THESIS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

The Challenges of Fast Fashion

Environmental and Social LCA of Swedish Clothing Consumption

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To my Grand Mother, Madarzari, My greatest supporter

The Challenges of Fast Fashion-Environmental and Social LCA of Swedish Clothing Consumption

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Abstract

Fast fashion is a clothing supply chain model that responds quickly to the latest fashion trends by frequently updating the clothing products available in stores. By rapidly transforming new trends into low price products, fast fashion drives up the frequency of purchases by consumers. Due to the adoption of fast fashion business models, industry sectors involved in the fashion supply chain pursue low-cost production techniques and source their materials from overseas markets, which can jeopardise environmentally and socially values. The research presented in this thesis aimed to contribute to the management of the environmental and social challenges of fast fashion consumption in Sweden.

One of the objectives of this research was to quantify potential environmental benefits of dematerialisation strategies including textile recycling and collaborative consumption. The results showed net environmental benefits associated with textile recycling and with collaborative consumption, but, in the latter case, the results also identified a garment lifespan extension threshold below which sub-optimisation occurs.

The second objective of this research was to identify and assess social challenges of fast fashion. In pursuit of this objective, one of the contributions of this research was an investigation of the key parameters in social impact assessment. Via surveys, a set of relevant social indicators for assessing social issues along the textile and fashion industry was suggested. Further, the social impact hotspots of Swedish fashion consumption have been quantified using an input/output analysis approach.

The third objective of the research was to quantify the scale of challenges and the potential of dematerialisation interventions in relation to global sustainability targets. The results showed that none of the modelled interventions are adequate to reach environmental targets, but it is possible to combine several interventions. On the other hand, evaluating the impact of the interventions in relation to meeting social targets was found to be difficult due to lack of available data to evaluate the social consequences of the interventions.

By means of research efforts in these three areas, important information for the planning and implementation of purposeful interventions in fast fashion value chains can be generated.

Keywords: fast fashion, sustainable fashion, circular economy, dematerialisation, social LCA, LCA

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Gothenburg, 2016

Bahareh Zamani

* Dear parents, you raised me and lift me up still.

List of publications
Appended papers

This thesis is based on the following papers, which are referred to in the text by their Roman numerals. The papers are appended at the end of the thesis.

I. **Bahareh Zamani**, Magdalena Svanström, Gregory Peters, Tomas Rydberg (2014) A Carbon Footprint of Textile Recycling: A Case Study in Sweden. *Journal of Industrial Ecology* 19 (4): 676–687. DOI: 10.1111/jiec.12208.

II. **Bahareh Zamani**, Gustav A. Sandin, Greg M. Peters (2016) Life cycle assessment of clothing libraries: can collaborative consumption reduce the environmental impact of fast fashion? Manuscript resubmitted to the *Journal of Cleaner Production* after peer review and revision.

III. **Bahareh Zamani**, Wencke Gwozdz, Magdalena Svanström, Greg M. Peters (2016) Priorities indicators of social impact assessment in the fashion industry - consumer and industry expert perspectives. Manuscript resubmitted to the *Journal of Cleaner Production* after peer-review and revision.

IV. **Bahareh Zamani**, Gustav A. Sandin, Magdalena Svanström, Greg M. Peters (2016) Hotspot identification in the clothing industry using social Life cycle assessment- opportunities and challenges of input-output modelling. *International Journal of Life Cycle Assessment*. DOI 10.1007/s11367-016-1113-x

V. Sandra Roos, **Bahareh Zamani**, Gustav A. Sandin, Greg M. Peters, Magdalena Svanström (2016) An LCA-based approach to guiding an industry sector towards sustainability: the case of the Swedish apparel sector. Manuscript resubmitted to the *Journal of Cleaner Production* after peer review and revision.

Work related to the thesis has also been presented in the following publications.

1. Bahareh Zamani, Magdalena Svanström, Greg M. Peters (2013) End-of-Life management: LCA of textile waste. *Proceedings of 6th international conference on Life Cycle Management*, 25-28 August, Gothenburg, Sweden

2. Gustav A. Sandin, Sandra Roos, Bahareh Zamani, Greg M. Peters, Magdalena Svanström (2015) Using the planetary boundaries for evaluating intervention for impact reduction in the clothing industry. Oral presentation by Bahareh Zamani and Sandra Roos at the *7th International Conference on Life Cycle Management*, 30 August - 2 September Bordeaux, France

3. Greg M. Peters, Magdalena Svanström, Sandra Roos, Gustav A. Sandin, Bahareh Zamani (2015) Carbon footprints in the textile industry. Chapter 1 in *Handbook of Life Cycle Assessment (LCA) of Textiles and Clothing*. Woodhead. Cambridge, UK. DOI: 10.1016/B978-0-08-100169-1.00001-0

4. Sandra Roos, Gustav A. Sandin, Bahareh Zamani, Greg M. Peters (2015) *Environmental assessment of Swedish fashion consumption. Five garments - sustainable futures*. Mistra Future Fashion report. Gothenburg. (www.mistrafuturefashion.com/ en/publications/ Sidor/ default.aspx)

5. Sandra Roos, Gustav Sandin, Bahareh Zamani, Greg Peters, Magdalena Svanström (2016) Will clothing be sustainable? Clarifying sustainable fashion. Invited book chapter in *Handbook of Life Cycle Assessment (LCA) of Textiles and Clothing*. Printing expected 2016.

Contribution report

The author of this thesis has made the following contributions to the appended papers.

I. Main author. Main contributor to formulating the research questions, exploring different routes, collecting data, carrying out life cycle assessment, and discussing the results.

II. Main author. Main contributor to formulating the research questions, constructing scenarios, carrying out the life cycle assessment (system modelling, sensitivity analysis and interpreting results), and discussing the results.

III. Main author. Main contributor to analysing the literature review, formulating the research questions, formulating questionnaire for survey of consumers´ and industrial experts´ perspectives, analysing and discussing the results.

IV. Main author. Main contributor to formulating the research questions, carrying out the input/output approach for negative social hotspot identification, analysing and discussing the results and key factors in methodological approach.

V. Co-author. Active in formulating the research questions, formulating the case studies in relation to textile waste recycling, collaborative consumption and social hotspot identification, carrying out the life cycle assessment (system modelling, interpreting results), and discussing the results.

List of abbreviations

CSS	Country Specific Sectors
GOTS	Global Organic Textile Standard
GTAP	Global Trade Analysis Project
GWP	Global Warming Potential
LCA	Life Cycle Assessment
NMMO	N-methylmorpholine-N-oxide
PBs	Planetary boundaries
SETAC	Society of Environmental Toxicology and Chemistry
SHDB	Social Hotspot Database
SLCA	Social Life Cycle Assessment
UNEP	United Nations Environmental Programme

Contents

1. Introduction

1.1 Circular economy

The concept of circular economy refers to approaches to resource minimisation and efficient resource use that entail prolonging the service life of a product and the recycling of waste and by-products into cycles of industrial input flows (Andersen, 2007). In recent years, circular economy has drawn increasing attention from academics and policy makers due to the increased pressure on ecosystems from fast-paced industrial production and consumption (Genovese el al. 2015).

Strategies for the development of a circular economy emphasise the need to produce products and materials which are compostable or recyclable and to recirculate materials and products as many times as possible. Thus, the main idea is to avoid linear production and consumption and move towards industrial systems that regenerate resources and prevent waste production, as shown in Figure 1 from the Ellen MacArthur Foundation (2016).

Material and energy flows through industrial systems are in focus in industrial ecology. One major aim in industrial ecology is to mimic the circular flows in nature by designing industrial systems for waste recycling and closed loops that increase resource productivity. This can help in the development of corporate strategies and policy instruments to manage the contradiction between looming resource shortages and conventional economic growth models (Mathews & Tan, 2011; Yuan et al. 2008).

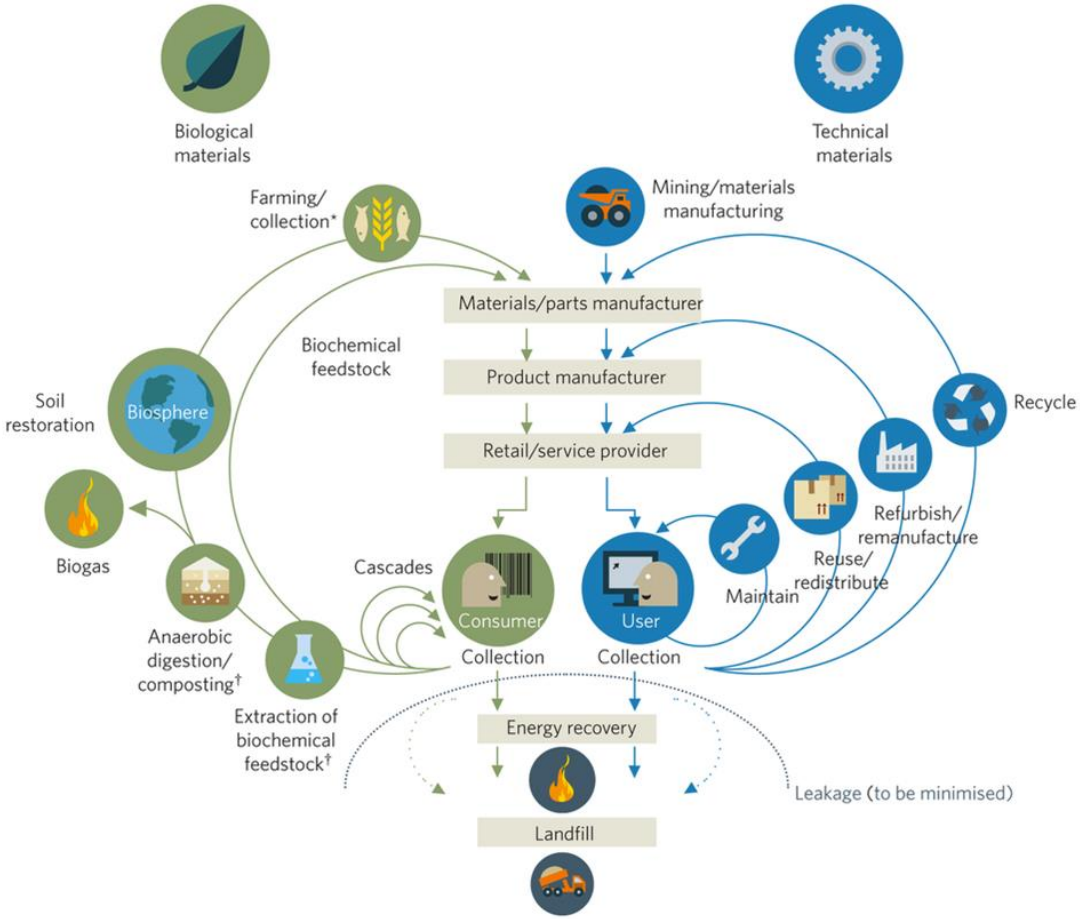

Figure 1 : Outline of a circular economy framework (Source: Ellen MacArthur Foundation 2016)

1.2 Circular economy and fast fashion

The fast fashion business model, which has been adopted by the fashion industry, is characterised by the combination of high speed production and rapid, high volume consumption (Fletcher, 2013). The aim of fast fashion is to design garments which transform new trends into low price products and, thus, drive up the frequency of purchases by consumers (Bhardwaj & Fairhurst, 2010; Sull & Turconi, 2008; Turker & Altuntas, 2014). This change in fashion industry has been manifested in an average price reduction of garments on the European market by 26% during the twenty-first century (Fletcher & Tham, 2014). Consequently the pattern of fashion consumption has changed.

Consistent with the norms of the fast fashion business model and the profit motive, industry sectors involved in the fashion supply chain adopt low-cost production techniques and source their material and labours from overseas markets (Barnes & Lea-Greenwood, 2006; Brito et al. 2008; McNeill & Moore, 2015). This globalisation of the fashion supply chain has become more intense during the last 30 years (MacCarthy & Jayarathne, 2010; Turker & Altuntas, 2014) and consequently leads to jeopardizing environmentally and socially sustainable practices.

The urge to produce cheap garments has motivated Western corporations to outsource to cheaper workers in Asia (Fletcher & Tham, 2014). In 2012, 42% of the monetary value of European (EU 27) textile consumption was supplied by China, the next two countries were Bangladesh and Turkey, accounting for a total of 26% of the textile supplies (EC, 2013). One of the negative sustainability impacts of this globalisation of the textile supply is the unemployment of workers in European textile industries due to the relocation of their work. From 2011 to 2012, the number of people working in the textile industry located in Western countries decreased by 3% (The European Apparel and Textile Confederation, 2013).

Another consequence of globalisation has been a reliance on a fashion industry workforce that is young, poorly skilled, and has little formal education. Such persons may not be in a position to resist the pressure for low cost production, which directly affects labour conditions causing long hours with lower wages under difficult working conditions (Koszewska, 2011). There are significant ethical issues related to forced labour, child labour, and employing women with low wages in developing countries (Viederman, 2014).

A third consequence of this globalisation is that the fashion industry manages a complicated network of suppliers and subcontractors in the supply chain. Large geographical distances have arisen between the garment production sites and the markets due to the relocation of clothing manufacturing facilities to less developed countries. This length and complexity of the fashion supply chain makes it easier for many factories to hide social and environmental breaches along the supply chain (Koszewska, 2015). Many textile factories push their responsibility for safeguarding labour rights further down to subcontractors in the supply chain. Therefore, it is not always possible for clothing importers to track down where and under which conditions garments are produced,

On the other hand, incidents, such as the Rana Plaza garment factory collapse in Bangladesh that killed more than 1000 people on 8th May 2013, have raised western consciousness regarding social issues in the textile supply chain. Consumers are increasingly demanding accountability for the ethically and environmentally responsible production of garments and fashion goods (see e.g. Clifford 2013) and are more generally interested in the sustainability of their intended purchases. Additionally, consumers frequently express concern regarding health issues due to chemicals used in textile production, the excessive use of local water resources in cotton production, and the exploitation of labour in clothing manufacturing (Steinberger et al. 2009, Pfister et al. 2009, Brooks 2010).

The concept of circular economy can be used to inspire long-term systematic changes in fast fashion industry towards socially and environmentally sustainable operations. Linking the concept of circular economy to fast fashion leads to a move from a linear supply chain with few feedback loops to a more circular supply chain. This means making possible the recovery of materials and energy, creating closed-loop recycling flows in the waste handling of garments, and promoting “sharing economy” for extending the service life of a garment in the use phase. Figure 2 is a simplified version of Figure 1 which identifies the dematerialisation efforts which were the main focus of this thesis. An example of a potential recycling loop (right-hand side of Figure 2) is the collection of used garments and the dissolution of their cellulosic content to allow the spinning of recycled yarn. An example of reuse is “sharing economy” or “collaborative consumption” (left-hand side of Figure 2), an alternative way of doing business to the conventional model of ownership-based consumption, and one that can potentially lead to the dematerialisation of fast fashion by prolonging the practical service life of clothing. Collaborative consumption is defined as “people coordinating the acquisition and distribution of a resource for a fee or other compensation” (Belk, 2014), which can include the renting, trading, swapping, and borrowing of goods (Piscicelli et al. 2014). In the fashion industry, an example of a collaborative consumption business model is the clothing library, in which a monthly membership fee allows members to borrow a specific number of clothing pieces over a set period of time.

