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Dressing up the environmental potential for product-service systems:

A comparative life cycle assessment on consumption in rental clothing vs. linear business models

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Abstract

Alternative business models such as product-service systems (PSSs) have been cited as a solution for the impacts from consumption and fast fashion, but there is a lack of evidence supporting the environmental claims of such business models for clothing. The research aimed to understand if rental clothing business models such as PSSs have the environmental benefits often purported by identifying ways to define the function of rental clothing, and quantifying the environmental impacts of rental clothing in a life cycle assessment (LCA). Since consumer behaviour can be reflected in different ways in how they engage with products, three functional units were analysed. These functional units offer alternative perspectives to the impact, yielding different consumption scenarios from cradle-to-grave to quantify the impact potential of a PSS in comparison with a linear business model. These scenarios include variation in use intensity, rental transport mode, and replacement rate of rental for purchased clothing. Summarising the total impact for one system in comparison to another is difficult since a single score would not fully capture the disparity in the contribution of the impacts for different categories. The variation in the impact by the scenarios throughout the different functional units indicates that the environmental savings potential for rental business models to replace linear business models are suitable when rental business models substitute the need to purchase garments to a high degree. Results also suggest that the replacement of one use or wear occasion by one rental garment does not create environmental benefits due to the high transportation burden needed to facilitate one rental. The research contributes to the development of a methodology to understand the environmental impact of shared goods and provides quantitative evidence of the environmental impacts of a clothing PSS for four impact categories. Business models such as PSSs do have environmental potential when given the right conditions to cultivate, and they can play an important role in shifting traditional consumption thinking and slowly dissolving the connection of consumers to ownership and products.

Keywords: product-service system, life cycle assessment, rental clothing, environmental impact, business model

Executive Summary

There is an emerging awareness and increasing global effort to change current consumption patterns, especially in regard to fast fashion. Fast fashion contributes to resource depletion, produces large amounts of waste water as well as solid waste, contributes to chemical and pesticide residues, and is known for the exploitation of workers, among many other negative impacts (Piontek & Müller, 2018). Clothing production globally has nearly doubled in the last 15 years, although clothing use has declined by nearly 40% (Ellen MacArthur Foundation, 2017). With diminishing natural resources and increasing greenhouse gas emissions (GHG), a change to conventional business models (BMs) and consumer patterns is critical to reduce current unsustainable impacts (Pohl et al., 2019).

Broad descriptions of BMs based on ideologies under the circular economy, the sharing economy, and collaborative consumption are reputedly named to contribute to sustainability objectives (Mont et al., 2019), and have been suggested as solutions in the fashion industry (Pal, 2016). Despite the many definitions of these concepts and the implications of their associated BMs, they overlap in their main goals of optimising resource use (Ellen MacArthur Foundation, 2015, 2017; European Commission, 2014). Business models like product-service systems (PSSs) often recognise these goals and are seen as pathways to the acceptance of service-based societies (Tukker, 2015). Reuse, and ideas of access over ownership have gathered increasing attention in media and academics, with an increasing number of economic activities relating to reuse (Castellani et al., 2015). The positive environmental effects from PSSs are supposed to stem from the increased use of goods through an extended lifespan or increased intensity, leading to implications such as resource efficiency and dematerialisation. However, there appears to be limited evidence for the environmental claims for shared clothing under PSSs despite available methods such as life cycle assessment (LCA) (Doualle et al., 2015).

There is a need to understand if the environmental potentials of alternative BMs such as PSSs are legitimate, however there is a lack of studies to indicate this (Amasawa et al., 2020; Amaya et al., 2014; Böcker & Meelen, 2017). From a theoretical perspective, PSSs can bring potential savings and additional environmental benefits, but this may backfire through consumer's behavioural responses and other systemic factors. It is recognised that LCAs can be used to assess such environmental impacts, but there are many challenges when applying it to a PSS.

Aim and research questions

The aim of this research is to progress the understanding of the potential sustainability outcomes for PSSs by contributing quantitative evidence of the environmental impacts of a business-to-consumer (B2C) use-oriented PSS. This research is of descriptive, evaluative, and explanatory nature. It aims to: a) describe the ways that the function of rental clothing can be defined in an LCA framework; b) evaluate the environmental impacts of rental clothing by quantifying and assessing them; and c) explain the factors that contribute to the variation of results of the associated environmental impact.

RQ1: What ways can the function of rental clothing be defined to assess the impacts in an LCA framework?

RQ2: What are the environmental impacts of a rental dress company, and how do they compare to the impacts of dress consumption in a linear business model?

RQ2.1: *To what extent do user behaviour variations impact the result of an LCA on a clothing PSS?*

Methodological approach

The research design employs case study research as a method to select empirical data through qualitative and quantitative methods. The company used for the case study is a B2C rental dress company in Stockholm, Sweden. The case study provides a description and explanation of contextual factors that alter the environmental impact outcomes for PSSs. A comparative LCA of dress consumption in a rental business model vs. linear business model was conducted using the SimaPro software. An overview of data collection and analysis methods and their contribution to the research questions are shown in the figure below.

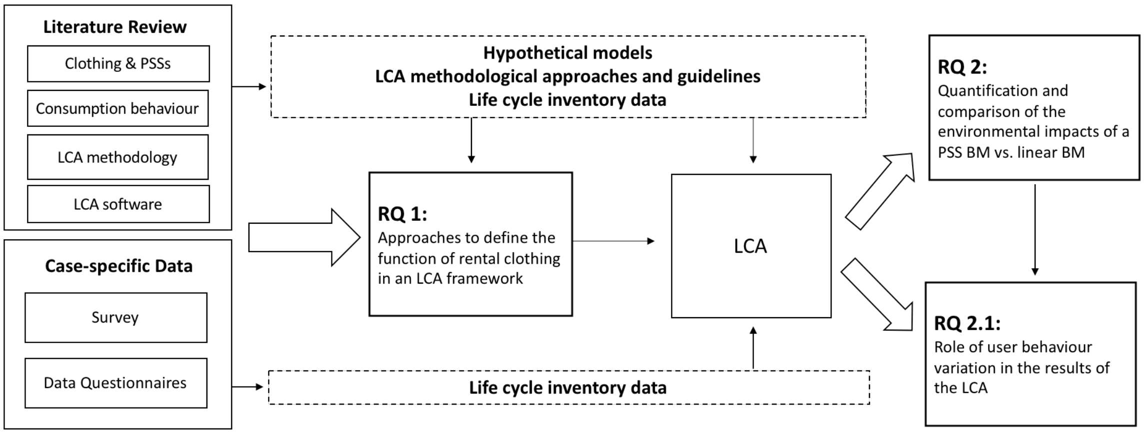

Figure I. Methodology and application to RQs.

Findings

RQ1: What ways can the function of rental clothing be defined to assess the impacts in an LCA framework?

While there are indications for why consumers choose to engage in PSSs, in particular rental clothing business models, it is not fully understood how consumers behave when doing so and how it affects their other consumption patterns. Since consumer behaviour can be reflected in different ways in how they consume and engage with products, three functional units (FUs) were analysed. These FUs offer different perspectives to the impact and impact potential of a PSS in comparison with a linear business model, yielding different consumption scenarios from cradle-to-grave. These scenarios include variation in use intensity, rental transport mode, and replacement rate of rental for purchased clothing.

The narrowly defined FU of "one average use" provides a somewhat simplistic, but a more concrete understanding of the impact associated with one use of a dress in a linear vs a rental scenario. This involves dividing certain activities or life cycle stages in the life cycle inventory (LCI), such as dress production, by the total number of uses or users in the scenario. Although it factors in variations in the use intensity of a garment, the scope of the FU is limited since it does not consider how rental clothing can displace the production needed for clothing under ownership. The other two FUs are more broadly defined, in which "4 years of consumer needs" for a formal dress are analysed. One FU is where the needs are satisfied through a number of garments purchased, and the other where the needs are satisfied though the number of wear occasions or uses. These FUs include a replacement rate where rental dresses replace linear dresses to some degree either by the garment itself, or by the wear occasion. These more broadly defined FUs take a systems-thinking approach by considering the potential for rental systems to displace linear consumption systems on a specific product-basis. However, rebound effects for purchasing of other type of products are not accounted for.

RQ2: What are the environmental impacts of a rental dress company, and how do they compare to the impacts of a dress consumption in a linear business model?

The most significant environmental impact categories consistent through all three FUs were freshwater ecotoxicity, marine ecotoxicity, and human carcinogenic toxicity. The scenarios and the results varied in each of the FUs. Summarising the total impact for one system in comparison to another, as well as stating which scenario is the most environmentally beneficial than the other is difficult. Furthermore, a single score would not fully capture the disparity in the contribution of the impacts for different categories, which imply different issues and solutions to address them.

The variation in the impact by rental and linear scenarios throughout the different FUs indicate that the environmental savings potential for rental business models to replace linear business models are suitable where rental business models substitute the need to purchase garments to a high degree. Furthermore, results suggest that the replacement of one use or wear occasion by one rental garment does not create environmental benefits due to the high transportation burden needed to facilitate one rental. Therefore, rental garments can be beneficial to replace the use of linear garments if rental garments are used multiple times in one rental period. This would require longer rental periods in order to provoke increased use.

RQ2.1: To what extent do user behaviour variations impact the result of an LCA on a clothing PSS?

The environmental savings potential that a PSS can have is influenced heavily by how consumers choose to engage with rental BMs. This is shown in how many times consumers use garments, how they use rental to substitute or complement their purchasing or use needs, and how they choose to travel to rental store locations. These causal mechanisms were tested in the LCA.

Consumers' use intensity of garments is important both in the linear and PSS BM. Increased use intensity of clothes they already own, or purchase can significantly decrease the environmental impacts from production. Consumers can also increase their use intensity of garments in the same rental period to decrease their impact from transportation, as well as engage in more rentals, if they use low-impact transportation modes.

The replacement rate of rental for purchased dresses plays an important role in discerning the environmental benefit of rental clothing. Users who rent solely in addition to normal purchasing are not creating any benefit, however as their engagement with rental reduces the need to purchase and produce products, the benefit of rental increases. The LCA, however, does not account for rebound effects, and it should be noted that use of rental scenarios may result in consumer savings which can be spent on other products and services that would result in a bigger impact.

Variation in transport modes was only modelled for the consumer transport to the rental store, and results between the high-impact transport and other transport modes were significant. Users who choose to take public transportation modes can significantly reduce their impact and increase the environmental potential for clothing rental. Consumers who use high-impact transport such as cars, negate the benefit that a PSS could have and result in a higher impact than linear scenarios.

Conclusions and Recommendations

As society begins to transition away from business-as-usual, and the fashion industry moves away from a take-make-dispose economy and towards circular strategies and sharing principles, it is important to not identify a blueprint of a business model as the most sustainable for all contexts. Business models with sustainability potential should be retrofit to each context and case, from the geographic location to the product and the consumer market. Business models such as PSS do have potential when given the right conditions to cultivate, and PSSs can play an important role in shifting traditional consumption thinking and slowly dissolving the connection of consumers to ownership and products. Local municipalities and governments can increase the sustainability potential of such business models by developing infrastructure and fostering an environment that encourages rental, as well as motivates consumers to act and think in ways with less environmental impact. Industry leaders can help to pave the way by honing their business models to provide choice architecture for consumers to behave sustainably.

This research contributed to an understanding of various factors that play a role in the sustainability potential of PSSs both inside and outside of a business model's control. Therefore, recommendations are provided both to local governments as well as current and prospective businesses involved in product-service systems.

