mistra
future
fashion

Illustration: Emma Cowlam

D4.1/D2.1

State of the art

By:
Rex D., Granberg H., Roos S.,
Zamani B., Peters G., Perzon E.

swerea|IVF CHALMERS

State of the Art Report for MISTRA Future Fashion

by

Swerea IVF, Innventia AB and

Chalmers University of Technology

A joint report between the
MISTRA Future Fashion

Project 2 and Project 4

(i.e. Deliverables 2.1 and 4.1)

March 2013

DOCUMENT STATUS RECORD

Project Title:	MISTRA Future Fashion
Client:	MISTRA Future Fashion Management Team
Document Title:	State of the Art Report
Document File Name:	20120917 Joint state of the art report MiFuFa.docx

Issue	Date	Description	Authors	Checked
1	20120630	Draft for internal review	D Rex, H Granberg, S Roos, B Zamani	G Peters
2	20120703	Document for delivery	D Rex, H Granberg, S Roos, B Zamani, G Peters	E Perzon
3	20130408	Final document	D Rex, H Granberg, S Roos, B Zamani, G Peters, E Perzon	Å Öslund

Disclaimer:

1. Chalmers, Innventia and Swerea IVF have taken all reasonable steps to ensure that the information contained in this publication is accurate at the time of production. In some cases, we have relied on information supplied by the client.
2. This report has been prepared in accordance with good professional practice. No other warranty, expressed or implied, is made as to the professional advice given in this report.
3. The authors maintain no responsibility for the misrepresentation of results due to incorrect use of information contained within this report.
4. This report should remain together and be read as a whole.

This report has been prepared solely for the benefit of the client listed above. No liability is accepted by the authors with respect to the use of this report by third parties without prior written approval.

Table of contents

1 Executive summary 3

2 Moving towards eco-efficient textile materials and processes 4

2.1 Background 4

2.2 Purpose and goal 5

2.3 Available textile materials on the market 5

2.3.1 Yarn Library 5

2.3.2 Other interesting fibers from the sustainability prospective 6

3 Chemicals in the textile industry and development of support tools for industry and the public sector 8

3.1 Background 8

3.1.1 Studies over the life cycle 8

3.1.2 Integrated assessment 9

3.2 Data collection for the support tool 10

3.2.1 Environmental evaluation of raw materials for new sustainable fibres 10

4 Available tagging systems on the market for clothing 12

4.1 Tagging and sensing can add value to textiles 12

4.2 Textile tagging today – logistics and antitheft 12

4.3 New smart phone tag readers empower the end consumer 13

4.4 Sensors gain access to the environment 13

4.5 Tag usage for garments 13

4.5.1 Example 1) Textile entertainment 14

4.5.2 Example 2) Textile provenance 14

4.5.3 Example 3) Visualise textile sustainability 14

4.5.4 Example 4) Consumer insight 14

4.5.5 Example 5) New business models 15

5 Social Life Cycle Assessment (S-LCA) 16

5.1 The Methodology and Impacts 16

5.1.1 Goal definition 16

5.1.2 Scope definition 16

5.1.3 System boundaries 17

5.1.4 Impact Assessment 17

5.1.5 Life Cycle Interpretation 21

5.2 Discussion 21

5.3 Case Study 22
5.3.1 Overview of the Indian textile industry..... 22
5.3.2 Sustainability evaluation of Indian textile suppliers 22
5.3.3 Research methodology..... 22
5.3.4 Result of the case study 23
6 References 24

Table of figures

Figure 1: Textile fibres from wood as alternative to cotton.....4
Figure 2: Sorona fibres 6
Figure 3: Technology roadmap for the Internet of Things (SRI consulting business intelligence).....12
Figure 4: Stakeholder categories and subcategories in S-LCA (UNEP/SETAC) 19

1 Executive summary

The MISTRA Future Fashion programme (MiFuFa) is a multidisciplinary research and development project which includes a range of activities. Applied scientific research is complemented by analysis of business models, political structures and customer perceptions. In this report, three of the key participants (Chalmers University of Technology, Innventia AB and Swerea IVF) have combined their initial assessment of the state of the art in several areas of relevance to the development of more sustainable textile product life cycles. They include improving the textile materials, the processes that manufacture them, knowledge of consumer use (through garment tagging/tracking), assessment of chemical issues in textile sustainability, social impacts and communication of sustainability information with designers and consumers.

Chalmers and Swerea IVF share an industrial PhD student and all of the areas of investigation mentioned above have the capacity to influence each other. Therefore it seemed appropriate to combine the deliverables D2.1 and D4.1 (both called ”state of the art report” in the MISTRA Future Fashion project documentation) as a reflection of our intent to foster collaboration between the researchers behind this report. The report is intended to inform management and update participants within the MISTRA Future Fashion team about our areas of work, and potentially provoke new information flows to the researchers. In the case where the reader has ideas to add, please contact the project managers for Project 2 or Project 4 in the first place: Greg Peters or Erik Perzon, respectively.

2 Moving towards eco-efficient textile materials and processes

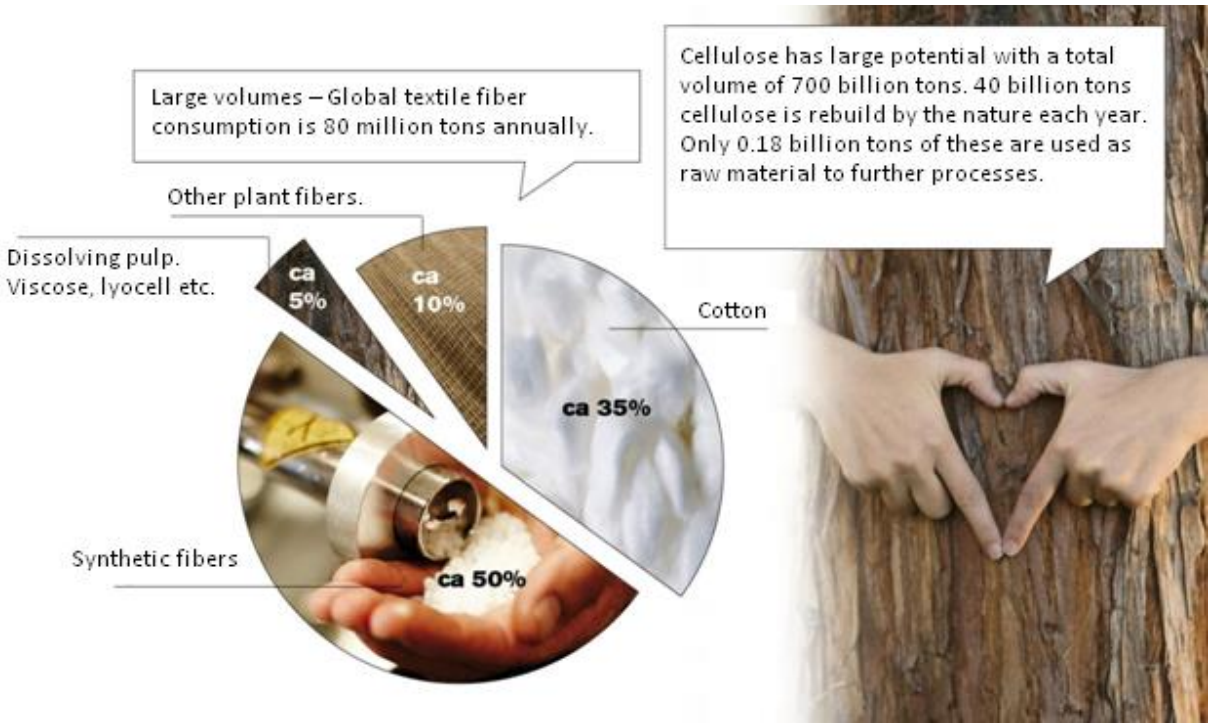
2.1 Background

The worldwide cotton production has reached a point called "peak cotton". Global production has stagnated. Farmland area cannot increase anymore and the prices of food and raw materials are rising significantly. Synthetic fibres cannot meet expectations regarding comfort and moisture that the natural ones can offer. The paper consumption has started to decrease and new solvents for cellulose create new business opportunities.