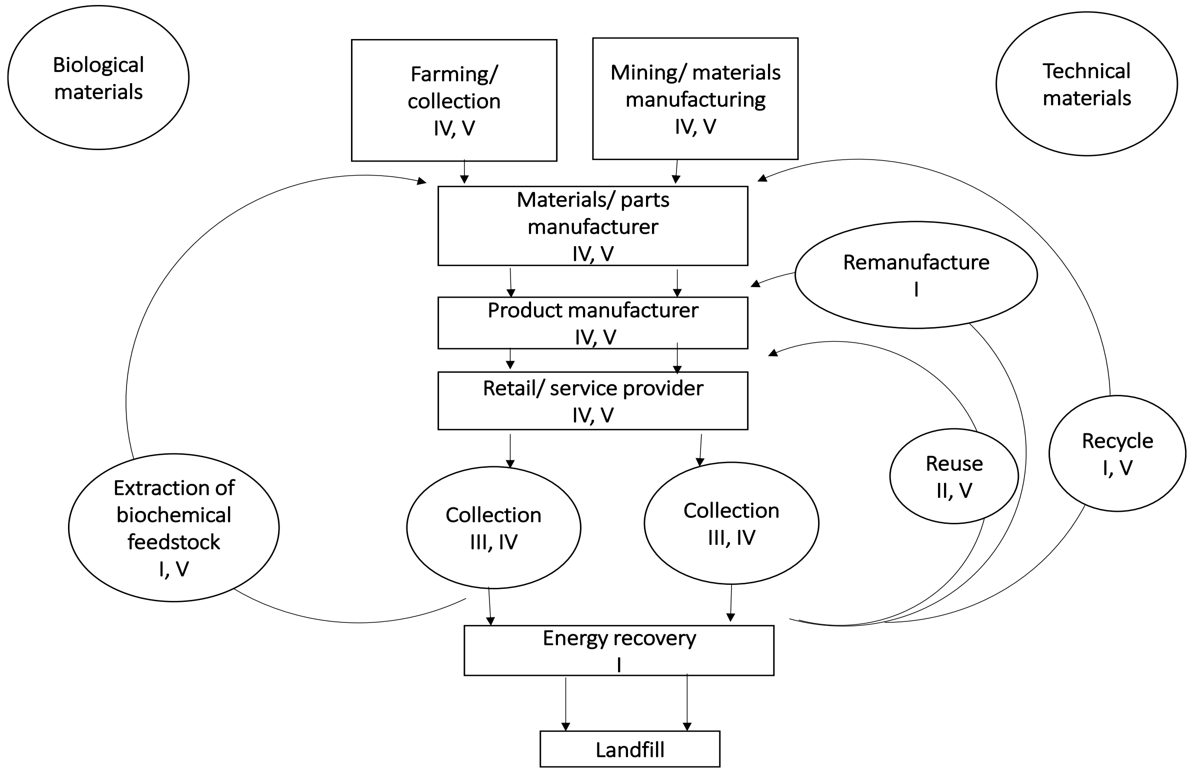

Figure 2: Dematerialisation interventions within a circular economy framework explored in this thesis. The Roman numerals indicate the papers associated with each part of the circular economy concept

1.3 The Mistra Future Fashion programme

The research presented in this thesis has been conducted within the ongoing Mistra Future Fashion programme (www.mistrafuturefashion.com). The programme runs from 2011 to 2019 and aims to develop insights and solutions which improve the sustainability of the Swedish fashion industry and strengthen its global competitiveness. The programme is funded by the publicly-owned Swedish Foundation for Strategic Environmental Research: Mistra. Within the first phase (2011-2015) of the programme, eight research projects were created, each focused on one aspect of the textile value chain. These included 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 first phase of Mistra Future Fashion had the objective of clarifying sustainability in relation to Swedish fashion industry. One of the focuses was improving sustainability assessment methodologies for ecolabelling and decision support tools. Different routes for the improvement of environmental and social impacts were identified and evaluated in relation to reaching sustainability targets. On account of the connection between the thesis and the Mistra Future Fashion project, the focus of the present study was on evaluating specific circumstances in relation to Swedish fashion consumption and to evaluate the environmental and social impacts of the Swedish fashion supply chain.

Work carried out in Project 2 has provided the principal input for this thesis, along with Project 4 (“Ecoefficient textile materials and processes”) and Project 7 (“Sustainable consumption and consumer behaviour

1.4 Overall research objectives

The overall goal of this thesis is to contribute to the management of environmental and social challenges of fast fashion in the Swedish context by identifying and evaluating dematerialisation interventions.

The first research objective (RO 1) is to quantify the potential environmental benefits of material reuse and recycling in textile waste management.

The second objective (RO 2) is to identify and assess the social challenges of fast fashion. In pursuit of this objective, it was identified early in this research that methods for the assessment of social impacts of the fashion industry are particularly in need of development. Therefore, a part of the research investigates key parameters in social impact assessment.

The third objective (RO 3) is to quantify the scale of challenges and the potential of dematerialisation interventions in relation to global sustainability targets.

By means of research efforts in these three areas, important information for the planning and implementation of purposeful interventions in fast fashion value chains can be generated.

1.5 Research questions

For addressing the research objectives, five research questions (RQs) were formulated:
RQ 1: Can textile recycling generate environmental benefits? (Paper I)

RQ 2: What are the key factors controlling the environmental impact in collaborative consumption business models? (Paper II)

RQ 3: What are the most relevant social indicators for assessment in and communication by the fashion industry? (Paper III)

RQ 4: What parameter settings are appropriate when constructing a model of the product system from an input/output approach to assessing social impacts? (Paper IV)

RQ 5: What is the scale of challenges and potential of interventions in relation to global sustainability targets? (Paper V)

The connection between research objectives and research questions are shown in Figure 3.

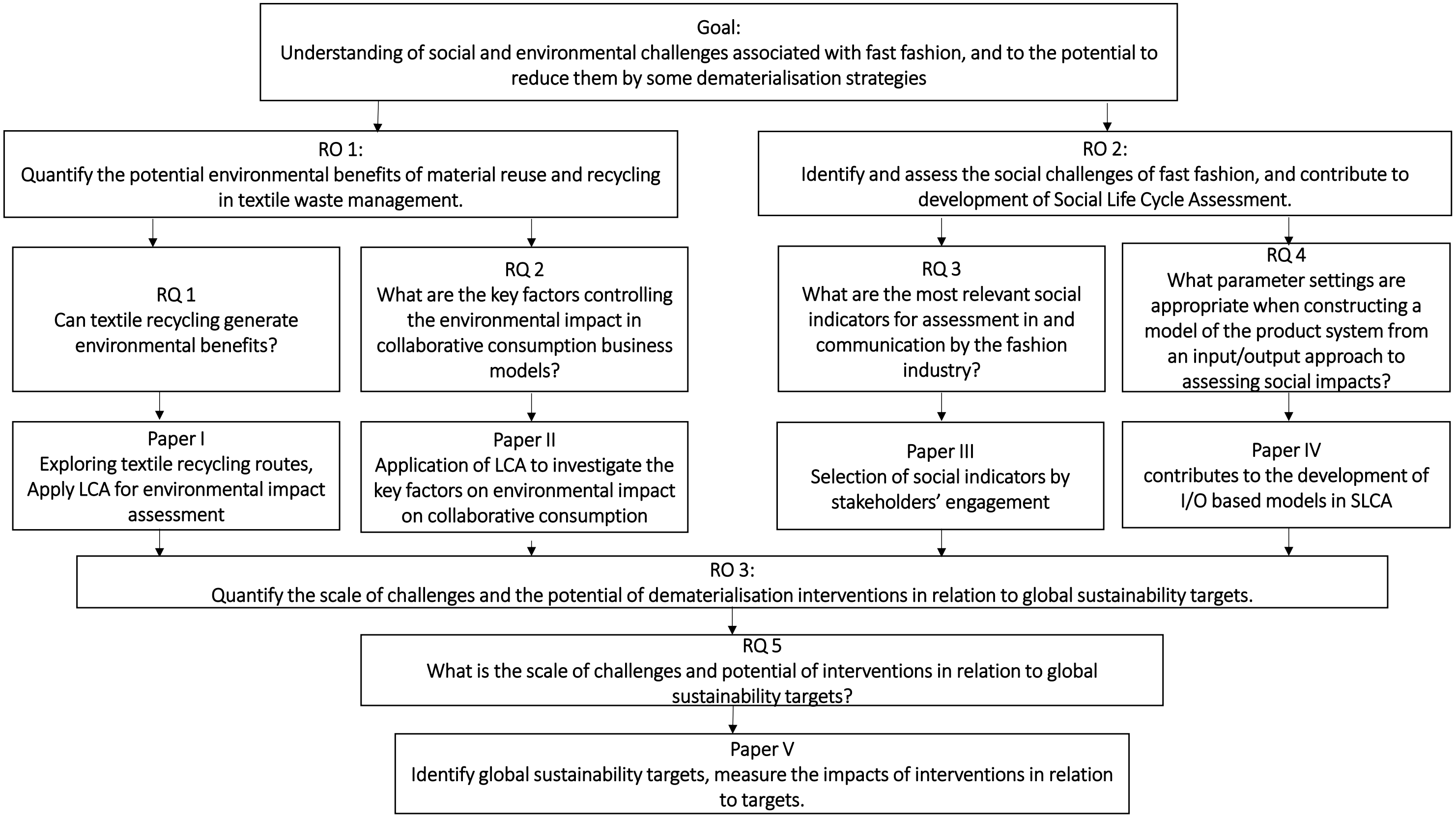

Figure 3: Overall structure of this thesis in terms of the connections between the thesis goal, the research objectives (ROs), the research questions (RQs), and the appended research papers (I-V).

1.6 Research approach

The work on RO 1 created the basis for Papers I and II.

The study described in Paper I has an explorative approach to different textile recycling routes for creating more circular flows in fast fashion value chains. Technical options are identified and environmental impacts are evaluated by means of environmental life cycle assessment (LCA). This created the foundation for discussing more sustainable textile waste management strategies in the present thesis summary; an integrated recycling approach for the Swedish textile waste is evaluated in this thesis.

While Paper I seeks to examine post-consumer interventions under traditional norms of garment ownership, Paper II aims at supporting the design of new collaborative consumption-based business models for waste reduction in fast fashion.

Because of the lack of methods for the assessment of social impacts of the fashion industry, RO 2 has partly a method-driven research objective with the aim of improving social life cycle assessment (SLCA) methodology. The research work focuses on two major challenges in applying SLCA, which are reflected in Papers III and IV.

Paper III discusses the challenges associated with the selection of relevant social indicators for assessment in the fashion industry. Therefore, in the paper, different stakeholders were engaged in the selection of a set of social indicators relevant to the fashion industry.

Paper IV explores the use of an input/output analytical approach with the intent to assess social impacts in the fashion industry. The set of indicators proposed in Paper III was used for social hotspot identification in fast fashion in Paper IV.

RO 3 is addressed in Paper V. Paper V identifies and assess the social and environmental challenges in the fast fashion industry by means of LCA and discusses a set of global sustainability targets in relation to environmental and social impacts. Obviously, Papers I and II have influenced Paper V, since Papers I and II assess the environmental consequences of different textile recycling routes and new business models in collaborative consumption, and Paper V assess the impact of implementing these interventions to reach these targets.

The results obtained in Paper IV provide a basis for the sections related to social sustainability in Paper V. The results from Paper IV influenced the framing of Paper V for addressing the main social issues associated with the fashion industry, the possible interventions for reducing social impacts, and to what extent these interventions can contribute to reaching the set social sustainability targets.

1.7 Thesis structure

The structure of the thesis in terms of the relation between research objectives, the research questions, and the appended research papers is visualised in Figure 3.

Chapter 1 provides an industrial context to the research and explains the research objectives and questions. Chapter 2 provides the theory and methods used to address the research questions. Chapter 3 summarises the content and main findings of Papers I-V. Chapter 4 discusses how the papers contribute to addressing the research questions. Chapter 5 summarises the main conclusions, and Chapter 6 provides recommendations for future research.

2. Theory and methods

For pursuing the objectives of this research, a set of methods was used. Table 1 shows which methods were applied in each paper. These methods are then described in the subsequent sections of this chapter.

Table 1: List of appended papers and methodological approaches used in each.

Paper	Methodological approach
Paper I	Life cycle assessment Scenario development for sensitivity analysis Comparative case studies
Paper II	Life cycle assessment Scenario development for sensitivity analysis
Paper III	Stakeholder opinion survey
Paper IV	Input/output analysis Social life cycle assessment
Paper V	Life cycle assessment Social life cycle assessment LCA-based approach to guiding an industry sector towards sustainability

In the next part of this chapter (Section 2.1), the details of LCA method used for the environmental impact assessment of different dematerialisation interventions associated with the first research objective are presented. Section 2.1.1 describes the details of application of life cycle assessment in this thesis. Secrion2.1.2 describes the use of sensitivity analysis in relation to LCA and scenario development.

Further, Section 2.2 provides a general introduction to SLCA as a method for social impact assessment. Sections 2.2.1, 2.2.2 introduce the methods and theory used to develop a set of relevant indicators with the aim of development of SLCA. Section 2.2.3 introduce the method and theory on input/output product system development used to pursue the second research objective connected with the development of SLCA.

Section 2.4 focused on determining sustainability targets for the fashion and textile sector for assessing the potential of dematerialisation interventions for reaching the targets.

2.1 Life cycle assessment

One of the objectives of the thesis is to identify the environmental benefits of dematerialisation interventions for fast fashion. For this purpose, the environmental impact of the proposed dematerialisation scenarios was assessed using the method of LCA.

LCA is an ISO standardised (ISO 14040-14044) tool which is widely used for assessing the environmental impacts of a product or a service from cradle to grave (Bauman & Tillman, 2004; Finnveden et al., 2009; Guinee et al., 2002; Pennington et al., 2004; Rebitzer et al., 2004; Peters, 2009; Guinée et al., 2011; Baitz et al., 2013) One of the application of LCA is assessing the environmental impacts of future technologies and business models (e.g. Frischknecht et al. 2009; Hetherington et al. 2013). In general, all the processes required to deliver a product or a service are considered in LCA, including the extraction of new materials, manufacturing processes, product usage, and end-of-life processes. LCA is a method that not only quantifies the overall environmental impact of a product or a service, but also identifies the life cycle activities which significantly contribute to the overall environmental impact.

According to ISO 14044, LCA includes the four steps described below. These interact with one another in an iterative manner (Bauman & Tillman, 2004).

1. Goal and scope definition

In this step, the intended purpose and application of the study, the intended audience, and how the results will be communicated are defined. These activities are very important since they determine the methodological choices which need to be considered in the study. Furthermore, the results of the study are directly dependent on the aim and the questions formulated in the goal definition.

The goal and scope step defines the functional unit. The functional unit is the function of the system or product to be assessed in quantitative terms and enables the comparison of different products with the same functionality. Further, System boundaries are defined, in terms of temporal and geographical parameters, in addition to cut-off criteria and allocation principles. Each of these elements of the first step help to define the scope of the technical system under study. The life cycle impact categories and methods are also identified in this step.