Recommendations to municipalities and local governments to support PSSs:

- Create robust public transportation, cycling, and walking infrastructure to encourage more sustainable consumer transportation.
- Create car free zones for shopping areas.
- Encourage central locations for companies offering rental or facilitating product sharing.

Recommendations to rental business leaders and companies:

- Incentivise consumers to increase their usage of a product per rental by increasing the rental time period to longer time frames that encourage a stewardship of garments.
- Centralise physical rental stores to minimise consumer travel distance and encourage use of public transportation.
- Offer logistic services using bike-delivery or create a network of local distribution points.
- Offer services to consumers that provide them with a choice architecture to select the most sustainable alternative.
- Minimise the need for internal company logistics for product procurement and repair.

Business models such as PSSs can help transition society to alternative pathways of consumption, leading to more community-oriented businesses and business values designed around decreasing overall environmental impacts and reducing waste. However, business models striving to be sustainable cannot stop at shifting to service-oriented business offerings, businesses need to begin to strive for sufficiency and a decrease in total consumption. This research provides caution to defining all PSSs as sustainable business models, however it recognises the value and positive environmental potential that they could have in certain contexts, and advocates for more PSSs to help transition society away from linear business models.

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Abbreviations

ALCA- attributional life cycle assessment

B2C- business-to-consumer

BM- business model

CLCA – consequential life cycle assessment

EoL- end of life

FU- functional unit

GWP- global warming potential

ILCD- International Reference Life Cycle Data System

ISO- International organization for standardization

LCA –life cycle assessment

LCI – life cycle inventory

LCIA – life cycle impact assessment

P2P – peer-to-peer

PSS – product-service system

RF- reference flow

RR – replacement rate

Life cycle impact category abbreviations:

Global warming- GWP

Stratospheric ozone depletion – ODP

Ionizing radiation – IRP

Ozone formation, Human health – HOFP

Fine particulate matter formation – PMFP

Ozone formation, terrestrial ecosystems – EOFP

Terrestrial acidification - TAP

Freshwater eutrophication - FEP

Marine eutrophication – MEP

Terrestrial ecotoxicity – TETP

Freshwater ecotoxicity – FETP

Marine ecotoxicity – METP

Human carcinogenic toxicity – HTPc

Human non-carcinogenic toxicity – HTPnc

Land use – LOP

Mineral resource scarcity – SOP

Fossil resource scarcity – FFP

Water consumption – WCP

1 Introduction

There is an emerging awareness and increasing global effort to change current consumption patterns, especially in regard to fast fashion. Fast fashion contributes to resource depletion, produces large amounts of waste water as well as solid waste, contributes to chemical and pesticide residues, and is known for the exploitation of workers, among many other negative impacts (Piontek & Müller, 2018). The textile and fashion industry contributes to 20% of global wastewater, and 8-10% of global carbon emissions (UN Environment, 2019). On the consumer end, fast fashion has promoted faster disposal of clothing, and contributed to a societal shift prompting increased consumption (Armstrong & Lang, 2013). Although global clothing production has nearly doubled in the last 15 years, clothing use has declined by nearly 40% (Ellen MacArthur Foundation, 2017). If the global fashion industry does not change, it could use more than 26% of the carbon budget for the 2°C global warming limit by 2050 (Ellen MacArthur Foundation, 2017). With diminishing natural resources and increasing greenhouse gas emissions, a change to conventional business models (BMs) and consumer patterns is critical to reduce current unsustainable impacts (Pohl et al., 2019).

Broad descriptions of BMs based on ideologies under the circular economy, the sharing economy, and collaborative consumption are reputedly named to contribute to sustainability objectives (Mont et al., 2019), and have been suggested as solutions in the fashion industry (Pal, 2016). The understanding and dialogue around these concepts lack consistency in definitions across literature as well as media. Despite the many definitions of these concepts and the implications of their associated BMs, they overlap in their main goals of optimising resource use (Ellen MacArthur Foundation, 2015, 2017; European Commission, 2014) and to "oppose the linear economy by closing the loops in terms of resources and materials" (Sposato et al., 2017, p. 1799). The sharing economy, often used synonymously with collaborative consumption (Hamari et al., 2016) is sometimes posited as a component strategy to transition to the circular economy (Ellen MacArthur Foundation, 2017; European Commission, 2014). The European Commission recognises that one way to increase the value of underutilised resources are through collaborative consumption models based on activities such as lending, renting, and product-service systems (PSSs) (European Commission, 2014). Furthermore, they mention the circular approach of "renting, lending, or sharing services as an alternative to owning products" (European Commission, 2014, p. 10).

One approach to conceptualising the circular economy and sharing economy's similarities into a business model, is through a PSS. Business models like PSSs are seen as pathways to recognizing rental and more service-based societies (Tukker, 2015). Reuse, and ideas of access over ownership have gathered increasing attention in media and academics, with an increasing number of economic activities relating to reuse (Castellani et al., 2015). Business model elements of PSSs can be understood in different ways, depending on the specific services and offerings to consumers. This thesis will focus on use-oriented PSS, in which the product is still central to the business model, but access to the product is provided as a service to a number of users at different times, in which the ownership of the product is retained by the company (Tukker, 2004, 2015). The positive environmental effects from PSSs are supposed to stem from the increased use of goods through an extended lifespan or increased intensity, leading to implications such as resource efficiency and dematerialisation. The Nordic countries have shown active interest in addressing the impact of textiles through efforts such as textile recycling, prolonged garment lifetime, and development of rental options, with an emphasis on the latter effort and specific attention to PSSs in the fashion industry (Corvellec & Stål, 2017). The fashion industry has gained increasing interest and media attention in the past few years, as more research is conducted on BMs offering clothing access through rentals (Pedersen & Netter, 2015; Zamani et al., 2017), and more consumers are showing an increased interest to support sustainable fashion (Becker-Leifhold, 2018; Holtström et al., 2019). However, there appears to be limited evidence for the environmental claims for shared clothing under PSSs despite available methods such as life cycle assessments (Doualle et al., 2015).

1.1 Problem Definition

Although PSSs can embody the values of the sharing economy and circular economy, a PSS itself does not necessitate sustainable outcomes. The environmental implications of PSSs are unclear (Amaya et al., 2014; Böcker & Meelen, 2017; Martin et al., 2019; Saksanian et al., 2020), and practical application of sharing and circular economy concepts lack quantitative evidence of their impact (Amasawa et al., 2020). PSSs may not lead to reduction in resource use or waste, as they could cause increases in consumption or rebound effects that counteract their environmental benefit (Corvellec & Stål, 2017). Furthermore, strategies to reduce resource use do not automatically lead to positive environmental outcomes (Kjaer et al., 2019).

Current literature research highlights the uncertainties and potential shortcomings of reuse strategies in PSSs. Zink & Geyer (2017) note that the potential to create environmental benefits with reuse strategies depend on the ability for such strategies to displace primary production and avoid the associated impacts. However, it is not clearly understood to what extent reused materials displace primary production, or if impacts from reuse add additional impacts. Kjaer et al. (2019) also note that the potential for absolute resource decoupling only occurs when accounting for the potential rebound effects of changes in user behaviour (Kjaer et al., 2016), and Sposato et al. (2017) point out that different consumption activities may not translate to less consumption. The potential for PSSs to result in unchanged or even increased consumption is pointed out by Corvellec & Stål (2017), who state that rental clothing business models offer consumers an opportunity avoid the waste responsibility that would usually come with ownership.

The environmental impacts of alternative consumption business models have been studied in a few industry sectors such as automobiles, vacation spaces, and toys, but the characteristics of consumption of these sectors are likely quite different than that of clothing. Since consumption practices differ, it is necessary to develop sector-specific understanding of consumption behaviour (Park & Armstrong, 2017). Garments are considered differently in comparison to other textile products, since the use phase is often considered to have the most environmental impacts, whereas some other textile products are considered to have the most impact during the production phase (Gwilt, 2013, p. 79). However, this is assuming that garments are actually used to their fullest technical durability and intended service life.

In order to understand the environmental impacts from clothing PSSs, it must be asked how environmental impacts from shared goods can be measured. Analysing a PSS through a life-cycle approach has been cited as one method to quantify impacts (Iran & Schrader, 2017; Kjaer et al., 2019; Peck et al., 2019), such as through a life cycle assessment (LCA). "LCA stands out as a tool that can give quantitative answers considering multiple environmental issues along the whole life cycle of alternative products, technologies and management procedures to designers, purchasers and consumers" (Roos et al., 2017, p. 38). LCAs show many different indicators that summarize a technical system's environment impacts— for example global warming potential, stratospheric ozone layer depletion, land use change, energy consumption, water pollution, and toxic emissions among others (Roos et al., 2017). The ability for LCAs to identify the impact of a system in various environmental categories helps to mitigate the risk of problem shifting impacts (Kjaer et al., 2019; Roos et al., 2017). LCAs also help to highlight hotspots or problem areas that can be improved or avoided through design solutions (Gwilt, 2013). The European Commission advises the use of LCAs to evaluate products, and bases the Product Environmental Footprint (PEF) methodology off of LCA principles (European Commission, 2013).

While an LCA is capable of providing a concrete indication of environmental impacts, many challenges exist in conducting an LCA for a reused good in a PSS. It is difficult to identify and measure how shared clothing can impact the environment since there is no clear information on whether consumers substitute conventional behaviour with sharing, or if it is seen as a complement and further encourages consumption. Amaya et al. (2014) note that the ISO standard guidelines for LCAs do not have specific recommendations for the calculation of impacts for PSSs, and there has been little research to focus on such strategies. These challenges contribute to the lack of quantitative evidence and clarity for the environmental outcomes of PSSs.

1.2 Background

Concerns for resource-efficiency is not a new topic, but there has been a revival of interest in it by exploring sustainable business models. In 2011, The European Commission stated resource efficiency as an essential initiative in its Europe 2020 Strategy (European Commission, 2011), and in 2015 released an action plan towards the circular economy to continue to realize the goals of a resource-efficient Europe (European Commission, 2014). This includes the recognition of the sharing economy in contribution to circular economy strategies and goals (European Commission, 2014).

The Ellen MacArthur Foundation recommends an approach to applying circular economy principles to the apparel and textile industry in four ways. This can be seen in Figure 1-1. The scope of this thesis will be focused on the second step, which is to "increase clothing utilisation" (Ellen MacArthur Foundation, 2017, p. 50) through changing the way is clothing is used and keeping clothes in their highest form of value (Ellen MacArthur Foundation, 2017, p. 50). This strategy can be operationalised through short-term rental, where customers rent clothing items for occasional needs (Ellen MacArthur Foundation, 2017) such as in the case study company.

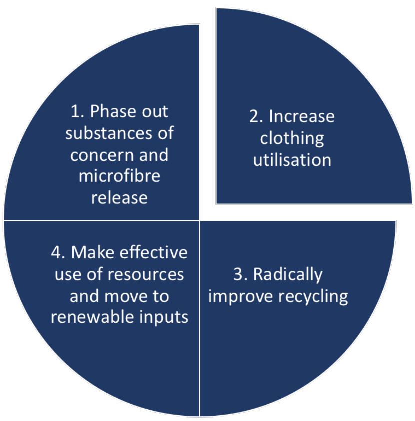

Figure 1-1: Circular strategies for textile and apparel industry.

Source: Adapted from Ellen MacArthur Foundation (2017).

