developed or improved upon. As mentioned in the discussion, the reuse scenario model is inaccurate and could be adjusted to provide more realistic data. A variable for the degrading of the textile fabrics could, if not being very precise, at least improve this model and others like it.

The flaws in the assumption that the reuse scenario model is closed are harder to counteract. The model would be more realistic if Swedish municipalities had similar ways of handling textile waste, but this is currently not the case, although things might change in the future if the waste management is improved. The accuracy of the LCA can however be improved by more detailed LCIA data. Currently lacking seems to be impact data for different recycling and down cycling processes related to textiles, such as production of insulation made from old textiles. As this study has shown, it is also important to be mindful of how such processes can be related to avoided production.

Since a major conclusion reached in the report is the importance of increased sorting of used textiles during waste management, a continuation of this study could be to investigate if and how information campaigns could be useful for reaching higher reuse rates. In connection to this, it could also be relevant to investigate if this is in some way done in municipalities, and if so, to what extent.

Finally, it is relevant to clarify that results and conclusions in the report focus on short term benefits in textile reuse and recycling. What potentially could be gained through technology advancements in reuse...
sorting, material labeling, recycling and fabric improvements is something that should be analyzed in future reports.

5 Conclusions

- When comparing the reuse and the incineration scenario textile waste management phases, the former phase has less environmental impacts when it comes to greenhouse gasses, resource use (both energy and water) and human toxicity potential, while the latter phase has less impacts related to eutrophication, acidification and eco-toxicity potential.
- The most influencing processes in the incineration scenario waste management phase are the incineration and the heat production, which in this scenario is displaced thanks to heat production due to incineration.
- The most influencing processes in the reuse scenario waste management phase are the international transportation and the Dutch energy production, where a significant amount of energy is displaced thanks to the recycling of textiles into wipers. From this one can conclude that certain textile recycling can be very significant for total impacts in a LCA waste management phase.
- The impacts of the production phase greatly excel that of the waste management phase in all impact categories. If the aim is to lower environmental impacts in the textile life cycle investigated in this report, the production phase is where focus should be directed. This being said, efforts can be made in the waste management phase to affect the production phase.
- The reuse scenario is preferable to the incineration scenario due to the fact that displaced production, thanks to the reuse of textiles, can greatly lower the effects of the impact dominant production phase.
- Since so much household textile is thrown in the household waste, much can be gained by changing the textile waste flows by making sure more of this waste is being thrown in reuse containers at recycling centers or at other relevant locations.
- LCA’s and reports in general concerning environmental impacts of household textile management seem to indicate the dominance of the production and the use phase of the textiles.
6 Bibliography


7 Appendix

Table 5 Global warming Potential

<table>
<thead>
<tr>
<th>Textile production phase</th>
<th>kg CO2 eq/FU</th>
<th>Relative contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Contributing processes</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Cotton fiber production</em></td>
<td>1,1</td>
<td>3,7%</td>
</tr>
<tr>
<td><em>Viscose fiber production</em></td>
<td>0,267</td>
<td>0,9%</td>
</tr>
<tr>
<td><em>Polyester production</em></td>
<td>2,37</td>
<td>7,9%</td>
</tr>
<tr>
<td><em>Nylon 66 production</em></td>
<td>1,32</td>
<td>4,4%</td>
</tr>
<tr>
<td><em>US wool/sheep production</em></td>
<td>3,53</td>
<td>11,7%</td>
</tr>
<tr>
<td><em>Fabric manufacturing</em></td>
<td>6,24</td>
<td>20,8%</td>
</tr>
<tr>
<td><em>Yarn spinning</em></td>
<td>5,03</td>
<td>16,7%</td>
</tr>
<tr>
<td><em>Wet processing</em></td>
<td>9,9527</td>
<td>31,6%</td>
</tr>
<tr>
<td><em>T-shirt production</em></td>
<td>0,704</td>
<td>2,3%</td>
</tr>
<tr>
<td><strong>Phase total</strong></td>
<td><strong>30,5137</strong></td>
<td><strong>100,0%</strong></td>
</tr>
</tbody>
</table>

International production-to-outlet transportation

<table>
<thead>
<tr>
<th>Converting processes</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Municipal waste incinerator Högdalen</td>
<td>1,812</td>
</tr>
<tr>
<td>Waste transportation</td>
<td>0,016</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1,828</strong></td>
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</tbody>
</table>

