THESIS FOR THE DEGREE OF LICENTIATE OF ENGINEERING

Towards Understanding Sustainable Textile Waste Management: Environmental impacts and social indicators

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Abstract

Global population growth and rising living standards have increased apparel consumption, and the generation of textile and clothing waste. This has raised concerns about lost resources and the environmental damage associated with these flows. The sustainable development of textile waste management from both environmental and social perspectives is explored in this thesis.

The first part of this thesis investigates the environmental impact of different options for textile waste treatment. In Sweden, the predominant method of textile waste treatment is incineration. The question is whether this is environmentally optimal or whether an alternative should be pursued by policy-makers. For this reason, three alternative textile waste recycling techniques were examined: the remanufacturing of new products from textile waste with adequate quality; the separation of cellulose from polyester using N-methylmorpholine-N-oxide as a solvent; and the chemical recycling of polyester. Life Cycle Assessment (LCA) was applied to estimate the carbon footprint and primary energy saved by each technique. The findings show that by applying these recycling technologies, the recovered products can provide major environmental gains since they may be able to replace products from primary resources.

The second part of the thesis focuses on the social sustainability aspects of textile waste treatment. There are a number of social concerns related to different textile waste management routes such as job creation, labour conditions and trading conditions. Social Life Cycle Assessment (SLCA) is one of the recently developed methodologies for assessing the potential positive and negative social impacts throughout the life cycle of a product or service. One of the challenges associated with carrying out an SLCA is the potentially large number of social indicators which need to be assessed. In order to provide a set of social indicators, this paper identified consumers' priorities for social indicators and investigated the similarities and differences between the perspectives of consumers and industry professionals. The findings show that the top 10 indicators prioritised by consumers are related to health and safety, child labour, fair salary, employment security, equal opportunities, discrimination, respect for human rights, avoiding misleading marketing and the voluntary promotion of social responsibility by companies. From industry's perspective the value chain and local communities were also important, so indicators such as avoiding unfair competition and having the possibility of filing complaints, appeared in the 10 top ranked indicators. This analysis allows some recommendations to be made regarding the future development of labels such as the Global Organic Textile Standard (GOTS) label. These results suggest some ecolabels may need to adjust focus to maintain salience with consumers.

Keywords: Textile waste management, Textile recycling, Sustainability, Life cycle assessment, Social life cycle assessment, Social indicators

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List of publication

This thesis is based on the research described in the following publications:

I. Zamani B, Svanström M, Peters G, Rydberg T (2014). A carbon footprint of textile recycling, case study: Sweden, Accepted for publication in Journal of Industrial Ecology, June 2014.

II. Zamani B, Gwozdz W, Peters G (2014) Preferences for socially sustainable labels on fashion products – consumers and industry perspective, submitted to Journal of Cleaner Production, October 2014.

Copies of these papers are appended at the end of the thesis.

Work related to the thesis has also been presented at the following presentations:

Zamani B, Svanström M, Peters G (2013) Life cycle assessment of textile waste treatment by applying recycling techniques, published in proceedings of LCM 2013, the 6th international conference of Life Cycle Management, Gothenburg, Sweden, August 2013.

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1 Introduction

1.1 The textile industry and textile waste

In recent years, textile production and consumption have risen drastically due to global population growth and improvements in living standards. Over-production in the textile industry is partly driven by the idea behind the fashion industry that consumers need a new clothing collection for each season. This increases the rate of replacement of the products and the rate of textile and waste generation (Fletcher 2008b). For example, during the last 10 years in Sweden, textile consumption has increased by 40%, and the annual clothing and home textile consumption is now 15 kg per capita (SEPA, 2011a). The consumption of textiles in other Nordic countries ranges between 13.5 kg per capita in Finland (Tojo et al. 2012) and 22 kg per capita in Norway (Statistics Norway 2013).

Clothing and textiles are produced from fibres which are either natural (e.g. silk, wool), natural cellulosic (e.g. cotton, linen), manufactured cellulosic (e.g. viscose, rayon) or synthetic (oil-based e.g. polyester, acrylic and nylon). Figure 1, shows the global consumption of fibres between 2000 and 2012. It can be seen that the global consumption of fibres reached a short-term maximum in 2007. Textile fibre consumption decreased by 4.3% to 66.1 Mt in 2008 due to the global financial recession (FAO/ICAC 2013). The demand for all textile fibres in 2012 was 74.8 Mt, which is an increase of 13% over 2008.

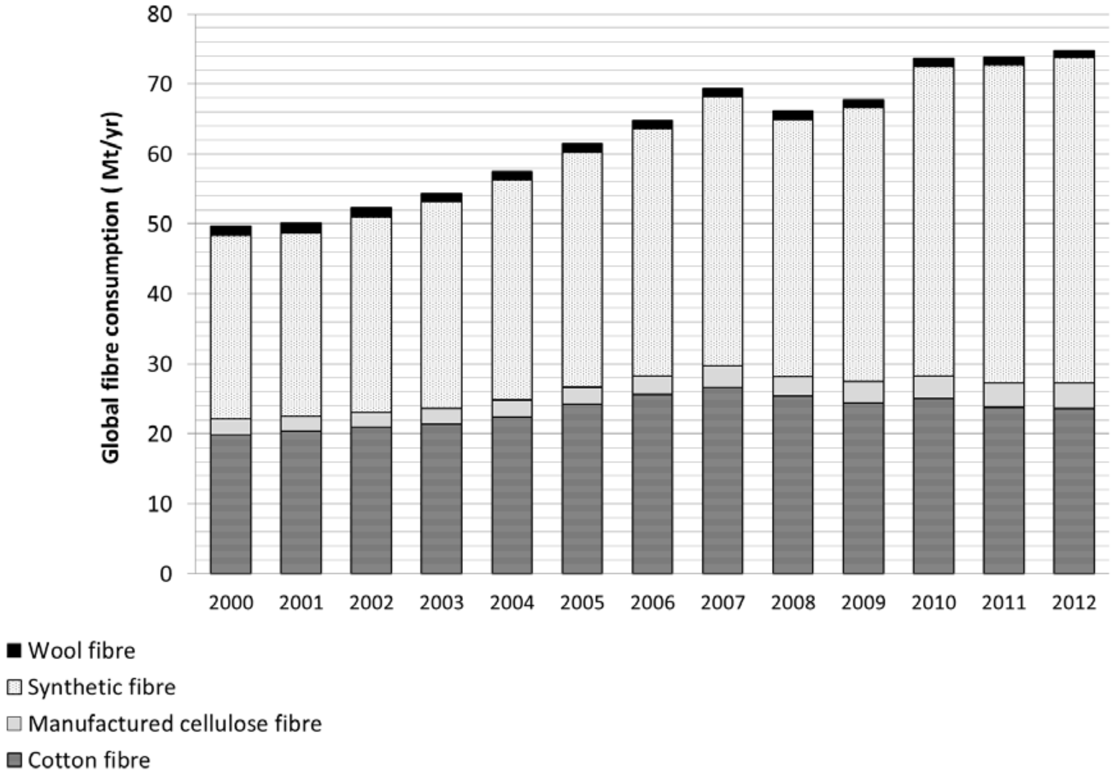

Figure 1 : Annual global fibre consumption (2000-2012).

Source : (OECD 2013)

The global consumption of cotton followed the same trend as the total global fibre consumption, which hit the highest point in 2007. Total demand for textiles fell in the following year but has since recovered and exceeded this short-term peak. However cotton demand has not recovered since then. The share of cotton fibers in global fibre consumption was falling from 38% in 2007 to 31% in 2012. Over the whole 2000-2012 period, cotton consumption increased by only 18%. The reasons for this decrease are the instability in cotton prices due to rising labour costs in China and cotton's competition with food production for irrigable land and water (OECD 2013). Based on a recently published report from OECD, it is predicted that world cotton consumption is expected to recover relatively slowly. However, total cotton consumption is predicted to reach 30.8 Mt in 2023 when it will exceed the 2007 peak (OECD 2014).

The consumption of synthetic fibres had increased by 77% between 2000 and 2012. The growing share of synthetic fibres in global fibre consumption has resulted in a rising demand for petroleum-based chemicals. For this reason, attempts at developing new oil extraction technologies have become significant for the textile industry. One innovative method is hydraulic fracturing of rock (‘fracking’) which keeps the price for petroleum-based chemicals and synthetic fibres low (Peters et al. 2014).