Cotton is considered the world's dirtiest crop due to its heavy use of insecticides and pesticides. Cotton covers 2.5% of the world's cultivated land yet uses 16% of the world's insecticides, more than any other single major crop (AWA/MR, 1995). In the same way it uses more than 10% of the world's pesticides (including herbicides, insecticides, and defoliants) (EJF, 2007).

Therefore is it necessary to find some alternative to cotton. Cellulose material has large potential and the dissolvent fabrics are waiting for new products to develop from their dissolvent pulp.

Figure 1: Textile fibres from wood as alternative to cotton



2.2 Purpose and goal

In MISTRA Future Fashion Project 4, one goal is to reduce the cotton "cake" and to increase the dissolving pulp "cake" as pictured in Figure 1, to be replaced by fibres that are sustainable and with as less environmental impact as possible. The whole chain is going to be evaluated, from-cradle-to-grave thinking and also including all chemical aspects during the processes and on the finished product during the using phase.

The purpose of this project is to develop or identify processes for turning new bio-based fibres into textiles. This includes also dying and washing processes with less environmental impact.

Textile demonstrators will be developed from bio-based materials that meet these high environmental demands and also manage the quality aspects that are required.

Another objective in this project is to develop tools, according to definition in MISTRA Future Fashion Project 2, which can give the consumer an overview of the environmental aspect of the product. Therefore a PhD student is employed to examine Life Cycle Assessment (LCA) issues,including the holistic thinking and finally create tools for these kinds of evaluations. This is discussed further in section 2 of this report.

Tagging in clothes will be developed to give a view of how much a certain garment will be used, number of washes and end-on-life choice, recycling.

2.3 Available textile materials on the market

2.3.1 Yarn Library

Collecting yarns in a yarn library is ongoing. The focus is on sustainable materials but also on other commercial materials to compare with. For finding materials internet home pages have been used. Some producers send the material for free and others want to get paid for them. Table 1 below shows the materials in Swerea IVF yarn library so far.

Table 1: Swerea IVF Yarn Library contents (empty field = no data)

Material	Quality	Tex	Twist	Amount	Company	Country
Polyester	75D/36F/1		Z-twist	50 kg	Y-Berger	Indonesia
Cotton	Ne 30/1	19	S-twist	75 kg	H&M	Turkey
Viscose			N/A	50 kg	Enka	Germany
Modal	Nm 36/1			57 kg	Tearfil	
Lyocell	Nm 36/1	16	Z-twist	57 kg	Tearfil	
Wool			Z-twist	1 kg		
CelluNova		154	N/A	500 g	IBWCh	Lodz,

						Poland

2.3.2 Other interesting fibers from the sustainability prospective.

2.3.2.1 Milk fibre, Qmilch, Domaske's MCC fashion

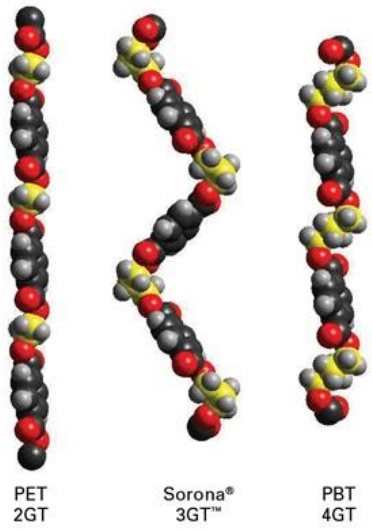
Milk fibre is based on the milk protein called casein. It is soft and smooth and good for people with sensitive skin. This fibre is produced in Germany without any process chemicals by reducing milk into powder. Then it is boiled and stretched to threads, whereas the thread can be woven or knitted to a fabric.

This company uses only organic milk that is rejected for sale as milk for human consumption. Milk fibre is approximately 40% more expensive than organic cotton. It though takes 2 litres of water to produce 1 kg fabric (Qmilch, 2013).

2.3.2.2 Sorona from DuPont

Sorona is made partly with annually renewable plant-based resources; it contains 37 % renewable plant-based ingredients by weight and 28% bio-based carbon. It was developed during 2009 and became available on the market from 2011. It has Oeko-Tex certification class 1. Sorona is one of the first bio-based textile polymers that have high technical and life cycle advantages for a wide range of products from apparel to carpets. It works well to blend with other materials, as Sorona has similar quality as polyester and is also known as 3GT or PTT (polytrimethylene terephtalate). The kink in the molecular structure of the fiber is unique, see Figure 2,and offers fiber memory leading to comfort stretch and full recovery in apparel applications. The fiber can therefore prevent baggy knees and elbows etc.

Figure 2: Sorona fibres



http://www2.dupont.com/Sorona_Consumer/en_US/index.html

2.3.2.3 Bamboo viscose

Bamboo is the fastest growing grass and it can grow up to 1 meter a day. It grows naturally without any pesticides, herbicides or fertilizers. It is ready for harvesting in about 4 years. The most common way to make fibres from the bamboo plant is to use the viscose method. This method can be performed in the same way as for other cellulosic materials and contains the same amount of chemicals. The advantages with using bamboo or wood viscose are several. The fibre is soft and round in cross-section and is suitable for people with sensitive skin, being hypoallergenic, and the fibre is easy to launder. The Bamboo plant is anti-bacterial and it has been proposed that also the Bamboo viscose fibre might show such properties. This is not scientifically proven yet but may be something we will examine in this project. The bamboo viscose absorbs water to a relatively high degree, and transports water from the body 3-4 times faster than cotton (anon, 2013). The structure makes the fabric more breathable than cotton and synthetic fibres. The bamboo fibre does not need to be mercerized to improve lustre and dye-ability like cotton requires. Clothes from bamboo are 100 % biodegradable and can be completely decomposed without any pollutants.

3 Chemicals in the textile industry and development of support tools for industry and the public sector

3.1 Background

We performed a literature review to examine how chemicals are treated in LCA studies of textiles and related product groups. The review also examined precedents for integrated assessment of impacts at different spatial scales.

3.1.1 Studies over the life cycle

Few LCA studies on textiles included chemicals in a quantitative way, which means that the use and emission of chemicals were not included in the life cycle inventory. Concerning the manufacturing of fibres, cotton is the most frequently examined textile material in the LCA related scientific literature and most studies bring up issues related to pesticide and fertilizer use in the cultivation phase, but only in a qualitative way (Güngör et al., 2009; Kalliala and Nousiainen, 1999; Steinberger et al., 2009). Detailed toxicity calculations were made using a semi-quantitative approach in one case (Pulli et al., 1997). The life cycle perspective of the use of pesticides generally in agriculture is described in Hellweg and Geisler (2003). Pfister et al. (2009) focused on total water use but included the loss of water quality due to pollution during water consumption for cotton cultivation. A review of LCA studies of polyolefins was made by Rajendran et al.(2012). The inventory data used for environmental assessment of synthetic fibres are usually life cycle inventory data from PlasticsEurope's Eco-profiles (Boustead, 2003). The toxicity, if it is mentioned, is generally all caused by the energy production system in studies of polyolefin manufacturing (Yuan, 2000).