LCA can be utilized for comparing products or services with the same function. There are two particular approaches in LCA called attributional and consequential LCA that relate to how systems are being modelled and what data are selected. Attributional LCA quantifies the environmental impact of a system or a product while consequential LCA assesses the environmental consequences of an action (Ekvall & Weidema, 2004). The choice of data for each approach is different. For attributional studies, average data are typically used to evaluate the average impact of the system per functional unit. For consequential studies, marginal data are typically used. The choice of either average or marginal data can directly affect the results of the study.

2. Inventory analysis

This step is focused on identifying and quantifying environmentally relevant flows. According to ISO 14044, the first activity in this step is the creation of a process flow chart to identify all relevant flows of input materials and resource use, and outputs including emissions and waste within the system boundaries and between the system and the environment. In the next step, the defined flows are quantified and scaled to the reference flow, which is defined based on functional unit.

One of the methodological aspects of an LCA that must be dealt with during inventory analysis arises from the problem of multifunctional systems. If a system produces several products, it is necessary to decide the share of environmental burden of each product. The same applies for the multi-input process in which it is necessary to know how to allocate the environmental burden of the system to each input. ISO 14044:2006 recommends dealing with this situation by collecting more detailed disaggregated data to subdivide the system. In case that this is not applicable, substitution or system expansion should be applied, which means giving the system a benefit for any functions provided by the system in addition to the main function under study. In the event that these approaches are not possible, allocation or partitioning can be applied, which means allocating the impacts between the products according to their physical properties or market value.

The development of inventory data in LCA are based on two different key approaches: the process-based approach and the input/output approach. The process-based approach begins with the quantification of mass and energy flows within the system boundaries. The input/output approach is based on the economic flows between national industry sectors (Rebitzer et al., 2004). Typically, in the input/output analysis, the LCA analyst begins with economic data provided by national statistical agencies that describe the scale of transactions between industry sectors. By adding information on the environmental impacts of each sector, the analyst can estimate the impact from all sectors caused by a purchase from one sector.

A major challenge in the process-based approach is the time-consuming process of acquiring relevant data for the LCA analyst. The input/output approach requires less effort to find relevant data and reduces the risk of ignoring system components. However, there is the risk of underestimating the environmental impacts associated with a particular product caused by using the average emissions for each sector of the economy (Peters et al. 2015). The choice between process-based and input/output-based life cycle inventory approaches or some kind of hybrid approach incorporating elements of both, depends on the goal and scope of the study, access to available resources, the required level of detail, and the acceptable level of uncertainty (Rebitzer et al., 2004).

3. Life cycle impact assessment

In this step, the environmental flows quantified in the inventory analysis steps are translated into environmental impacts. Different activities are included in this step: classification, characterisation, and weighting.

During classification, inventory analysis data are associated with environmental impact categories such as global warming potential, fossil resource depletion, acidification potential, eutrophication potential, and toxicity impact potential.

During characterisation, conversion factors are used to calculate the results for the impact categories. For example, the significance of a product's greenhouse gas emissions can be expressed in terms of the impact on planetary radiative forcing (the global heat balance) of an equivalent mass of carbon dioxide. This is termed a "mid-point indicator" on account of its position in the middle of the cause-effect sequence between the emissions and their ultimate undesirable consequences. These consequences include, for example, health impacts on humans via effects such as flooding, diseases and increased thermal stress (Pennington et al., 2004). Aside from impacts on human health, there are endpoints for impacts on natural resources and environmental quality to consider in the characterisation step (Bauman & Tillman, 2004).

Weighting and normalisation are optional actions for highlighting the most important potential impacts. Normalisation calculates the importance of impacts in relation to a reference point. Weighting enables the aggregation of the endpoint level results for several impact categories into one single indicator (Pennington et al., 2004). Different weighting methods, such as ReCiPe (Goedkoop et al., 2009) or EDIP (Bauman & Tillman, 2004), can be applied to aggregate results into a single number that is more convenient to communicate. The down-side of this convenience is that weighting is highly value-based. Therefore, when all the results are aggregated into a single number, some critical details may have been neglected.

4. Interpretation

Since LCA is an iterative method, interpretation is an important activity in each step, which can result in the modification of each step. The results obtained from a life cycle impact assessment must be interpreted according to the goal and scope of the study. Data quality analysis, including sensitivity analysis or uncertainty analysis, can be applied to examine the robustness of the outcomes of the LCA. Depending on the robustness of the output data, practical recommendations can be made to the audience of the study.

2.1.1 Application of life cycle assessment in this thesis

In the present thesis, LCA is used in Papers I and II to evaluate the potential environmental benefits of fast fashion dematerialisation routes, looking into future textile recycling techniques and collaborative consumption business models, respectively. In addition, the results obtained by applying LCA are used as background knowledge in Paper V to quantify the scale of environmental challenges associated with the fashion industry and to examine the environmental benefits of the proposed interventions in Papers I and II for reaching the planetary boundaries targets. The basic specifications of the LCA case studies carried out in each paper are shown in Table 2.

Table 2: Specifications on the LCAs in the appended papers

Paper	Goal	Functional unit	System boundaries	Environmental impact categories
I	Identify the environmental advantages of applying textile recycling techniques	Treatment of 1 tonne of textile waste	Implementing textile recycling techniques in Sweden For system expansion, the virgin materials are produced in China Gate to grave	Primary energy demand Climate change
II	Identify key factors controlling the environmental impact in collaborative consumption business models	One average use of a garment by a Swedish consumer	For the production phase it was assumed that each garment was produced in China, Bangladesh and Turkey Retailing, use and end of life handling occur in Sweden Cradle to grave	Climate change Freshwater consumption Fresh water ecotoxicity Fresh water eutrophication
V	Map the environmental impact of Swedish fashion consumption and the potential consequences of proposed interventions for impact reduction	One average use of a garment by a Swedish consumer	For the production phase it was assumed that each garment was produced in China, Bangladesh and Turkey Retailing, use and end of life handling occur in Sweden Cradle to grave	Climate change

2.1.2 Sensitivity analysis and scenario development

According to Huijbregts et al. (2003), the key uncertainties in LCA are related to:

- Data uncertainty due to missing data, the use of estimation, and the presence of immature technologies in the technical system
- Model uncertainty due to missing appropriate characterisation factors or a lack of clear meaning in the real world
- Scenario uncertainty due to the potential relevance of multiple approaches to the definition of system boundaries, choice of impacts, and choice of method for solving allocation problems.

In this research, uncertainties due to parameters and scenarios are directly related to the emerging status of the processes and business models considered in Papers I, II, and III. The challenges associated with this uncertainty are the choices of data and methodology for evaluating the environmental impact of the processes being assessed. To tackle these types of uncertainties in LCA, scenario development and sensitivity analysis have commonly been practiced in previous studies (Hospido et al. 2009; Kunnari et al. 2009; Frischknecht el al. 2009), which was therefore applied in Papers I, II, and V.

A scenario in the context of LCA has been defined as "a description of a possible future situation relevant for specific LCA applications, based on specific assumptions about the future and, when relevant, a description of a path from the present to the future" (Pesonen et al., 2000). In fact, in the field of LCA, scenarios are frequently more narrowly defined. Börjeson et al. (2005) provide a systematology with three types of scenarios: predictive (what will happen?); explorative (what can happen?); and normative (how can a specific target be reached?). Pesonen et al. (2000) provide guidelines for the construction of scenarios including cornerstone and what-if approaches in LCA. What-if approaches are used for comparing the environmental consequences of selecting near-term future scenarios which are built on a well-known and simple situation. The cornerstone approach is used in situations with a long-time horizon, and unknown and complex surroundings. Considering the time horizon of the assessment, the scenarios in Papers I and II were constructed using a cornerstone approach. These scenarios deal with case studies in an emerging state (recycling technologies and collaborative consumption business models) with the purpose of investigating more environmentally beneficial options for the dematerialisation of fast fashion. The scenarios used in Paper V were constructed using an explorative approach. The scenarios for each garment's life cycle were built up with very specific assumptions to explore each scenario's potential environmental impacts.

2.2 Social life cycle assessment

A part of the research presented in this thesis is directed towards using a life cycle perspective to identify social impacts associated with fast fashion. According to the Inter-organisational Committee on Guidelines and Principles for Social Impact Assessment, social impact represents "the consequences to human populations of any public or private actions that alter the ways in which people live, work, play, relate to one another, organize to meet their needs, and generally cope as members of society. The term also includes cultural impacts involving changes to the norms, values, and beliefs that guide and rationalize human population's cognition of themselves and their society" (IOCGP, 2003).

Social or Socio-Economic Life Cycle Assessment (SLCA) is a method for assessing the potential positive and negative social and socio-economic impacts of products throughout their life cycles. Similar to traditional environmental 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.

A collaboration between the United Nations Environmental Programme (UNEP) and the Society of Environmental Toxicology and Chemistry (SETAC) has resulted in the release of guidelines for SLCA (Benoit & Mazijn, 2009). According to these guidelines, SLCA methodology is built on the environmental LCA methodology described in Section 2.1 and it likewise consists of four iterative steps.

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 activity is choosing the functional unit which describes the product's function and social utility described as "a range of social aspects such as time requirement, convenience, prestige, etc." (Benoit & Mazijn, 2009) System boundaries also need to be determined. In these respects, an SLCA is not conceptually different from an LCA.

2. Life cycle inventory analysis

In this step, relevant data are collected for prioritisation, hotspot assessment, evaluation, and impact assessment. The first activity is to determine if generic or site-specific data are needed in relation to the goal and scope. The second activity 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 third activity concerns the collection of 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 inputs and outputs for the processes. However, most social impacts are more directly connected to the conduct of the company as a human resource manager rather than the engineering processes within the supply chain. This means that an inventory analysis should focus on the social characteristics of the companies and regions involved in the product system in order to assess the social impact of the product.

3. Life cycle impact assessment

This step consists of a set of activities. The first activity is to select relevant social impact categories and subcategories as well as characterisation models. The impact categories address social issues of interest to different stakeholders involved in the technical system. The subcategories address the detailed indicators within each impact category. The social indicators are quantitative, qualitative, or semi-qualitative, depending on the type of social impact. The selection of indicators is based on the goal and scope of the study.

The second activity is to relate the inventory data from the second step to each social impact category and subcategory. The inventory results are attributed to a specific affected stakeholder category and social impact category.

The third activity is characterisation, which involves the calculation of the results for each subcategory indicator. This activity provides an estimation of the social impact of the product or service. For the evaluation of both qualitative and quantitative social indicators, a scoring system needs to be developed to assess the meaning of inventory data in relation to a performance reference point. The performance reference point may be developed based on international social impact threshold values or some goal values based on conventions and best practices.

4. Life cycle interpretation

This step identifies significant social issues, and the consistency and the completeness of the study, and conclusions and recommendations are made based on the findings in the previous steps.

2.2.1 Selection of indicators

Even though the UNEP/SETAC guidelines were a result of an agreement on SLCA methodology, there remain some issues for which consensus has not yet been reached, and which, therefore, deserve further research. In the present study, one of the objectives was to identify and evaluate the social issues in relation to fast fashion. Since the SLCA is not fully mature, a part of this thesis focuses on the improvement of SLCA methodology in relation to the selection of indicators.

One of the challenges associated with performing SLCA is the selection of relevant social indicators. This is a challenge since currently no universally accepted set of indicators exists (Klöpffer & Renner 2008; Kruse et al. 2008; Jørgensen et al. 2009). Properly-selected and well-defined indicators are powerful instruments for a social impact assessment (Falck & Spangenberg, 2014; Mascarenhas et al. 2010). Indicators should be selected based on their relevance to the system under study. Due to the sheer number of potential social indicators for analysis, the task of selecting the indicators to be studied in depth is important.

According to the UNEP/SETAC guidelines, social 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 presented in the UNEP/SETAC guidelines are shown in Table 3.

Table 3: UNEP/SETAC social criteria classification

Stakeholders categories	Subcategories
Employees	Freedom of association and collective bargaining Child labour Fair salary Working hours Forced labour Equal opportunity/ 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 Delocalisation and migration Cultural heritage Safe and healthy living conditions Respect for 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 for 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 an impact on human well-being. In order to carry out a comprehensive and consistent sustainability assessment, several principles have been suggested by different guidelines. When indicators are used to compare alternatives, they must satisfy certain demands. Bouyssou (1990) has identified three key characteristics of a consistent set of indicators for the evaluation of alternatives:

- exhaustive: the set of indicators should contain every important point of view. In particular, this condition implies that if, for all the indicators, we have an equal indicator score for two alternative options, every stakeholder must agree to consider that alternatives are of equal preference,
- monotonic: the partial preferences that are modelled by each indicator have to be consistent with the global preferences expressed for the alternatives. This condition implies that if option A is judged to be better than option B, taking into account all the points of view, the same judgment will hold for an alternative C that is judged at least as good as A on every criterion,
- minimal: for obvious reasons, this condition implies excluding unnecessary indicators from the set, i.e. indicators which when excluded still lead to a set that continues to satisfy the first two conditions

Lundie et al (2008) likewise emphasise that the number of indicators must be large enough to comprehend the issues but still be manageable (i.e. low enough) so that the decision maker can mentally absorb them.

One of the usual approaches for the selection of indicators is to use expert opinions and/or stakeholder engagement (Mascarenhas et al. 2015). Within SLCA methodology, stakeholder participation is mentioned as a means for reflecting the result user´s interests, for the selection of impacts or for the development of weighting approaches (Jorgensen et al. 2009; Reap et al. 2008). In order to generate a set of social indicators that is comprehensive and relevant to local and sectoral context, stakeholder participation in selecting and rating indicators is recommended and has been applied in some previous studies (Blanchet & Girois 2013; Lundie et al. 2006; Mascarenhas et al., 2010; Sandin et al. 2011). In Paper IV, a survey was carried out to investigate the preferences of consumers and industry experts on the selection of social indicators for social impact assessment in the textile and fashion industry.

2.2.2 Stakeholder surveys

Questionnaires and surveys are methods that can provide statistics on the opinion of a population (Gaines et al. 2006). If a representative sample is targeted, unbiased and reliable conclusions can be drawn (Kuechler, 1998).

Early models for surveys to measure peoples´ responses were developed by Gutmann, Guildford, Likert, and Thurston (Erişen et al. 2013). Choosing a representative sample, designing the questions in an unbiased way, and the method for data collection are essential elements of survey development.

Different means of data collection are practiced in surveys including face-to-face interviews, telephone interviews, and internet questionnaires (Fowler, 2013).

Some random and non-random errors are associated with survey methods, and they can affect the reliability of data. Respondents may, for example, provide different answers to questions if questions are phrased in different ways, or are asked at different points in time (Erişen et al., 2013).

In Paper IV, the main focus is on the selection of relevant social indicators that can used in identifying the social impacts associated with fast fashion. Therefore, consumers and industry experts were selected as different stakeholder groups, and their priorities among social indicators were surveyed. The questions were developed for ranking the social indicators. Firstly, the questionnaire was developed in English based on a 5-point Likert scale and reviewed by a group of social marketing experts from Copenhagen Business School. After subsequent changes, the questionnaire for consumers was translated into Swedish. The final language check was conducted by GfK Sweden - a survey company (www.gfk.com). For investigating consumers' opinions, GfK carried out computer-assisted web interviews (Gwozdz et al. 2013). For investigating industry experts' opinions, the English version of the questionnaire was distributed at a symposium in which managers and experts in the fashion industry participated.