The characteristics of the circular economy are analysed in conjunction with the sharing economy, since the concepts overlap in some principles. Circular economy strategies can be broadly understood as the slowing, closing, and narrowing of material loops. Slowing resource loops encompasses extending product life for example through reuse, repair or remanufacturing (Bocken et al., 2016), in which resource yields are optimised by keeping materials circulating at their highest utility (Ellen MacArthur Foundation, 2015). Closing resource loops strategies involve designing for disassembly and recycling, and narrowing loops as reducing resource use in production (Bocken et al., 2016). Since the focus of this study is on PSS and rental, slowing loops through reuse is emphasised. This also corresponds with one of six business actions to move towards a circular economy, as defined in the ReSOLVE framework by the Ellen MacArthur foundation. One of the business actions in this framework is specifically "share", which employs strategies to keep products in the loop by maximising the use through sharing between different users (Ellen MacArthur Foundation, 2015). This is where the sharing economy and collaborative consumption can fit into the circular economy, as shown in Figure 1-2. While many authors choose to point out the differences and the preference to perceive them independently, Holtström et al. (2019) notes that by understanding these concepts in conjunction, it may help to increase transition to business models with lowered environmental impacts.

The strategies associated with the innermost loops depicted in the figure have a higher potential for resource decoupling and material efficiency in comparison, for example to textile recycling. Reuse is also considered to be the top of the waste hierarchy behind prevention by the EU WFD. The EU defines reuse as "any operation by which products or components that are not waste are used again for the same purpose for which they are conceived" (European Commission, 2008). Although the circular and sharing economy can be understood in different ways, they overlap in their strategy to increase reuse. The sharing economy is often perceived as means to realize the circular economy (Camacho-Otero et al., 2019; Chen & Huang, 2019; European Commission, 2014; Sposato et al., 2017). This is the perspective taken for this research with the intention to establish relevance for learning opportunities of the outcomes of this thesis to proponents for both concepts.

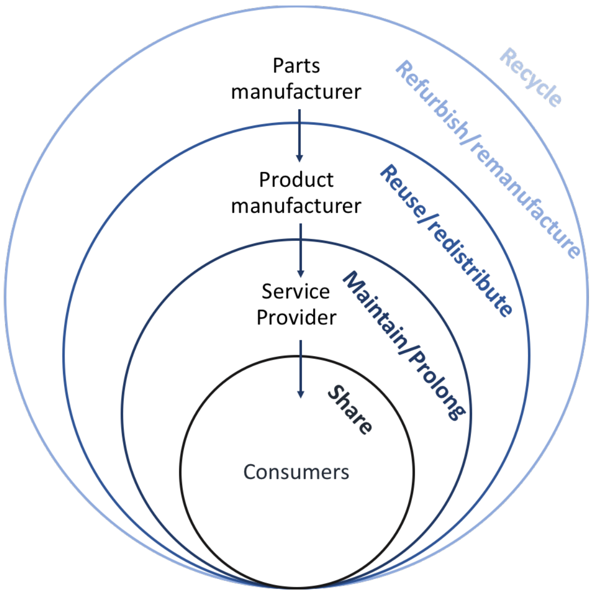

Figure 1-2. Circular economy strategies and application of sharing economy principles.

Source: Adapted from Ellen MacArthur Foundation (2015)

1.3 Aim & Research Questions

The aim of this research is to progress the understanding of the potential sustainability outcomes for PSSs by contributing quantitative evidence of the environmental impacts of a B2C use-oriented PSS. It aims to contribute by conducting a comparative LCA of consumption in a rental dress business model vs. a linear (ownership) model.

This research is of descriptive, evaluative, and explanatory nature. It aims to: a) describe the ways that the function of rental clothing can be defined in an LCA framework; b) evaluate the environmental impacts of rental clothing by quantifying and assessing them; and c) explain the factors that contribute to the variation of results of the associated environmental impact. These also help to predict how changes to consumption behaviour in rental business models can improve the environmental potential of PSSs.

RQ1: What ways can the function of rental clothing be defined to assess the impacts in an LCA framework?

RQ2: What are the environmental impacts of a rental dress company, and how do they compare to the impacts of dress consumption in a linear business model?

RQ2.1: To what extent do user behaviour variations impact the result of an LCA on a clothing PSS?

1.4 Scope

The scope focuses on use-oriented PSS for clothing, meaning rental clothing business models. Shared, or rental clothing in this thesis entails facilitation of use and provision of access. Second-hand clothes are excluded since that indicates ownership, rather than access. The case study used in this thesis is specifically on rented pre-owned, formal dresses. The LCA compares the PSS business model of a case company in Stockholm, Sweden to a hypothetical linear business model. It examines how different aspects of consumer behaviour can affect the environmental impacts of a clothing PSS. It also considers the influence of the business model on impacts by including logistics and reverse logistics, consideration of the rental time frame, and company proximity to consumers. These are analysed under geographical restrictions to Sweden, as transportation infrastructure and energy mixes are specific to Sweden in which these factors may be highly influential in the results. Furthermore, consumer behaviour data collected is specific to customers who are already engaged with rental with the case company.

While it would be interesting to include all three pillars of sustainability (environmental, social, and economic factors), environmental impacts are the focus for this thesis. This is due to the complexity of measuring just environmental impacts from sharing initiatives, and that the method to measure environmental impacts and the associated indicators greatly differs from the measurement of social and economic impacts. Furthermore, traditional LCAs are primarily limited to quantification of environmental impacts. Rebound effects are formally excluded in this thesis due to the methodological and practical constraints to create a reliable knowledge on these complex effects. Rebound effects can be understood as the environmental consequences of when the environmental impacts of a supposed improvement alternative is less than anticipated due to system or behaviour responses (Kjaer et al., 2019).

The question of market stability of sharing and circular economy business models is prominent in academic discussion, however, is not discussed in this paper. There are various types of clothing sharing platforms in alignment with these concepts that have had to close down.

However, this was not of initial concern to this research since the case study company has been maintaining its business since opening in 2018 and had been seeing indication of increased interest and profit. However, this was before COVID-19 and the general economic stability for the company is currently unknown. The case company selected is still considered relevant to research, as the characteristics of the case company's business model still represent a common example of a generic use-oriented PSS BM, and it embodies the principles of sharing and reuse from the sharing economy and the circular economy. Data collected from the case company is also comprehensive of its activities since opening, and various scenarios are included in the LCA to account for assumptions made for uncertain factors described in section 6.3.4.

1.5 Ethical Considerations

The research design of this thesis has been reviewed against the criteria for research requiring an ethics board review at Lund University, and has been found to not require a statement from the ethics committee. No ethical problems are present as this is an unfunded study and results are deemed as non-problematic and non-harmful to participants involved. The relationship with the case company was strictly to receive data, and the collaboration did not influence the conduct of the research, as it was made clear of the relationship and intention of the research from initial contact. The company provided this research with information in regard to the company's general activities, average information in regard to user practices and interaction with the company, and acted as a liaison between the researcher and clients to distribute a survey.

Participation in the survey was voluntary, and responses were incentivised by a 500 SEK credit to rent a dress, offered by the case company. No personal information was collected on participants in the survey, and participants were informed about the research intention and purpose. Email addresses were collected only at will of the participants, stored separately from responses, and only used for contact to the winner of the raffle, which was done by the case company. A copy of the thesis was submitted to the case company before final submission to provide the case company with the option of remaining anonymous in the study, as agreed upon initiation of contact.

1.6 Audience

The intended audience includes prospective or current PSSs, as well as local governments, and academics in the field. It is important for businesses with sustainable intentions that are offering rental services to understand where their business model may have the greatest impact and how they can mitigate it. This research is beneficial for local governments to help focus their efforts to better support sharing or circular initiatives to improve their sustainability potential and displace current societal consumption patterns. This research is also important for researchers examining reuse strategies in BMs, since the defining of the FUs and its implications may be helpful to further research desiring to quantify the impacts of shared and rented products.

1.7 Disposition

Chapter 1 provides the background and introduction to understand the problem explored in this research. It provides the aim of the study and research questions, along with the scope and limitations.

Chapter 2 provides the conceptual foundations to understand the characteristics of business models, the different types of PSSs, the principles of the circular economy and sharing economy, and life cycle thinking. It then analyses the research gaps and summarises what is currently understood about clothing PSSs, limitations of LCA studies on PSSs, applied LCA studies on clothing PSSs, and consumer behaviour patterns.

Chapter 3 presents the research design and methodology, and also provides support from literature to explain methodological choices made in the LCA.

Chapter 4 presents the case study by providing an overview of the case company, as well summarises the survey results on consumer behaviour for clothing purchasing and rental consumption. It then presents the goal and scope of the LCA, along with the activities of the business models in the life cycle inventory.

Chapter 5 provides the results of the life cycle impact assessment by comparing the impact contribution for four impact categories between the linear and rental scenarios.

Chapter 6 interprets and discusses the implications of the results, and notes methodology and data limitations.

Chapter 7 concludes the research and provides recommendations to prospective and current PSSs, as well as local governments.

2 Literature Review

2.1 Conceptual foundations

This section will define the concepts central to the understanding of the thesis, as well establish their relationship with one another in the context of this study. The definitions here serve to facilitate understanding of the concepts' broader implications and how they are used in media as well as academia.

2.1.1 Business models and product-service systems (PSS)

Understanding what a business model means and what characterises it is important in order to understand its effect on consumer behaviour and engagement in consumption, and further to understand how variations in the business model can alter the environmental consequences of the offered products or services of the company. However, research regarding BMs lack a consensus on a consistent definition, with some researchers perceiving a business model as a "statement", others a "description", "representation", "architecture", "conceptual tool", "method", and more (Zott et al., 2011, p. 1022). Despite how the business model is described as a unit of analysis (Zott et al., 2011), most definitions share the idea of value creation as a central tenet in its description (Lüdeke-Freund et al., 2019; Osterwalder & Pigneur, 2010; Pedersen et al., 2019; Teece, 2010; Zott et al., 2011).

Acknowledging the many existing characterisations of the business model concept, it can be broadly understood as a business's organisational architecture (Teece, 2010) that explains how it creates, delivers, and captures values (Osterwalder & Pigneur, 2010) through its activity systems (Zott et al., 2011). Values and strategies of the circular economy and sharing economy show up in various sustainable BM archetypes in academia, as described by Bocken et al. (2014). Archetypes of BMs that facilitate reuse through provision of services are often based on literature on PSSs.

A PSS constitutes conceptual elements of a business model, and has been named as a type of value proposition that enables sustainable business model innovation (Piscicelli et al., 2015). Sustainable business model innovation alters BMs through redesign, development, and transformation to integrate sustainability objectives (Geissdoerfer et al., 2018). Armstrong et al. (2016) perceive a PSS as a "social archetype of business models for sustainability" (p.21), and it can be defined as "a marketable set of products and services capable of jointly fulfilling a user's need" (Corvellec & Stål, 2017; M. J. Goedkoop et al., 1999; Piontek & Müller, 2018, p. 758). The benefit of a PSS is characterised by its potential to change consumption behaviour and reduce the need of ownership by introducing alternative access for product use (Mont, 2002), as well as to incentivise manufacturers to make longer lasting products that can be easily repaired and reduce product volume (Bocken et al., 2014).