Once the raw fibre has been created, the next step in the textile life cycle is fabric manufacturing, which includes such processes as yarn spinning, knitting/weaving and wet treatment. Descriptions of the use and emissions of different spinning oils, knitting oils and sizing agents for weaving are not found in any scientific publication. A recent description of textile finishing in China that includes inventory of chemicals was offered by Yuan et al. (2012) who describe continuous pad dyeing of cotton with reactive dyes. Older studies include e.g. a report by (Beck et al., 2000) that discussed the fate modelling of four wet treatment chemicals, and an LCA of a cotton T-shirt with detailed modelling of chemicals in the wet treatment and the user phase (Pulli et al., 1997). "Easy care" treatment chemicals, which reduce ironing and/or washing requirements, are discussed by (De Saxce et al., 2012). Textile printing techniques were described and suggestions for improvements were made by (Tong et al., 2012). The environmental concerns with anti-odour and anti-stain treatment of garments using nanosilver were described by several authors (Chen et al., 2011; Meyer et al., 2010; Walser et al., 2011). An inherent process in textile wet treatment is the treatment of waste water, on site or at an external waste water treatment plant, which is examined by many authors, e.g. Gabarrell et al. (2012) but often excludes the chemicals issues, e.g. Hsu et al. (2012) and Jiang et al. (2010). A life cycle assessment has been made by

Rajakumari and Kanmani (2008) considering the chemicals used in the waste water treatment but not impact from chemical emissions.

The most thorough description of the quantity of chemicals used in textile processes is today offered by the Textile BREF document from 2003 (European Commission, 2003). As a consequence of the Council Directive 96/61/EC of 1996 concerning integrated pollution prevention and control (IPPC), a series of Best Reference documents (BREF) were developed for the concerned industries on commission by the European IPPC Bureau. The textile industry was one area and in 2003, a textile BREF was developed as a result of a COST Action (Nieminen et al., 2007). The aim with the document created in the COST Action was to document the Best Available Technology (BAT) for textile processes and to develop criteria for ISO (Type III) Environmental Product Declaration (EPD) standards. The polymer production industry was another area where synthetic fibre production etc. is described in the polymer BREF, updated 2007 (European Commission, 2007).

Several LCA reports describe the user phase in some detail, for example the chemicals used for laundry, both for household laundry, industrial laundry as well as dry cleaning, and different challenges for the modelling of them in LCA (Hellweg et al., 2005; Keoleian et al., 1997; Krozer et al., 2011; Saouter et al., 2011; Schulze et al., 2001; Skaar and Jørgensen, 2012). The exposure of end users is another aspect of chemicals in the use phase, an aspect that has been considered in an LCA of footwear (Herva et al., 2011), but no references were found that describes this aspect in LCA for textile products.

Incineration is the most common waste management method for textiles in Sweden (Carlsson et al., 2011) although this is a phase where the processes differ a lot between countries. In the United States for example, the most common waste management method for textiles is on the contrary landfill (United States Environmental Protection Agency, 2010) as well as in the UK (Allwood et al., 2006). The aspects of the end of life that concerns chemicals can be emissions that are caused by uncontrolled incineration processes or degradation of textile material in the nature. Recycling methods for textiles may include chemical usage but these are still under development (Farrant et al., 2010) Zamani et al. (submitted)).

3.1.2 Integrated assessment

The Textile BREF document states that "it is recognised that knowledge of the quality and quantity of substances (e.g. preparation agents, pesticides, knitting oils) applied on the fibre during the upstream processes is essential to enable the manufacturer to prevent and control the environmental impact resulting from these substances"(European Commission, 2003). The development of EPDs of textile products still lags behind other product groups, and only recently in December 2012, Product Category Rules (PCRs) for woven textiles have been published (The International EPD system, 2013). Another recent initiative for EPDs of textile products has been taken by the Sustainable Apparel Coalition (SAC) (2012) that is currently finishing the work with developing guidance material for developing PCRs for textile

products. However, the guidance for how the impact from chemicals should be declared in textiles is still under development, an interim solution proposed at the SAC Metrics Working Group meeting in January 2013 is to hold all regulated chemicals declarable in the EPD.

In several unique publications, other researchers have discussed possible approaches for merging the life cycle perspective with that provided by chemical risk information, and the application of different methods for bridging data gaps regarding chemicals in LCA (Finnveden et al., 2009; Laurent et al., 2012). Quite a few of claim to be novel, a claim which is supported by the fact that they all use different subsets of information and impact assessment methodologies, such as combining LCA with risk assessment and multi criteria analysis (Liu et al., 2012)(Scheringer, 1999), combining LCA and REACH information (Askham, 2011), inclusion of the acidification aspect in Ecological Footprint (Herva et al., 2012), combining ERA with LCA or Ecological Footprint (Grieger et al., 2012; Herva et al., 2011) or combining input-output LCA with risk assessment (Wright et al., 2008). To summarise the literature study, it can be stated that a consistent integration between LCA and chemicals has still not been fully completed, consistent with the conclusions made by (Sala et al., 2012). Looking from the other direction, on how the life cycle perspective is managed in chemical risk assessment, there is still a need for ”life cycle awareness” in risk assessment according to Kuczenski et al. (2011).The Textile BREF document also presents a semi-quantitative tool, the Score System, developed in the 1990s by the Federation of Danish Textile and Clothing in Denmark (Laccasse and Baumann, 2004). The Score System was implemented in 1992 in Ringkøbing County in Denmark, where it was integrated into the waste water permits or environmental approvals of companies. This method can be used to calculate the potential eco-toxic impact from textile chemicals, and has been used as a supporting assessment method in the case studies described below.

3.2 Data collection for the support tool

3.2.1 Environmental evaluation of raw materials for new sustainable fibres

In project 4 of MiFuFa (Moving towards eco-efficient textile materials and processes), new sustainable fibres will be technically assessed (see above) new. The selection of fibres to test will be based on environmental considerations and also economical and practical considerations such as if the fibres are available in suitable quantities etc.

An environmental evaluation was made of several fibres that are marketed as “new” and “environmentally friendly” textile fibres, see table 2 below. The criteria applied for the evaluation was based on the criteria in Bra Miljöval[1] eco-label. The fibres should be renewable and cultivated without pesticides or irrigation.

[1] The Swedish Society for Nature Conservation (SSNC) runs the eco-label Bra Miljöval with the aim to guide consumers to make a "Good Environmental Choice". The requirements are stricter than other labels as there is no demand for market share of companies to be able to fulfill the criteria and thus be possible clients for the eco-label.

Table 2 Preliminary environmental evaluation of different fibres marketed as new and environmentally friendly.