The consumption of manufactured cellulosic fibres increased by 63% between 2000 and 2012. Although the current rate of demand for manufactured cellulosic fibres is not fast enough to offset the production rate for cotton, it indicates the keen demand for cellulosic fibres with similar properties to cotton (Eichinger 2012).

In this context, different approaches have been suggested for increasing cellulose-based fibre production:

1. Different technological alternatives for cotton production: Genetically Modified (GM) cotton could compensate for reduced Chinese cotton supplies to some extent. This entails using genetic engineering techniques in which the genetic coding for a common soil bacterium, *Bacillus thuringiensis* (BT), is inserted into cotton to promote the production of a natural insecticide in cotton tissues (Vitale 2010). This approach has been implemented in China, and after commercialisation, the plantation area for BT cotton in China increased from 16,700 hectares to 3.8 million hectares in 2007, which is 69% of the Chinese cotton farming lands (Zhao et al. 2011). Studies show that by implementing this method, the yield of cotton plantations can increase up to 24% (Peters et al. 2014) .

2. The development of new forest-based fibres: one example is Cellunova which is a regenerated cellulosic fibre from wood pulp (Paper Province 2013). The newly developed fibers can be blended with cotton fibers since it they have cotton-like quality (Sandin 2013).

3. Recycle and reuse: One solution is to turn the discarded cellulosic textiles into a new resource by developing technologies for the mechanical reuse of textiles or for chemical recycling of fibres.

1.2 Current textile waste management

When consumers decide to give up their garments, they have a number of choices: discard, sell, or donate to used textile collectors such as charity organizations, municipalities, retail collectors or professional collectors. In Europe, discarded textiles are either incinerated or landfilled together with municipal solid waste. The donated or sold textiles are sorted and sent afterwards to reuse or recycling plants depending on their quality. Most of the textiles which retain high enough quality for reuse are sent to East European or African countries (Palm et al. 2014), and the remaining flow is sent to recycling plants. Since only a few different methods for textile recycling exist today, the majority of the flow is downcycled into wipes, rags or is used as insulation in different industries. The remainder of the collected used textiles is either landfilled or incinerated. In some cases, clothing which is no longer in use is accumulated in closets or exchanged informally between friends or family members (Palm et al. 2014).

Presently, only 25% of the textile waste generated in the European Union is collected by charity organizations or industry enterprises with the purpose of reusing or recycling. The rest is sent to landfill or municipal waste incinerators (Briga-sá et al. 2013a).

Currently, a lack of practical technologies for recycling various types of fibres limits the potential for applying recycling techniques. However, a few small-scale recycling schemes have been implemented, with the aim of producing recycled fibres (Zamani 2011).

Textile waste management in the UK

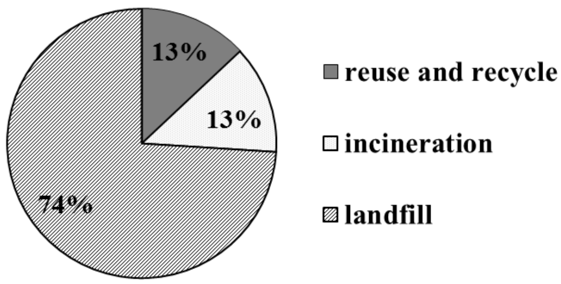

Figure 2 : Textile waste management in the UK

Source:(Allwood et al. 2006)

There are differences between textile waste management situations in many countries within the European Union. For example, as shown in Figure 2, 74% of the textile waste flow in the UK ends up in landfills, while 13% is sent to incineration. The remaining 13% is either reused or downcycled into wipes, upholstery fillings or insulation materials (Allwood et al. 2006). In Sweden, approximately 20% of textile waste is collected by charity organisations, 50% is sent to incineration plants in mixed waste streams and the remaining 30% is either stored in household closets or discarded at recycling centres (Palm et al. 2014).

The statistical data are not fully comparable between the UK and Sweden since the definition of textile waste is different in each reference. However it can be noticed that landfilling has been removed as a textile waste management strategy in Sweden and the majority of the waste is sent to incineration for energy recovery.

The updated target of the European Union´s landfill directive entails forcing the reduction of biodegradable municipal waste landfilled to 35% of the 1995 level by 2020 for the UK. Therefore, the UK faces challenges regarding the collection and recovery of biodegradable waste including textiles (EFRA 2005).

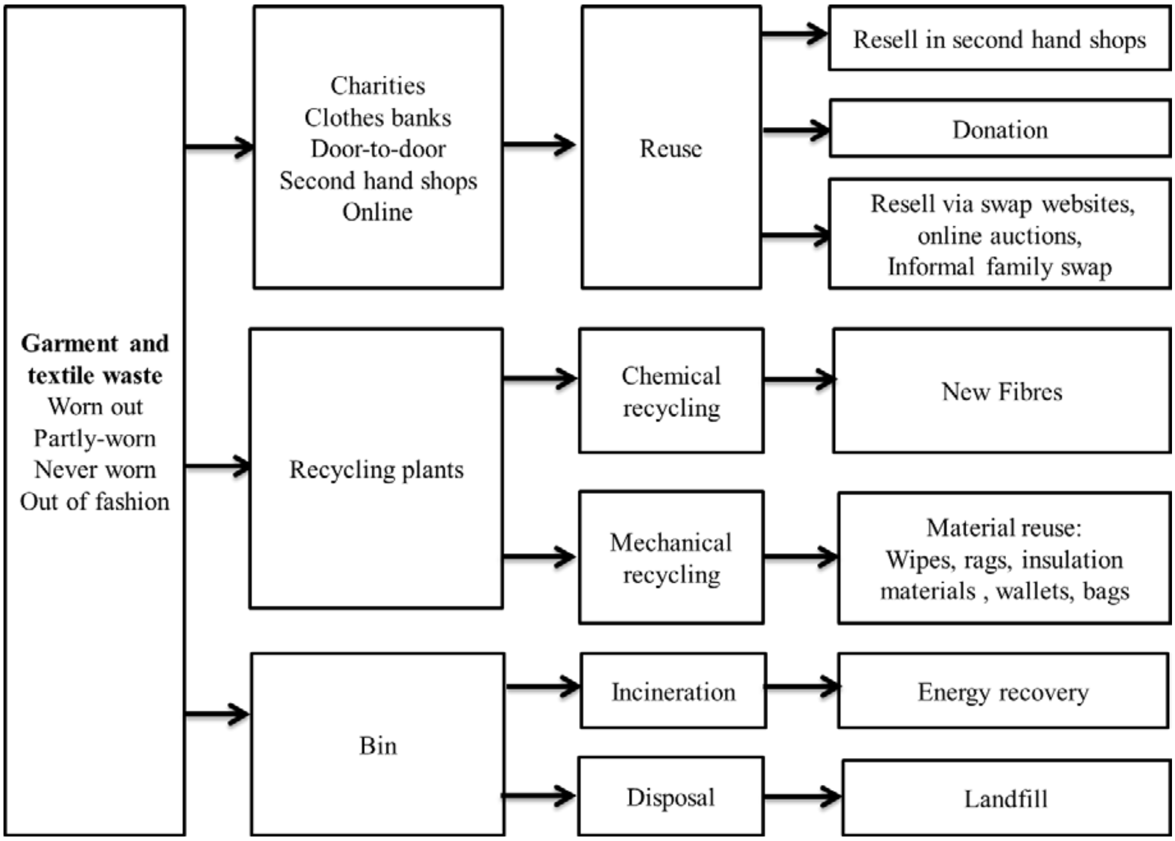

Figure 3 : Strategies that can potentially be applied for textile waste management

Figure 3 shows possible post-consumer routes for textile waste management. The processes in the figure that provide some kind of benefit are described in the sections below.

1.2.1 Energy recovery

Incineration with energy recovery is the dominant textile waste treatment technology in some countries, for instance Sweden. Collected textile waste from bins and sacks is sent to incineration together with other collected municipal waste. The recovered heat and power can potentially replace other sources of energy (Palm 2011).

1.2.2 Reuse of textiles

A share of the textiles and garments collected by charity organisations or collectors is transferred to second hand shops with the aim of sending used clothes into the market. Large amounts of clothing of adequate quality are shipped abroad for selling to other traders in Eastern Europe or Africa. 26,000 tonnes of collected used clothes and shoes in Sweden were donated to Africa and Eastern Europe in 2008 (David Palm 2011) .

Another example of the reuse of textiles are the new concepts of reselling or swapping second hand clothes through websites and online auctions that have emerged recently with the aim of extending the life span of garments (Cassidy et al. 2013).