2.2.3 Input/output approach for social life cycle inventory

One of the steps in applying SLCA is the definition of the product system. According to ISO 14040, the scope of the system needs to be well-defined to sufficiently cover the breadth and depth of the study and to address the goal (ISO, 2006).

Based on the UNEP/SETAC guidelines, the product model can either be developed based on a process approach and/or on an economic input/output approach (Benoit & Mazijn, 2009).

As discussed in Section 2.1, the process-based approach in a typical LCA is based on the flow of engineered materials or energy between life cycle phases, and this provides a detailed picture of the specific processes involved in the whole life cycle (Benoit & Mazijn, 2009). The LCA databases associated with some major LCA software tools, like Gabi (thinkstep.com), are based on this approach. However, service-based sectors, such as legal services, advertising, commerce, real estate, renting and financial services, are not typically included in these process-based product models. Consequently, one of the concerns raised in the UNEP/SETAC guidelines is the hidden share of the total contribution of such sectors on social impacts (Benoit & Mazijn, 2009).

Input/output analysis, developed originally by Leontief (1986), can be used to identify supply chains based on global trade flows (Moran et al. 2015). Input/output analysis is increasingly used to generate LCI data in both LCA and SLCA. Conveniently for the inclusion of hidden elements of supply chains that contribute to social impacts, model systems developed using input/output approaches cover all upstream production sectors. Input/output analysis has been used in SLCAs or SLCA-like case studies, such as the assessment of the effect of implementing a small-scale biogas project on the amount of employment in a region (Heiho et al., 2015). Hybrid input/output LCA approaches have been used to investigate negative social impacts of the production of columbite-tantalite ore, also known as coltan (Moran et al., 2015), and the quantitative social assessment of sediment remediation (Hou et al., 2014).

In Paper IV, social hotspots in the fast fashion life cycle are identified. An input/output approach was used for product system development. The influence of a number of parameters, such as cut-offs and the definition of hotpots, were analysed within this approach.

2.4 Determining sustainability targets for the fashion and textile sector

To answer the fifth research question, which focuses on the scale of challenges and the potential of interventions in relation to global sustainability targets, a practical definition of environmental and social sustainability was needed for the textile sector. Although defining this is recognized as a value-based task (Glavič and Lukman, 2007; Weidema and Brandao, 2015; White, 2013) a definition assists in assessing the performances of interventions in relation to targets. Various practical definitions might be possible, for example, one offered by the comparison of an ecological footprint with the productive area of the earth's surface (Kissinger et al, 2013). To define environmental sustainability and set environmental sustainability targets in a way that is more compatible with traditional LCA, the planetary boundaries framework was selected, which outlines the biophysical limits of the Earth system that must be respected to avoid risks of global ecosystem collapse (Steffen et al., 2015). Previous publications which have complemented the planetary boundaries framework with social sustainability objectives were used to guide the definition of social sustainability and for setting social sustainability targets, (Dearing et al., 2014; Raworth, 2012).

Environmental sustainability targets based on planetary boundaries

The planetary boundaries framework outlines nine global biophysical boundaries which cannot be transgressed if humanity wants to avoid risks of global non-linear functional collapses of ecosystems and catastrophic societal consequences (Steffen et al., 2015). The current nine boundaries are: climate change, introduction of novel entities, stratosphere ozone depletion, atmospheric aerosol loading, ocean acidification, biochemical flows (divided into phosphorus and nitrogen flows), freshwater use, land-system change, and biosphere integrity change. For each boundary, the framework outlines affected earth system processes and one or several so-called control variables that express current states of nature or anthropogenic pressures in relation to the tolerable states/pressures (Steffen et al., 2015).

For setting the improvement targets, Sandin et al. (2015) have proposed matching the planetary boundaries earth system processes with LCA impact categories, and then using the distance current between current performance and a performance level that respects the planetary boundaries at a global level, as a basis for quantifying targets for impact-reduction at the product level. It should be noted that the process of extracting LCA-compatible impact-reduction targets from the planetary boundaries framework is not a trivial exercise. For example, the process depends on whether each planetary boundary can be directly interpreted in terms of a global target for impact reduction (step 1 in the procedure of Sandin et al. (2015)) and on how well the control variable(s) of the planetary boundary matches the chosen LCIA method. A number of value-based choices also influence the exercise, for example, the chosen time horizon and the ethical principles applied in allocating a finite impact space between different market segments (Sandin et al. 2015). Because of the uncertainties and normative elements of the procedure, the targets from Sandin et al. (2015) used in the present study are regarded as "order-of-magnitude" indicators of the necessary reduction of impact. In Paper V, the LCA impact categories that were used in the LCA of the Swedish apparel sector had to be matched to the earth system processes of the planetary boundaries framework, as shown in Table 4.

Table 3: The planetary boundaries that were quantified and deemed relevant in the context of the Swedish clothing sector, related LCA impact categories and the identified global targets for impact reduction

Planetary boundaries (PBs)	Related impact categories	Global target for impact reduction until 2050 implied by planetary boundaries
Climate change	Climate change Non-renewable energy use	100%
Interferences with the nitrogen cycle (part of the biogeochemical flows PB)	Eutrophication Marine eutrophication Terrestrial eutrophication Terrestrial acidification	59%
Interferences with the phosphorus cycle (part of the biogeochemical flows PB)	Eutrophication Freshwater eutrophication	56%
Freshwater use	Freshwater consumption	-54%
Land-system change	Land transformation (in particular, transformation of forest land)	100%
Changes in biosphere integrity	Land occupation (midpoint) Land transformation (midpoint) Biodiversity loss (endpoint)	99%

Social sustainability targets based on a socially just operating space

In the context of the planetary boundaries debate, the inclusion of social issues adds a relatively new dimension. The combination of social boundaries and planetary boundaries has popularly been visualized as a “doughnut-shaped space ”, as shown in Figure 4, which represents a framework for achieving an “environmentally safe and socially just operating space” (Dearing et al., 2014). This means that beyond the planetary boundaries, in the outer layer of the “doughnut-shaped space”, environmental degradation is faced which endangers humanity, and, below the social boundary, which is the inner layer of the “doughnut-shaped space”, resource deprivations that are risking human well-being are faced.

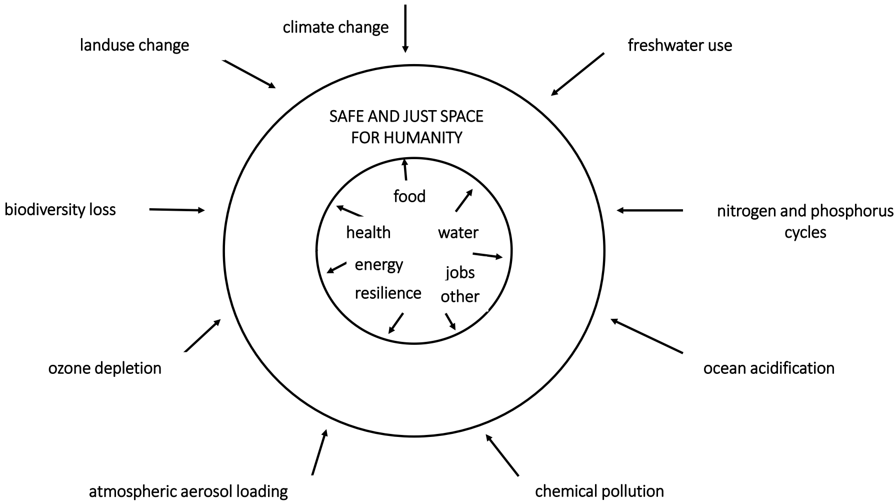

Figure 4: An "environmentally safe and socially just operating space", modified from Dearing et al. (2014).

For setting the qualitative social sustainability targets in Paper V, a set of 11 social targets were identified based on the Rio+20 Conference (Leach, Raworth, & Rockström, 2013) in relation to "environmentally safe and socially just operating space" defined by Dearing et al. (2014). For the context of Paper V, the social sustainability targets were matched with a set of social indicators- based on the consumer preferences presented in Paper III- shown in Table 5. Five of the indicators could be matched with the social targets, namely those related to adequate income, providing education, decent wage, resilience to shocks and gender equality.

Table 4: Social targets according to the Rio+20 conference, as defined by Leach et al. (Leach et al., 2013) and equivalent social indicators used in hotspot identification

Social target	**Equivalent social indicators**
Food security	Not identified
Adequate income	Risk of wages being under 2 USD per day Risk of a sector average wage being lower than country´s minimum wage
Empowered water and sanitation	Not identified
Adequate health care	Not identified
Provide education	Risk of child labour in sector
Decent job	Risk that country has not ratified ILO conventions by sector Risk that country does not provide adequate labour laws by sector Risk that country lacks or does not enforce collective bargaining rights
Access to modern energy services	Not identified
Resilience to shocks	Risk of fatal injury by sector Risk of non-fatal injury by sector Overall risk of loss of life years by exposure to carcinogens in occupation Overall risk of loss of life years by airborne particulates in occupation
Gender equality	Risk of gender inequality by sector based on representation in the workforce
Social equality	Not identified
Having political voice	Not identified

3. Summary of Papers I – V

This chapter summarises the findings of Papers I–V. Further details are provided in the appended papers.

3.1 Paper I

In paper I, the aim was to explore the potential environmental opportunities of various textile recycling techniques and thereby direct textile waste management strategies towards purposeful dematerialisation efforts. For this purpose, available technical options were identified, and an LCA was conducted to quantify the primary energy usage and global warming potential (GWP) of selected textile recycling options. The intended audience was policy makers and research managers in the textile industry.

Three different recycling techniques for managing a model waste consisting of 50% cotton and 50% polyester were studied. The recycling processes were: material reuse of textile waste of adequate quality (often referred to as remanufacturing); separation of cellulose from polyester using N-methylmorpholine-N-oxide as a solvent and respinning the cellulose; and chemical recycling of polyester. In order to correct for differences in functions between the systems, system expansions were made for products and by-products that take into account avoided emissions and energy use. These techniques were compared to incineration, representing current textile waste treatment in Sweden. Many variations in the studied recycling techniques could be proposed, a cornerstone scenario analysis was therefore performed to examine the possible spread of LCA outcomes.

The results showed that incineration has the highest GWP and primary energy usage. The material reuse process exhibited the best performance of the studied systems, with savings of 8 tonnes of carbon dioxide equivalents (CO_2-eq) and 164 GJ of primary energy per tonne of textile waste due to avoided production of products from primary materials. Sensitivity analyses showed that findings were particularly sensitive to the considered yields of the processes and to the choice of replaced products.

Technologies with the aim of textile recycling at an industrial scale are of strategic interest in Sweden as demonstrated by large, long-term investments in research projects, such as the Mistra Future Fashion programme. In practice, an industrial decision maker is unlikely to face a choice between exactly this set of alternative recycling techniques given that the techniques target different parts of the textile waste flow, and a direct comparison may, therefore, not be relevant. On the other hand, it may be feasible to integrate all four methods of managing textile waste. An integration of these recycling technologies for optimal usage of their different features for the treatment of 1 tonne of textile waste shows that 10 tonnes CO_2-eq and 169 GJ of primary energy could be saved.

The reason these findings show an environmental advantage in implementing textile recycling techniques is the fact that the manufacturing of products from primary resources is avoided. Paper I is a preliminary environmental assessment based on the best available data at the time and represents the Swedish situation. The findings highlight the environmental advantages of textile reuse and recycling techniques as dematerialisation strategies that can reduce the environmental impacts of textile use in society.

3.2 Paper II

In Paper II, LCA was used to explore the environmental performance of clothing libraries as one of the possible ways in which collaborative consumption can be implemented, and the study compared the advantages and disadvantages of this alternative in relation to conventional business models for fast fashion.

Different parameters were varied to generate 12 clothing library scenarios including: (i) the extension of a garment's service life (two or four times the garment's service life originally assumed in the baseline scenarios); (ii) whether the business is set up as an offline (physical store) or online (internet, with a pick-up point for deliveries) solution; and (iii) the type of customer transportation (high impact consumer transportation: 100% car; medium impact consumer transport: 50% car/50% bus; low impact consumer transport for online: 100% bus; low impact consumer transport for offline: bicycle/walk,).

The focus of the study lay on investigating environmental impacts for climate change, fresh water consumption, fresh water ecotoxicity and fresh water eutrophication since these environmental impacts appeared to be among the indicators with highest relevance for the clothing sector (Roos et al. 2015). Results for land use, human toxicity and acidification were excluded from this paper since result for the land use was correlated with freshwater consumption, results for human toxicity were correlated to fresh water ecotoxicity, and results for acidification were correlated with freshwater eutrophication. The assessment was based on three key garments that are stocked in clothing libraries: jeans, T-shirts, and dresses.

The overall results for all indicators show more environmental benefits for online scenarios than offline scenarios due to the closer package pickup point to customers (one third of the distance). This underlines the importance that the locations of stores and/or the locations of pickup points are close to customers or accessible by public transportation. The results for the GWP of T-shirts show that the offline scenario which doubles the garment's service life and which has the highest transportation impact potentially leads to a 26% higher GWP than the baseline scenario with medium impact transportation. The results for freshwater consumption of T-shirts show savings of up to 75% in the clothing library scenarios in comparison with the baseline scenario with medium impact transportation. The overall results for freshwater consumption show that the type of transportation does not play a major role since most of the water consumption is related to the production phase. In terms of freshwater eutrophication, the results for T-shirts show that the online scenario with four times longer service life and low transportation impact potentially leads to 60% lower impact than the baseline scenario. For a pair of jeans, all clothing library scenarios show more savings than the baseline scenario. The results for the dress show a robust difference in results with respect to a change of type of transportation with the exception of the offline scenario with a doubling of the service life. In terms of freshwater ecotoxicity for a dress, the results in relation to the potential for medium impact customer transport for both online and offline scenarios are up to 3.4 times higher than the baseline scenarios. The results show that since major freshwater ecotoxicity impacts are related to customer transportation activities, only the low impact costumer transportation online collaborative consumption scenarios have less environmental burden than baseline scenarios.

Furthermore, in Paper II, the key factors influencing the environmental impact of clothing libraries were investigated. The results quantitatively indicate the significant contribution of use phase transport in the collaborative consumption scenarios. The results demonstrate the potential risk of problem-shifting in the life cycle: increased consumer transportation can completely offset the benefits gained from reduced production.

Moreover, a sensitivity analysis was carried out changing the number of customers for one of the clothing library scenarios. The results showed that the number of customers per garment life cycle can considerably influence the environmental impact of clothing libraries, as a higher number of customers leads to more transport to and from the clothing libraries. This highlighted the need for accounting for logistics when implementing collaborative consumption business models.

3.3 Paper III

One of the challenges associated with performing an SLCA is the selection of social indicators to evaluate social subcategories. In Paper III, the aim was to provide a set of social indicators related to the fashion industry that can be used in social impact assessments and also in communication tools such as product labels.