	Crop based			**Wood based**		
Brand name	Ingeo	Sorona	Tencel	CelluNova	Lenzing Modal	XXX (not public)
Fibre	PLA	PDO/polyester	lyocell	viscose	lyocell	viscose
Raw material	corn	corn/mineral oil	eucalyptus	spruce	beech	bamboo
Claims of environmental friendliness	Well dressed[2]	Well dressed	Well dressed	Gustav	Well dressed	XXX (not public)
Manufacturer	Nature Works LLC	DuPont	Lenzing	IBWCh	Lenzing	XXX (not public)
Available for test at Swerea IVF	?	?	Yes	Yes	?	Yes
FSC/ISO 65 certified forestry (Bra Miljöval)	N/A	N/A	Yes	No	Yes?	?
Fair Wild Foundation certified forestry? (Bra Miljöval)	N/A	N/A	?	No	?	?
IFOAM/ISO 65 certified ecological cultivation? (Bra Miljöval)	?	?	N/A	No	N/A	N/A
BCI/CmiA certified cultivation? (Bra Miljöval)	?	?	N/A	No	N/A	N/A
Cultivated without pesticides and irrigation	?	?	Yes	Yes	Yes	Yes
No genetical modification? (Bra Miljöval)	?	?	N/A	N/A	N/A	N/A

[2] Allwood J.M., Bocken N., Laursen S. E. and Malvido de Rodriguez C. (2006), Well Dressed? The Present & Future Sustainability of Clothing & Textiles in the UK, Cambridge: University of Cambridge, Sustainable Manufacturing Group, Institute for Manufacturing

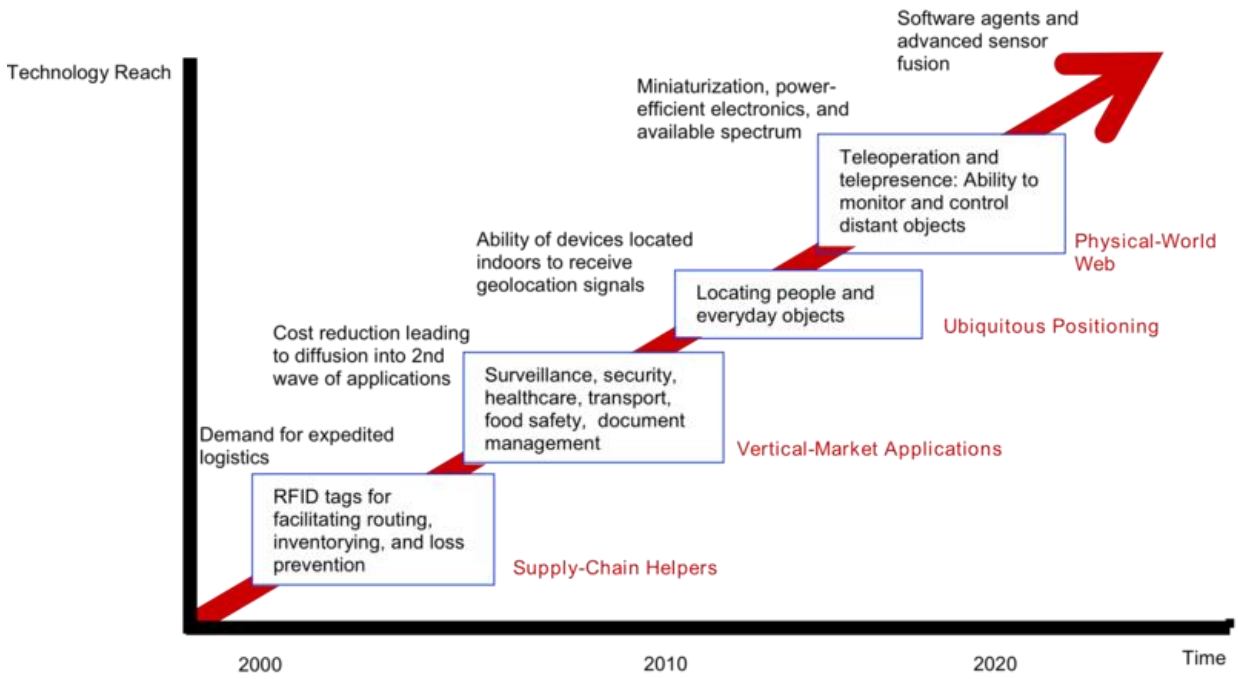
4 Available tagging systems on the market for clothing

4.1 Tagging and sensing can add value to textiles

The Internet of Things is a vision based on the trend to connect commodity objects with the Internet, see Figure 3. The figure summarises the past and suggests future development in how we relate to object tagging. Objects are connected to the Internet using different tagging technologies. The most common tagging technologies are radio frequency identification (RFID) and optical barcodes. The tags can be directly coupled to sensors that read e.g. ambient temperature or moisture, position, time, speed or mechanical stress. Almost anything can be read, stored, and communicated by a sensor-tag-internet system. However, to make a tag system meaningful, useful, and cost effective one has to carefully design it for each application and its specific needs.

Tag systems for textiles open up a vast and to some extent unexplored territory to adding customer value. Below we present some ideas that have been identified as useful for textiles and some that even could be potential areas for innovation.

Figure 3: Technology roadmap for the Internet of Things (SRI consulting business intelligence)



4.2 Textile tagging today – logistics and antitheft

The retailing industry makes use of the far most common and low cost tags, namely the barcode and the electronic article surveillance (EAS) systems. The 1D printed barcode is a very mature technology that is read by an optical device and can be of use throughout the logistic chain to keep track of the goods. However, the 1D barcode does not contain enough information to have a unique ID and its use is therefore

limited. The EAS tags can be attached to and detached from the textiles by personnel at the counter in a store. The tag does not contain any ID information but is used to reduce thefts because it sends an alarm when unpaid good are passing the control gates of the store.

Closed loop systems such as textiles for the public sector use tags that are sewn into the textile to identify each individual textile item when they are passing certain reading gates. This enables monitoring of the position and treatment of each item. By wise positioning of the reading gates one can e.g. monitor the circulation time, the time between washes, the total number of washes, and the position of each textile. This information is used to optimise logistics, withdraw worn textiles from circulation and to take measures against pinpointed positions with high theft rates.

4.3 New smart phone tag readers empower the end consumer

Recent advances in smart phones enable reading of advanced low cost tags directly by the end consumer. E.g. traditional 1D barcodes and new 2D barcodes containing unique IDs can be scanned by the camera in handheld smart phones. Also, the coming generation of smart phones allows for even simpler reading by tapping the phone close (< 4 cm) to passive (no battery is needed) low cost near field communication (NFC) tag in order to extract information from it. These technologies clearly empower the end consumer and give them the means to read low cost unique ID tags that earlier were limited to dedicated readers within the logistics chain. Also, since the mobile phone has a unique ID that is strongly connected to its user, the tags enable the possibility to create a link between personal preferences and things.

4.4 Sensors gain access to the environment

There are sensors on the market that can collect lots of data from the surrounding environment such as temperature, humidity, mechanical stress, force, tilt, position, pressure, flow, speed, gas composition, chemical composition, electric current or voltage. By combining many sensors and linking them to the internet through tags, smart phones or wireless connections, the sensor data becomes available on the internet. As tags with sensors tend to be more expensive and complex (e.g. sensors need an energy source) it can be advantageous to separate a sensor system that stores information on the internet from low cost tags that can be used to gain access to the data.

4.5 Tag usage for garments

It will be possible to create new values when combining modern apparel with tags, sensors and the digital world. The given examples below represent a small selection of what is possible, and it is up to the combined efforts of the industry and research organisations to unlock its full potential

4.5.1 Example 1) Textile entertainment

A unique tag ID code can be used as a key to gain access to different data channels (e.g. WiFi, bluetooth) and copyright material such as film, music, games and literature. By placing the textile and its tag in the right context it becomes possible to associate a specific textile with positive experiences obtained when the textile is worn. This could be e.g. new interactive games for socialising, augmented reality, or access to interesting information at the right time and place; clothing could interact with other persons clothing and give a positive feedback to social networks or internet games, different fashion could trigger different media play at a museum, the clothing could give instructions to the acting in role playing games or improvisation theatres, tables could give different hotel menus and offerings based on the combination of fashion that is worn for the night.