1.2.3 Recycling textiles

Another option for potentially saving resources in waste management is recycling. There are several different technologies available or under development for recycling textile waste. This section summarises the different textile recycling technologies.

Mechanical recycling of textile waste

Different mechanical techniques exist for recycling textile waste. The applicability of each technology depends on the quality of the textile waste.

The most common mechanical recycling method is to cut and shred the fabric into small pieces which can be used as filling in mattresses or upholstery, as insulation or as carpet underlay. The SOEX group (www.soexgroup.com) has facilities in 10 different countries that apply mechanical recycling techniques to convert more than 15000 tonnes of used clothing per year to insulation materials for construction and automobiles.

Another mechanical recycling method is material reuse without shredding. In this process, pieces of textiles with sufficiently high quality are separated and turned into different types of products. Small-scale upcycling enterprises, such as Worn Again (www.wornagain.co.uk) and Loopt Works (www.looptworks.com), produce T-shirts, wallets and textile carrier bags (Palm et al. 2014). This process is also known as upcycling or remanufacturing (Fletcher 2008b).

Another kind of mechanical recycling is the production of fibres and yarns from discarded textiles. The textile waste is first cut into small pieces, then passed through a rotating drum and turned into fibres. The physical quality of the fibres produced using this method is low due to the mixed colour of the fibres and the different fibre lengths. Therefore, the obtained fibre can only be used in upholstery filling, carpet underlay, sound and heat insulation materials, disposable diapers, napkins and tampons. One way to improve the quality of this product is to mix these fibres with virgin fibres and blend them into yarns. Since the properties of such yarns are dependent on textile quality, they are mostly used in producing woven filtration systems or geotextiles (Palm et al. 2014) .

Chemical recycling of textile waste

In principle, Chemical recycling methods can be applied to synthetic fibres (polyester, nylon or polypropylene) or blends of natural and synthetic fibres. During chemical recycling processes, the fibres are chemically separated and degraded to the molecular level. The synthetic feedstock is then repolymerized to new fibres (Palm et al. 2014) .

In 2000, a Japanese company, Teijin Fibre Ltd., developed a closed-loop polyester recycling technique process in collaboration with Patagonia Inc. Initially, the main goal of the process was 100% polyester uniforms (Patagonia Inc. 2011) . In this process, polyester fabrics from other types of fabrics such as polyester/cotton, acrylic, wool, polyurethane or leather are completely separated. The collected material is then cut into small pieces and broken down into small granules. By applying a chemical reaction, the granules are decomposed to dimethyl terephthalate (DMT), an intermediate chemical for the production of polyethylene terephthalate (PET) (Patagonia Inc. 2011). The actual chemical reaction applied by Teijin has not been published, but a fair assumption is that the reaction is the depolymerization of polyethylene terephthalate in methanol, see Figure 4 (Yang et al. 2002). The obtained DMT is repolymerized to polyester granules and turned into polyester yarns through melt spinning (Patagonia Inc. 2011).

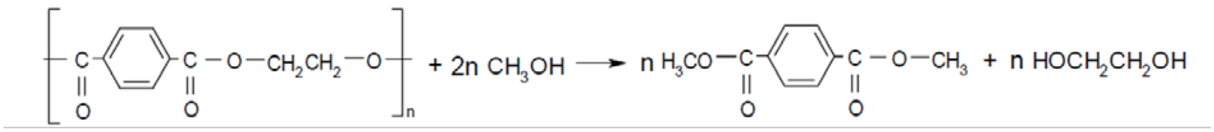

Figure 4 : Chemical equation of methanolysis of PET

1.2.4 Emerging technologies for textile waste management

There are a number of emerging technologies for the chemical recycling of textile waste. One example is a process developed by the Swedish company Re:newcell (http://www.renewcell.se/), which regenerates viscose fibres from discarded cellulosic textiles. During this process, discarded textiles are mechanically cut into small pieces and the cellulosic share of the textiles is chemically separated, dissolved into an alkali solution, and, finally, filtered to produce regenerated viscose. Small-scale tests on different types of blended textiles have been conducted. However, little information is available on the process as it is still under development.

There are currently ideas for using the Lyocell process for recycling cellulosic and synthetic fibres from discarded textiles. In the Lyocell process, cellulose in wood pulp is dissolved with N-methylmorpholine-N-oxide (NMMO). The solution is filtered and cellulose fibres are extracted. Cellulose fibres are then washed and spun into yarns. The NMMO is recovered and sent back to the process for reuse (Shen and Patel 2010).

It has been suggested that separating and recycling cellulosic and synthetic fibres by using NMMO can be developed further. In the first step, blended textiles are cut into pieces and mixed with NMMO. The cellulosic part dissolves into NMMO and is pumped through filters to separate the solution from polyester residue, and the remaining polyester can be recycled into polyester fibres (Jeihanipour et al. 2010).

1.3 Environmental impacts of textile waste treatment

The reuse and recycling of discarded textiles has several potential environmental benefits. For example, reusing textile and clothing products results in energy savings, since the amount of energy required for collecting, sorting and reselling second hand garments is 10 to 20 times less than for the production of the same products from virgin materials (Fletcher 2008b). Since the benefits vary so much, the quantitative assessment of alternatives is warranted. In order to quantify the environmental impacts of alternative textile waste management systems, there are a number of factors which must be assessed:

• The demands for energy and material during the mechanical, chemical or biological processes in the textile recycling value chain; and

• The emissions into air, water and soil that occur while applying textile recycling processes.

Thus, for evaluating the benefits of the recycling schemes, one must calculate whether the consumption of energy and resources and the emission of pollutants by the recycling process are compensated for by avoiding the manufacturing of products from virgin materials.

The first part of this thesis assesses the environmental benefits of three textile recycling techniques in order to investigate the options for improving textile waste management. For this purpose, an environmental life cycle assessment (LCA) was carried out to quantify the energy usage and global warming potential of different textile recycling options. The studied technologies are: remanufacturing for material reuse, chemical separation of cellulose from polyester using NMMO, chemical recycling of polyester, and incineration with energy recovery.

1.4 Social issues related to textile waste treatment

1.4.1. Existing social issues in the textile industry

Consumer expectations on low price products and companies' competition for market share result in a number of social violations. Some of the significant issues in the textile and clothing value chain include low worker wages, gender discrimination, excessive working hours, temporary working contracts or child labour and local residents who are subjected to health risks (Weller 2013) .

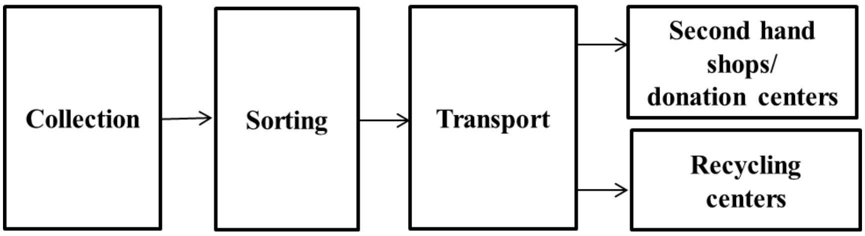

Figure 5 : Phases in the life cycle of textile waste reuse/ recycling

Figure 5 presents the life cycle of textile and clothing waste reuse and recycling. Both reuse and recycling approaches create employment in each phase indicated by a box.

As mentioned in Section 1.2, a share of the collected textile and clothing waste is shipped abroad to be donated or sold as second hand clothes. The second hand clothing industry provides a number of jobs in the receiving countries during transportation, distribution, cleaning, repairing and restyling. For instance, approximately 150,000 Ghanaians work in second hand clothing sector in Africa (Baden and Barber 2005).

The overall impact of the second hand clothing industry on employment in developing countries is not clear, since it is likely that it plays a role in the decline in domestic textile and clothing production. In West Africa, up to 80,000 jobs were lost in the local textile and clothing industry between 1990 to 2004 (Baden and Barber 2005). However, the pressure on the local textile and clothing industry is not only caused by the second hand clothing sector. Another factor is the import of cheap clothing from China (Baden and Barber 2005).

An additional concern is the poor regulation of second hand clothing imports in developing countries. Corruption is known to occur when new garments are imported under the label of second hand clothes to avoid the payment of the appropriate, higher import tariffs for new clothing (Baden and Barber 2005).

Finally, working conditions in the textile reuse and recycling sectors are other important social concerns. These sectors face challenges in dealing with working conditions in developing countries. In Senegal, 24,180 people have full time employment in the second hand clothing sector, of which 60% of are male (Baden and Barber 2005). Gender discrimination, adequate wages, reasonable working hours, health and safety issues must be assessed along the entire value chain of the industry.