PSSs can be classified into three categories: product-oriented, use-oriented and result-oriented (Kjaer et al., 2016; Tukker, 2004). This thesis focuses solely on use-oriented PSSs, which is where a product is still central to the business model offering, but the product stays in ownership with the provider and is made available to a number of users at different times (Tukker, 2004). Products are therefore not sold in a use-oriented PSS, and according to Tukker (2004), can be offered in three forms: product leasing, product renting or sharing, and product pooling (p. 248-249). An example of how these forms of use-oriented PSSs could show up in the apparel industry are shown in Figure 2-1. Lang & Armstrong (2018) identify clothing rental companies as one of five business models seen in reality under clothing PSSs. The value these services provide are to offer customers classic or unique, quality fashion items that consumers can wear without paying the full price, nor having to commit to ownership. This type of strategy is perceived to increase the use intensity of products (Lang & Armstrong, 2018).

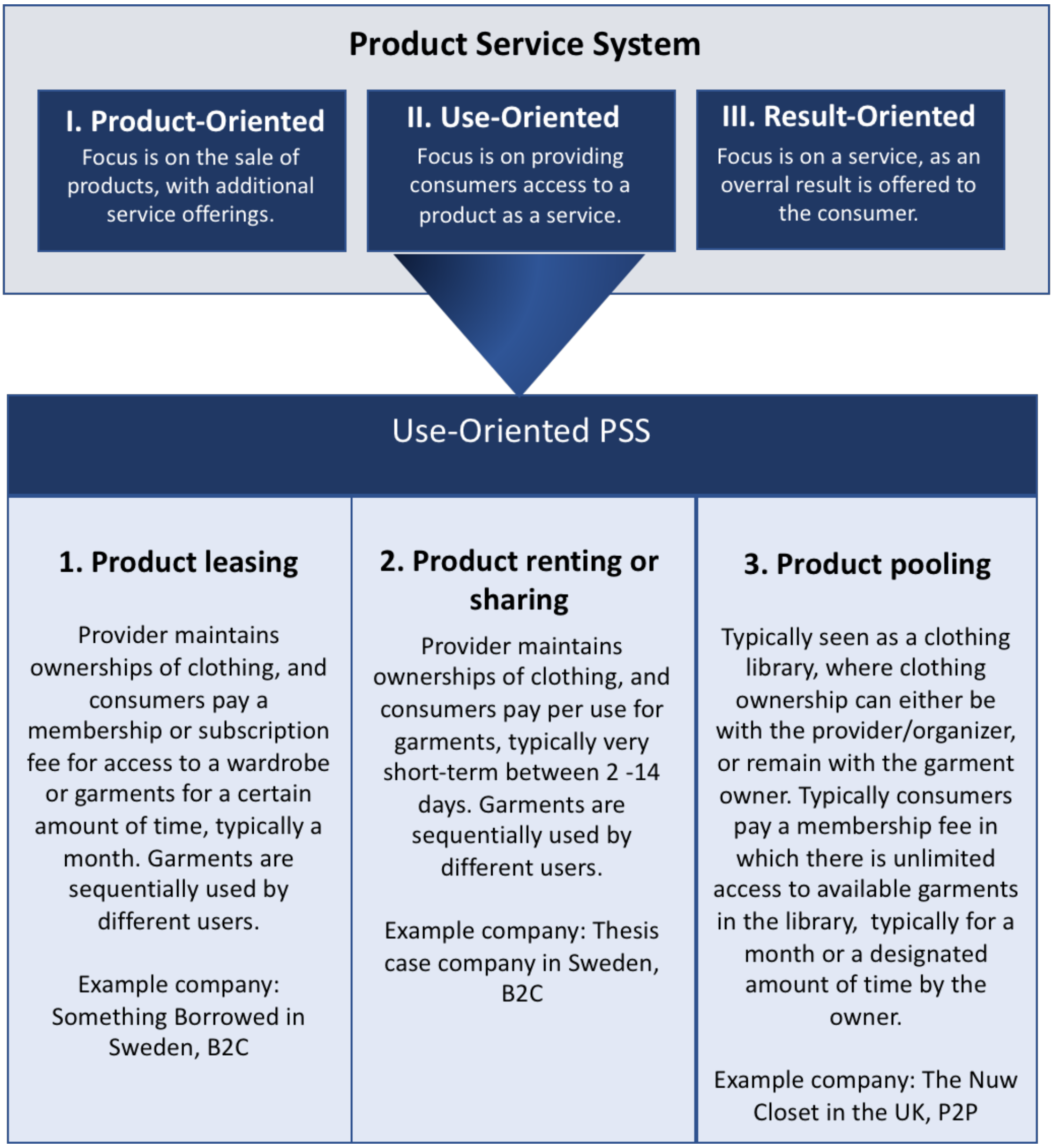

Figure 2-1. Types of PSS and practical examples of use-oriented PSSs in the apparel industry.

Source: Categories of PSS taken from Tukker (2004) with application to the apparel industry by author.

PSSs have been linked together with the sharing economy (Somers et al., 2018; Verboven & Vanherck, 2016), as well as been cited as a pathway to fulfil circular economy strategies (Kjaer et al., 2019). However, not all types of PSSs utilise the strategies and goals corresponding with either of these concepts (Kjaer et al., 2016). A PSS does not inherently encapsulate a business model that meets the standards of either of these concepts. However, it is used in this research as a conceptual framework to understand the elements of a business model that has *the potential* to fulfil the objectives and strategies of the sharing economy and circular economy, and is therefore important for this research as an example to show how the objectives of these concepts could practically be realised.

PSSs can be pathways to facilitate the circular economy through product sharing and extension of service life (Bocken et al., 2017; Kjaer et al., 2019). PSSs encourage circularity for example by selling usage rather than ownership, "and breaking the link between profit and production volumes" (Bocken et al., 2017; Bocken et al., 2014, p. 480). A PSS's potential to promote dematerialization is connected to the lack of personal ownership, increase in use intensity of products, and to the company's control over product lifetime (Armstrong et al., 2016; Tukker, 2004).

The blurred lines of distinction of whether PSSs belongs to the sharing economy or circular economy is important to highlight, as more businesses participate in business model innovation, or more niche start-ups offer hybrid models. The case company for this research is situated somewhere in between the sharing economy and the circular economy; in strict interpretations of both concepts, the case company PSS does not adhere to any. The original garments in the case company are not designed for circularity. Rather, the company offers access to second-hand formal dresses to create its product inventory, with the additional services of laundry, and clothing maintenance and repair.

2.1.2 The sharing economy

The sharing economy appears in various forms and has had increasing interest due to its potential to solve issues regarding resource scarcity, and increased awareness in the need to change consumption patterns (Holtström et al., 2019). This thesis takes a broad definition of the sharing economy, understanding it to represent "a social and economic system that supports a sharing access to goods, services, information and competencies aiming at optimizing and redistributing the use of resources" (Sposato et al., 2017, p. 1798; World Economic Forum, 2013). This shares the same values as the definition for collaborative consumption, which can be understood as "people coordinating the acquisition and distribution of a resource for a fee or other compensation" (Belk, 2014; Zamani et al., 2017, p. 1368). Curtis & Lehner (2019) in their literature synthesis to define the sharing economy, note that the sharing economy is often seen as an umbrella term for various activities and BMs (Curtis & Lehner, 2019), in which collaborative consumption is perceived as part of it (Hamari et al., 2016). However, in other literature, the sharing economy is used as a synonymous term with collaborative consumption, and this is the perspective that will be taken for the purpose of this thesis. These terms are used interchangeably in this research.

The sharing economy is most typically defined by both peer-to-peer (P2P) and business-to-consumer (B2C) models (Botsman & Rogers, 2011), although not all researchers in academia agree with the inclusion of B2C models in the sharing economy (Curtis & Lehner, 2019). Although the notion of sharing is not new since informal, non-monetary exchanges have taken place for centuries and simple sharing between friends and family are common, sharing in this thesis refers to renting of rivalrous goods and involves monetary practices. The term 'rivalrous' can be understood as "the use of shared goods that prevent simultaneous use of it by another" (Curtis & Lehner, 2019, p. 14), meaning goods must be used at different times.

Although the sharing economy is commonly recognised on its own entity in academia, it is recognised in the thesis as contributing towards circular economy strategies and objectives, as stipulated in "Towards a Circular Economy: A Zero Waste Programme for Europe" (European Commission, 2014), and is therefore positioned as component under circular economy.

2.1.3 The circular economy

The circular economy is an umbrella concept that has been promoted as way to move forward towards sustainable consumption (Ellen MacArthur Foundation, 2017). The Ellen MacArthur Foundation (EMF) has played a fundamental role in engaging businesses and disseminating information to visualize strategies of circularity in practice. However, many applications of the circular economy in various scales and sectors have resulted in its many disputed definitions (Linder et al., 2020). Rather than define the circular economy, this section will provide an overview of the values and strategies that the circular economy employs.

The ideology behind the circular economy is to keep products and materials "at their highest utility and value at all times" (Bocken et al., 2017, p. 476). This can be realized in various strategies to extend product lifetime, and includes reuse, repair, and remanufacturing, as well as recycling. Alternatively, or additionally, products can also be used more efficiently or intensively through sharing. These strategies can realised for example through PSSs (Bocken et al., 2017).

There are three main strategies associated with the circular economy, which are narrowing, slowing, or closing loops (Bocken et al., 2016). While narrowing the loops has to do with improving the efficiency in terms of material inputs towards the product, and closing the loop has to do with the ability to disassemble, recycle or remanufacture parts of the product at the end of its useful life, slowing the loop focuses on the use and functionality of the product itself. More specifically, slowing the loop aims to extend the service life of the product by re-use and repair, or sometimes remanufacture (Lüdeke-Freund et al., 2019). Business models that work to "slow the loop" aim to keep products at their highest value as long as possible, which is where clothing rental business models fit in (Lüdeke-Freund et al., 2019), since the company's goal is to continue rental of the same garment without changes to the product itself. This is also where the sharing economy fits as a concept, due to the idea of sharing resources in order to prevent the need for more products and therefore incentivizing decreased consumption. Further, this is where PSSs are placed, as it involves loops between different users and the distributor or retailer.

Slowing the loop can mean product lives are extended or intensified, and in the case of the rental clothing company, it aims rather to intensify use. This is unique to a clothing rental company for formal dresses, as in terms of material, it likely could have a long life time, but due to style changes and obsolescence, the lifetime is shortened usually without regard to durability (Birtwistle & Moore, 2007; Iran & Schrader, 2017). The strategy of intensification of the use of formal dresses here is therefore considered more appropriate in incur increased usage rather than increased lifetime in years.

2.1.4 Life cycle thinking

Life cycle thinking considers the resource flows to and from the environment of a product and its organisation through its supply chain from cradle-to-grave. This means from raw material extraction to processing and production, distribution, use, and end of life (World Economic Forum, 2013). Applying a life cycle approach is essential to understand potential environmental trade-offs in the supply chain (Baumann & Tillman, 2004; World Economic Forum, 2013), and to avoid burden shifting environmental impacts between life cycle stages (Kjaer et al., 2019). Burden-shifting for example could occur when one life cycle stage is optimised, but it causes increased consumption, resource-use or negative consequence in another stage. Kjaer et al. (2019) therefore emphasizes the use of LCAs as a tool to support circular economy strategies and PSSs. An LCA is a quantitative method used to analyse the life cycle stages to determine a product's environmental impact across a variety of categories by quantifying the emissions and resources associated with a product and/or service. LCA is an internationally standardised method through the ISO 14040 and 14044:2006 standards. LCAs are done in four phases, as summarised in Figure 2-2.