Displaced processes

<table>
<thead>
<tr>
<th>Converting processes</th>
<th></th>
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</thead>
<tbody>
<tr>
<td>Swedish heat production</td>
<td>-0,0476</td>
</tr>
<tr>
<td>Swedish energy production</td>
<td>-0,01008</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>-0,05768</strong></td>
</tr>
</tbody>
</table>

**Phase total**

<table>
<thead>
<tr>
<th></th>
<th><strong>1,7804</strong></th>
</tr>
</thead>
</table>

Reuse scenario waste management phase

<table>
<thead>
<tr>
<th>Converting processes</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Swedish energy production</td>
<td>0,0205</td>
</tr>
<tr>
<td>Diesel at refinery</td>
<td>0,0424</td>
</tr>
<tr>
<td>Truck transport international</td>
<td>0,343684</td>
</tr>
<tr>
<td>Truck transport domestic</td>
<td>0,0116</td>
</tr>
<tr>
<td>Municipal waste incinerators</td>
<td>0,228</td>
</tr>
<tr>
<td>Swedish heat production</td>
<td>0,04758</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>0,693764</strong></td>
</tr>
</tbody>
</table>
Displaced processes

<table>
<thead>
<tr>
<th>Process</th>
<th>Amount</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dutch energy production</td>
<td>-1,548</td>
<td>94,54%</td>
</tr>
<tr>
<td>Dutch heat production</td>
<td>-0,08946</td>
<td>5,46%</td>
</tr>
<tr>
<td>Total</td>
<td>-1,63746</td>
<td>100,00%</td>
</tr>
</tbody>
</table>

**Phase total**

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>-0,94369</td>
<td>100,00%</td>
</tr>
</tbody>
</table>

Table 6 Water use

<table>
<thead>
<tr>
<th>Textile production phase</th>
<th>l/kg textile</th>
<th>Relative contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy production for processes</td>
<td>679,9</td>
<td>12,7%</td>
</tr>
<tr>
<td>Wet processing</td>
<td>235,3</td>
<td>4,4%</td>
</tr>
<tr>
<td>Cotton production</td>
<td>4114,8</td>
<td>79,6%</td>
</tr>
<tr>
<td>Viscose production</td>
<td>83,7</td>
<td>1,6%</td>
</tr>
<tr>
<td>Polyester production</td>
<td>77,1</td>
<td>1,4%</td>
</tr>
<tr>
<td>Nylon 66 production</td>
<td>108,8</td>
<td>2,0%</td>
</tr>
<tr>
<td>Wool production</td>
<td>50</td>
<td>0,9%</td>
</tr>
<tr>
<td>Other</td>
<td>3,6</td>
<td>0,1%</td>
</tr>
<tr>
<td><strong>Phase total</strong></td>
<td>5353,2</td>
<td>100,0%</td>
</tr>
</tbody>
</table>

**International production-to-outlet transportation**

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0,0033</td>
</tr>
</tbody>
</table>

Incineration scenario waste management phase

**Contributing processes**

<table>
<thead>
<tr>
<th>Process</th>
<th>l/kg</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waste incinerators</td>
<td>1,97</td>
<td>99,91%</td>
</tr>
<tr>
<td>Diesel production</td>
<td>0,0017</td>
<td>0,09%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>1,9717</td>
<td>100,0%</td>
</tr>
</tbody>
</table>

**Displaced processes**

<table>
<thead>
<tr>
<th>Process</th>
<th>Amount</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Swedish heat production</td>
<td>-0,83</td>
<td>39,7%</td>
</tr>
<tr>
<td>Swedish energy production</td>
<td>-1,2592</td>
<td>60,3%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>-2,0892</td>
<td>100,0%</td>
</tr>
</tbody>
</table>

**Phase total**

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>-0,1175</td>
</tr>
</tbody>
</table>

Reuse scenario Waste management phase

**Contributing processes**

<table>
<thead>
<tr>
<th>Process</th>
<th>l/kg</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Swedish Energy production for processes</td>
<td>2,56</td>
<td>69,5%</td>
</tr>
<tr>
<td>Waste incinerators</td>
<td>0,25</td>
<td>6,8%</td>
</tr>
<tr>
<td>Diesel production</td>
<td>0,042</td>
<td>1,1%</td>
</tr>
<tr>
<td>Swedish heat production</td>
<td>0,83</td>
<td>22,5%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>3,682</td>
<td>100,0%</td>
</tr>
</tbody>
</table>
### Displaced processes

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Dutch Energy production</td>
<td>-30,12</td>
<td>99,7%</td>
</tr>
<tr>
<td>Dutch heat production</td>
<td>-0,096</td>
<td>0,3%</td>
</tr>
<tr>
<td>Total</td>
<td>-30,216</td>
<td>100,0%</td>
</tr>
</tbody>
</table>