The complexity of the textile and clothing industry has made it difficult to assess the social issues along the supply chain. Emerging ecolabels´ claims for textile products cover a variety of different indicators. Some examples of indicators are natural resource management (e.g. Global Organic Textile Standard, Textile Exchange and Soil Association), restriction on chemical usage (e.g. Blue sign, Svanen and EU Ecolabel), improved working conditions in the textile and fashion industry (Fair Wear Foundation) and health issues for consumers (e.g. OEKO-Tex). Each label does not cover all indicators, but the major ecological issues are considered by most of the labels.

1.4.2 Current social guidelines in the textile industry

The development of social guidelines, standards and codes of conduct helps brands and companies to demonstrate their responsibility throughout a product´s supply chain. Different stakeholders such as workers, trade unions and NGOs are engaged in the development of social standards.

During the past decades, a number of guidelines and initiatives have been developed with the focus on textile and clothing value chains. These include those driven by the Nordic Initiative Clean and Ethical (NICE), the Fair Wear Foundation (FWF), the Sustainable Apparel Coalition (SAC) and the MADE-BY organisation.

NICE is a project founded in 2008 by representatives from different stakeholders involved in the Nordic fashion industry. It provides a code of conduct and manual for monitoring and evaluating the textile and fashion companies' supply chains in different aspects of sustainability such as human rights, labour conditions, occupational health and safety, environmental performance and corruption prevention (Nordic Fashion Association, 2012) .

The FWF is another organization that aims to improve labour conditions throughout the garment life cycle. This initiative monitors its members' fulfilment of eight criteria that describe labour conditions (Fair Wear Foundation, 2010).

The SAC concentrates on the recognition and assessment of social and environmental issues in the textile and fashion industry (Sustainable Apparel Coalition, 2013). The SAC has developed a scoring system, the Higg Index, for assessing the sustainability performance of garments and footwear. The Higg Index is a sustainability assessment tool based on a life cycle perspective but utilises the presence of environmental management systems as a proxy indicator of product environmental performance. The social aspect of the index has been developed based on different initiatives such as the global social compliance program, the SAI Social Fingerprint and the FLA Sustainable Compliance Initiative (Sustainable Apparel Coalition, 2013).

MADE-BY is a non-profit organisation which developed a social benchmark with the aim of improving the social and environmental issues associated with the life cycle of textiles and clothing products. The social benchmark is based on six different ethical initiatives including the Business Social Compliance Initiative, the Ethical Trading Initiative, the Fair Labour Association, the Fair Wear Foundation, Social Accountability 8000 and Worldwide Responsible Apparel Production (MADE-BY 2013). Table 1 shows the different criteria covered by these six compliances and initiatives used in the MADE-BY social benchmark.

Table 1: List of social initiatives and their criteria

Standards, Initiatives	Covered social indicators	Reference
Business Social Compliance Initiative (BSCI)	• The rights of freedom of association and collective bargaining • Fair remuneration • Occupational health and safety • Special protection for young workers • No bonded, forced , trafficked or non-voluntary labour • Ethical business behaviour: no act of corruption, extortion, embezzlement, bribery • No discrimination including gender, age, race, caste, birth, social background, disability, ethnic and national origin, nationality, memberships in unions, political opinion, sexual orientation, family responsibility, marital status, disease or any other conditions • Decent working hours	(BSCI 2014)

	• No child labour • No precarious employment • Protection of the environment	
Ethical Trade Initiative (ETI)	• Employment is freely chosen • Freedom of association and right to collective bargaining is respected • Working conditions are safe and hygienic • Child labour shall not be used • Living wages are paid • Working hours are not excessive • No discrimination based on race, caste, national origin, religion, age, disability, gender, marital status, sexual orientation, union membership or political affiliation is practised • Regular employment is provided • No harsh or inhumane treatment is allowed	(ETI 2014)
Fair Labour Association (FLA)	• Employment relationship: adopt and adhere to rules and conditions of employment that respect workers and, at a minimum, safeguard their rights under national and international labour and social security laws and regulations. • No discrimination on the basis of gender, race, religion, age, disability, sexual orientation, nationality, political opinion, social group or ethnic origin is practiced. • No sexual, physical, physiological or verbal harassment or abuse • No forced Labour • No child Labour • Freedom of association and collective bargaining • Health, safety and environment • No excessive working hours • Compensation: the minimum wage should be sufficient to meet the workers´ basic needs. • Every worker has the right to compensation for a regular	(FLA 2011)

	work week that is sufficient to meet the worker's basic needs	
Fair Wear Foundation (FWF)	• Employment is freely chosen (No prison or forced labour) • There is no discrimination in employment (including : wage policy, admittance to training program, promotion policy, sex, religion, colour, race, union membership, deficiencies, social origins) • Prohibited child labour • Freedom of association and the right to collective bargaining • Payment of a living wage (the minimum wage should to be sufficient to meet basic needs) • No excessive working hours • Safe and healthy working conditions • Legally-binding employment relationship	(FWF 2009)
Social Accountability 8000 (SA8000)	• No child labour • No forced and compulsory labour • Healthy and safe working conditions • Freedom of association and right to collective bargaining • No discrimination based on based on race, national or social origin, caste, birth, religion, disability, gender, sexual orientation, union membership, political opinions and age. • Disciplinary practices: All personnel are to be treated with dignity and respect; no mental or physical abuse of labour • No excessive working hours • Living wages are paid • Management systems: Facilities seeking to gain and maintain certification must go beyond simple compliance to integrate the standard into their management systems and practices	(SAI 2014)

Worldwide Responsible Accredited Production (WRAP)	• Compliance with laws and workplace regulations • Prohibition of forced labour • Prohibition of child labour • Prohibition of harassment or abuse • Compensation and benefits including all mandate wages, allowances and benefits • Hours of work not to exceed the limitations of the country’s law. Prohibition of discrimination • Health and safety • Freedom of association and collective bargaining • Environment • Customs compliance • Security	(WRAP 2010)

As shown in Table 1, each initiative considers different social indicators. One of the challenges associated with assessing social issues is the potentially large number of social indicators which need to be assessed. PROSA, a sustainability consultation firm, lists a total of 159 social indicators arranged based on the different impacted stakeholders throughout the product´s life cycle (PROSA 2007), representing a formidable analytical and resource challenge for any small and medium enterprises (SME) wishing to engage in social sustainability. The list includes the indicators presented in the most important laws or codes such as ILO standards, OECD Guidelines for Multinational Enterprises, the Global Reporting Initiative and SA 8000 (PROSA 2007). A key need is to prioritise the social aspects so as to simplify the social sustainability metrics in SMEs and broaden their application.

In order to help prioritise social indicators for communication with consumers, the second part of the thesis focuses on:

1. Examine prioritised social indicators from different perspective of consumers and industry professionals’

2. Identify similarities and differences between consumers and industry professionals’ perspectives

3. Examine the similarities between consumers’ priorities and social indicators that are covered by one of the labels used for textiles

1.5 Mistra Future Fashion programme

The research presented in this thesis has been conducted within the Mistra Future Fashion program, www.mistrafuturefashion.com. The programme aims to develop insights and solutions, which improve the sustainability of the Swedish fashion industry. For this purpose, eight research projects, within the programme, focus on one aspect each of the textile value chain including changing business models, sustainable design, technology development for new fibres, waste management, fashion in the public sector, sustainable consumption, policy instruments and clarifying the definition of sustainability.

Project 2 in the Mistra Future Fashion programme has as its objective to improve sustainability assessment methodologies for ecolabelling and decision support tools.

This objective necessitates the enhancement of sustainability assessment by the inclusion of social impact assessment.

2 Methodology: Sustainability assessment

2.1 Environmental Life Cycle Assessment

Since the first part of this thesis focuses on comparing the environmental impacts of different textile recycling techniques with incineration, Life Cycle Assessment (LCA) is applied as an assessment tool. LCA is an ISO standardized (ISO 14040-14044) tool which is widely used (Guinee et al. 2002), and can be applied to assess the environmental performance of a product or a service from cradle to grave. All the processes required to deliver the product or the service are considered in LCA including the extraction of new materials, the manufacturing phase, the use phase, waste treatment and the disposal of the product.

According to ISO 14044, LCA includes four steps as presented in Figure 6 (Bauman and Tillman 2004). The bidirectional arrows show that the procedure is iterative and considers the new insights and findings obtained during each step.