4.5.2 Example 2) Textile provenance

The history of things is so important for the estimation of the value of antiquities that it has gotten its own name – the provenance. The company Artek (2013) has understood the worth of the provenance and adds silicon tags to their Alvar Alto furniture. The tag records the position of the furniture thus keeping track of part of its history. The data can later be read by a tag reader and by the time the items are sold in second hand, the value of the furniture has increased depending on its history.

Tags can be added to fashion in a similar way to support its provenance value. The history could include anything from former owners (e.g. celebrities), cat walk exhibitions, and famous happenings (Nobel Prize dinner, awards), uniqueness identifiers, and geographic history.

4.5.3 Example 3) Visualise textile sustainability

Tags read by smart phones can be used to gain access to internet media that gives extra information about a textile. This could be a video that shows how the material is treated in the production process or other sustainability promotion. It could also be a tag that stores the provenance of the textile and how many times it has been sold in second hand. The consumer could also get the means to show and reclaim bad quality clothes by keeping track of natural wear, number of washes and its degradation.

Another application could be to start a real life sustainability game with your friends. The application collects information about how you live your life and how that impact the environment compared to how well your friends do. Textile tags and sensors automatically record and give input to the game about how the textile is treated; e.g. how often it is worn and how it is washed.

4.5.4 Example 4) Consumer insight

The fashion industry is very interested in how consumers behave in a shopping situation and when they use the fashion. Tags and sensors can help gaining input data which can be mined and refined by different mathematical methods. E.g. a sensor on the t-shirt hanger in a fashion store can record the number of times a shirt has been

lifted from the hanger compared to how often it has been tested in the fitting room and how often the t-shirt is sold at the counter. Does the consumer behave differently at the sports, the underwear, and the expensive suit section? Why?

By using test groups having clothing equipped with sensors and tags, it becomes possible to automatically measure different wearing, handling and washing behaviour. What does a consumer group choose to wear on a rainy day, a holiday, on a party, or at work? What do they choose between and what triggered the decision? Where does the consumer put the clothing after one day at work? How often do they wash, what washing program is used, and what differs in behaviour between young and old, male and female users? These issues can be investigated by designing tailor made tag-sensor solutions for each application.

4.5.5 Example 5) New business models

Today, the most common business model for fashion is that people buy to own their clothes, use them, store them, wash them, and finally sell them to second hand, put them into the recycle bin or throw them into the garbage. By treating textiles as a service new business models may arise. Some current unmet needs are that people may experience anxiety when going to a party because all their clothes have been used before on other parties. Others find it boring to buy clothing but enjoy being perceived as well dressed. Some don't have the time to go twice to the washing machine (before and after washing) or even have the space to store clothes. These needs can be met by letting the consumer pay for the functionality of the garment rather than for owning the goods.

The consumer could subscribe to access to clean clothes on a daily basis. The subscription could be presented as a weekly menu including different taste and personal preferences (functional, aesthetical style). The cost would vary depending on how much the textile has been worn and its popularity. The right outfit for the night could also be obtained by hiring a garment pool service (based on the library of unused textiles in many homes) that combines different clothes into aesthetical combinations or finds the missing piece in a themed outfit.

In such a service tags and sensors can be used to automate the handling of the large amount of different clothes that is needed to obtain a good garment subscription or garment pool service. Information such as fitting measures (arm length, waist etc.), previously accepted clothing and colour combinations by different consumer groups, popularity, and number of previous uses and washes can be important to monitor.

5 Social Life Cycle Assessment (S-LCA)

Social, or Socio-Economic, Life Cycle Assessment is a technique which aims to assess the social and socio-economic aspects of products and their potential positive and negative impacts along their life cycle.

Social life cycle assessment (S-LCA) encompasses extraction and processing of raw materials; manufacturing; distribution; use; re-use; maintenance; recycling; and final disposal.

S-LCA complements environmental life cycle assessment (E-LCA) with social and socio-economic aspects and it can either be applied on its own or in combination with E-LCA. The assessment can be both performed by using generic or site specific data depending on the goal and scope of the study (UNEP 2009).

Furthermore, S-LCA provides guidance on social and socio-economic aspects for decision making, instigating dialogues for production and consumption, the prospect of improving performance of organisations and ultimately the well-being of stakeholders (UNEP 2009).

5.1 The Methodology and Impacts

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:

1. Goal and scope definition
2. Life cycle inventory analysis
3. Life cycle impact assessment
4. Life cycle interpretation

5.1.1 Goal definition

Several goals of S-LCA can be defined such as: product or process comparison; identification of product or process improvement potentials.

5.1.2 Scope definition

The objective of the study is specified in this phase.

A product or service system is composed of different processes according to Environmental Life Cycle Assessment (E-LCA). There is a connection between these processes and environmental impacts since the environmental assessment is based on aggregated inventory of input and output for the processes.

On the other hand, most social impacts are not directly related to the processes but rather to the conduct of the company, consequently the linkage can be traced between the conduct of the company and its social impacts. This means that the S-LCA inventory analysis should focus on the companies involved in the product system

even when some methods emphasise the production process being the basis for the assessment.

5.1.3 System boundaries

Two alternative ways to establish the system boundaries are proposed:

- If the goal of the study is supporting the management decisions, the boundaries are narrowed to those parts of life cycle where the company performing the assessment can directly influence in their production.
- Another approach by including the whole life cycle but preclude the parts which do not change has a significant influence.

5.1.4 Impact Assessment

The main steps of this part are:

- Selection of the impact categories and subcategories
- Classification of the inventory data by relating them to the impact categories and subcategories
- Characterisation by calculating the results for the subcategories indicators

The classification of the categories will be discussed in this section whereas different approaches for impact assessment will be discussed in section 5.1.4.2.

5.1.4.1 Classification: development of impact categories and subcategories

The basis of S-LCA assessment is the subcategories which are socially significant themes or attributes. The classification of the subcategories depends on two aspects of stakeholders and impact categories.

- How organisations involved in the product life cycle treat their stakeholders, leading to the stakeholder category classification: consumers; workers; local community; society and other value-chain actors.
- Alternatively sorting according to the social impact of the product on consumers and society leads to impact-based categories such as: human rights; health and safety; working conditions; governance; cultural heritage and socio-economic repercussions.

The purpose of the classification into impact categories is to support identification of stakeholders, to classify subcategory indicators within groups that have the same impacts, and to support further impact assessment and interpretation.

Social sustainability impacts are consequences of positive or negative pressures on social endpoints such as the well-being of stakeholders; therefore the social sustainability impact of a product can be viewed as its impact on human well-being throughout its life cycle.

As mentioned above, S-LCA evaluates the social impacts of all products' life cycle stages including resource extraction, processing, manufacturing, assembly, marketing

and sales, usage and end-of-life management. Each of these phases is associated with a geographical location in which different types of stakeholders are impacted. The proposed stakeholder categories are classified as

- Workers/employees
- Local community
- Society (national and global)
- Consumers (end-consumers as well as consumers in each phase of the supply chain are covered)
- Value chain actors

Social and socio-economic subcategories have been defined according to international agreements (conventions, treaties etc.). A set of subcategories are shown in Figure 44.