**Phase total** -26,534

---

**Table 7 Energy Demand**

<table>
<thead>
<tr>
<th>Textile production phase</th>
<th>MJ/FU</th>
<th>Relative contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Contributing processes</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chinese energy production</td>
<td>286,115</td>
<td>67,06%</td>
</tr>
<tr>
<td>Cotton production</td>
<td>19,118</td>
<td>4,48%</td>
</tr>
<tr>
<td>Viscose production</td>
<td>13,602</td>
<td>3,19%</td>
</tr>
<tr>
<td>Polyester production</td>
<td>49,772</td>
<td>11,67%</td>
</tr>
<tr>
<td>Nylon 66 production</td>
<td>21,848</td>
<td>5,12%</td>
</tr>
<tr>
<td>Wool production</td>
<td>30,558</td>
<td>7,16%</td>
</tr>
<tr>
<td>Others</td>
<td>5,624</td>
<td>1,32%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>426,637</td>
<td>100,00%</td>
</tr>
</tbody>
</table>

| Phase total | 426,637 |

**International production-to-outlet transportation** | 4,317 |

**Incineration scenario waste management phase**

<table>
<thead>
<tr>
<th>Contributing processes</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Diesel at refinery</td>
<td>0,225</td>
<td>14,81%</td>
</tr>
<tr>
<td>Municipal waste incinerator</td>
<td>1,2946</td>
<td>85,19%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>1,5196</td>
<td>100,00%</td>
</tr>
</tbody>
</table>

**Displaced processes**

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Swedish heat production</td>
<td>-1,08</td>
<td>36,02%</td>
</tr>
<tr>
<td>Swedish energy production</td>
<td>-1,9183</td>
<td>63,98%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>-2,9983</td>
<td>100,00%</td>
</tr>
</tbody>
</table>

**Phase total** -1,4787

**Reuse scenario waste management phase**

<table>
<thead>
<tr>
<th>Contributing processes</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Diesel at refinery</td>
<td>5,6279</td>
<td>52,19%</td>
</tr>
<tr>
<td>Swedish heat production</td>
<td>1,08</td>
<td>10,01%</td>
</tr>
<tr>
<td>Fuel oil light at refinery</td>
<td>0,0106</td>
<td>0,10%</td>
</tr>
<tr>
<td>Swedish energy production</td>
<td>3,9027</td>
<td>36,19%</td>
</tr>
<tr>
<td>Municipal waste incinerators</td>
<td>0,163</td>
<td>1,51%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>10,7842</td>
<td>100,00%</td>
</tr>
</tbody>
</table>
Displaced processes

Dutch energy production -24,873 94,43%
Dutch heat production -1,467 5,57%
Total -26,34 100,00%

Phase total -15,558

Table 8 Eutrophication Potential

<table>
<thead>
<tr>
<th>Textile production phase</th>
<th>kg phosphate eq/FU</th>
<th>Relative contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy production</td>
<td>0,010116</td>
<td>21,1%</td>
</tr>
<tr>
<td>Cotton production</td>
<td>0,0133</td>
<td>29,1%</td>
</tr>
<tr>
<td>Viscose production</td>
<td>0,000769</td>
<td>1,7%</td>
</tr>
<tr>
<td>Polyester production</td>
<td>0,000816</td>
<td>1,8%</td>
</tr>
<tr>
<td>Nylon 66 production</td>
<td>0,00131</td>
<td>2,9%</td>
</tr>
<tr>
<td>Wool production</td>
<td>0,0176</td>
<td>38,5%</td>
</tr>
<tr>
<td>Other</td>
<td>0,00176</td>
<td>3,9%</td>
</tr>
<tr>
<td>Total</td>
<td>0,045671</td>
<td>100,0%</td>
</tr>
</tbody>
</table>

Phase total 0,045671

International production-to-outlet transportation 9,89E-04

Incineration scenario waste management phase

Contributing processes

Municipal waste incinerators 3,63E-04 80,0%
Transportation 1,89E-05 4,2%
Total 3,82E-04 100,0%

Displaced processes

Swedish heat production -2,22E-04 97,5%
Swedish energy production -5,61E-06 2,5%
Total -2,28E-04 100,0%

Phase total 1,54E-04

Reuse Scenario Waste management phase

Contributing processes

Swedish energy production 1,14E-05 1,5%
Municipal waste incinerators 4,57E-05 5,9%
Truck transport international 4,57E-04 59,3%
Truck transport domestic 1,54E-05 2,0%
Table 9 Acidification potential