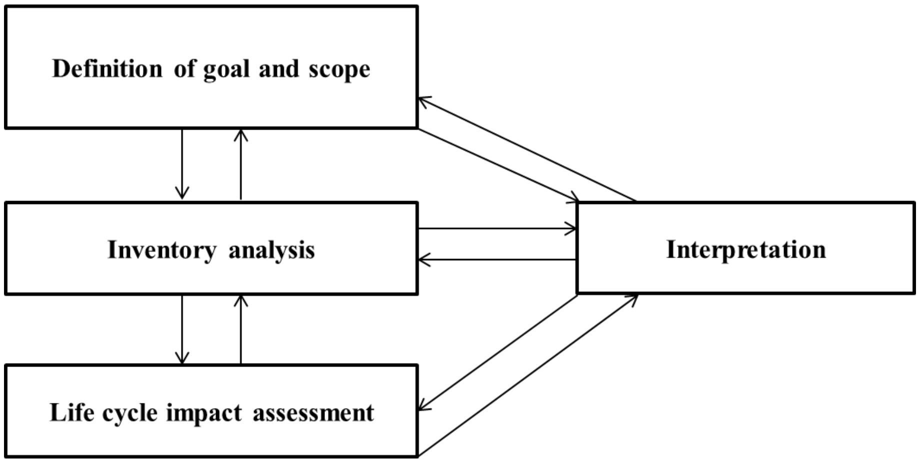

Figure 6: Different phases of Life Cycle Assessment

I. Goal and scope definition

In this step, the purpose of the study and the questions to be answered are defined, and the functional unit is quantified. The functional unit reflects the service a system provides in quantitative terms and enables the comparison of different products with the same functionality.

The next task is to clarify the system boundaries that specify the geographical and time limits of the study and the activities included in the assessment. In addition, the list of impacts to be assessed is determined.

Environmental impacts are categorised into impacts on human health, resource use and environmental quality (Bauman and Tillman 2004). These primary impact groups can be further categorised into potential impact categories such as global warming potential, fossil resource depletion, acidification potential, eutrophication potential and toxicity.

II. Inventory analysis

The first step in the inventory analysis is the creation of a process flow chart based on the assumptions considered in the goal and scope definition. In this step, all relevant flows of input materials and energy, emissions and output waste within the system boundaries and between the system and the environment are defined. Next, the appropriate data related to defined flows are quantified and scaled to the reference flow, which is defined based on functional unit.

III. Life cycle impact assessment

The environmental consequences of the emissions and resource usage quantified in the inventory analysis are described in this phase. An impact assessment contains different steps: classification, characterisation and weighting.

In the classification step, inventory analysis data are associated with environmental impact categories such as global warming potential, acidification, primary energy usage and other categories, based on their potential environmental impact.

In a characterisation step, conversion factors are used to calculate the results within the impact categories. The characterisation of the inventory results means multiplying the flows by linear equivalency factors and summarising them into different impact groups.

Weighting and normalising are optional steps for highlighting the most important potential impacts. Different weighting methods, such as ReCiPe (Goedkoop et al. 2009) or EDIP (Bauman and Tillman 2004), can be applied to aggregate the results of the impact assessment, resulting in a single number that is more convenient to communicate. On the down-side, when all the results are aggregated into a single number, some critical details can be neglected.

IV. Interpretation

In this final step, the results obtained from the life cycle impact assessment are interpreted according to the goal and scope of the study. In uncertain situations, some tests, such as data quality analysis using sensitivity analysis or uncertainty analysis, can be applied. Further recommendations can be made for the audience of the study.

2. 2 Social Life Cycle Assessment

Social or Socio-Economic Life Cycle Assessment (SLCA) is a method for assessing the social and socio-economic aspects of products and their potential positive and negative impacts throughout their life cycle. Similar to traditional LCA, the different phases of a product's value chain are considered in SLCA, including the extraction and processing of raw materials, manufacturing, distribution, use, re-use, maintenance, recycling and final disposal. Each of these phases is associated with a geographic location in which different types of stakeholders are impacted.

SLCA complements the environmental life cycle assessment (LCA) with social and socio-economic aspects and it can either be applied on its own or in combination with an LCA (UNEP 2009).
According to the recent UNEP/SETAC (UNEP 2009) guidelines, S-LCA methodology is built on environmental life cycle assessment methodology consisting of four iterative steps as shown in Figure 6.

1. Goal and Scope definition
The goal of applying SLCA can be: product or process comparison or identification of product or process improvement potentials. The objectives of the study and system boundaries are specified in a scope definition. The next step is choosing the functional unit which describes the product's function and social utility. System boundaries also need to be determined. In these aspects an SLCA is not different from an LCA.

2. Life cycle inventory analysis
In this phase, relevant data are collected for prioritisation, hotspot assessment, evaluation and impact assessment. The first step is to determine the type of data that is related to the goal and scope. The second step is a hotspot analysis which is an overview of the significant social issues within the defined geographical boundaries in order to decide which site specific data need to be collected.

The next step is related to collecting the main data for an impact assessment and an evaluation of data quality. A product or service system is composed of different engineering processes in its value chain. When an LCA is performed, there is a direct connection between these processes and the environmental impacts since the environmental assessment is based on an inventory of input and output for the processes. On the other hand, most social impacts are not directly related to the engineering processes within the supply chain, but rather to the conduct of the company as a human resource manager. This means that the inventory analysis should focus on the social characteristics of the companies involved in the product system in order to assess social impact, however, some methods emphasise the engineering processes as the basis for the assessment. This is discussed further in Section 2.2.3.

3. Life cycle impact assessment

The main steps of this part are:

1. Selection of the social criteria (different types of social criteria are explained in Section 2.2.1.),
2. Classification of the inventory data by relating them to the social criteria, and
3. Characterisation by calculating the results for each social criterion.

4. Life cycle interpretation

This section identifies significant social issues, the consistency and the completeness of the study is evaluated and the conclusion and recommendations are made based on findings.

2.2.1 Classification of social indicators

The basis of S-LCA is the social indicators that are evaluated. These criteria may be classified according to

1. The type of stakeholder that is affected by the product supply chain, and

2. The kind of social impact the product will have on different stakeholders.

This leads to subcategories such as human rights, health and safety, working conditions, governance, cultural heritage and socio-economic repercussions.

The social and socio-economic subcategories defined by UNEP/SETAC are shown in Table 2.

Table 2: UNEP/SETAC social indicators classification

Stakeholders categories	Subcategories
Employees	Freedom of association and collective bargaining Child labour Fair salary Working hours Forced labour Equal opportunities/ Discrimination Health and safety Social benefits/ Social security
Consumer	Health and safety Feedback mechanism Consumer privacy Transparency End of life responsibility
Local community	Access to material resources Access to immaterial resources Delocalization and Migration Cultural heritage Safe and healthy living conditions Respect to indigenous rights Community engagement Local employment Secure living conditions
Society	Public commitment to sustainability issues Contribution to economic development Prevention and mitigation of armed conflicts Technology development Corruption
Value chain actors (not including consumers)	Fair competition Promoting social responsibility Supplier relationships Respect to intellectual property rights

Social sustainability impacts are consequences of positive or negative pressures on social endpoints such as the well-being of stakeholders, therefore, a social sustainability impact can be interpreted as the impact on human well-being.

2.2.3 Different approaches of Social Life Cycle Assessment

Currently, the three principal impact assessment methods proposed include: The UNEP/SETAC Taskforce method, the Hunkeler method (2006) and the Weidema method (Weidema, 2006). The outcome resulting from each of the methods will provide different types of information relating to the social issues associated with the products (Parent et al. 2010) .

In the UNEP/SETAC Taskforce method, a "performance reference point" is developed to assist understanding the magnitude and significance of the inventory data. The performance reference point "may be internationally set thresholds, goals or objectives according to conventions and best practices" (UNEP 2009). By using the performance reference points, the inventory data can be evaluated and translated into semi-quantitative forms. For example, one of the subcategories proposed in the UNEP guidelines is "fair salary", which can be assessed by comparing the inventory data with the performance reference point and interpreted into semi-quantitative values.

Using the Hunkeler method (2006), social benefits that can be assigned to the processes of the product life cycle can be assessed. The procedure of the proposed S-LCA is similar to a conventional LCA. First, a geographically specific life cycle inventory is needed for each unit process. Since the proposed social indicators are regionally dependent, the Hunkeler method requires specifying the geographical distribution of working hours throughout a product's life cycle in the life cycle inventory phase. Furthermore, the working hours required for each unit process in each relevant geographical area are to be calculated. By using the regional characterisation factors, the required hours of labour in each process are converted into the capacity of the wage earner to acquire social necessities such as housing, healthcare, education and suchlike.