For selecting a set of social indicators that can be used for addressing the social concerns of fashion industry stakeholders, consumers' and industry experts' priorities for social issues were identified and the overlaps and differences between them were investigated. Further, the study matched the top ten social indicators as prioritised by consumers and industry experts with the UNEP/SETAC guidelines. Moreover, the overlap between consumers' priorities and social issues covered by one prominent product sustainability label, the Global Organic Textile Standard (GOTS) label, was mapped.

The findings in the study show that the top ten prioritised indicators for both consumers and industry experts are related to employees' health and safety, child labour, fair salary, employment security, avoidance of discrimination, and fair competition. Consumers were also highly concerned about providing social benefits for employees and the company's commitment to human rights. There were also several indicators for which the rankings were quite different. Social concerns relating to commitment to human rights and decent salaries of workers compared with senior executives were more important for consumers. On the other hand, the relationship between textile production and the implementation of a proper internal and external complaints procedure for factory workers and local communities were important issues for the experts.

Matching of consumer and industry expert priorities to the UNEP/SETAC stakeholders' categories showed that the emphasis of both consumer and industry expert priorities is on how industry treats its Employees as affected stakeholders. Even though the Society stakeholder category was well covered by the list of social indicators, the only indicator in this category that was highly prioritised by consumers was the Voluntary commitment to human rights. For Local community and Value chain actors, coverage was not high, but nevertheless, some aspects such as Fair competition and Community engagement were highlighted.

Considering the subcategories defined in the UNEP/SETAC guidelines, the top prioritised subcategories from both perspectives (consumers and industry experts) were Freedom of association and collective bargaining, Forced labour, Equal opportunities/Discrimination, Employees' health and safety, Child labour, Fair salary, and Fair competition in relation to value chain actors. Public commitment to sustainability issues and providing social security for employees were highly prioritised only by consumers. On the other hand, community engagement in filing complaints was highly ranked by industry experts.

This study thus points out both which of the UNEP/SETAC subcategories and stakeholder categories are emphasised more by consumers and industry experts and should therefore be covered in assessment and communication around social issues in the fashion industry.

All the social indicators presented by GOTS were covered in the survey. However, not all indicators in the survey were covered by the GOTS indicators. Eight out of the ten most significant indicators as ranked by consumers are covered by GOTS; they are all related to social issues associated with labour conditions. Two indicators focus on other aspects of ethical practices in a company, including fair competition, and voluntary commitments to human rights, and these issues are not directly addressed by GOTS. Maintaining the salience of labels for consumers requires to ensure that labels reflect consumer perspectives and priorities. Therefore, it would be more meaningful for consumers if the GOTS label focused on covering the social impacts on other affected stakeholders, such as society and value chain actors throughout a product's life cycle social indicators. The selection of sustainability indicators by the engagement of different stakeholders can be useful for SLCA, eco-design processes, annual sustainability reporting, labelling, and certification systems that allow companies to implement, evaluate, and communicate their performance. Moreover stakeholder opinions, such as those represented in the paper, can be helpful for setting weighting factors based on different stakeholder preferences (Fontes 2016).

3.4 Paper IV

In Paper IV, a cradle-to-gate, input/output-based SLCA was made for Swedish clothing consumption in order to identify negative social hotspots. The aim was to identify negative social hotspots on country and sector levels for Swedish fashion consumption by means of the Social Hotspot Database (SHDB).

Further, the aim of the study was to contribute to the development of input/output-based models in SLCA by determining the influence of cut-off rules and of the definition of "hotspot", as well as the benefits and drawbacks in relation to process-based modelling.

The case study was based on the SLCA methodology provided in the Guidelines for Social Life Cycle Assessment of Products (Benoît & Mazijn, 2009). An input/output approach was used to define the product system from cradle to gate using the SHDB and the Global Trade Analysis Project input/output-based model, as implemented in the OpenLCA software. The social hotspots were evaluated for a set of social indicators that were selected by consumers as identified in Paper III. The impact assessment was conducted on a country and sector level by using the SHDB. The identified country specific sectors (CSS) with high and very high levels of risk were listed for each social indicator. The results pinpointed some hotspots throughout the supply chain for Swedish clothing consumption. Some sectors that are not normally identified in LCA process analysis, such as commerce and business services in Bangladesh, were identified as important hotspots. Moreover, the findings showed that some main sectors in the production phase such as plant fibres, textiles, and garments that would be expected also on the basis of a traditional process based product system were also important hotspots.

The role of cut-off value was investigated by calculating the number of CSSs that appeared for different cut-off levels, namely 1–4 %, in steps of 1 %. The results indicated that a 2 % cut-off value showed 60 % of the major CSSs which appeared with a 1 % cut-off value. To shed further light on the importance of the cut-off value, a sensitivity analysis was carried out for three different indicators including child labour, fatal injury and labour wages under 2 USD, for no cut-off, 2 % cut-off and 4 % cut-off values. The result showed that the choice of cut-off value can directly affect the number of CSSs included in the product system model and therefore influence the results.

The influence of hotspot definition was investigated by evaluating the working hour intensity for low and medium risk levels for three different indicators. The results showed that for child labour, 92% of the share of working hours were associated with low and medium risk levels. Therefore, it was possible to see that the evaluation of risk levels, other than high and very high, can provide a more complete picture of social hotspots.

3.5 Paper V

The aim in Paper V was to use an industry sector approach to enable the assessment of different interventions in terms of how they contribute to reaching targets for environmental and social sustainability on the sector level. To clarify what sustainable practices are for an industry sector, three questions were identified as necessary to answer:

1) What is the current sustainability performance of the sector?
2) What is the maximum acceptable impact for the sector?

3) Are proposed interventions enough to reach the acceptable sustainability performance?

Answering these questions would make it possible to measure performance in relation to sector level targets. Moreover by answering these questions, we learn which types of interventions (technical improvements, behavioural changes, or circular business models) and which actors (textile manufacturers, retailers, consumers, or authorities) can potentially provide the greatest benefits.

To answer question 1, the methodological framework was based on the LCA and SLCA studies carried out by Roos et al. (2015). The results drawn from Paper IV were used to identify the social hotspots in the current performance of the fashion sector. To answer question 2, quantitative environmental targets were identified for 2050, and were, for the purpose of the paper, based on what scientists have suggested is necessary to avoid global ecosystem collapse according to the planetary boundaries framework (Steffen et al., 2015). Qualitative social targets were based on how the planetary boundaries framework has been complemented with social sustainability objectives(Dearing et al., 2014; Raworth, 2012). For answering question 3, for different interventions were proposed and their impact in relation to reaching the environmental targets were assessed. The details of the dematerialisation interventions are discussed in Papers I and II.

The results from the environmental impact assessment on the sector level show that the interventions that are most likely to be effective are those that are directed towards reducing the burden of the production phase of the garments. User behaviour is, however, very important when it comes to the service life of garments, including consumer laundry behaviour which is key to prolonging the service life of a garment. Results from the social hotspot identification show the significant social risks in the textile and clothing industry related to wage, child labour, and safe working conditions.

The results for different interventions show their different potential to reduce environmental impacts. In the case of collaborative consumption, for offline scenarios, climate impact might in fact increase due to consumers travelling more often to and from the store (under certain transportation assumptions), while water use decreases due to the longer lifespan of cotton garments. The online collaborative consumption scenario sees an 11% decrease in climate change, while the polyester and mechanical recycling scenarios reduce climate change to a lesser degree.

From the social impact perspective, several social actions have been initiated by the industry for improving wage conditions. Today, it is not possible to measure the social impact of company level interventions, such as technology or management system interventions. The available data are on country and economic sector level. Social metrics need, thus, to be refined in order to measure the influence of company level interventions on reaching targets. Relevant social metrics are required to measure the social value created with each intervention towards long-term higher level goals. Nevertheless, it can be expected that social risk levels will be reduced by applying the suggested company level interventions.

To spur the industry sector's stakeholders to actualize the full potential of the most effective environmental interventions, a scheme for structured evaluation of LCA results directed towards these prospective actors was developed in this paper. Some advices for retailers were enabling and encouraging consumers to use low-impact transport. Consumers were advised to reduce purchasing of new clothes, together with a thoughtful transportation to and from the store (or pick-up point in case of online shopping). Authorities are advised to direct policy instruments towards interventions that will have the greatest potential.

The approach used in Paper V was intended to provide support to and simplify collaboration between different actors in the sector through a common understanding of the sustainability challenges and the potential of possible interventions. Also, this approach can help clarify which impact categories and social risks the Swedish fashion sector are likely to manage adequately if the proposed interventions are implemented, and which impact categories and social risks that will require more radical interventions for impact reduction.

4. Discussion

This chapter discusses how the findings of the research contribute to addressing the research questions formulated in Chapter 1. This chapter is divided into three sections, corresponding to the research objectives. The research questions are addressed one at a time in the respective sections.

4.1 Identify environmental benefits of interventions for dematerialisation (RO 1)

4.1.1 Can textile recycling generate environmental benefits?

The intention of Paper I was to identify possible recycling techniques and to determine if the suggested recycling techniques could potentially result in a net environmental benefit compared to current practices. A review of the literature and dialogue with colleagues in the Mistra Future Fashion project suggested four key technical routes for the end of life of textile waste in Sweden. The recycling routes were: material reuse of textile waste of adequate quality (or "remanufacturing" in the context of Figures 1 and 2), chemical separation of cellulose, and chemical recycling of polyester - three cornerstone scenarios for recovery of materials. Since end of life activities related to consumption in Sweden was the main focus of the paper, incineration with energy recovery was considered the principal alternative and the basis for comparison. An LCA was performed to quantify the environmental profile of different scenarios for textile waste management.

This assessment was performed at an early stage in the development of chemical textile recycling, therefore, available data mainly relate to energy consumption. GWP and primary energy usage indicators were selected to be assessed in this study in order to have a consistent data set. Some data are still highly uncertain. However, assuming that input data are reasonable, based on the presented results, for both primary energy usage and GWP, all recycling techniques show environmental savings owing to the fact that the manufacture of products from primary resources is avoided.

There are other environmental impacts that are potentially important for the fashion industry. To complete the study, a semi-quantitative evaluation of the toxicity of the chemicals used in these recycling techniques showed that the toxicity impact of the N-methylmorpholine-N-oxide (NMMO) and Methanol used are lower than the effects of pesticides used for the production of cotton. Consequently, one of the advantages of applying recycling techniques and producing recycled cotton yarns is that some contributions to human toxicity, terrestrial ecotoxicity, and water consumption will be averted.

Previous studies assessed the environmental benefits of different reuse and recycling routes of textile waste (Farrant et al. 2010; Woolridge et al. 2006; Östlund et al., 2015) Those studies showed that the environmental benefits of textile reuse and recycling routes are associated with avoiding the production of textile products from primary materials. According to Östlund et al. (2015), recycled materials need to replace the fibres produced from primary resources to gain environmental benefits. Östlund et al. (2015) quantified the environmental benefits of recycling cotton fibres due to the avoidance of fertilizers and pesticides used in agriculture, which lead to toxicity and eutrophication impacts. Moreover Östlund et al. (2015) showed both mechanical and chemical polyester recycling generate environmental benefits by avoiding the need to produce polyester from primary materials. This is consistent with the results obtained in this thesis.

In the present study, the results show that the decision to perform a system expansion is clearly an important methodological choice because it dominates the total results of the systems. One of the challenges acknowledged in previous studies is the estimation of the prevented environmental load determined by the quantity of product replacement with recycled materials (Farrant et al., 2010; Woolridge et al., 2006). Many aspects of future textile recycling techniques are inherently uncertain, including the type and quantity of products replaced. For capturing such uncertainties in LCAs of technologies under development, sensitivity analysis and scenario modelling were applied (see Paper I).

In practice, an industrial decision maker is unlikely to face a choice between the individual techniques in the set of alternative recycling techniques examined in this thesis or in Östlund et al (2015). This is because the techniques target different parts of the textile waste flow. A direct comparison may, therefore, not be relevant. For this reason, the four recycling technologies examined in the present study were integrated for optimal usage of their different features for the treatment of 1 tonne of textile waste. Assuming the technical feasibility of this integrated process, the integration of the recycling technologies does provide large environmental benefits from either GWP or energy usage perspectives, in comparison to incineration with energy recovery.

One of the limitations of the study was the exclusion of some operations such as collection, sorting, and separation. Paper I assumed that there was already an established collection and sorting infrastructure for textile waste. Previous studies have highlighted the technical challenges associated with the sorting and separation of blended textile materials and access to life cycle inventory data in relation to these steps (Muthu et al., 2012; Cuc et al., 2015).

Another limitation of Paper 1 was the scope of the investigation of the environmental impacts of different textile recycling techniques. In this study the aim was to find one example of each return route in the circular economy concept (shown in Figure 1). The material reuse technique is an example of the remanufacturing route. The two other methods of separation using NMMO and closed-loop polyester recycling techniques were examples of chemical recycling routes. Another textile recycling techniques is mechanical recycling that can be used to produce filling or insulation materials or new fibres from shredded used textiles (Palm et al. 2014). There are also examples of spinning used fibres with virgin fibres to make a blended-aged yarn. Mechanical recycling processes such as these have been subjected to little scrutiny by the LCA community in recent years (see e.g. AITEX, 2007). According to Östlund et al (2015), compared with chemical recycling, there is a relatively limited market for both the material recycling process described in this thesis and the spinning of mechanically recycled yarn due to the loss of material quality.

4.1.2 Key factors controlling the environmental impact in the design of collaborative consumption business models

In Paper II, an LCA was used to investigate the key factors influencing the environmental impact of clothing libraries as one of the possible implementations of collaborative consumption. The aim of collaborative consumption is to prolong the use of garments, thereby also leading to dematerialisation.

Previous studies have shown that reusing garments can contribute to a reduction of the environmental burden of clothing, since the environmental burden associated with the reuse of garments is insignificant in comparison with the replacement of primary materials (Farrant et al. 2010; Woolridge et al. 2006). Woolridge et al. (2006) have shown that the energy consumption of the retailing and distribution activities associated with the traditional business model of retailing second hand clothes is much lower than the energy consumption associated with the production of primary materials. Previous studies with a specific focus on the collaborative consumption business model have qualitatively discussed the idea that leasing garments can potentially contribute to more efficient resource use (Agrawal et al. 2011; Leismann et al. 2013). The results in Paper II showed that achieving a substantial increase in service life is important for collaborative consumption to reduce the environmental impacts per garment use. Moreover, Leismann et al. (2013) have hypothesized the existence of a negative environmental rebound effect in collaborative consumption due to increased transportation. This hypothesis was confirmed by our quantified results showing that increased customer transportation in some scenarios can offset the environmental gains from reduced production.

The results quantitatively indicate the significant contribution of use-phase transport in the collaborative consumption scenarios. This shows that the burden of production in Asia and the Middle East is exchanged for user transport impacts- which is an example of geographical problem shifting. These findings highlight the need to consider logistics when implementing a collaborative consumption business model, for example, by placing a physical rental service or clothing library in locations close to customers and/or public transportation.