The use of LCAs have increasingly been used in the clothing industry, by authorities, researchers, and the industry itself in environmental product declarations, product design, and more (Curwen et al., 2013; Roos et al., 2017). Castellani et al. (2015) considers LCAs the best method to evaluate reuse, as it is capable of identifying associated benefits of reuse based on avoided impacts from production. Gwilt (2013) notes the importance of life cycle thinking upstream in clothing production besides direct production impacts, since the design of products dictates the use phase, for example the laundering and potential repair. Life cycle thinking becomes critical to create change in how garments are made and used. With this in mind, life cycle thinking in sharing and circular strategies is key to assess the potential opportunities or drawbacks that may result from different business model scenarios (Sposato et al., 2017). Baumman & Tillmann (2004) highlight that a life cycle approach is advantageous as it "provides a framework for gathering and analysing environmental information on products" (p.294).

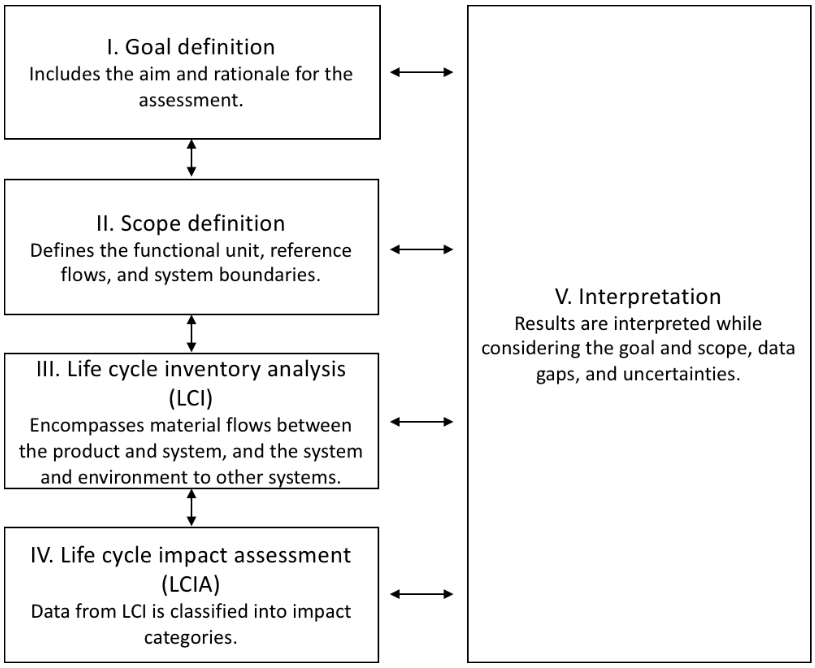

Figure 2-2. Overview of LCA process.

Source: Modified from European Commission-JRC-IES (2010).

2.2 Understanding what is currently known about the environmental impacts of clothing PSS

In traditional LCAs for clothing, it was found that clothing items used for longer were effective in reducing garments' environmental impacts from production. Roos et al. (2019) found that "twice as many uses per garment's life-cycle eliminated almost 50% of impact regardless of impact category", even including the impacts for the increased need for laundry (p. 116). If this were to happen, it could reflect a societal change where the quality of clothing is improved, consumption habits shift, and collaborative business models become more common (Sandin et al., 2019). This provides a good basis to support PSSs since it aims to increase the usage of garments. Business models such as PSS has provided consumers the ability to "access products with necessitating ownership" (Pohl et al., 2019, p. 5). Since single items can be used by many consumers, products can be used more efficiently and so less production is needed to meet demand, therefore creating the potential to save resources and reduce emissions (Pohl et al., 2019).

While increased usage of clothing has the potential to reduce impacts and can be facilitated through PSSs, the associated impacts are dependent on individual consumption behaviour and the behaviour during a garment's use. Zamani et al. (2017) notes for example that clothing libraries have the possibility to reduce the speed of fashion if clothing items are used more times. However, clothing libraries could also promote consumption if users update their closets more frequently (Zamani et al., 2017). The potential of increased consumption from sharing business models is also supported by Corvellec & Stål (2017), as they note that participating in sharing initiatives does not necessarily mean substitution of conventional consumption. Verboven & Vanherck (2016) also agree with this and note that some "sharing business models even facilitate consumption, e.g. by offering a service contract which includes regular replacement of a product" (p. 307). Furthermore, such business models are attractive to consumers because of lower transactions costs for sharing, potentially resulting in increased consumption and rebound effects. Rebound effects can be understood as the environmental consequences of when the environmental impacts of a supposed improvement becomes less than anticipated due to system or behaviour responses (Kjaer et al., 2019). There is a need to understand "whether the promised environmental potentials are met or not, for example due to a boost in consumption activities or due to the use of more efficient products" (Pohl et al., 2019, p. 6), however there is a lack of studies to indicate this (Martin et al., 2019). From a theoretical perspective, PSSs can bring potential savings and additional environmental benefits, which may backfire through consumer's behavioural responses and other systemic factors. It is recognised that LCAs can be used to assess such environmental impacts, but there are many challenges to applying it to a PSS. These challenges will be discussed in the following section.

2.2.1 Known challenges to quantify PSS impacts through an LCA

This section focuses on highlighting the key challenges found in literature to conduct an LCA for PSSs. The challenges were categorised into five themes as identified from the literature. They are: **1) defining the functional unit and reference flows; 2) assessing the use phase and user behaviour; 3) access to data; 4) defining system boundaries to account for indirect services; and 5) rebound effects.** Although conventional LCAs have general challenges, these become more complex when analysing a PSS.

Defining the functional unit (FU) and reference flows (RF)

An LCA is based on a "precise, quantitative description of the function(s) provided by the analysed system" (European Commission - JRC - IES, 2010, p. 60), which is established through the FU. Defining the FU is complex but critical in comparative LCAs, as it should enable the adequate definition of reference flows and allow fair comparison of the systems under analysis. Furthermore, just one function of the system(s) under analysis should be selected. In a PSS, the FU must encompass the function of both the product and included services, whereas in a linear model it is simpler to define the function of the product (Doualle et al., 2015). It is difficult to define the specific functionality of PSSs, as they often include "intangible elements" (M. J. Goedkoop et al., 1999) that are not easy to define in a functional unit (Kjaer et al., 2016).

More conventionally-used FUs for clothing are not suitable for PSS due to the alternative use of shared clothing (Piontek & Müller, 2018), and Pohl et al. (2019) note that in general for LCAs, FUs are often chosen based on comparability instead of accuracy. This is further complicated by the complexity of different consumption behaviour between collaborative consumption and linear consumption, which requires a more specific definition of the function and benefits. Goedkoop et al. (1999) notes that FUs for PSSs can be defined narrowly, in which the FU is more clearly delineated but limited to technical aspects of the system, or more broadly where the definitions are more complete and considers effects from human behaviour. Although broader definitions can seem more comprehensive, they include more uncertainty. Defining the FU depends on the decision of what scope to evaluate for a PSS's environmental performance (Kjaer et al., 2016). The determination of the FU is critical as it must reflect the goal of the assessment and be comparable while accurate. The FU is closely related with the use of the product or service under analysis, in which there are additional complexities and challenges to assess.

Assessing the use phase and user behaviour

The major challenge with assessing the use phase in LCAs is that studies often make assumptions about use patterns and the behaviour of consumers. Conventional LCAs give low priority to the use phase, but this phase requires more attention when assessing PSS BMs (Pohl et al., 2019), since the environmental impacts quantified from an LCA depend on how users engage in a PSS.

LCA studies often use aggregated data to model average usage behaviour. However, this does not effectively capture variations in behaviour, meaning LCA results often reflect uncertainty in the impacts for actual behaviour (Pohl et al., 2019). Some studies focus on laundry activities in the use phase, while others look at transport to and from the retailer (Piontek & Müller, 2018). The challenge regarding transport will be further discussed later in this section. As mentioned with the challenge with defining the FU, variations in the use patterns and patterns of consumption mean that subfunctions of PSSs must be taken into account when determining the FU. However, this may not effectively capture variations in behaviour, meaning LCA results often reflect uncertainty in the associated environmental impacts for actual behaviour (Pohl et al., 2019).

User behaviour also depends on the context, as well as the BM of the PSS. For example, the physical location of a rental service or clothing library can affect user transportation. Furthermore, the BM can affect user behaviour as the payment system can affect how many items or how often consumers make a transaction, and each transaction can have an environmental impact, in particular for transportation (Zamani et al., 2017). This is also supported by Kjaer et al. (2016) who notes that a PSS in a B2B versus a B2C model can influence user behaviour. Roos et al. (2019) note that user behaviour surveys can give vague answers and that self-reported surveys often are not reliable, meaning that a lot of assumptions must be made in terms of usage, wash, and transport. The challenge with variations of behaviour is complex due to the inconsistencies of human behaviour and is further pronounced to the lack of access to reliable data for consumption behaviours.

Access to data

Most challenges around access to data stem from data collection of user behaviour. This challenge is associated with the lack of a consistent method for data selection, collection, and general availability of data. This differs from the variations of user behaviour from the previous section. Many assumptions have to be made by LCA practitioners due to the challenge of "finding and gathering suitable data on user behaviour and rebound effects" (Pohl et al., 2019,

p. 9). Different scenarios for use in LCAs are based on assumptions, so uncertainties on data to the lack of or from the variability of sources remains a challenge. Practitioners often need to simplify reality when defining inventory flows and allocation in LCAs, so data selection can be based on data availability as well as subjectivity in what is important (Pohl et al., 2019). Data on behaviour is challenging to find, for example, if shared clothing substitutes conventional consumption, and this uncertainty affects the results (Kjaer et al., 2016). Newer companies involved in clothing PSS may also be unwilling to share this type of information. Furthermore, there is a scarcity of data on the chemical information such as dyes, pesticides and detergents and their associated toxicity and impacts (Piontek & Müller, 2018). It has been identified as a problem that many assumptions are made and that they are many variations in data collection methods (Allais & Gobert, 2016; Piontek & Müller, 2018).

Defining system boundaries to account for indirect services

Another challenge is the difficulty to define system boundaries in order to consider the effects of other related services. Processes and associated effects outside of the direct BM must be accounted for (Pohl et al., 2019). For example, transportation in the use phase is a key factor to consider in a PSS, and Zamani et al. (2017) found that the impacts from transport are of higher importance than laundry in a PSS in Sweden. While other studies may focus on laundry activities, this is perhaps less impactful in Sweden where the electricity grid is mostly powered by nuclear and hydro energy sources (Zamani et al., 2017). The expansion of system boundaries and the selection of services that should be considered depend on the context and location of the PSS.

Pohl et al. (2019) also agree that processes and associated effects outside of the direct business model must be accounted for. Different transportation scenarios and even business models can alter the impact, as Zamani et al. (2017)'s results indicated a "a huge influence of the mode and distance of transport which would be neglected if they would only assess directly product related impacts" (Pohl et al., 2019, p. 7). According to Zamani et al. (2017), logistics must be accounted for in business models that facilitate sharing and reuse, for example by assessing the location of the physical rental service in proximity to customers and public transportation. Previous studies often exaggerate the effect of laundry and customer transportation is excluded (Zamani et al., 2017). The influence of the BM on number of user transactions is "important for clothing libraries in locations that induce user transportation with high environmental impact (e.g. remote areas with poor access to public transportation)" (Zamani et al., 2017, p. 1374). The complexity of a PSS with its intangible elements and its reliance on supportive systems, such as transportation, make it difficult to define system boundaries and to compare different systems (Kjaer et al., 2016). This is also linked to the challenge of assessing rebound effects.