Alternatively, Weidema (2006) offers a method in which the social impacts are measured in terms of a reduction in well-being. As defined by Weidema (2006), there are six damage categories to be identified under the heading of human life and well-being. These include life and longevity, health, autonomy, equal opportunities, participation and influence, safety, security and tranquillity. To be able to measure social impacts in terms of a reduction in well-being, Weidema proposes the quantitative term of Quality Adjusted Life Years. Weidema's intention with this quantitative term is to build impact pathways that link quantitative inventory items to damage categories (Parent et al. 2010).

The distinction in the methods lies in the indicator results. According to the UNEP/SETAC Taskforce method, the performance reference point is used to derive the state of a dimension of the social context, whereas, by using the other approaches, the social impacts derived from inventory data can be measured.

Both Hunkeler and Weidema offer methods according to which an indicator shows the impact of a functional unit in a quantitative form. However, in the Taskforce method, the relative importance of each context unit for the product system is shown by defining a share factor which represents “the given weight to a company´s social profile in the aggregation of social impacts along the product’s chain” (Dreyer et al. 2006).

2.2.4 Challenges to applying Social Life Cycle Assessment

One of the challenges associated with the applying SLCA is the selection of social indicators. Due to the sheer number of potential social indicators for analysis, the task of selecting the indicators to be studied in depth is important.

In order to carry out a comprehensive and consistent sustainability assessment, several principles are suggested by different guidelines. According to Lundie et al. (2008), the different principles that should be taken into account in any sustainability assessment are :

- System boundaries: all relevant social impacts need to be covered; therefore there should be no risk of neglecting a criterion.
- Comprehensiveness: The selected indicators need to be comprehensive to be able to monitor and measure all the systems under study. The selection should allow for observing a problem, shifting between criteria and avoiding double counting.
- Applicability: being able to examine the results of each indicator by applying the same method.
- Transparency: the process of selecting and excluding any indicator needs to be justified clearly.
- Data quality: the quality of the data plays an important role in drawing meaningful conclusions from the obtained results. The data quality needs to be consistent across all indicators.
- Practicability: the selected indicators need to be in line with the system under study, the applied assessment tool and the complexity of the system in order to cover all sustainability aspects.

- Temporal-spatial aspects: since social life cycle assessment has a full life-time perspective, all indicators need to consider the same temporal and geographical boundaries.

Rowley et al. (2012) suggest similar principles to consider for the selection of criteria in multi-criteria decision analysis but express them more mathematically:

- Exhaustive: all different sustainability aspects should be covered for the system under study.
- Minimal: the number of selected criteria should be reasonable to be able to interpret and aggregate the related criteria.
- Cumulative: the system under study can be evaluated by either a subset of indicators or a single indicator.
- Independent: the selected criteria should have independent functions.
- Monotonic: there is a consistent trend for local and global preferences.

Considering all these aspects while selecting the indicators would not be possible. However, both Lundie et al. (2008) and Rowley et al. (2012) emphasize the selection of a meaningful number of indicators which include all different aspects within the defined system boundaries. This is also the priority of Spillemaeckers et al. (2004), who pragmatically emphasise: 1. Measurability, 2 . relevance to the specific product, 3. feasibility with regard to the resources at hand, 4. applicability in the particular project ; as key principles.

As mentioned above, one of the challenges in measuring social sustainability of a product's life cycle is the selection of relevant social indicators. It is a challenge since currently no universally accepted set of indicators exist (Kruse et al. 2008; Jørgensen et al. 2008; Klöpffer and Renner 2008). To tackle this and cover the opinions and values of all stakeholders, some researches have applied the process of engaging stakeholders in selecting and rating the indicators (Lundie et al. 2006; Sandin et al. 2011). Sandin et al. (2011) narrowed a list of 74 social indicators found in a literature review, down to a list of 36 by applying the criteria of Spillemaeckers et al. (2004). This was used as a starting point for this research.

3 Aims and approaches

This thesis focuses on assessing environmental impacts and selecting social indicators for textile waste management. The results of the research have been partly presented in Papers I and II, which are appended. Paper I focuses on exploring the environmental benefits of three different textile waste methods and comparing them to incineration, the conventional textile waste treatment in Sweden. Paper II focuses on the selection of a set of social indicators with the potential to cover different stakeholders' preferences.

3.1 Research questions

Research question 1: What is the most environmentally beneficial option for textile waste management?

The aim of Paper I is to explore the potential environmental benefits of various textile recycling techniques, and, thereby, direct textile waste management strategies towards more sustainable options. An environmental LCA was performed on three different textile waste recycling techniques. The findings were then compared to incineration, which represents conventional textile waste treatment in Sweden. Another scenario was the integration of these recycling technologies for optimal usage of their different features for the treatment of textile waste. The calculated results were also compared with incineration.

Research question 2: Which social indicators are the most relevant and important to use in a social impact assessment of textile waste management?

Paper II investigates which social indicators are important for consumers. These preferences were compared with those of the industry professionals to examine similarities and differences between these stakeholder groups. This analysis allows for some recommendations to be made regarding the future development of ecolabels using the Global Organic Textile Standard (GOTS) label as a template.

3.2 Overall methodological approach

The research presented in this thesis applies life cycle thinking in understanding sustainability in textile waste management.

In the first part of the research, an LCA was performed for assessing the carbon footprint and energy usage of three different textile waste recycling techniques, and for comparing them to incineration for the treatment of 1 tonne of textile waste. The same method was applied for assessing the carbon footprint and energy usage of a combination of recycling techniques for treating 1 tonne of textile waste (Paper I). For assessing the toxicity of the chemicals used in some of the recycling techniques, a qualitative assessment was carried out by checking the European Chemical Agency classification and labelling inventory databases (ECHA 2013). A semi-quantitative assessment was applied to assess the human toxicity and terrestrial ecotoxicity of the avoided cotton production by using the ReCiPe method.

The second part of the research focuses on choosing a set of social indicators (Paper II).

A survey of 31 social indicators was developed. The indicators used in the survey were taken from the list of indicators suggested by Sandin et al. (2011). Sandin et al. (2011) narrowed a list of 74 social indicators found in a literature review, down to a list of 36 by applying the criteria of Spillemaeckers et al. (2004). This was used as a starting point for this research. By looking into overlaps and merging the indicators together, a survey including 31 social indicators was developed.

The survey was used to examine the consumers' perspective on social issues in the textile and fashion industry. The target group of the survey was Swedish fashion consumers between 16 and 30 years of age. The sample is representative of Swedish fashion consumers regarding age, sex, region and education. 1,175 people participated in the survey and answered both parts of the questionnaire in the spring of 2012. The questionnaire was developed in English, translated into Swedish and then translated back. The same questionnaire was used to investigate the opinion of industry professionals. 108 people participated in the survey as part of a symposium about sustainable fashion in Sweden on May 2013. It should be noted that the participants were self-selected as having a personal interest in promoting sustainability in the textile and fashion industry.

4 Discussion of research findings

The thesis is built on the work presented in Papers 1 and 2. The objectives of the two papers are to better understand sustainability in textile waste management from environmental and social perspectives. This chapter provides a summary of the two appended papers and discusses how each paper contributes to answering the research questions stated in Chapter 3.

4.1 Environmental impacts of textile waste treatment

4.1.1 Summary of Paper I

Paper I reports on the current situation of textile waste management in Sweden. Since there is no textile recycling in Sweden, and current systems are focused on garment reuse, the aim was to explore the environmental benefits of different textile recycling techniques, and, thereby, direct textile waste management strategies towards more sustainable options. Three different recycling techniques were identified and an explorative LCA was made to quantify the carbon footprint and energy usage of each of them. The recycling processes examined in the paper are: material reuse for textile waste of adequate quality; the separation of cellulose from polyester by using N-methylmorpholine-N-oxide as a solvent; and chemical closed-loop recycling of polyester. The findings are then compared to incineration, which represents conventional textile waste treatment in Sweden.

Since 55% of the global production of clothes and textiles is based on synthetic fibres, mainly polyester, and the remainder is natural materials, mainly cotton (Jørgensen and Jensen 2012), the model waste considered in this study was discarded household textiles consisting of 50% cotton and 50% polyester.