Figure 4: Stakeholder categories and subcategories in S-LCA (UNEP/SETAC)

Stakeholder categories	Subcategories
Stakeholder "worker"	Freedom of Association and Collective Bargaining Child Labour Fair Salary Working Hours Forced Labour Equal opportunities/Discrimination Health and Safety Social Benefits/Social Security
Stakeholder "consumer"	Health & Safety Feedback Mechanism Consumer Privacy Transparency End of life responsibility
Stakeholder "local community"	Access to material resources Access to immaterial resources Delocalization and Migration Cultural Heritage Safe & healthy living conditions Respect of indigenous rights Community engagement Local employment Secure living conditions
Stakeholder "society"	Public commitments to sustainability issues Contribution to economic development Prevention & mitigation of armed conflicts Technology development Corruption
Value chain actors* not including consumers	Fair competition Promoting social responsibility Supplier relationships Respect of intellectual property rights

5.1.4.2 Impact assessment approaches in S-LCA

Some of the impact assessment methods calculate the results relating to the social impacts directly at the activities of the unit processes, other approaches propose a way to assess how unit processes will lead to potential human health results, and some other methods provide interpretations of social performance by using the inventory data (Parent et al. 2010).

At this time, the three principal impact assessment methods proposed include: The UNEP/SETAC Taskforce´s method, Hunkeler´s method (2006) and Weidema´s method (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).

According to the Taskforce's method, usage of "performance reference point" is developed to assist understanding of 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 UNEP guidelines is "fair salary", which can be assessed by comparing with the performance reference point and interpreted into semi-quantitative values. Afterwards, by using a weighting system, the semi-quantitative values can be aggregated into Subcategory Indexes.

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

Alternatively, Weidema (2006) offered a method during which the social impacts are measured in terms of reduction of well-being. As mentioned by Weidema (2006) six identified damage categories under the heading of human life and well-being includes: life and longevity, health, autonomy, equal opportunities, participation and influence, and safety, security and tranquillity. For being able to measure social impacts in terms of a reduction of well-being, the quantitative term of Quality Adjusted Life Years is proposed. According to his method, he attempts to build impact pathways linking quantitative inventory items to damage categories (Parent et al. 2010).

The distinction in the methods lies in the indicator results. According to Taskforce´s method, using the performance reference point results in deriving the state of a dimension of the social context. Whereas by using the other approaches the social impacts derived from inventory data are measured.

Both Hunkeler and Weidema offer methods according which the indicator show the impact of the functional unit in a quantitative form. However, in Taskforce's method the relative importance of each context unit on the product system are shown by defining a share factor which represent "*the given weight to a company´s social profile in the aggregation of social impacts along the product´s chain*" (Dreyer et al. 2006). According to Parent´s definition "*When the stressors- Equivalent to the elementary flow in E-LCA- are collected at an organisational level"*, e.g., country, sector, or enterprise, the unit assessed becomes the social context, which can be called "context units" parallel to the unit processes" (Parent et al. 2010).

In the first method the weights of the different processes are implicitly carried through the impact pathways allowing the indicator results to represent the impact of the functional unit, of a quantitative amount of the studied product

5.1.5 Life Cycle Interpretation

The robustness of the case study is verified in this phase, furthermore necessary conclusion for further decision making will be made.

5.2 Discussion

Three different approaches of social impact assessment are introduced in this report.

By using Performance Reference Points in Taskforce´s method, the social performance of different components of the product's life cycle can be obtained at different organisational levels. Nevertheless the social burdens of a quantified amount of product are not measured.

Hunkeler´s and Widema´s methods, which are structurally closer to E- LCA, assess the social impacts derived either from technical nature or sociosphere surroundings of the processes. Thus they have the potential advantage of allowing the analyst doing a full sustainability assessment to perform an S-LCA which is more consistent with an E-LCA performed in parallel, reducing the risk of burden shifting. Up to the present time only a few social issues are assessed by using impact pathways methods as the set of the qualitative social indicators are larger than the set of quantitative ones. This disadvantage presents a different kind of risk of burden-shifting to unassessed categories (Parent 2010).

The main motivation of developing a method is its usability. Several different intentions of S-LCA are proposed in relation to applying it in a company context. Several different purposes of applying S-LCA are suggested concerning the relevance of S-LCA in company context. Dreyer et al. (2006) propose an approach that can identify the hotspots of the social issues in the product's life cycle and assist in further improvements in the product´s or service life cycle. Whereas Schmidt et al. (2004) suggest a tool for comparing two products with similar functionality from social aspects.

Based on the results of a series of interviews performed by Jorgensen among potential company users (2009), the achievements by performing an S-LCA can be attractive for the companies in the sense of justifying the social impact of their product life cycle to external stakeholders. Availability of data can be the challenging issue as the social impacts in the product´s life cycle are related to remote parts of the upstream or downstream chain such as management of the production and use phase and not to the process of production. Developing an S-LCA is not an easy task as companies are mostly unable to provide sufficient data about far up and downstream processes in the product´s life cycle (Jørgensen 2010).

5.3 Case Study

5.3.1 Overview of the Indian textile industry

The Indian textile supply chain is one of the longest and most fragmented supply chains in the world. It includes the ancillary suppliers, garment producers and multinational garment retailers (Baskaran et al. 2012).There is a significant gap between the availability of skilled workforce and the requirement of the textile industry in India, particularly in weaving, dyeing and processing.

Supplier evaluation is a decision making process for selecting strategic suppliers with the aim of improving the competitive advantage. Therefore the criteria relating to sustainability issues are selected for the evaluation of the suppliers.

5.3.2 Sustainability evaluation of Indian textile suppliers

Supply chain of the textile consists of garment retailers, manufacturers, suppliers for garment and ancillary. According to Baskaran´s study (2012) a sample including 63 suppliers were assessed, and 6 sustainability categories including discrimination, human right abuse, child labour, long working hours, unfair competition and pollution were considered. The social life cycle assessment is based on a qualitative social sustainability ranking on a scale of "good", "moderate" or "performance up not to expectation" (Baskaran et al. 2012).

This study looked into some of the critical aspects of industry sustainability including social issues such as workforce practices, corruption, discrimination, child labour, human rights and long working hours.

5.3.3 Research methodology

The textile garment manufacturer includes 1500 knitting units, 700 dying and bleaching units, 500 fabric printing units, 250 embroidery units, 300 compacting and calendaring units and 500 other ancillary units.

During the interviews with chief executives and owners, the information in the list below was obtained.

General information including number of employees, financial information

Examination of the prevalence of discriminatory practices.

Abuse of human rights in the workplace, training of workers, disciplinary actions, determine the child labour involvement, maintenance of record regarding date of birth or proof of age.

Clarified working hours details.

Number of working hours, overtime and rest days, identified unfair competition practices such as procedures to prevent corruption (bribery, extortion or embezzlement) and pollution issues (whether firms follow environmental policies and procedures).

5.3.4 Result of the case study

The Gray approach advised by Deng (2005) for analysis was applied in order to categorise the 63 suppliers into three groups labelled “good performer” which means the suppliers are capable of handling sustainability issues, “moderate performer” which means the suppliers need to improve in order to meet the specified requirements by multinational garment retailers and “performance not up to expectation” which shows the suppliers need to improve in all aspects of sustainability.