Accounting for rebound effects

A major challenge in quantifying the impacts for the sharing economy are the associated rebound effects. As noted by Martin et al. (2019), the availability of collaborative consumption BMs may promote increased consumption because the money saved by sharing can be spent on other products/services that may have a higher environmental impact. Rebound effects are not often addressed in LCA studies, and the ISO standard does not suggest how to approach them. It is considered a challenge due to its complexity and the need to include products and activities that are not part of the direct value chain (Pohl et al., 2019). Kjaer et al. (2016) notes that consumption or user patterns and context dictate the rebound effects, and the determination of the scope of the study influences whether rebound effects can be captured. Rebound effects may be able to be captured in the system boundaries, and this ties into the challenge of accounting for indirect services, such as transportation. For example, a higher impact from transportation "can offset the environmental gains from reduced production", which is essentially problem shifting from one life cycle phase to another (Zamani et al., 2017, p. 1374). Assessing the possible impacts from rebound effects remains a challenge (Allais & Gobert, 2016), but understanding rebound effects and the other challenges in conducting an LCA for a PSS is important to understand the limitations of such a study and how it can affect the results.

2.2.2 Applied LCAs for clothing PSS

Few LCA studies regarding clothing PSS were found in the literature review, and these were used to understand what characteristics of a clothing PSS should be further examined. These studies provided different perspectives on how to conduct an LCA for shared clothing and different FUs and approaches that could be employed.

Zamani et al. (2017) performed an LCA on clothing libraries in Sweden, in which the goal was to "assess the environmental impacts associated with different clothing library setups" (p. 1369). Twelve different scenarios were modelled of clothing library BMs and were compared to a regular fashion BM of purchasing and ownership. Three garments were analysed and "one average use" was defined as the FU, with one use implying the use of a garment in a 24-hour period. The different scenarios compared the service life of the garments, online or offline setups, and different transportation modes (Zamani et al., 2017). The study emphasised the impact of transportation modes and distances, and the results showed more environmental benefits for online scenarios since package pick-up distances were closer than offline scenario locations. This study focused on the impacts for climate change, freshwater consumption, freshwater ecotoxicity and freshwater eutrophication, and performed a sensitivity analysis for the global warming potential by increasing the number of customers who rent a garment, but kept the total number of uses the same (Zamani et al., 2017).

Piontek et al. (2020) conducted a comparative LCA on clothing rental in Germany vs Japan, where the FU used was "one wearing of a certain garment" (p. 2). It modelled 12 different scenarios which included changes to variables such as the materials and weight of the garments, number of uses, and variations in laundry. The study focused on the impacts for climate change, marine eutrophication, freshwater eutrophication, and freshwater usage. A sensitivity analysis was conducted on the number of uses and the electricity mix for activities in the use phase (Piontek et al., 2020).

Another proposed FU for clothing PSSs found in literature is "one year of varied use of clothing" (Piontek, Rehberger, et al., 2019, p. 101), which represents the clothing consumption of one consumer in Germany during one average year. This study proposes to compare conventional consumption alone vs. renting combined with conventional consumption over one year. Piontek et al.'s (2019) proposed study specifically contrasts itself to Zamani et al.'s (2017), in which they note that the purpose of their study was to focus on the different impacts from one consumer changing her patterns from buying to renting, while Zamani et al. (2017) focuses on the impact of prolonged service lives of garments.

2.2.3 Clothing consumption behaviour

As textile consumption has increased over the years due to increasing disposable income and the influence of fast fashion, so has the waste of textiles. A study by Hultén et al. (2016) showed that Swedes produce 7.5 kg per person of textile waste in the residual waste per year (p.6), yet in 2019 the average consumption of textiles for a Swede was 13.7 kg, 9.9 kg of which was clothing (Naturvårdsverket, 2020). This is a total increase of 3 kg per person since 2000 (Naturvårdsverket, 2020). While some of the disposal could be attributed to low quality garments that can no longer be worn, many clothing items are disposed of due to changes in fashion trends and consumer style preferences (Birtwistle & Moore, 2007; Iran & Schrader, 2017; Lang & Armstrong, 2018). This is quantitatively reflected in Swedish textile residual waste, as Hultén et al. (2016) found that 59% of annual textile residual waste was in a condition that could have been reused (p.7). This is common in industrialised countries, where clothes are consumed at higher rates than what the technical lifespans of the garments actually demand (Roos et al., 2017). WRAP (2017) assumes the average lifetime of use of a garment to be 3.3 years based on consumer behaviour, not its technical capabilities. This was estimated to be 3.62 years for a dress. In addition to the 7.5 kg of waste, Swedes send about 3.8 kg of textiles to charities or second-hand per use. Out of this donated amount, 72% of total collected textiles are exported (Belleza & Luukka, 2018, p. 12). Palm et al. (2014) state a 20% collection rate for these used textiles in Sweden, and assume that half of the remaining 80% is mixed with municipal residential waste and gets incinerated. The other half is likely kept in home storage, later collected in municipal recycling centres and likely incinerated later.

Can alternative consumption business models replace linear consumption?

The notion of displacing ownership with access and rental clothing to save material input resources may be true, but it depends on consumer's actual behaviour. Realizing the benefits of a PSS would depend on the extent that production is substituted or replaced (Sandin & Peters, 2018). There are little existing studies indicating how consumers behave when renting apparel.

Pedersen et al. (2019) note that companies attempting to offer more sustainable products or services must be accompanied by business model innovations, else they will render as merely positive initiatives that suggest sustainability but lack the rigor to replace the dominant linear fashion business models. However, it is not only the business model, nor the product or design that determines the overall sustainability, but consumers' intentions, behaviours, and habits (Iran & Schrader, 2017). A consumer may choose to rent clothes to increase their wardrobe choices, rather than replace their normal purchasing, in which there would be no decrease in waste. A PSS's ability to prevent waste is conditional since customers who choose to borrow or rent clothes do not necessarily abstain from purchasing clothes (Corvellec & Stål, 2017).

There are a variety of reasons in the apparel market of why alternative business models such as rental may not replace linear consumption. One example is that if rental is too expensive, customers may prefer to purchase an affordable alternative (Iran & Schrader, 2017). When having to consider paying per garment use, rather than owning a product, consumers reconsider their desire to wear a rental garment. Iran & Schrader (2017) compare this to car sharing, as when a consumer considers the full price of driving, he or she may decide to use public transport, in comparison to a car owner who would only consider the price of gas since they do not have to pay additional fees from already owning the car. Similarly with clothing, if clothing is needed for a certain event and rental is a high price, consumers may decide to wear what they already have or borrow from friends (Iran & Schrader, 2017). Park & Armstrong (2017) point out the differences between sharing for other types of goods. For example, renting a car or bike is driven by purpose, while renting clothing could be more emotional and more related to a consumer's identity. Furthermore, Park & Armstrong (2017) state that little is understood about how consumers' experiences differ and how they are shaped with other products, even with the linear consumption of apparel. On the other hand, if rental clothing is considered cheap or affordable, they may not motivate customers to change habits as they offer customers to wear certain brands or looks without paying the full price (Corvellec & Stål, 2017).

The ability for alternative business models such as clothing PSSs to replace traditional consumption highly depends also on consumer acceptance of such models, and if clothing PSSs can offer consumers what they need. Lang & Armstrong (2018) show that demographic variables including age group, gender, income, and education influence "fashion leadership" and that fashion leadership can be an indicator of intention to participate in clothing PSSs. The potential to displace ownership is discussed in consideration to substitution and replacement rates in the following section.

Clothing reuse and substitution

The ability for rental clothing to substitute clothing under ownership can be understood as a replacement rate (RR). Understanding realistic RRs of how consumers use rental services over traditional consumption is important in calculating the benefits, as this can influence an LCA's results extensively. Sandin & Peters (2018) point out that a 1:1 RR of reused goods for purchased goods is unrealistic. This is shown in a few studies that found the overall environmental benefit of textile reuse is highly influenced by the percentage of substitution of new garments (Dahlbo et al., 2017; Piontek, Rehberger, et al., 2019; Schmidt et al., 2016).

According to Castellani et al. (2015), substitution of reused goods for new goods can be understood as: complete substitution, partial substitution (there is an extension of lifetime of the product, but it does not cover the full lifespan), and no substitution (meaning no impact is avoided). A study by Farrant et al. (2010) investigated how second-hand clothing could substitute the purchase of new clothes, and found that in Sweden, the purchase of 100 second-hand garments would replace about 60 new garments. It is evident from this number that the reused clothes are not a direct substitution for new garments.

Farrant et al. (2010) also conducted an LCA using this information, and found that the processes (collection, processing, transportation) needed to facilitate reuse for second-hand clothing had insignificant impacts on the environment in comparison to savings achieved by replacement of primary production for clothing in linear business models. However, Iran & Schrader (2017) point out that this does not translate to the same result for renting or leasing, as rental business models involve multiple users and need for increased transportation. The role of replacement rates is important in order to quantify the environmental potential of clothing PSSs.

2.3 Summary of literature

The literature review provided insight into the conceptualisation of PSSs and how they can embody sharing economy strategies as well as circular economy strategies. It established how life cycle thinking is critical to designing sustainable business models, and that this can be applied through an LCA. A broader understanding of the concepts described allows for the results of this thesis to be applicable in different contexts. Although the sharing economy and circular economy have different research goals and characterisations, principles and strategies of both concepts can be found in practice in PSSs. Furthermore, while a PSS can be understood as a business model template that offers combined products and/or services, PSSs are characterised differently depending on the specific business model activities and customer relationships. Since PSS supply chains and the need for forward and reverse logistics are often more complicated than in traditional product retail, it is important to consider the environmental impact of each process and activity in its life cycle. Life cycle thinking is therefore useful to understand the environmental impacts that may occur at each life cycle stage, and this can be applied through an LCA.

The literature review delivered an understanding of the status quo of currently available clothing PSSs, and the known sustainability implications of them. Although PSSs are characterised as conceptualisations of sustainable business models, the potential for their positive environmental implications are reliant on a variety of factors. The positive impacts for PSSs primarily hinge on consumer behaviour in how they interact with PSSs, and ultimately how their interaction with PSSs can displace or add-on to the conventional consumption patterns. This displacement is what defines the replacement rate.

LCAs on PSSs have been done before, but have focused primarily on cars, vacation spaces, and toys. Applying LCA methodology to PSSs is challenging, and five challenges were identified: definition of the FU and reference flows, assessment of the use phase, access to data, delineation of system boundaries, and consideration of rebound effects. These challenges help to put common issues into perspective and to aid in the navigation of the development of an approach to the LCA conducted in this study.

LCAs focusing on clothing PSS were also reviewed with consideration of how the function of rental clothing can be defined. This established generalisations of how PSS business models and the resulting consumer behaviours to engage with it influence the environmental outcomes. The environmental impacts are influenced by the BM's revenue scheme, whether it is offline or online, the type of product(s) it offers and whether use necessitates energy consumption, and the geographic location as well as rental store location to consumers. This affects consumer behaviours such as use intensity, choice of transportation mode to engage in rental, the replacement rate for rental for linear, and if consumers choose to spend savings on other products or activities (rebound effects). These generalisations are considered, and some are factored into hypothetical models in the research design, explained in the following chapter.