Another important factor behind the environmental impact of collaborative consumption by means of clothing libraries is the number of users per garment life cycle. More users mean more transport to and from the store or pick-up point. In other words, the frequency of garment transactions between users and the clothing libraries and the number of times a garment is used per each user matter greatly. These factors can be influenced by the setup of a clothing library membership system, for example, by the number of clothing pieces the user can borrow within a set time period, and the length of that time period. Fewer items and a longer time period could give an incentive to reduce the number of users per garment life cycle, which would be environmentally preferable. Also, a payment system could have an impact. For example, if the user must pay for each clothing transaction, this could reduce the number of transactions and the associated environmental impacts. Overall, the setup of such a membership system, and its influence on the frequency of transactions, is particularly important for clothing libraries in locations that induce user transportation with high environmental impact (e.g. remote areas with poor access to public transportation). Consequently, the setup of a membership system is less important in locations that induce user transportation with low environmental impact (e.g. downtown areas with good access to public transportation).

Although a large number of scenarios and variables were examined in Paper II, there remain additional factors that constrain the potential for clothing libraries to reduce impacts. In particular, consumer behavioural responses to collaborative consumption, and the financial basis for such businesses, are critical. These factors were beyond the scope of Paper II but will be further examined in the second phase of the Mistra Future Fashion project.

4.2 Identify and evaluate social challenges to fast fashion and contribute to development of SLCA (RO 2)

4.2.1 Selection of relevant social indicators for assessment in the fashion industry

In Paper III, the aim was to create a set of relevant social indicators which can reflect different stakeholder priorities for social issues within the fashion and textile sector, including Swedish consumers and fashion industry experts. Mathe (2014) is an example of a previous study which developed a framework to implement stakeholder participation into impact selection and evaluation, particularly in the fish farming sector.

In Paper III, the perspectives of different stakeholders were identified and compared to determine the relative significance of 31 social indicators for the life cycle of apparel. Findings show that aspects of working conditions, such as the promotion of a healthy and safe working environment for employees, and evidence of child labour and gender discrimination are high priority indicators for both consumers and industry experts. Social concerns related to commitment to human rights and decent salaries for workers compared with the senior executives of the companies are more important for consumers than industry experts. On the other hand, the relationship between textile production and the implementation of proper internal and external complaints procedures for factory workers and local communities are more important issues for the experts but are very low among consumer priorities.

The quality of the findings in the stakeholder participation approach are dependent on the credibility of the process including aspects like the choice of a representative sample of stakeholders, the transparency of the procedure, having access to different stakeholders, and the choice of stakeholder categories (Mascarenhas et al. 2010). As recommended in previous studies (Mascarenhas et al. 2010; Mascarenhas et al. 2015) involving a broad range of stakeholders is crucial for identifying a relevant set of indicators that truly reflects sustainability issues in the context. The difference in results regarding consumer and industry expert opinions in Paper III highlight the necessity of including different groups of stakeholders in the selection of indicators to avoid biased assessment. This issue is connected to the key characteristics identified by Bouyssou (1990), i.e. that the set of indicators for evaluation needs to be exhaustive and contain every important point of view. An important criticism of Paper III is that the people most effected in the supply chain by its social violations, such as workers or local communities, were not part of the survey process. It would be interesting and worthwhile to extend the survey to include the priorities of workers in Bangladesh, for example. There are at least two factors worth considering in the context of that criticism. One of these factors is including the extent to which obtaining a representative sample of respondents in producing countries is actually feasible. In addition to the shear logistical challenge of identifying and approaching workers in each of the major clothing manufacturing countries, there are cultural barriers to survey work across multiple countries. These were pointed out long ago (Kuechler, 1998) and remain an ongoing challenge that is a field of research in its own right. For example, Keuchler (1998) says that "broadening the number of countries in a survey will most likely lead to more abstract conceptualizations, to less specific questions and thus to vague stimuli allowing ample room for subjective response to question contents by the respondents and in the end to responses the true meaning of which is wide open to speculation and second guessing”. A second factor is the need to ensure the salience of communication instruments directed at western audiences, who have their own values and norms regarding social impacts. To communicate persuasively it is essential to address the values and norms of an audience. This might be a challenge to the concept of monotonicity, one of the characteristics identified by Bouyssou (1990) for setting indicators. As an example, findings in Paper III showed that Swedish consumers were strongly against child labour. However, if people in Bangladesh were asked whether child labour should be a highly prioritised social issue in the textile industry, there may be some people who feel that the possibility of occasional child labour is a social good, as an important survival mechanism for destitute families, but that an industry built entirely on child labour is morally bankrupt. In such a case, the indicator may not be monotonic.

A mapping of the indicators suggested by UNEP/SETAC onto the results of the present study showed that the emphasis of both consumer and industry expert priorities were associated with labour-related subcategories such as Freedom of association and collective bargaining, Forced labour, Equal opportunities/Discrimination, Employee health and safety, Child labour, Fair salary, and Fair competition in relation to value chain actors. Relating the social indicators in the present study to UNEP/SETAC guidelines is, however, challenging in terms of finding the most relevant subcategories and affected stakeholders. One of the indicators that was highly prioritised by industry experts, related to filing complaints, was not matched with any indicator in the UNEP/SETAC guidelines. This indicated the potential need for complementing the UNEP/SETAC guidelines with additional indicators in studies with a focus on the textile and fashion industry in order to achieve a set of indicators that is exhaustive (Bouyssou, 1990). Nevertheless, the present study identifies which of the UNEP/SETAC subcategories and stakeholder categories are emphasised more by consumers and industry experts and should, therefore, be covered in assessment and communication around social issues in the fashion industry. It also identifies areas that remain to be further explored.

In addition to social indicators’ potential role in SLCA for industrial eco-design processes within a corporate entity, indicators can be useful for communication instruments with stakeholders, such as labels (Mascarenhas et al. 2014). Each standard and label covers different social indicators, a factor which results in confusion among stakeholders, such as consumers who want to make socially responsible purchases and companies that want to steer their activities towards greater social responsibility in the value chain. Maintaining the salience of labels for consumers requires that labels reflect consumer perspectives and priorities. In Paper III, consumer priorities were compared to the aspects covered by one of the labelling schemes used in the fashion industry: GOTS. Findings indicate that it would be more meaningful for consumers if the GOTS label also focused on covering other affected stakeholders than workers, such as local community and society throughout a product's life cycle.

The approach presented in Paper III can be useful for utilizing SLCA, eco-design processes, annual sustainability reporting, labelling and certification systems that allow companies to implement, evaluate, and communicate their performance. Moreover, such an approach can be helpful for setting weighting factors based on different stakeholder preferences (Fontes, 2016).

4.2.2 Appropriate parameter settings for constructing an input/output model

In Paper IV, a cradle-to-gate, input/output-based SLCA was conducted, using Swedish clothing consumption as a case study. The social performance of countries and sectors was used for identifying negative social hotspots in the clothing production supply chain for Swedish consumption. Since SLCA is not a mature methodology, there is currently a lack of consensus and a great deal of academic discussion of some issues in relation to SLCA methodology (Arcese et al. 2016). In this paper, the focus was on topics such as the definition of hotspots and appropriate cut-off values for the system model.

To define the product system with an input/output model of global trade, the analyst needs to specify the CSSs that are involved in the clothing supply chain. For defining a manageable set of CSSs, cut-off rules must be defined. Cut-off criteria are not mentioned in most of the previous peer-reviewed SLCA studies (Chhipi-Shrestha et al. 2015). Therefore, there is no common agreement on the cut-off rules for constructing a product system (Benoit et al., 2010). Lagarde and Macombe (2013) have suggested the application of cut-off criteria for the construction of a product system. Therefore, in the present study, the role played by the cut-off value in the findings was quantified. If no cut-off rule is applied, the consequence is the appearance of a very large number of CSSs. In the case of the SHDB, approximately 5,800 CSSs appear in the product system, with high and very high risk level for each indicator. From the point of view of providing practical advice to companies, this was an unmanageably large number of CSSs, and of little significance since each CSS has a very small number of working hours associated with 1 USD price of the final product. To shed further light on the importance of the cut-off level, the number of CSSs that appeared for different cut-off values were calculated, namely 1-4%, in steps of one percent. For example, a 2% cut-off value shows 60% of the major CSSs which appear with a 1% cut-off value. The findings show that the selection of cut-off rule is one of the key parameters that can directly affect the results.

Further, the definition of "hotspots" in SLCA was investigated. The SLCA guidelines define hotspots as activities in the product supply chain that highlight potential risk of violation and social concerns that need to be considered in a specific country and sector (Benoit-Norris et al. 2012). Some previous studies have only considered "very high" and "high" risk ratings as hotspots (Ekener-Petersen & Finnveden, 2012; Ekener-Petersen et al. 2014). Another study selected CSSs as hotspots if they were responsible for a large share of working hours and were at high level of risk for different social indicators based on the Hotspot Index developed by SHDB (Benoit-Norris et al., 2012). The findings in Paper IV show that 92% of the share of working hours are attributed to low and medium risk level for the child labour indicator. This is in contrast to the findings for fatal injuries and wages under 2 USD, which are dominated by high and very high risk categories. This thesis, therefore, indicates that for hotspot analysis, in which fatal injuries or wages under 2 USD are the indicators of concern, this approach is warranted. On the other hand, if the use of child labour is a key concern, there is good reason to expand the assessment beyond that suggested by Ekener-Petersen et al. (2014).

Regarding differences between input/output- and process-based modelling, it is noteworthy that many of the CSSs identified in the input/output-based approach would probably not have been identified with process-based modelling. In the present study, sectors such as commerce and business services appear as hotspots for many indicators but are typically not included in process-based product models in SLCAs. This may perhaps be on account of the absence of a flow of energy and materials, even though these sectors can be expected to be part of most product systems. Merely eliminating the commerce, business services, and financial services sectors from the model used in the present report resulted in a truncation error (lost estimated risk exposure time) of 34% when the cut-off rule was defined as 2% of the contributing financial flow. This provides an indication of the extent to which input/output-based modelling provides a more complete set of hotspots than process-based modelling. That input/output-based modelling can provide a more complete picture, and avoid truncation errors in SLCA contexts is consistent with findings from environmental LCA publications (Lenzen, 2000; Rowley et al. 2012; Majeau-Bettez et al. 2011).

On the other hand, there are some limitations associated with input/output-based modelling. Input/output tables show the financial transactions between sectors of the economy. However, the number of sectors covered in the input/output tables (such as the Global Trade Analysis Project (GTAP) database used in the SHDB) is limited, and this means that sector average data may hide important details (Papong et al. 2015). For example, the Bangladeshi "Commerce" sector identified in Paper IV may include a range of different scales of commercial businesses, and it is possible that the larger ones have better working conditions than the smaller ones (or vice versa). Such information is lost in input/output-based modelling. Moreover, the data provided in input/output tables are on the sectoral level rather than being product-specific. For example, the findings presented in the present paper are related to an industry that produces a group of products (garments) rather than a specific product (cotton T-shirt or polyester dress). While these factors limit the value of the approach with respect to product assessment and labelling, it should be noted that the context of the paper – identification of hotspots connected to national consumption of a certain product category – is a particularly suitable application of input/output-based modelling. On the other hand, process-based modelling has many benefits in studies which, instead, focus on a particular product chain (e.g. including studies aimed at learning specific technologies and site-specific data collection and risk assessment).

4.3 Identify the scale of challenges and potential of interventions in relation to global sustainability targets. (RO 3)

4.3.1 The scale of challenges and potential of interventions in relation to global sustainability target

In Paper V, an approach to an industry sector sustainability assessment is presented to enable the assessment of different interventions in terms of how they contribute to reaching targets for environmental and social sustainability on the sector level. The Mistra Future Fashion research project was performed within the context of the Swedish apparel sector, and, therefore, this sector is used as an example in the paper to illustrate the approach. In paper V, A set of sector level environmental and social targets are suggested for achieving a sustainable Swedish fashion sector. In light of these targets, the performance of different circular economy model interventions were measured, and it was learned which types of these interventions are required to reach the targets.

In the case of collaborative consumption, the sustainability benefit derives from an increase in the service life of garments, bringing garments abandoned in closets or waste back into use, while the number of garments a given consumer uses is not reduced. In Sweden, statistics show that many garments are not used for their whole technical lifespans (Roos et al., 2015). It should be noted that the scenarios with collaborative consumption based business models are strongly dependent on how much the service life of a garment is extended and on transport modes. Also, since techniques for material recycling have not yet been developed on the industrial scale, their environmental performances depend on assumptions about future efficiency of foreseen technical solutions.

With the aim of reaching social targets, Paper V discusses some company level interventions which could decrease the risk assessed by the wage-related indicator. One of the weaknesses of the overall approach used here is that currently it is not possible to measure the social impact of the proposed interventions in Paper V. The available data in the SHDB is built on an established input/output GTAP database, which shows economic relationships between 113 countries and 57 economic sectors in 2004. For modelling the reduction in negative social impacts created by interventions, a new database would need to be developed in order to measure the consequences of the changes on the economic relationships between the sectors due to the implementation of the interventions. Both the financial flows (trade patterns) and the sectoral risk profiles may change in such a development. Therefore, it is not possible to accurately predict the social impact of interventions by using the SHDB.

Currently there is an absence of consensus models for impact pathways that reflect actual damage or benefit of company-level activities on a social end-points such as human well-being or staff turnover rate (Arvidsson et al. 2014; Russo Garrido et al. 2016). Therefore, one of the limitations in the present study was that it could not assess the impact of company level interventions on safeguard subjects and endpoints further down the cause-effect pathways. Relevant social pathways must be developed to measure the social benefits created with each intervention aimed at achieving long-term social sustainability goals. This would assist in deciding how to evaluate and invest in these company level interventions.

One of the limitations in this research is that the planetary boundaries are not very compatible with the chosen LCA impact categories, except in the case of climate change. Thus, there is a need for research on how the planetary boundaries framework (and other similar frameworks) can be matched with LCA impact categories, for example, by selecting other, potentially more compatible sets of mid-point indicators (e.g., eco costs; Vogtländer, 2001), or by expressing planetary boundaries in a different way. Another way of approaching the planetary boundary debate is the one taken by proponents of ecological footprinting. For example, Kissinger et al. (2013) have estimated the global hectares necessary for supplying all the textiles (and 11 other materials) required by urban populations. By allowing for comparisons between the area demanded by the textiles and the productive area of the earth, this has the advantage of simpler communication than the proposal in the present study, however, the present approach deals with the problem of missed pollution indicators inherent in ecological footprinting (Peters et al. 2008) by including some pollution-related and social LCA indicators.

A number of other authors have assessed garment life cycles from cradle to gate (e.g. Steinberger et al, 2009). As previously discussed in Steinberger et al. (2009), applying explicit country level data can take into account the global production-consumption chain. Therefore, utilizing national level data is a promising method for reflecting the globalized supply chain. In Paper V, performing the LCA on the level of the Swedish fashion sector puts the impact from this sector into perspective and enables comparisons with, for instance, the total environmental footprint of Swedes or with other industry sectors.

4.4 LCA versus reality

Young (1964) has defined system as "a set of objects together with relationships between the objects and between their attributes". System analysis has been utilized to deal with problems related to system behaviour or interactions between systems. A sub-category of system analysis is environmental system analysis, which focuses on handling the sustainability challenges of interactions between socio-technical and environmental systems (Finnveden & Moberg, 2005). The challenges of dealing with such systems are due to the fact that these systems are difficult to formulate, have a high degree of complexity, and require transdisciplinary problem solving (Coyne, 2005). When dealing with the "wickedness" of these systems based on reductionist approaches, there is a risk of oversimplification and creating a biased picture of the real world (Seager et al. 2012).