This LCA was performed at an early stage in the development of textile recycling, and, consequently, most of the data available for this investigation was related to energy consumption. Global warming potential and primary energy usage indicators were, therefore, selected to be assessed in this study in order to have a consistent data set with sufficient coverage. The findings showed that incineration has the highest global warming potential and primary energy usage. The material reuse process exhibits the best performance of the studied systems, with a savings of 8 tonnes of CO_2-equivalents and 164 GJ of primary energy per tonne of textile waste.

As the LCA was performed for exploratory purposes at an early technology development stage and there was a lack of data, a sensitivity analysis was performed to examine different assumptions. The sensitivity analysis showed that the results are particularly sensitive to the considered yields of the processes and to the choice of the replaced products. There are other potentially important environmental impacts that are not covered by carbon footprint and energy usage indicators. Therefore, a semi-quantitative evaluation was carried out on toxicity potential and water consumption. As substantial amounts of chemicals such as NMMO or methanol are used in chemical textile recycling techniques, the potential toxicity of NMMO and methanol was investigated by checking the European chemical agency classification and labelling inventory databases (ECHA 2013). NMMO is considered to be non-toxic. Even though methanol is classified as acutely toxic, as long as it is used in closed systems and risk management measures are applied, occupational exposure will be low and environmental emissions are negligible. The replaced usage of pesticides in cotton production was evaluated using the inventory data provided by Aalthaus et al. (2007), and was calculated using the ReCiPe method. The human toxicity and terrestrial ecotoxicity potentials of cotton fibre are 0.132 and 0.0036 kg 1,4-DB eq per kg of fibre, respectively. In addition, cotton production also has very high water consumption, which may lead to significant impacts in arid locations. One of the advantages of applying recycling techniques and producing recycled cotton yarns is that some of these contributions to human toxicity, terrestrial ecotoxicity and water consumption potentials can be averted. This indicates the potential savings of the recycling technologies as they replace cotton production.

The potential environmental advantages of a combination of textile recycling techniques for optimal usage were also assessed. For this purpose, three scenarios based on the yield variation of each technique were developed. Combining the different technologies into an integrated system for the treatment of one tonne of textile waste could provide major savings in comparison to current practices. By applying the integrated textile recycling system, 10 tonne CO_2-eq and 169 GJ could be saved per tonne of textile waste; however, the number strongly depends on the yield of the processes.

4.1.2 Integration of the scenario for annual Swedish textile waste treatment

In this section, the different recycling techniques are combined in order to assess the possible net savings in terms of global warming potential and primary energy usage for the treatment of the annual net flow of textile waste in Sweden. Three different cases were considered: base, worst and best, categorised according to variations in yield of each technique as described in Table 3. These results were compared with incineration as the reference case for the same functional unit. The functional unit was, here, chosen as the treatment of the net textile consumption in Sweden: 131,800 tonnes per year (SEPA 2011a), also assumed as consisting of 50% cellulose and 50% polyester.

Table 3: Yield of the processes for 3 different cases: worst, base and best cases

Process	Worst case scenario	Baseline scenario	Best case scenario
Yield of material reuse process	15%	50%	85%
Yield of dissolution of cellulose using NMMO	50%	75%	95%
Yield of DMT production	50%	90%	100%
Loss percentage in cotton yarn spinning from primary resources	35%	20%	5%
Loss percentage in cellulose yarn spinning	35%	20%	5%

In the process that was set up for this purpose, collected textile waste was initially sent to a reuse facility. The whole inlet flow was washed and dried, and reusable parts of the waste with sufficiently high quality were separated manually for the sewing stage. Residues of the sewing step plus the unused textile were collected and treated further. In a subsequent step, NMMO was used to separate cellulosic and polyester fibres from each other by dissolving the cellulose. Cellulosic yarns were then spun from the solution of NMMO and cellulose. The polyester residues were directed to the process for polyester recycling. At this point, the collected polyester residues were cut into smaller granules and broken down into DMT molecules by applying methanol. Afterwards, DMT was used as an intermediate material for polymerising to PET. Polyester yarns were spun from the PET granules in the next stage. Finally, the residues of the whole process were collected and sent to an incineration plant.

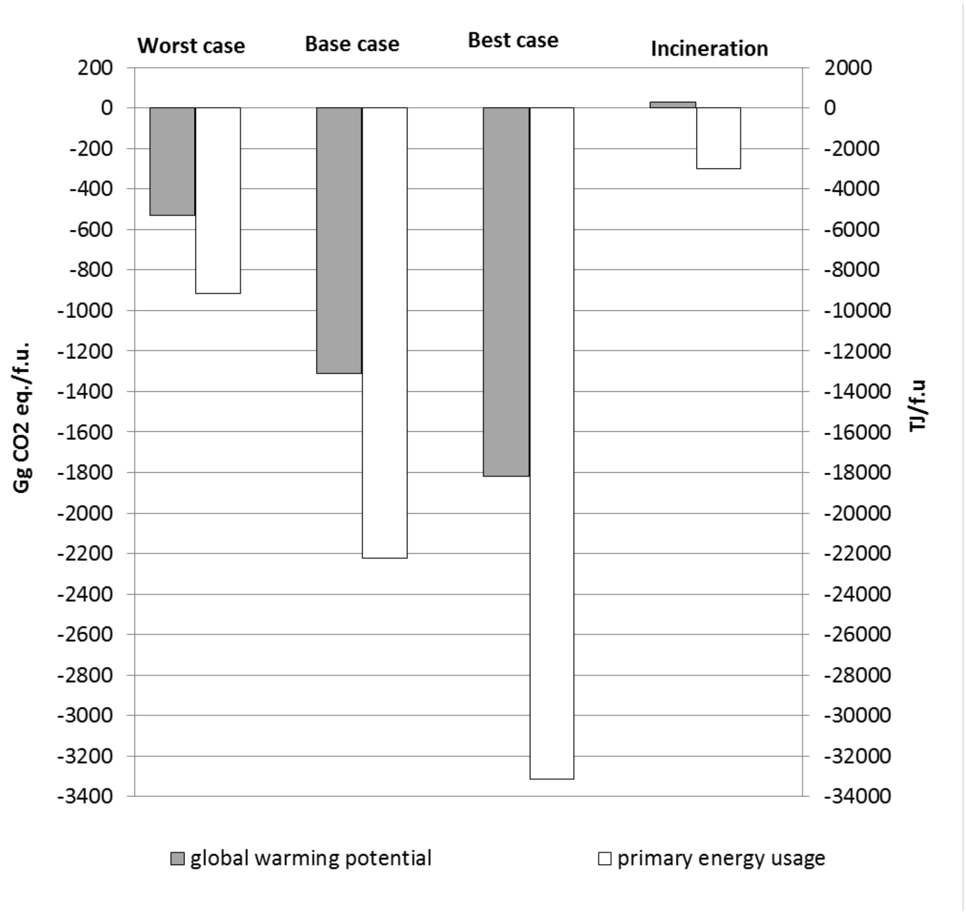

Figure 7: Total environmental system performance of the integrated textile waste recycling system (worst case, base case and best case categorised according to variations in yield of the unit processes, as shown in Table 2) compared to incineration with energy recovery, net primary energy usage and net global warming potential

Figure 7 shows the total performance of the combined recycling system and incineration with energy recovery per functional unit (131,800 tonnes per year) in terms of global warming potential and primary energy usage. Assuming the technical feasibility of this integrated process, the integration of the cases provides large environmental benefits from both the global warming potential and energy usage perspectives in comparison to incineration with energy recovery.

Greenhouse gas emissions related directly to Swedish consumption plus international transports to Sweden, were approximately 95 million tonnes of CO_2-equiv in 2003 (SEPA 2011c). By applying integrated textile recycling techniques, 0.5 to 1.8 million tonnes of CO_2-eq could be saved annually. This means that applying the integrated textile recycling techniques have the potential of reducing Sweden´s total contribution to climate change by up to 1.8%.

4.1.3 Contribution to research question

"What is the most environmentally beneficial option for textile waste management?"

The intention of the first paper was to identify possible recycling technologies and to determine if the suggested recycling techniques could potentially result in a net environmental benefit compared to current practices. Sweden was the main focus of the paper, therefore, incineration with energy recovery was considered as the basis for comparison.

An LCA was performed to quantify the environmental profile of different scenarios for textile waste management. First, as presented in Paper I, the carbon footprint and energy usage for each textile waste recycling technology were assessed for the treatment of 1 tonne of textile waste. To complete the study, a semi-quantitative assessment was applied to estimate the toxicity impact of consumed chemicals in two of the three recycling techniques.