3 Research Design, Materials and Methods

3.1 Research Approach

The thesis was conducted through an inductive and retroductive logical approach. It began with an inductive approach through a literature review of existing knowledge in regard to the environmental consequences of clothing rental companies. This established generalisations about the characteristics of PSS business models and consumer behaviour that could influence the results of a comparative LCA of linear vs. rental dress consumption, which formed the causal mechanisms that were used to construct hypothetical models[1]. The hypothetical models help to explain the relationship of consumer behaviour and PSS business model characteristics to the environmental consequences of a rental garment by utilising a retroductive logic[2] (Blaikie & Priest, 2019).

Retroductive logic is possible "in closed systems under experimental design" (Blaikie & Priest, 2019, p. 82), and therefore rationalised the use of a case study company for this research. Figure 3-1 illustrates the application of retroductive logic to the case study that is the foundation of empirical evidence for the thesis. According to Blaikie & Priest (2019), a retroductive logic constructs a model of how a mechanism may be responsible for the regularity, and the context of which it operates, and looks for evidence that the mechanisms may behave the way they were postulated to do. Regularity in this case is the association between rental dress use and its environmental impact as found through an LCA. There are two mechanisms: PSS business model characteristics and consumer behaviour and characteristics. The context is based on a rental dress company in Stockholm, Sweden.

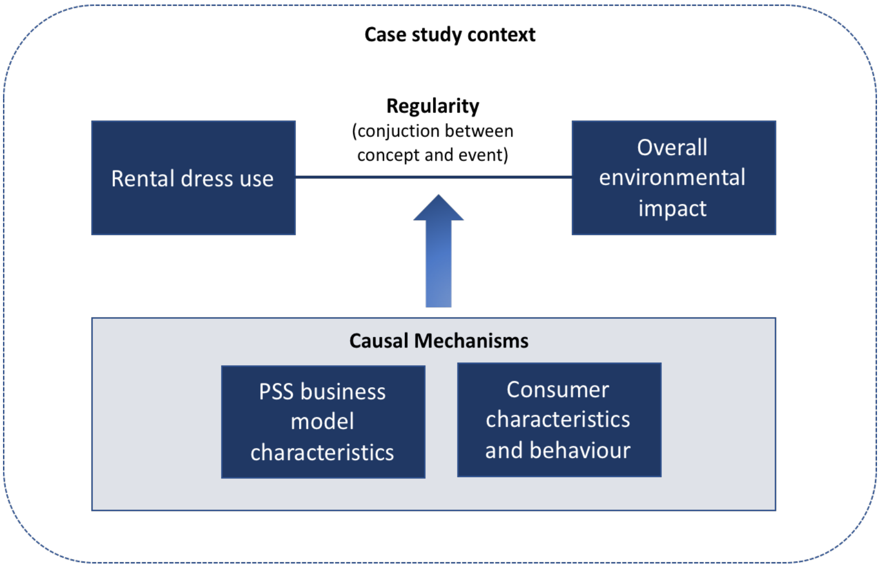

Figure 3-1. Application of retroductive logic to the research approach.

Source: Adaptation from Blaikie & Priest, (2019).

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[1] Models are defined as "a hypothesized set of relationships between concepts or a hypothetical explanatory mechanism" (Blaikie & Priest, 2019, p. 24).

[2] In a retroductive logic, events or observed regularities are explained by identifying structures or causal mechanisms that generate them (Blaikie & Priest, 2019; Leca & Naccache, 2006; Sayer, 1992).

The model offers an explanation for the variations in the environmental impact of a clothing PSS by postulating that variations in consumer behaviour resulting from BM characteristics create positive or negative consequences in the context of the case study. It implies that rental business models as a whole cannot be characterised to be more environmentally sustainable, and that this is also dependent on the causal mechanisms. The hypothetical models were tested through the use of an LCA software, SimaPro, by changing specific parameters to reflect how the changes in consumer behaviour can affect the environmental impacts of dress consumption. The outcome of these tests show reason to believe the relevance of the mechanisms to explain the regularities in this context.

The postulated models are:

Hypothetical model 1: The use intensity of garments (total number of wear occasions in the garment's service life) affect the environmental impact for both purchased and rental dresses.

Hypothetical model 2: The percentage of substitution, or replacement rate (RR) for rental consumption to substitute linear consumption significantly changes the environmental benefit of the rental business model. This is reliant on individual consumption behaviour and motivations.

Hypothetical model 3: The transportation mode affects the environmental impact of the dress. How users choose to commute will alter the overall impact of the PSS in comparison to a linear business model. Consumer transport modes are influenced by the BM's location.

3.2 Research Design

The research design employs case study research as a method to select empirical data through qualitative and quantitative methods. The company used for the case study is a B2C rental dress company in Stockholm, Sweden. Data on various aspects of the company's business model and activities was collected through questionnaires to the company's CEO, and data on consumer behaviour was collected through a digital survey to the company's users. This is complemented with secondary data gathered in the literature review, and data from the available databases in the LCA software. Survey data for consumer behaviour is analysed in excel, then analysed and interpreted with the other data by conducting a comparative LCA through SimaPro software.

3.2.1 Case Study Perspective

A case study is an "empirical inquiry that investigates a contemporary problem within its real-life context" (Blaikie & Priest, 2019, p. 183; Scholz & Tietje, 2002, p. 9; Yin, 2014). Selection of a company as a case study was deemed relevant for this thesis in order to collect data of the actual use of rental clothing from a successful company with a PSS business model. The rental company is the unit of analysis for the case study.

While there are criticisms of generalisability to the use of case studies, Flyvbjerg (2006) argues that concrete knowledge is context-dependent, and details from real-life situations can be of more value than universal predictive theories. This case study follows the retroductive logic and its goal is to describe and explain the postulated theories in a Swedish consumer and business context. It is not to create statistical generalisations such as in an experiment (Yin, 2014). This case study offers a description and explanation of the causal mechanisms and contextual factors that alter the environmental impact outcomes, and this can reinforce or reject the theories postulated how certain characteristics of the business model (ie. transport, rental time frame, company proximity to consumers, etc) and certain consumer behaviour characteristics can alter the environmental sustainability of the company. The case study can be generalised then judging by its transferability to different contexts of similar understandings (Blaikie & Priest, 2019).

This is an embedded case study, meaning it observes more than one unit of analysis by including subunits that focus on significant characteristics of the case study (Scholz & Tietje, 2002). The main unit of analysis is the case company, and the smaller units observed are consumer behaviour characteristics in reference to the characteristics of the business model's services. This case study is used for explanatory purposes and it seeks to "test cause-and-effect relationships" (Scholz & Tietje, 2002, p. 12) that were established in the hypothetical models.

When selecting the case study approach, the research design and analysis is tested by the construct validity, internal validity, external validity, and reliability (Yin, 2014).

Construct validity refers to "identifying correct operational measures for the concepts being studied" (Yin, 2014, p. 46). This can be achieved through employing three strategies during the data collection phase (Yin, 2014). The first strategy is utilising multiple sources of evidence. This is done by collecting data from literature, the CEO, general observations about the company and context, and a survey to company users. Maintaining a chain of evidence is the second strategy, which is achieved through the organisation and documentation of methods used to collect and analyse, as well as transparency of data used in the LCA. The last strategy is to have the case study reviewed by key informants, which was done by reviewal of the contact at the case company and the supervisors of the thesis.

Internal validity refers to the validity of the relationship between the causal mechanisms and the outcome (Blaikie & Priest, 2019; Yin, 2014). There are two strategies used to establish internal validity, and this is done during the data analysis (Yin, 2014). The first strategy is pattern matching, which is done by comparing the study's findings with the predicted patterns in the hypothetical models. The second strategy is explanation building, which is done by examining the data from the company and theory from literature in order to describe and explain the variations of business models in the environmental impact results in the LCA.

External validity refers to the context of which the study's findings can be related to or generalised (Yin, 2014). External validity is determined in the research design by asking appropriate research questions that justify the use of a case company and its ability to conclude with findings that can be transferable to similar contexts.

Reliability refers to the ability of the study's methods to be repeated and yield the same results (Yin, 2014). The reliability of the case study findings is done through documentation of the sources, methods, and logic used to collect and analyse data.

3.2.2 Case Study Selection

A list of platforms representative of the sustainability values of sharing and/or circular platforms were found through non-structured online research utilizing search words such as: clothing rental, peer-to-peer clothing rental, clothes sharing, clothing sharing economy. A list of companies was developed that, through a brief skimming of their webpage content, appeared to be synonymous with a use-oriented PSS and represented principles of either the sharing economy or the circular economy. Companies had to be active and currently offering their services.

A list of criteria was then established to filter out companies that did not truly represent "sharing" principles, based on Curtis & Lehner (2019). These criteria were:

- Characteristics needed to entail PSS (offer pay-per-use rental or subscription membership rental)
- Activities included only rental services, no product sales (e.g. companies that offered dual business models of traditional retail and rental were excluded)
- P2P or B2C
- Included a digital platform
- Pre-owned clothing
- Short rental period (no more than a few months, preferably less than a month)

This yielded a list of six companies in which the company business models and activity models were analysed. The companies were contacted through email inquiring of their interest to collaborate in the thesis. Three companies responded in which a brief screening was conducted through an interview in order to assess if the company had enough data available to conduct an LCA, and to assess the relative interest. One company was ruled out based on their lack of availability and time to dedicate to the thesis. Outlines of the life cycle of the other two companies were drawn out in order to have better understanding of the data that would be needed to conduct the LCA. The company selected was chosen due to the more simplistic set-up of the BM, the company's interest and location, activities and logistical set-up, and data availability.

3.3 Methods for Data Collection & Analysis

Qualitative and quantitative data was collected in three ways: through a literature review, data questionnaires, and a survey. The literature review acted as both a foundation to understand what data is needed to be collected, as well as to provide secondary data support to the questionnaires and surveys. Data questionnaires were completed by the CEO of the case company to gather data specifically for company activities such as laundry, and specific data regarding rentals and consumer engagement. The survey was sent to the rental company's clients to gather data on their normal purchasing behaviour, laundry behaviour, and their behaviour and engagement with the rental company. Data from the questionnaire and the survey were used to both compare and complement data. Data collected and initially analysed was then used for further analysis in SimaPro when performing the LCA.

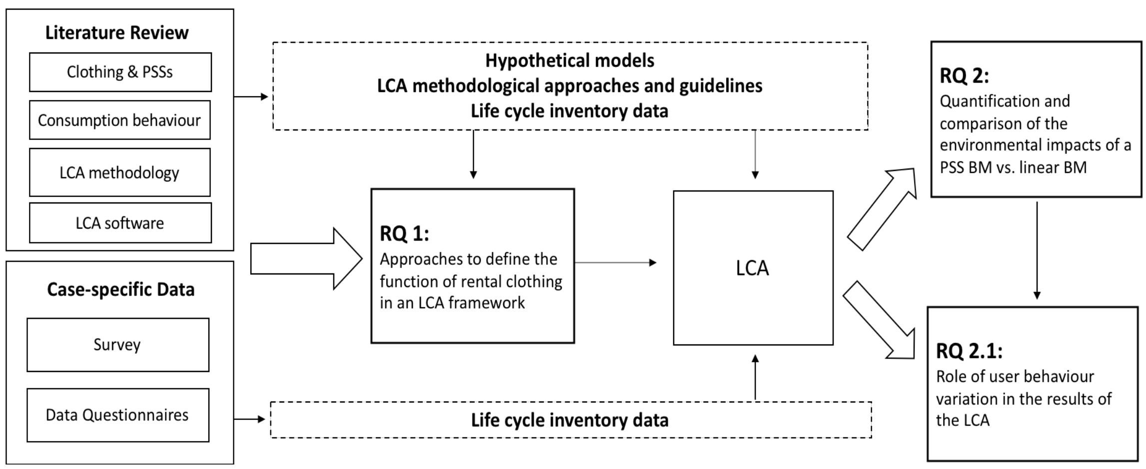

Figure 3-2. Data collection and analysis methods, and their contribution to the research questions.