<table>
<thead>
<tr>
<th>Textile production phase</th>
<th>kg SO2-eq/FU</th>
<th>Relative contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chinese energy production</td>
<td>0,20452</td>
<td>65,58%</td>
</tr>
<tr>
<td>Cotton production</td>
<td>0,03</td>
<td>9,62%</td>
</tr>
<tr>
<td>Viscose production</td>
<td>0,00749</td>
<td>2,40%</td>
</tr>
<tr>
<td>Polyester production</td>
<td>0,00962</td>
<td>3,08%</td>
</tr>
<tr>
<td>Nylon 66 production</td>
<td>0,00474</td>
<td>1,52%</td>
</tr>
<tr>
<td>Wool production</td>
<td>0,0532</td>
<td>17,06%</td>
</tr>
<tr>
<td>Other</td>
<td>0,002311</td>
<td>0,74%</td>
</tr>
<tr>
<td>Total</td>
<td>0,311881</td>
<td>100%</td>
</tr>
</tbody>
</table>

**Phase total**  
0,311881

International production-to-outlet transportation

1,06E-02

Incineration Scenario Waste management phase

Contributing processes

| Municipal waste incinerator             | 0,00213      | 94,97%                |
| Truck transport                         | 0,0001022    | 4,55%                 |
| Diesel at refinery                      | 1,07E-05     | 0,48%                 |
| Total                                   | 0,00224      | 100,00%               |

Displaced processes

| Swedish heat production                 | -0,00114     | 96,75%                |
| Swedish energy production               | -3,83E-05    | 3,25%                 |
| Total                                   | -1,18E-03    | 100,00%               |

**Phase total**  
1,07E-03

Reuse Scenario Waste management phase
### Table 10 Human Toxicity Potential

<table>
<thead>
<tr>
<th>Textile production phase</th>
<th>kg DCB eq/FU</th>
<th>Relative contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Contributing processes</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy production</td>
<td>5,0772</td>
<td>60.3%</td>
</tr>
<tr>
<td>Cotton production</td>
<td>0.79</td>
<td>9.4%</td>
</tr>
<tr>
<td>Viscose production</td>
<td>0.27</td>
<td>3.2%</td>
</tr>
<tr>
<td>Polyester production</td>
<td>0.41</td>
<td>4.9%</td>
</tr>
<tr>
<td>Nylon 66 production</td>
<td>0.063</td>
<td>0.7%</td>
</tr>
<tr>
<td>Wool production</td>
<td>1.21</td>
<td>14.4%</td>
</tr>
<tr>
<td>Bleaching</td>
<td>0.5</td>
<td>5.9%</td>
</tr>
<tr>
<td>Starch</td>
<td>0.094</td>
<td>1.1%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>8,4142</td>
<td>100.00%</td>
</tr>
</tbody>
</table>

**Phase Total**

8,4142

**International production-to-outlet transportation**

0,0074

### Incineration Scenario Waste management phase

**Contributing processes**

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Municipal waste incinerators</td>
<td>0.005</td>
<td>87.11%</td>
</tr>
<tr>
<td>Truck transport + diesel prod.</td>
<td>0.00074</td>
<td>12.89%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>0.00574</td>
<td>100.00%</td>
</tr>
</tbody>
</table>

**Displaced processes**

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Swedish heat production</td>
<td>-0.0547</td>
<td>93.51%</td>
</tr>
<tr>
<td>Swedish energy production</td>
<td>-0.0038</td>
<td>6.49%</td>
</tr>
</tbody>
</table>
### Reuse Scenario Waste management phase

#### Contributing processes
- **Swedish energy production**: 0.007729, 9.64%
- **Municipal waste incinerators**: 0.00063, 0.79%
- **Truck transport international**: 0.0123, 15.34%
- **Truck transport domestic**: 4.14E-04, 0.52%
- **Diesel at refinery**: 0.00442, 5.51%
- **Swedish heat production**: 0.0547, 68.21%

**Total**: 0.080193, 100.00%

#### Displaced processes
- **Dutch energy production**: -0.1239, 96.44%
- **Dutch heat production**: -0.00458, 3.56%

**Total**: -0.12848, 100.00%

#### Phase Total
-0.05276

---

### Textile production phase

#### Contributing processes
- **Energy production**: 0.03946, 7.62%
- **Cotton production**: 0.449, 86.73%
- **Viscose production**: 0.00977, 1.89%
- **Polyester production**: 0.0118, 2.28%
- **Nylon 66 production**: 0.000738, 0.14%
- **other**: 0.00694, 1.34%