It was concluded that the most important indicator for both categories of suppliers is long working hours. Child labor is the most significant indicator for ancillary suppliers and unfair competition is the most important criteria in the garment manufacturing sector (Baskaran et al. 2012).

6 References

Allwood J, Laursen S E, de Rodríguez C M, Bocken N (2006). Well dressed? – The present and future sustainability of clothing and textiles in the United Kingdom. University of Cambridge, Institute for Manufacturing. http://www.ifm.eng.cam.ac.uk/sustainability/projects/mass/uk_textiles.pdf (Accessed April, 2012)

Allwood, J.M., Laursen, S.E., Rodriguez, C.M., Bocken, N.M.P., 2006. Well dressed? The present and future sustainability of clothing and textiles in the United Kingdom, University of Cambridge Institute for Manufacturing.

Anon, 2013. Bamboo: facts behind the fibre. organicclothing.blogs.com/my_weblog/2007/09/bamboo-facts-be.html accessed March 2013.

Artek, 2013. The Artek Manifest. www.artek.fi/company/manifest accessed March 2013.

Askham, C., 2011. Environmental Product Development Combining the Life Cycle Perspective with Chemical Hazard Information. Aalborg University, Department of Planning, Aalborg.

AWA/MR (1995) Cotton: The Crop and its Agrochemicals Market. Allen Woodburn Associates Ltd./Managing Resources Ltd.,

Baskaran, V., Nachiappan, S. & Rahman, S., 2012. Int . J . Production Economics Indian textile suppliers ' sustainability evaluation using the grey approach. Intern. Journal of Production Economics, 135(2), pp.647-658. Available at: http://dx.doi.org/10.1016/j.ijpe.2011.06.012.

Beck, A., Scheringer, M., Hungerbühler, K., 2000. Fate modelling within LCA: The case of textile chemicals. International Journal of Life Cycle Assessment 5, 335–344.

Boustead, I., 2003. Eco-profiles of the European Plastics Industry: Conversion Processes for Polyolefins. Brussels.

Carlsson, A., Hemström, K., Edborg, P., Stenmarck, Å., Sörme, L., 2011. Kartläggning av mängder och flöden av textilavfall. Norrköping.

Chen, J., Lu, Y.G., Sun, C., 2011. Safety and Health Assessment of Manufactured Nanoparticles in Nano-Coated Textile Products. Advanced Materials Research 175-176, 722–728.

De Saxce, M., Pesnel, S., Perwuelz, A., 2012. LCA of bed sheets – some relevant parameters for lifetime assessment. Journal of Cleaner Production 37, 221–228.

Deng, J.L., 2005, The Fundamental Methods of Gray system, Science and technology of Central China university press, Wuhan, China., pp. 3-8.

Dreyer L, Hauschild M, Schierbeck J (2006) A frame work for social life cycle impact

assessment (10pp) .International Journal of Life Cycle Assessment 11(2):88–97

EJF. (2007). The deadly chemicals in cotton. Environmental Justice Foundation in collaboration with Pesticide Action Network UK: London, UK. ISBN No. 1-904523-10-2.

European Commission, 2003. Integrated Pollution Prevention and Control (IPPC) Reference Document on Best Available Techniques for the Textiles Industry.

European Commission, 2007. Integrated Pollution Prevention and Control (IPPC) Reference Document on Best Available Techniques in the Production of Polymers.

European IPPC Bureau (2003). Reference Document on Best Available Techniques for the Textiles Industry.

Farrant L, Olsen S I, Wangel A (2010). Environmental benefits from reusing clothes. International Journal of Life Cycle Assessment, 2010, 15, pp. 726-736.

Farrant, L., Olsen, S.I., Wangel, A., 2010. Environmental benefits from reusing clothes. The International Journal of Life Cycle Assessment 15, 726–736.

Fimreite L, Blomstrand K (2009). Beräkning av textila produkters CO2-avtryck (Calculation of textile products CO2 emissions). Master's thesis in collaboration with Klättermusen AB, Textilhögskolan, Högskolan i Borås.

Finnveden, G., Hauschild, M.Z., Ekvall, T., Guinée, J., Heijungs, R., Hellweg, S., Koehler, A., Pennington, D., Suh, S., 2009. Recent developments in Life Cycle Assessment. Journal of environmental management 91, 1–21.

Gabarrell, X., Font, M., Vicent, T., Caminal, G., Sarrà, M., Blánquez, P., 2012. A comparative life cycle assessment of two treatment technologies for the Grey Lanaset G textile dye: biodegradation by Trametes versicolor and granular activated carbon adsorption. The International Journal of Life Cycle Assessment 17, 613–624.

Grieger, K.D., Laurent, A., Miseljic, M., Christensen, F., Baun, A., Olsen, S.I., 2012. Analysis of current research addressing complementary use of life-cycle assessment and risk assessment for engineered nanomaterials: have lessons been learned from previous experience with chemicals? Journal of Nanoparticle Research 14, 958.

Güngör, A., Palamutçu, S., Ikiz, Y., 2009. Cotton textiles and the environment: Life cycle assessment of a bathrobe. Tekstil ve Konfeksiyon 19, 197–205.

Hellweg, S., Demou, E., Scheringer, M., McKone, T.E., Hungerbühler, K., 2005. Confronting workplace exposure to chemicals with LCA: examples of trichloroethylene and perchloroethylene in metal degreasing and dry cleaning. Environmental science & technology 39, 7741–8.

Hellweg, S., Geisler, G., 2003. Life cycle impact assessment of pesticides. The International Journal of Life Cycle Assessment 8, 310–312.

Herva, M., Álvarez, A., Roca, E., 2011. Sustainable and safe design of footwear

integrating ecological footprint and risk criteria. Journal of hazardous materials 192, 1876–81.

Herva, M., Franco, A., Ferreiro., S., Alverez, A., & Roca, E., 2008. An approach for the application of the Ecological Footprint as an environmental indicator in the textile sector. Journal of Hazardous Materials, 156, 478-487.

Herva, M., García-Diéguez, C., Franco-Uría, A., Roca, E., 2012. New insights on ecological footprinting as environmental indicator for production processes. Ecological Indicators 16, 84–90.

Hsu, C.-A., Wen, T.-N., Su, Y.-C., Jiang, Z.-B., Chen, C.-W., Shyur, L.-F., 2012. Biological degradation of anthroquinone and azo dyes by a novel laccase from Lentinus sp. Environmental science & technology 46, 5109–17.

Hunkeler, D., 2006. Societal Life Cycle Assessment (Subject Editor: David Hunkeler) Societal LCA Methodology and Case Study *. International Journal of Life Cycle Assessment, 11(6), pp.371 - 382.

Jelse K, Fridell E, Zackrisson M (2011). Life cycle assessment of the prototype S'wash laundry machine and detergent. Preliminary report for the S'wash project, IVL Swedish Environmental Research Institute.

Jiang, W., Yuan, Z., Bi, J., & Sun, L., 2010. Conserving water by optimizing production schedules in the dyeing industry, Journal of Cleaner Production, 18, 1696-1702.

Jiang, W., Yuan, Z., Bi, J., Sun, L., 2010. Conserving water by optimizing production schedules in the dyeing industry. Journal of Cleaner Production 18, 1696–1702.

Jorgensen A, Hauschild M, Jorgensen MS, Wangel A (2009), Relevance and Feasibility of Social Life Cycle Assessment, International Journal of Life Cycle Assessment 14(3) pp. 204-214

Jørgensen, A., 2010. Developing the Social Life Cycle Assessment - addressing issues of validity and usability. PhD Thesis

Kalliala, E., Nousiainen, P., 1999. Environmental profile of cotton and polyester-cotton fabrics. Autex Research Journal 1, 8–20.