Second, these recycling technologies were integrated for the optimal usage of their different features for the treatment of 1 tonne of textile waste. In addition to the study presented in Paper I, a new scenario was evaluated as described in Section 4.1.2. The objective was to provide an insight into the broader impact of textile recycling techniques on a reduction in the total average global warming potential in Sweden. By doing so, the scope of the study changed from the treatment of 1 tonne of textile waste to the annual net flow of textile waste in Sweden. The net savings in terms of global warming potential and primary energy usage for the combination of textile recycling techniques were quantified.

The obtained results show a positive bias toward implementing textile recycling techniques as the most environmentally beneficial option for textile waste management.

4.2 Social issues related to textile waste treatment

4.2.1 Summary of Paper II

There is a lack of agreement on which social criteria that need to be selected for ecolabels. Currently, most ecolabels focus on environmental criteria. However, there are a number of emerging initiatives and ecolabels that promote social sustainability in different industries.

A label's indicator must be salient for the consumer and the industry, alike, to be efficient. Therefore, this study examined which social criteria are important for consumers and the results were compared with industry professionals' preferences.

The first part of the paper focuses on consumers' preferences regarding social indicators. Therefore, a survey consisting of two sections was developed to examine consumer recognition of ecolabels and their preferences for social issues in the textile and fashion industry. Five different ecolabels were selected to be evaluated for consumer perceptions and awareness of textile ecolabels and certifications. The labels were: the EU Flower Label, Bra Miljöval, GOTS, Nordic Swan and Oeko-tex Standard 100. Some of the labels were not restricted only to the fashion and textile industry. Among all considered ecolabels, GOTS and Oeko-tex Standard 100 focus solely on environmental issues regarding textile products. However GOTS has broadened its criteria by looking into social issues in textile life cycles (IWG 2011).

In the second part of the survey, the importance of 31 different social indicators which might be used in ecolabelling were examined by using a five-point scale ranging from (1) extremely unimportant, (2) unimportant, (3) neutral, (4) important and (5) extremely important. The indicators had been previously shortlisted as part of a wide-ranging literature review process described previously (Sandin et al. 2011).

The target group of the survey was Swedish fashion consumers between the ages of 16 and 30 years of age. 1,175 people participated in the survey in the spring of 2012.

In the second part of the paper, these preferences were additionally contrasted with those of the industry to compare similarities and differences between these stakeholder groups. Therefore, the same questionnaire was used to investigate the opinion of industry professionals. 108 people participated in the survey as part of a symposium about sustainable fashion in Sweden on May 2013.

The survey showed that the top 10 prioritised indicators for consumers were related to health and safety, child labour, fair salary, employment security, equal opportunities, discrimination, respect for human rights, avoiding misleading marketing and the voluntary promotion of social responsibility by companies.

By comparing consumer preferences with those of industry professionals, it was found that aspects of working conditions such as the promotion of a healthy and safe working environment for employees, and avoiding child labour and gender discrimination are high priority indicators for both consumers and professionals.

Social concerns relating to human rights and decent salaries are more important from a consumer perspective. On the other hand, the relationship between textile production and fair marketing and the implementation of proper internal and external complaints procedures are more important issues for the industry professionals, but very low on the consumers' priority list.

In the third part of the study, the most significant social criteria chosen by consumers were compared with the social criteria covered by the Global Organic Textile Standard (GOTS) label to capture the gap between current labels and consumer preferences. This analysis allowed some recommendations to be made regarding the future development of ecolabels using the GOTS label as a template.

The findings from the study show that the social indicators covered by GOTS are derived from the key norms of the International Labour Organization (ILO), therefore, they are mainly related to social issues such as health and safety, working and contract conditions, employment security, child labour, fair salary, equal gender opportunities, social benefits and respect for human rights. Social indicators related to other stakeholders such as the local community, society, consumers and value-chain actors are neglected in the GOTS social concerns. Maintaining the salience of indicators for consumers requires that the industry ensures ecolabels that reflect consumer perspectives and priorities. Therefore, it would be more meaningful for consumers if the GOTS label focused on covering other affected stakeholders throughout a product's life cycle.

4.2.2. Contribution to research question

"Which social indicators are the most relevant and important to use in a social impact assessment of textile waste management?"

The selection of different practices for textile waste management results in a number of social issues that indicate the need for a social impact assessment, as presented in Section 1.4.1.

One of the challenges that needs to be addressed before even applying a social impact assessment, is the selection of social indicators. One of the approaches for tackling this challenge is engaging different stakeholders in selecting and rating the indicators. For this purpose, in Paper II, the perspectives of different stakeholders on the relative significance of 31 social indicators for the life cycle of apparel were compared. A set of 10 indicators which were prioritised by consumers was identified. The consumers' preferences were additionally contrasted with those of the industry to compare similarities and differences between these stakeholder groups.

The survey took all aspects of the clothing life cycle, including waste management, into consideration. As mentioned in section 1.4.1, the expansion of the textile reuse and recycling industry is dependent on the management of social issues, due to labour intensity of this industry. Using the proposed set of social indicators in Paper II will help to ensure that the expanded systems are sustainable.

In the next step of the paper, the set of 10 indicators chosen by consumers were compared with the social criteria covered by the GOTS label to capture the gap between current labels and consumer preferences. The results show that the social indicators covered by GOTS are derived from the key norms of the International Labour Organization (ILO). Therefore they are mainly focused on social issues related to employment. Social indicators related to other affected stakeholders such as the local community, society, consumers and value-chain actors are neglected in the GOTS social concerns. Maintaining the salience of indicators for consumers requires that the industry ensures ecolabels that reflect consumer perspectives and priorities. Therefore, it would be more meaningful for consumers if the GOTS label focused on covering other affected stakeholders throughout a product's life cycle.

5 Conclusions

The results obtained in this thesis contribute to the overall aim of the research, which is to understand sustainability in textile waste management. The focus of the thesis is on both environmental and social aspects of sustainability by providing an inventory of environmental impacts and social issues related to textile waste management.

The findings in Paper I provide a guide to more environmentally beneficial textile waste management strategies. Paper II complements the first study by offering a set of social indicators for assessing the social impacts of those strategies.

The research provides answers to the following questions:

Research question 1: What is the most environmentally beneficial option for textile waste management?

Three different textile recycling technologies were identified in Paper I. An LCA was carried out to quantify the energy usage and global warming potential of different scenarios for textile waste recycling in comparison with energy recovery. The obtained findings quantitatively suggest that implementing textile recycling techniques is preferable to current practice.

Research question 2: Which social indicators are the most relevant and important to use in a social impact assessment of textile waste management?

Paper II examined consumer preferences for the relative significance of 31 social issues related to the life cycle of apparel. A set of 10 indicators which were highly prioritised by consumers was developed. The consumers´ preferences were additionally contrasted with those of the industry to compare similarities and differences between these stakeholder groups. The survey took all aspects of the clothing life cycle, including textile waste management, into consideration. Therefore, using the suggested set of indicators can help to evaluate the social sustainability related to different strategies for textile waste management.

This analysis allows some recommendations to be made regarding the future development of socially sustainable labels such as the Global Organic Textile Standard (GOTS) label. The social issues covered by GOTS are all related to workers in the textile product´s supply chain. It would be more meaningful for consumers if GOTS reflects social issues in relation to other affected stakeholders in product´s Life cycle.

6 Further research

The findings of Paper I provide insight into guiding textile waste management towards more environmentally beneficial options. The assessment was a preliminary LCA based on the best available data. The positive results related to the environmental impacts of suggested textile recycling options indicate a promising effect of introducing recycling, however more detailed studies are needed to determine how to implement textile recycling options to reduce the environmental footprint of textile waste management most optimally.

In practice, the selection and set-up of textile recycling techniques are directly influenced by the actual composition and quality of the collected textile waste, therefore more laboratory research on recycling different types of blended fabrics is necessary.

Paper II investigated the most significant social indicators for consumers and industry. A survey was used to examine the perspectives of consumers and the industry on social issues in the textile and fashion industry. The targeted group from the industry was selected from attendants at a symposium about sustainable fashion in Sweden. Since it was assumed that the participants were already aware of the concept of sustainability, the results may not reflect the actual opinion of stakeholders in the industry. To complete the picture with missing input, more studies are required that involve leaders from the industry.

In order to investigate the success factors for ecolabelling systems, further investigation is needed on how to best communicate this information to consumers and industry to inform their decision-making.

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