LCA and SLCA were the tools of sustainable system analysis which were utilised in this research to understand the environmental and social challenges of the fast fashion sector. One of the criticisms of these tools is their inadequacy in modelling real world systems since simplification of either the static content or dynamics of systems is unavoidable while using these tools.

As an example of the first issue, the content of the model of the collaborative consumption system in Paper II is necessarily a simplification based on available data. One surprising result from the assessment of the collaborative consumption business models was the increase in freshwater ecotoxicity especially in scenarios using high impact transportation systems. It is possible that this represents an imbalance between the level of detail in LCI data for textile production compared with transportation. Toxic emissions from the textile production phase are seldom inventoried in database information (Roos, 2015)). USEtox was the characterisation method used in the present study, and while this consensus method covers most chemicals, it lacks characterisation factors for many textile chemicals (Roos & Peters, 2015). On the other hand, the toxic emissions from energy production and transportation systems are relatively well inventoried and characterisation factors are typically available for the main toxicants, so that these processes tend to dominate all toxicity calculations. In other words, missing data is one reason why readers should be careful in interpreting LCA results.

An example of missing dynamics is the challenge of applying SLCA to management interventions. In implementing SLCA, an input/output-based social hot spot identification was performed in the present study for the Swedish apparel sector. These findings can be used to help identify the potential of interventions that reduce the need to import textiles from countries in which social hotspots were identified, to reduce risk that products are associated with social deprivations. However, in reality, when interventions are implemented on a large scale, market effects might lead to completely different consequences as the value chains are reorganized to accommodate the major change. As an example, if consumers avoid clothing products from Bangladesh on account of concerns about labour abuse, this might depress the price of such products from that country and drive the wages and conditions of textile workers in Bangladesh down further. For this reason, it would be a rather facile form of analysis to merely shift production from one country to another in a static input/output model and concern oneself with industry in the country to which the production is moved. Therefore, more dynamic modelling and social impact research is needed into how increased circularity of textile flows will change the environmental and social impacts of the fashion industry.

5. Conclusion

This chapter summarises the main conclusions from the discussion in Chapter 4. The research presented in this thesis contributes to the overall aim of better understanding of the social and environmental challenges associated with fast fashion and how these challenges can be reduced by applying dematerialisation interventions. With that aim in mind, the research focused on applying LCA for assessing environmental and social impacts of fast fashion. Since SLCA is not a mature methodology for assessing social impacts of the fashion industry, the research focused on major challenges in applying SLCA for assessing social challenges. Further, the research focused on identifying the scope of the dematerialisation interventions to reach sustainability targets. The research contributes to answering the following research questions:

Research question 1: Can textile recycling generate environmental benefits?

In Paper I, three different recycling techniques for a model waste consisting of 50% cotton and 50% polyester were identified. The recycling processes were: material reuse of textile waste of adequate quality; separation of cellulose from polyester using N-methylmorpholine-N-oxide as a solvent; and chemical recycling of polyester. The results of applying LCA showed that these recycling techniques can, in theory, deliver environmental benefits compared to incineration, which represents conventional textile waste treatment in Sweden. The material reuse process exhibits the best performance of the studied systems. Sensitivity analyses showed that these results are particularly sensitive to the considered yields of the processes and to the choice of replaced products. The LCA results for a scenario with an integrated use of these recycling technologies for optimal usage of their different features showed there are major potential savings in comparison to current textile waste management practices.

Research question 2: What are the key factors controlling the environmental impact in collaborative consumption business models?

In Paper II, LCA was implemented to explore the environmental performance of clothing libraries as one of the possible ways in which collaborative consumption can be implemented. Furthermore, the key factors that influence the environmental impact of clothing libraries were investigated. The assessment was based on three key popular garments that are stocked in clothing libraries: jeans, T-shirts, and dresses. The results show the significant contribution of use phase transport for the collaborative consumption business models. Moreover, the results showed that to achieve environmental gains by implementing collaborative consumption business models, it is important to substantially increase garment service life. The results quantitatively demonstrated the potential risk of problem-shifting: increased customer transportation can offset the benefits gained from reduced production. This highlights the need for considering logistics when implementing collaborative consumption business models.

Research question 3: What are the most relevant social indicators for assessment in and communication by the fashion industry?

In order to select the most relevant social indicators for assessment and communication of social issues related to the fashion industry, a survey was conducted in Paper III. The study identified consumer and industry expert priorities for social issues and investigated the similarities and differences between them. The results show that the top ten prioritised indicators for both consumers and industry experts are related to employee health and safety, child labour, fair salary, employment security, avoidance of discrimination, and fair competition. Consumers were also highly concerned about the provision of social benefits for employees and about corporate commitment to human rights in societies in which companies operate. However, from the industry expert perspective, the potential for employees and external stakeholders to file complaints were highly prioritised.

Furthermore, the results of the survey were mapped with the indicators suggested in the UNEP/SETAC guidelines. Considering the subcategories suggested by UNEP/SETAC, both consumer and industry expert priorities were related to labour-related subcategories, such as Freedom of association and collective bargaining, Forced labour, Equal opportunities/Discrimination, Employee health and safety, Child labour, Fair salary, and Fair competition in relation to value chain actors. However, one of the indicators that was highly prioritised by industry experts, relating to filing complaints, was not matched with any indicator in the UNEP/SETAC guidelines. This indicates the potential need of complementing the UNEP/SETAC framework with additional indicators in studies with a focus on the textile and fashion industry.

The comparison with the social indicators of the GOTS labelling scheme showed that GOTS covers most of the social issues ranked highly by consumers, in particular the issues related to worker conditions such as health and safety, contracts, employment security, child labour, fair salary, equal gender opportunities, social benefits, and respect for human rights. On the other hand, the results suggest that GOTS, an example of one of the labels used in the fashion industry, would be more meaningful to consumers if it extended its coverage to additional affected stakeholders such as commitment to human rights in relation to society and avoiding misleading marketing in relation to value chain actors throughout a product's life cycle.

Research question 4: What parameter settings are appropriate when constructing a model of the product system with an input/output approach to measuring social impacts?

Paper IV explored an application of SLCA on the clothing production supply chain by applying input/output-based modelling. The study investigated some important parameters including the cut-off value and the definition of "hotspot" in constructing an input/output-based product system. The study pinpointed social hotspots in the clothing production supply chain for 11 different social indicators selected by clothing product consumers. Some sectors, such as commerce and business services in Bangladesh, were identified as hotspots for a number of social indicators. Some main sectors from the foreground system, such as plant-based fibre, textiles, and wearing apparel production, were also identified as social hotspots. The role of the cut-off value in the input/output-based model was investigated by carrying out a sensitivity analysis for three different indicators. The result shows that the choice of cut-off value can directly affect the number of CSSs included in the product system model and, therefore, influence the results. However, it was found that the majority of CSSs involved in the clothing supply chain could be captured by applying a 2 % cut-off value, which was used in the model. In addition, the definition of "hotspot" in relation to risk level was investigated. The results show that for the indicator child labour, the working hours attributed to the low- and medium-risk levels was higher than for the high- and very high-risk levels. Therefore, the evaluation of risk levels other than high and very high can provide a more complete picture of hotspots in some cases.

Research question 5: What is the scale of challenges and potential of interventions in relation to global sustainability targets?

In Paper V, the social and environmental performance of the fashion industry in relation to sector-level sustainability targets was compared and revealed which types of dematerialisation interventions (technical improvements, behavioural changes and new business models), can potentially provide sufficient improvements. The results from the environmental impact assessment on the sector level showed that the interventions that are most likely to be effective are those directed towards reducing the burden of the production phase of the garments. User behaviour is, however, very important when it comes to the service life of garments, including the consumer laundry behaviour, which is a key to prolonging the service life of a garment. It was concluded that none of the interventions are stand-alone solutions to reaching environmental targets, however, several interventions are possible to combine.

The risk of workers being paid a low wage (under 2 USD per day) appeared as one of the social hotspots associated with the Swedish apparel sector. However, evaluating the impact of interventions in relation to meeting living wages as a goal for 2050 was found to be difficult to measure due to the lack of available data to evaluate the social consequences of implementing interventions

6. Recommendations for Future Research

This chapter summarises future research needs identified during the research for this thesis.

In relation to dematerialisation interventions, there is a need for further research on different possible recycling interventions. Relatively little research has been conducted in the academic LCA community to characterise the life cycle impacts of chemical and mechanical recycling technologies. It would be worthwhile to expand such efforts and contrast these technologies with other kinds of recycling. Moreover, work is currently underway in research projects such as Mistra Future Fashion, to improve knowledge about the processes for chemical recycling of textiles. The creation of more life cycle inventory data from such research is critical to the development of better LCAs of chemical recycling options.

There is a need for more research on attributional and consequential LCAs for the studied dematerialisation routes to investigate the circumstances related to each of the approaches, and to investigate how to implement and interpret these two approaches in relation to the goal and scope of a study.

In relation to choosing a set of relevant indicators for social LCA, consumer priorities were used in Paper III. It would be challenging but worthwhile to investigate the indicator preferences of other stakeholders, including workers in garment producing countries, other value chain actors, and industry partners.

The impact assessment methods of SLCA need to be further developed. In Paper IV, the social hotspots of Swedish fashion consumption were assessed using performance reference points developed for the SHDB. In this research, the results of the social impact categories were not aggregated. Another interesting potential development would be the creation of a weighting system to aggregate social impacts.

By investigating the potential of interventions for achieving sustainability goals, Paper V clarified which environmental impact categories are likely to be manageable in relation to planetary boundaries if the proposed interventions are implemented. Moreover, particular social impact hotspots associated with the Swedish apparel sector were identified which require interventions to decrease the level of risk of negative social impacts. As the next step, there is a need to develop relevant social metrics to measure the social value created with each intervention and the risk level after implementing these interventions with the aim of achieving long-term social sustainability goals. This would assist in deciding how to evaluate and invest in company level interventions bearing in mind the time horizon.

7. References

Agrawal, V., Ferguson, M., Toktay, B., & Thomas, V. (2011). Is leasing greener than selling? *Management Science*, 58(3). 523 – 533

AITEX. (2007). Comparative study of the environmental impact of recycled cotton yarns vs conventional cotton yarns. Retrieved from www.eco-gear.ca/ecogear-Comparative-Study.pdf (Accessed December 2015).

Andersen, M. S. (2007). An introductory note on the environmental economics of the circular economy. *Sustainability Science*, *2*(1), 133–140.

Arvidsson, R., Baumann, H., & Hildenbrand, J. (2014). On the scientific justification of the use of working hours, child labour and property rights in social life cycle assessment: three topical reviews. The International Journal of Life Cycle Assessment, 20(2), 161–173.

Baitz, M., Albrecht, S., Brauner, E., Broadbent, C., Castellan, G., & Conrath, P. (2013). LCA's theory and practice: like ebony and ivory living in perfect harmony? *The International Journal of Life Cycle Assessment*, *18*. 5-13.

Barnes, L., & Lea ‐ Greenwood, G. (2006). Fast fashioning the supply chain: shaping the research agenda. *Journal of Fashion Marketing and Management: An International Journal*, *10*(3), 259–271.

Bauman, H., & Tillman, A.-M. (2004). *The hitch hiker´s guide to LCA*. Lund: Studentlitteratur. ISBN-13: 978-9144023649.

Belk, R. (2014). You are what you can access: sharing and collaborative consumption online. *Journal of Business Research*, *67*(8), 1595–1600.

Benoit, C., Norris, G., Valdivia, S., Ciroth, A., Moberg, A., Bos, U., Beck, T. (2010). The guidelines for social life cycle assess- ment of products: just in time! *The international Journal of Life CycleAssess*, *15*(1), 156–163.

Benoit-Norris, C., Cavan, D. A., & Norris, G. (2012). Identifying Social Impacts in Product Supply Chains:Overview and Application of the Social Hotspot Database. *Sustainability*, *4*(12), 1946–1965.

Benoit-Norris, C., & Mazijn, B. (2009). *Guidelines for Social Life Cycle Assessment of Products*. *Sustainable Development*. UNEP/SETAC.

Bhardwaj, V., & Fairhurst, A. (2010). Fast fashion: response to changes in the fashion industry. *The International Review of Retail, Distribution and Consumer Research*, *20*(1), 165–173.

Blanchet, K., & Girois, S. (2013). Selection of sustainability indicators for health services in challenging environments: balancing scientific approach with political engagement. *Evaluation and Program Planning*, *38*, 28–32.

Börjeson, L., Höjer, M., Dreborg, K.-H., Ekvall, T., & Finnveden, G. (2005). *Towards a user's guide to scenarios – a report on scenario types and scenario techniques*. Stockholm.

Bouyssou, D. (1990). Building criteria: a prerequisite for MCDA. In *Bana e Costa, C.A. (ed.) Readings in Multiple Criteria Decision Aid.* (pp. 58–80). Berlin: Springer-Verlag.

Brito, M. P. De, Carbone, V., & Meunier, C. (2008). Towards a sustainable fashion retail supply chain in Europe : Organisation and performance, *International Journal of Production Economics*, *114*, 534–553.

Brooks, A. (2010). Spinning and Weaving discontent: Labour relations and the production of meaning at Zambia-China Mulungushi textiles. *Journal of Southern African Studies*, *36*(1), 113–132.

Chhipi-Shrestha, G. K., Hewage, K., & Sadiq, R. (2015). "Socializing" sustainability: a critical review on current development status of social life cycle impact assessment method. *Clean Technologies and Environmental Policy*, *17*(3), 579–596.

Clifford, S. (2013). Some Retailers Say More About Their Clothing's Origins. *The New york times*. Retrieved from http://www.nytimes.com/2013/05/09/business/global/fair-trade-movement-extends-to-clothing.html?pagewanted=1&_r=1&adxnnlx=1393581905-51khFzWIGfe3oMkir8DS4w (Accessed May 2016)

Coyne, R. (2005). Wicked problems revisited. *Design Studies*, 26(1), 5–17.

Cuc, S., Girneata, A., Iordanescu, M., & Irinel, M. (2015). Environmental and socioeconomic sustainability through textile recycling. *Industria Textila*, 66(3), 156–163.

Dearing, J. a., Wang, R., Zhang, K., Dyke, J. G., Haberl, H., Hossain, M. S., Poppy, G. M. (2014). Safe and just operating spaces for regional social-ecological systems. *Global Environmental Change*, 28, 227–238.

EC. (2013). European Commission. Retrieved from http://ec.europa.eu.proxy.lib.chalmers.se/growth/sectors/fashion/textiles-clothing/ (Accessed May 2016)

Ekener-Petersen, E., & Finnveden, G. (2012). Potential hotspots identified by social LCA—part 1: a case study of a laptop computer. *The International Journal of Life Cycle Assessment*, *18*(1), 127–143.

Ekener-Petersen, E., Höglund, J., & Finnveden, G. (2014). Screening potential social impacts of fossil fuels and biofuels for vehicles. *Energy Policy*, 73, 416–426.