**Total**: 0.517708, 100.00%

#### Counteracting processes
- **Wool production**: -0.0189, 100.00%

#### Phase total
0.498808

### International production-to-outlet transportation

1.05E-04

### Incineration Scenario Waste management phase

#### Contributing processes
- **Municipal waste incinerators**: 9.75E-05, 100.00%

---

**Table 11 Eco Toxicity Potential**
<table>
<thead>
<tr>
<th>Process</th>
<th>Value</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Truck transport + diesel prod.</td>
<td>0</td>
<td>0,00%</td>
</tr>
<tr>
<td>Total</td>
<td>9,75E-05</td>
<td>100,00%</td>
</tr>
</tbody>
</table>

**Displaced processes**

<table>
<thead>
<tr>
<th>Process</th>
<th>Value</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Swedish heat production</td>
<td>-0,00307</td>
<td>96,90%</td>
</tr>
<tr>
<td>Swedish energy production</td>
<td>-9,83E-05</td>
<td>3,10%</td>
</tr>
<tr>
<td>Total</td>
<td>-0,00317</td>
<td>100,00%</td>
</tr>
</tbody>
</table>

**Phase total**

-3,07E-03

**Reuse Scenario Waste management phase**

**Contributing processes**

<table>
<thead>
<tr>
<th>Process</th>
<th>Value</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Swedish energy production</td>
<td>0,0002</td>
<td>5,76%</td>
</tr>
<tr>
<td>Municipal waste incinerators</td>
<td>0</td>
<td>0,00%</td>
</tr>
<tr>
<td>Truck transport international</td>
<td>0</td>
<td>0,00%</td>
</tr>
<tr>
<td>Truck transport domestic</td>
<td>0</td>
<td>0,00%</td>
</tr>
<tr>
<td>Diesel at refinery</td>
<td>0,0002</td>
<td>5,76%</td>
</tr>
<tr>
<td>Swedish heat production</td>
<td>0,00307</td>
<td>88,47%</td>
</tr>
<tr>
<td>Total</td>
<td>0,00347</td>
<td>100,00%</td>
</tr>
</tbody>
</table>

**Displaced processes**

<table>
<thead>
<tr>
<th>Process</th>
<th>Value</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dutch energy production</td>
<td>-0,00107</td>
<td>96,17%</td>
</tr>
<tr>
<td>Dutch heat production</td>
<td>-4,26E-05</td>
<td>3,83%</td>
</tr>
<tr>
<td>Total</td>
<td>-1,11E-03</td>
<td>100,0%</td>
</tr>
</tbody>
</table>

**Phase total**

2,36E-03
Figure 28: Production Phase (GaBi)

- CN: Electricity production
  - Mix CN
- CN: Cotton fibres, ginned, at farm
  - Mix CN
- BLD: Viscose fibres, at plant
  - Mix CN
- FER: Fleece production, polyethylene terephthalate
  - Mix CN
- FER: Nylon 66, at plant
  - Mix CN
- US: Wool, sheep, at farm
  - Mix CN
- DE: Potato starch, at plant
  - Mix CN
- US: Thermal energy from hard coal PE
  - Mix CN
- RE: Hydrogen peroxide, 50% in H2O, at plant
  - Mix CN
- Dyeing
  - Mix CN
- CN: Electricity production
  - Mix CN
- CN: T-shirt production
  - Mix CN

Production Phases:
- Washing
- Dyeing
- Finishing
- Transportation
- Drying
- Cutting
- Producing
Figure 29 Incineration Waste Management Phase (GaBi)

SE: electricity, production mix SE

EU-15: Diesel at refinery ELCD/PE-GaBi

GLO: Truck 14 - 20 t total cap. / 11.4 t payload / Euro 1 PE [b]

RER: Textiles in municipal waste incinerator PE

CH: heat, softwood chips from forest, at furnace 1000 kW

Avoided energy through incineration

0.95989 MJ

0.02099 MJ

0 MJ

0 MJ

-10.149 MJ

10.149 MJ

10.149 MJ
Robert Bodin

TO REUSE OR TO INCINERATE?

A CASE STUDY OF THE ENVIRONMENTAL IMPACTS OF TWO ALTERNATIVE WASTE MANAGEMENT STRATEGIES FOR HOUSEHOLD TEXTILE WASTE IN NINE MUNICIPALITIES IN NORTHERN STOCKHOLM, SWEDEN

Supervisor:
Miguel Brandão

Examiner:
Miguel Brandão