Keoleian, G., Blackler, C., Denbow, R., Polk, R., 1997. Comparative assessment of wet and dry garment cleaning Part 1. Environmental and human health assessment. Journal of Cleaner Production 20, 279–289.

Kocabas, A.M., Yukseler, H., Dilek, F.B., & Yetis, U., 2009. Adoption of European Union's IPPC Directive to a textile mill: Analysis of water and energy consumption, Journal of Environmental Management, 91, 102-113.

Krozer, A., Björk, A., Hanning, A.-C., Wendel, A., Magnusson, E., Persson, F., Holmberg, K., Jelse, K., 2011. S'wash Final report. Stockholm.

Kuczenski, B., Geyer, R., Boughton, B., 2011. Tracking toxicants: toward a life cycle aware risk assessment. Environmental science & technology 45, 45–50.

Laccasse, K., Baumann, W., 2004. Textile Chemicals- Environmental Data and Facts. Springer-Verlag, Dortmund, Germany.

Laursen et al. (2007). EDIPTEX – Environmental assessment of textiles.

Liu, K.F.-R., Ko, C.-Y., Fan, C., Chen, C.-W., 2012. Combining risk assessment, life cycle assessment, and multi-criteria decision analysis to estimate environmental aspects in environmental management system. The International Journal of Life Cycle Assessment 17, 845–862.

McCarthy, B.J., & Burdett, B.C., 1998. Eco-labelling and textile eco-labelling, Rev. Prog. Coloration, 28, 61-70.

Meyer, D.E., Curran, M.A., Gonzalez, M. a., 2010. An examination of silver nanoparticles in socks using screening-level life cycle assessment. Journal of Nanoparticle Research 13, 147–156.

Nieminen, E., Linke, M., Tobler, M., Beke, B. Vander, 2007. EU COST Action 628: life cycle assessment (LCA) of textile products, eco-efficiency and definition of best available technology (BAT) of textile processing. Journal of Cleaner Production 15, 1259–1270.

Ozturk, H.K., 2005. Energy usage and cost in the textile industry: A case study for Turkey, Energy, 30, 2424-2446.

Palanichamy, C., Nadarajan, C., Naveen, P., Babu, N.S., & Dhanalakshmi, 2001. Budget Constrained Energy Conservation – An Experience With a Textile Industry, IEEE Transactions on Energy Conversion, 16, (4), 340-345.

Palm D (2011). Improved waste management of textiles. IVL Report B1976, April 2011.

Parent, J., Cucuzzella, C. & Revéret, J.-pierre, 2010. Impact assessment in SLCA: sorting the sLCIA methods according to their outcomes. International Journal of Life Cycle Assessment, pp.164-171.

Pfister, S., Koehler, A., Hellweg, S., 2009. Assessing the environmental impacts of freshwater consumption in LCA. Environmental science & technology 43, 4098–104.

Posner, S., Olsson, E., Roos, S., and Wilson, K. "Kartläggning av kemikalieanvändning i kläder", Swerea IVF rapport 09/52 (2010) on commission of Swedish Chemicals Agency (KemI).

Pulli, R., Beck, A., Weidenhaupt, A., Hungerbühler, K., 1997. Okobilanz eines Baumwoll-T-Shirts mit Schwerpunkt auf den verwendeten Chemikalien.

Qmilch, 2013. The innovative eco milk fibre. www.milkotex.com accessed February 2013.

Rajakumari, S.P., Kanmani, S., 2008. Environmental life cycle assessment of zero liquid

discharge treatment technologies for textile industries , Tirupur – A case study 67, 461–467.

Rajendran, S., Hodzic, A., Soutis, C., 2012. Review of life cycle assessment on polyolefins and related materials. Plastics, Rubber and Composites.

Sala, S., Pant, R., Hauschild, M., Pennington, D., 2012. Research Needs and Challenges from Science to Decision Support. Lesson Learnt from the Development of the International Reference Life Cycle Data System (ILCD) Recommendations for Life Cycle Impact Assessment. Sustainability 4, 1412–1425.

Saouter, E.G., Perazzolo, C., Steiner, L.D., 2011. Comparing chemical environmental scores using USEtoxTM and CDV from the European Ecolabel. The International Journal of Life Cycle Assessment 16, 795–802.

Scheringer, M., 1999. Comparing the environmental performance of fluorescent whitening agents with peroxide bleaching of mechanical pulp. Journal of Industrial ... 3, 77–95.

Schmidt I, Meurer M, Saling P, Kicherer A, Reuter W ,Gensch C(2004) SEE balance—managing sustainability ofproducts and processes with the socio-eco-efficiency analysis by BASF .GreenManage In45:79–94

Schulze, C., Jödicke, A., Scheringer, M., Margni, M., Jolliet, O., Hungerbühler, K., Matthies, M., 2001. Comparison of different lifeâ€cycle impact assessment methods for aquatic ecotoxicity. Environmental Toxicology and Chemistry 20, 2122–2132.

SEPA (2011). Kartläggning av mängder och flöden av textilavfall (Mapping of amount and flows of textile waste). Swedish Environmental Protection Agency . Stockholm.

Shen L, Patel M K (2010). Life Cycle Assessment of Man-Made Cellulose Fibers. Lenzinger Berichte, 2010, 88, pp. 1-59.

Skaar, C., Jørgensen, R.B., 2012. Integrating human health impact from indoor emissions into an LCA: a case study evaluating the significance of the use stage. The International Journal of Life Cycle Assessment 636–646.

Steinberger, J.K., Friot, D., Jolliet, O., Erkman, S., 2009. A spatially explicit life cycle inventory of the global textile chain. The International Journal of Life Cycle Assessment 14, 443–455.

Sustainable Apparel Coalition (SAC), 2012. Sustainable Apparel Coalition (SAC) [WWW Document]. URL http://www.apparelcoalition.org/

The International EPD system, 2013. The International EPD system [WWW Document]. URL http://www.environdec.com/ (accessed 3.6.13).

Tong, O., Shao, S., Zhang, Y., Chen, Y., Liu, S.L., Zhang, S.S., 2012. An AHP-based water-conservation and waste-reduction indicator system for cleaner production of textile-printing industry in China and technique integration. Clean Technologies and

Environmental Policy 14, 857–868.

UNEP/SETAC, Life Cycle Initiative, Guidelines of Social life cycle Assessment of Products,2009

United States Environmental Protection Agency, 2010. Municipal Solid Waste in The United States: Facts and Figures 2009.

Walser, T., Demou, E., Lang, D.J., Hellweg, S., 2011. Prospective environmental life cycle assessment of nanosilver T-shirts. Environmental science & technology 45, 4570–8.

Wright, H., Zhang, Q., Mihelcic, J., 2008. Integrating economic input–output life cycle assessment with risk assessment for a screening-level analysis. International Journal of Life Cycle Assessment 13, 412–420.

Yuan, C., 2000. A study on the life cycle impact assessment of polyester fabric. Journal of the China Textile Institute 10, 206–216.

Yuan, Z.-W., Zhu, Y.-N., Shi, J.-K., Liu, X., Huang, L., 2012. Life-cycle assessment of continuous pad-dyeing technology for cotton fabrics. The International Journal of Life Cycle Assessment.