Ekvall, T., & Weidema, B. (2004). System boundaries and input data in consequential life cycle inventory analysis. *The International Journal of Life*

Cycle Assessment, *9*(3), 161–171.

Erişen, C., Erişen, E., & Özkeçeci-Taner, B. (2013). Research Methods in Political Psychology. *Turkish Studies*, 14(1), 13–33.

Falck, W. E., & Spangenberg, J. H. (2014). Selection of social demand-based indicators: EO-based indicators for mining. *Journal of Cleaner Production*, 84(1), 193–203.

Farrant, L., Olsen, S. I., & Wangel, A. (2010). Environmental benefits from reusing clothes. *The International Journal of Life Cycle Assessment*, 15(7), 726–736.

Finnveden, G., Hauschild, M. Z., Ekvall, T., Guinée, J., Heijungs, R., Hellweg, S., Suh, S. (2009). Recent developments in Life Cycle Assessment. *Journal of Environmental Management*, *91*(1), 1–21.

Finnveden, G., & Moberg, Å. (2005). Environmental systems analysis tools – an overview. *Journal of Cleaner Production*, 13(12), 1165–1173.

Fletcher, K. (2013). *Sustainable fashion and textiles: design journeys*. Routledge. ISBN:184407463

Fletcher, K., & Tham, M. (2014). *Routledge handbook of sustainability and fashion*. Routledge. ISBN:1134082959

Floyd J Folwler, J. (2013). *Survey research methods*. SAGE publications. ISBN-13: 978-1412958417

Fontes, J. (2016). Handbook-for-Product-Social-Impact-Assessment-3.0. PRé Sustainability, The Netherlands.

Frischknecht, R., Büsser, S., & Krewitt, W. (2009b). Environmental assessment of future technologies: how to trim LCA to fit this goal? *The International Journal of Life Cycle Assessment*, *14*(6), 584–588.

Gaines, B. J., Kuklinski, J. H., & Quirk, P. J. (2006). The Logic of the Survey Experiment Reexamined. *Political Analysis*, 15(1), 1–20.

Genovese, A., Acquaye, A. A., Figueroa, A., & Koh, S. C. L. (2015). Sustainable supply chain management and the transition towards a circular economy: Evidence and some applications. Omega.

Goedkoop, M., Heijungs, R., Huijbergts, M., De Schreyver, A., Struijs, J., & Zelm, R. van. (2009). ReCiPe 2008 . Report 1 : Characterisation. Retrieved from http://www.leidenuniv.nl/cml/ssp/publications/recipe_characterisation_addenum.pdf (Accessed May 2016).

Guinée, J. B., Heijungs, R., Huppes, G., Zamagni, A., Masoni, P., Buonamici, R., Rydberg, T. (2011). Life cycle assessment: past, present, and future. *Environmental Science & Technology*, 45(1), 90–6.

Guinee, J., Gorree, M., Heijungs, R., Huppes, G., Kleijn, R., & De Konning, A. (2002). Handbook on life cycle assessment : operational guide to the ISO standards. Dordrecht: Kluwer Academic Publisher. ISBN 978-0-306-48055-3

Gwozdz, W., Netter, S., Bjartmarz, T., & Reisch, L. A. (2013). Report on Survey Results on Fashion Consumption and Sustainability among Young Swedes. Copenhagen.

Hetherington, A. C., Borrion, A. L., Griffiths, O. G., & McManus, M. C. (2013). Use of LCA as a development tool within early research: challenges and issues across different sectors. *The International Journal of Life Cycle Assessment*, *19*(1), 130–143.

Hospido, A., Davis, J., Berlin, J., & Sonesson, U. (2009). A review of methodological issues affecting LCA of novel food products. *The International Journal of Life Cycle Assessment*, *15*(1), 44–52.

Huijbregts, M. A. J., Gilijamse, W., Ragas, A. M. J., & Reijnders, L. (2003). Evaluating Uncertainty in Environmental Life-Cycle Assessment. A Case Study Comparing Two Insulation Options for a Dutch One-Family Dwelling. *Environmental Science & Technology*, *37*(11), 2600–2608.

IOCGP. (2003). Interorganizational Committee on Principles and Guidelines for Social Impact Assessment, Principles and Guidelines for Social Impact Assessment in the USA. *Impact Assessment and Project Appraisal*, *21*(3), 231–250.

ISO. (2006). *Environmental management – life cycle assessment – principals and framework. International Standard ISO 14040*. Geneva, Switzerland: International Organization for Standardization – ISO.

Jørgensen, A., Hauschild, M. Z., Jørgensen, M. S., & Wangel, A. (2009). Relevance and feasibility of social life cycle assessment from a company perspective. *The International Journal of Life Cycle Assessment*, *14*(3), 204–214.

Kissinger, K., Sussman, C., Moore, J., & Rees, W. (2013). Accounting for the Ecological Footprint of Materials in Consumer Goods at the Urban Scale. *Sustainability*, *5*(5), 1960–1973.

Klöpffer, W., & Renner, I. (2008). Life-Cycle Based Sustainability Assessment of Products. In *Environmental management accounting for cleaner production* (pp. 91–102). Dordrecht: Springer.

Koszewska, M. (2011). Social and eco-labelling of textile and clothing goods as a means of communication and product differentiation. *Fibres and Textiles in Eastern Europe*, *87*(4), 20–26.

Koszewska, M. (2015). Life cycle assessment and the environmental and social labels in the textile and clothing industry. in *Handbook of Life Cycle Assessment (LCA) of Textiles and Clothing*. Elsevier Ltd. ISBN: 9780081001691

Kruse, S. a., Flysjö, A., Kasperczyk, N., & Scholz, A. J. (2008). Socioeconomic indicators as a complement to life cycle assessment—an application to salmon production systems. *The International Journal of Life Cycle Assessment*, *14*(1), 8–18.

Kuechler, M. (1998). The survey method an indispensable tool for social science research everywhere? *American Behavioral Scientist*, (2), 178–200.

Kunnari, E., Valkama, J., Keskinen, M., & Mansikkamäki, P. (2009). Environmental evaluation of new technology: printed electronics case study. *Journal of Cleaner Production*, *17*(9), 791–799.

Lagarde, V., & Macombe, C. (2013). Designing the social life cycle of products from the systematic competitive model. *The International Journal of Life Cycle Assessment*, *18*, 172–184.

Leach, M., Raworth, K., & Rockström, J. (2013). Between social and planetary boundaries: Navigating pathways in the safe and just space for humanity. In *Social Science World Social Science*. Paris: UNESCO.

Leismann, K., Schmidt, M., Rohn, H., & Baedeker, C. (2013). Collaborative consumption: towards a tesourcesaving consumption culture. *Resources*, *2*(3). 184-203.

Lenzen, M. (2000). Errors in conventional and input-output-based life-cycle inventories. *Journal of Industrial Ecology*, *4*(4), 127–148.

Lundie, S., Peters, G., Ashbolt, N., Lai, E., & Livingston, D. (2006). A sustainabillity framework for the Australian water industry. *Journal of Australian Water Assciation*, *33*, 83–88.

MacCarthy, B. L., & Jayarathne, P. (2010). Fast fashion: achieving global quick response (GQR) in the internationally dispersed clothing industry. In *Innovative Quick Response Programs in Logistics and Supply Chain Management* (pp. 37–60). Berlin Heidelberg: Springer.

Majeau-Bettez, G., Strømman, A., & Hertwich, E. (2011). Evaluation of process- and input-output-based life cycle inventory data with regard to truncation and aggregation issues. *Environmental Science & Technology*, *45*(23), 10170–10177.

Mascarenhas, A., Coelho, P., Subtil, E., & Ramos, T. B. (2010). The role of common local indicators in regional sustainability assessment. *Ecological Indicators*, *10*(3), 646–656.

Mascarenhas, A., Nunes, L. M., & Ramos, T. B. (2014). Exploring the self-assessment of sustainability indicators by different stakeholders. *Ecological Indicators*, *39*, 75–83.

Mascarenhas, A., Nunes, L. M., & Ramos, T. B. (2015). Selection of sustainability indicators for planning: combining stakeholders' participation and data reduction techniques. *Journal of Cleaner Production*, *92*, 295–307.

Mathe, S. (2014). Integrating participatory approaches into social life cycle assessment: The SLCA participatory approach. *International Journal of Life*

Cycle Assessment, *19*(8), 1506–1514.

Mathews, J. A., & Tan, H. (2011). Progress towards a circular economy in China- The drivers (and inhibitors) of Eco-industrial inititative. *Journal of Industrial Ecology*, *15*(3). 435–457

McNeill, L., & Moore, R. (2015). Sustainable fashion consumption and the fast fashion conundrum: fashionable consumers and attitudes to sustainability in clothing choice. *International Journal of Consumer Studies*, *39*(3), 212–222.

Moran, D., McBain, D., Kanemoto, K., Lenzen, M., & Geschke, A. (2015). Global Supply Chains of Coltan. *Journal of Industrial Ecology*, *19*(3), 357–365.

Muthu, S. S., Li, Y., Hu, J. Y., & Ze, L. (2012). Carbon footprint reduction in the textile process chain: Recycling of textile materials. *Fibers and Polymers*, *13*(8), 1065–1070.

Östlund, Å., Wedin, H., Bolin, L., Jönsson, C., Posner, S., Eriksson, M., & Sandin, G. (2015). *Textilåtervinning- Tekniska möjligheter och utmaningar*. Retrieved from: www.naturvardsverket.se/Documents/publikationer6400/978-91-620-6685-7.pdf?pid=15536tioner6400/978-91-620-6685-7.pdf?pid=15536 (Accessed May 2016)

Palm, D., Ealender, M., Watson, D., Kiorboa, N., & Salmenpera, H. (2014). Towards a Nordic textile strategy - Collection, sorting, reuse and recycling of textiles. Copenhagen.

Papong, S., Itsubo, N., Malakul, P., & Shukuya, M. (2015). Development of the social inventory database in Thailand using input-output analysis. *Sustainability (Switzerland)*, *7*(6), 7684–7713.

Pennington, D. W., Potting, J., Finnveden, G., Lindeijer, E., Jolliet, O., Rydberg, T., & Rebitzer, G. (2004). Life cycle assessment part 2: current impact assessment practice. *Environment International*, *30*(5), 721–39.

Pesonen, H. L., Ekvall, T., Fleischer, G., Huppes, G., Jahn, C., Klos, Z. S., Wenzel, H. (2000). Framework for scenario development in LCA. *International Journal of Life Cycle Assessment*, 5(1).21-30.

Peters, G. M. (2009). Popularize or publish? Growth in Australia. *The International Journal of Life Cycle Assessment*, *14*(6), 503–507.

Peters, G., Sack, F., Lenzen, M., Lundie, S., & Gallego, B. (2008). Towards a deeper and broader ecological footprint. *Engineering Sustainability*, 161(1), 31–37.

Peters, G., Svanström, M., Roos, S., Sandin, G., & Zamani, B. (2015). *Handbook of Life Cycle Assessment (LCA) of Textiles and Clothing*. *Handbook of Life Cycle Assessment (LCA) of Textiles and Clothing*. Elsevier. doi:10.1016/B978-0-08-100169-1.00001-0

Pfister, S., Koehler, A., Hellweg, S. (2009). Assessing the environmental impacts of freshwater consumption in LCA. *Environmental Science & Technology*, *43*, 4098–4101.

Piscicelli, L., Cooper, T., & Fisher, T. (2014). The role of values in collaborative consumption: insights from a product-service system for lending and borrowing in the UK. *Journal of Cleaner Production*, *97*, 21–29.

Raworth, K. (2012). A Safe and Just Space For Humanity: Can we live within the Doughnut? *Nature*, *461*, 1–26.

Reap, J., Roman, F., Ducan, S., & Bras, B. (2008). A survey of unresolved problems in life cycle assessment. Part 1: goal and scope and inventory analysis. *The International Journal of Life Cycle Assessment*, *13*(4), 209–300.

Rebitzer, G., Ekvall, T., Frischknecht, R., Hunkeler, D., Norris, G., Rydberg, T., … Pennington, D. W. (2004). Life cycle assessment part 1: framework, goal and scope definition, inventory analysis, and applications. *Environment International*, *30*(5), 701–20.

Roos, S. (2015). *Towards Sustainable Use of Chemicals in the Textile Industry: How life cycle assessment can contribute*. Chalmers University of Technology. Gothenburg.

Roos, S., & Peters, G. M. (2015). Three methods for strategic product toxicity assessment—the case of the cotton T-shirt. *The International Journal of Life Cycle Assessment*, 20(7),903-912.

Roos, S., Sandin, G., Zamani, B., & Peters, G. (2015). *Environmental assessment of Swedish fashion consumption. Five garments-sustainable future*. Stockholm, Sweden: Mistra Future Fashion.

Russo Garrido, S., Parent, J., Beaulieu, L., & Revéret, J.-P. (2016). A literature review of type I SLCA—making the logic underlying methodological choices explicit. The International Journal of Life Cycle Assessment.

Rowley, H. V, Peters, G., Lundie, S., & Moore, S. J. (2012). Aggregation sustainability indicators: beyond the weighted sum. *Journal of Environmental Management*, *111*.24-33.

Sandin, G., Peters, G., Pilgård, A., Svanström, M., & Westin, M. (2011). Integrating Sustainability Considerations into Product Development: A Practical Tool for Prioritising Social Sustainability Indicators and Experiences from Real Case Application. In Towards life cycle sustainability management (pp. 3–14). Berlin: Springer.

Seager, T., Selinger, E., & Wiek, A. (2012). Sustainable engineering science for resolving wicked problems. *Journal of Agricultural and Environmental Ethics*, *25*, 467–484.

Steffen, W., Richardson, K., Rockström, J., Cornell, S., Fetzer, I., Bennett, E., Sörlin, S. (2015). Planetary Boundaries: Guiding human development on a changing planet. *Science*, 347 (6223), 1259855-1259855.

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*(5), 443–455.

Sull, D., & Turconi, S. (2008). Fast fashion lessons. *Business Strategy Review*, *19*(2), 4–11.

The European Apparel and Textile Confederation. (2013). EURATEX. Retrieved from http://euratex.eu/fileadmin/user_upload/documents/key_data/Euratex_Keyfigures_2013.pdf (Accessed May 2016)

Turker, D., & Altuntas, C. (2014). Sustainable supply chain management in the fast fashion industry: An analysis of corporate reports. *European Management Journal*, *32*(5), 837–849.

Viederman, D. (2014). Supply chains and forced labour after Rana Plaza. *The Guardian*. Retrieved from: www.theguardian.com/global-development-professionals-network/2013/may/30/rana-plaza-bangladesh-forced-labour-supply-chains (Accessed May 2016).

Woolridge, A. C., Ward, G. D., Phillips, P. S., Collins, M., & Gandy, S. (2006). Life cycle assessment for reuse/recycling of donated waste textiles compared to use of virgin material: An UK energy saving perspective. *Resources, Conservation and Recycling*, *46*(1), 94–103.

Young, O. (1964). A survey of general systems theory. *General Systems Yearbook Society for General Systems Research.*, *9*, 61–80.

Yuan, Z., Bi, J., & Moriguichi, Y. (2008). The Circular Economy: A New Development Strategy in China. *Journal of Industrial Ecology*, *10*(1-2), 4–8.