3.3.1 Literature Review

The literature review primarily followed a systematic approach. This can be understood as several phases according to Jesson, J.K., Matheson, L., & Lacey, F.M. (2011), and are described similarly in the following four phases.

Phase 1: Mapping and scoping

This phase involved gaining a foundational understanding of what areas the environmental impacts of clothing had been measured (i.e. second-hand clothing, recycled clothing, or shared clothing), and to ensure the relevance and validity of the proposed analysis for shared clothing through an LCA. A variety of keyword combinations around the terms 'sharing economy', 'circular economy', 'collaborative consumption', and 'clothing' were searched. A snowballing effect was used based off of these results and revealed PSS as a framework business model that encapsulated the sought-after concepts. The majority of the literature was sourced from academic sources, complemented by grey literature. Phase 1 of the literature review was structured around five categories:

1. Identification of relevant concepts and defining of concepts;
2. Sustainability impacts from clothing sharing initiatives (what evidence is already there?);
3. Known challenges to quantify impacts of shared clothes;
4. Examples from existing LCAs for clothing PSSs and general PSSs;
5. Consumption behaviour.

A second phase was required to gain an understanding of LCA methodology and its practical application. This phase is not formally included in the literature review but is used in the application of methodology choices necessary to conduct an LCA. It was structured around the following:

1. LCA methodology and process;
2. Attribution vs. consequential approaches;
3. Datasets;
4. Life-cycle impact assessment (LCIA) methods and impact categories.

Phase 2: Comprehensive search

The initial search query focused on defining conceptual foundations of 'collaborative consumption', 'sharing economy', 'PSS', and 'circular economy'. A common understanding and selection of relevant definitions and characteristics of these concepts were selected in order to act as basis of criteria to structure the literature search for the other categories.

Since there is not as much literature on LCAs conducted for shared clothing in a PSS, some LCAs from general PSSs were analysed. The literature on other PSSs was considered relevant, as the major area of analysis and importance was how to address the use phase of LCAs for PSSs, and in general many assumptions must be made regarding consumer behaviour of use no matter the category of the product in an LCA. Relevant literature identified for this category included 3 academic articles on LCAs on PSSs and clothing, one LCA on 6 items of clothing, and 5 academic articles on LCAs for PSSs. Sources for the LCA methodology literature review ranged from academic articles to software and government reports.

Phase 3: Quality assessment and data extraction

Literature in phase 1 of the literature review was assessed in two screenings. The first screening was used to sort literature into the categories, while the second screening summarised papers into a synthesis matrix. Papers were further analysed in detail as themes developed through connections with other literature. Further sources were found through analysing references in the collected papers (bread crumbing) and searching for new citations (pearl growing). Because of the quick development of the research happening around 'sharing economy', 'collaborative consumption', and 'circular economy', most literature used is from after 2015, with the exception of some seminal sources, and older sources for LCA methodology guidance.

Literature for phase 2 with the LCA methodology was found through a snowballing method to locate seminal papers. Literature was also analysed in a synthesis matrix and certain handbooks and reports were used regularly to consult during LCA software use.

Phase 4: Synthesis

The synthesis matrix helped to identify commonalities, and some categories were broken down further. Data from category 3 in phase 1 was made into an additional table to codify phrases and concepts to more clearly identify themes. Category 5 in phase 1 was analysed further in NVivo 12 in order to identify key themes and concepts in consumer behaviour to help develop the user behaviour survey. Literature in phase 2 was synthesized in conjunction with the development and writing of the method and approach for the LCA.

3.3.2 Data questionnaires

A series of questionnaires were sent to the case company in order to collect company-specific data. Data collected was both of qualitative and quantitative nature, with some information directly from the CEO, and other information from the company's sale system. The data collected was from May 2018 until February 2020, as that is the time period that the company began operations up until the date that the information was requested for the thesis. Data collection was split into three types of information needed: user data, item (dress) data, and business activity data. Data gathered here, along with the behaviour survey, helped inform the activities modelled in the LCA. The data questionnaires involved important data for the LCA, some of which is listed here[3]:

- Average number of rentals per user;
- Company laundry activity;
- General dress material;
- General dress mass;
- Number of rentals per garment;
- Average time frame of rentals.

3.3.3 Consumption behaviour survey

A survey was conducted using Google forms, and was provided in both English and Swedish to customers who were signed up for the case company's newsletter. Most answers received were in Swedish. The survey was selectively sent out through the case company's newsletter to

[3] Additional data collected can be found in Appendix A: Consumer survey and Appendix B: General information collected from data questionnaires to the case company

its subscribed customers. Participants who completed the survey were entered into a raffle to win 500 SEK of credit towards a dress rental at the case company.

The purpose of the survey was to assess different behavioural consumption patterns of how users engage with the rental company. It was comprised of two main parts, where the first focused on the consumer's typical purchasing and use behaviour for formal dresses. The second part focused on the consumer's relationships with the case company and how they participate in renting, as well as how it affects their normal purchasing. It also asked hypothetical questions on how consumers would potentially behave if there was a different business model in place, such as an unlimited membership instead of the current pay-per-use model.

While a survey does not typically capture actual behaviour, it provides an indication of the behaviour of users engaged in the platform, and is more specific and insightful, in addition to literature and other studies on consumption behaviour. There were 57 total respondents, with 52 responses in Swedish. Information from the survey was used to gather data for consumer activities in the life cycle inventory in the LCA, and survey questions can be found in Appendix A. Results were analysed through Excel. Survey data contributed to: garment use intensity; number of dresses purchased yearly; transport modes and consumer transport distance; washing behaviour; and replacement rate for rental dresses for purchased dresses.

3.3.4 LCA

The LCA was conducted through the software SimaPro, and follows the guidelines stipulated in the ILCD handbook (2010). The following section blends the LCA methodology employed in this study with background information regarding LCA methodology and common practice, in order to establish understanding of the author's approach.

I. Goal definition

The definition of the goal and scope guides the modelling that should be applied to the study. The goal should be defined by 6 main aspects according to the ILCD Handbook (2010): the intended application of the study, the rationale for the study, limitations, target and type of audience, if comparisons are involved, and identification of the commissioner of the study. Furthermore, the goal definition should specify the decision-context. This can be determined by answering the questions depicted in Figure 3-3. The decision-context guides the choices needed to determine the LCA's methodological approaches and assumptions, particularly in the life cycle inventory (LCI). These approaches are commonly referred to as an attributional life cycle assessment (ALCA) or consequential life cycle assessment (CLCA) (Ekvall, 2020; European Commission - JRC - IES, 2010; Finnveden et al., 2009), but have also been referred to as "accounting" and "change-oriented" (Baumann & Tillman, 2004).

The attributional approach aims to "describe the environmentally relevant physical flows to and from a life cycle and its subsystems"(Ekvall, 2020, p. 4). The consequential approach models all the processes of the background of a system in consequence of decisions made in the foreground system[4] (European Commission - JRC - IES, 2010, p. 21). The attributional approach corresponds to Situation A, as it deals with micro-level decisions, and the consequential approach is associated with Situation B, where macro-level decisions result in

[4] The foreground system concerns processes specific to the system under investigation (European Commission - JRC - IES, 2010) , while the background system concerns all other modelled processes, such as production of generic materials, energy, and transport (M. Goedkoop et al., 2016).

large-scale structural consequences outside of the foreground system (European Commission - JRC - IES, 2010). The attributional approach is used more often than consequential (European Commission - JRC - IES, 2010) and is more established (Ekvall, 2020).

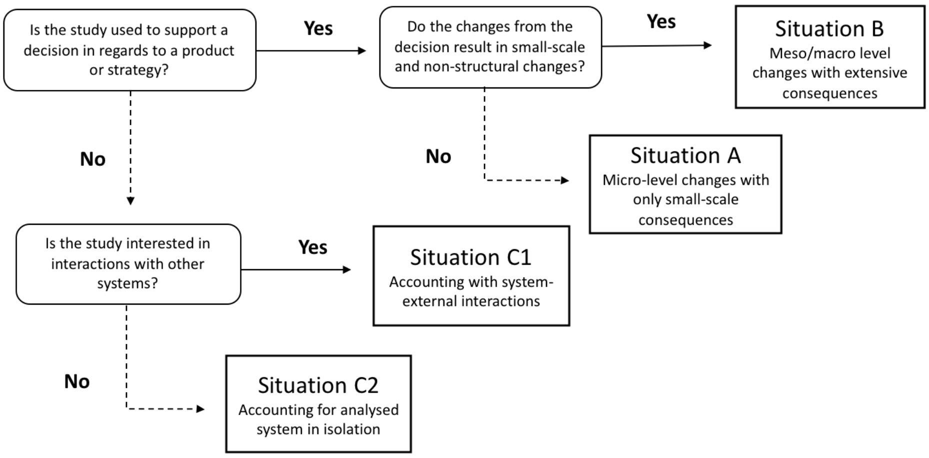

Figure 3-3.Classification of the decision-context.

Source: Adapted from European Commission-JRC-IES (2010).

The goal of the LCA was determined in conjunction with the aim of the thesis, and through the assessment of the case company's business model and available primary and secondary data. The decision-context was determined using the framework described in Figure 3-3. The study is most in alignment with Situation A, since it compares systems with an individual consumer perspective at a specific product and service level. It provides decision support in the sense that the study identifies alternatives with better or worse environmental performance. Since the consequences of the systems under analysis are considered small in sense that they do not cause structural changes[5], it is associated with the "micro-level decision support" for Situation A. Situation A is often associated with "product comparison" and "comparative assertion" (European Commission - JRC - IES, 2010, p. 39). If for example, the entire linear business model system was compared to a rental system, or all consumers in Sweden, then it is likely Situation B would be selected.

II. Scope definition

The scope should define what products, design, or processes are to be analysed (Baumann & Tillman, 2004). This is what Pohl et al. (2019) refers to as the "object of investigation" for a LCA on a PSS. Pohl et al. (2019) offers three perspectives on how a PSS can be evaluated as an object of investigation: 'product and service perspective', 'organisational perspective', and 'user and household perspective' (p.6). Product and service perspective is the most commonly used in LCAs and focuses on the product, which can lead to an underestimation of the use phase. The organisational perspective aims to analyse the impacts of the sharing organisation itself. The user or household perspective accounts for user behaviour and is the only perspective that considers behavioural changes and potentially rebound effects.

[5] Structural changes are understood as extensive consequences where parts of technologies or equipment in the background system or other systems change as a consequence of the system in analysis. This could mean additionally installed equipment or production infrastructure, or the decommissioning of it. It occurs outside of the foreground system, and structurally affects other parts of the economy ((European Commission - JRC - IES, 2010).

The object of investigation can help to define the FU. The FU should describe the function provided, the quantity, duration, and how and what way the function is provided, as well as consideration for how functional performance may change over time (European Commission - JRC - IES, 2010). The FU corresponds to a reference flow (RF) that relates all other input and output flows of the system (Baumann & Tillman, 2004; European Commission - JRC - IES, 2010). One function must be chosen to be expressed through the FU and analysed in the LCA, and comparative studies must also ensure that the FU is representative for both products and systems under investigation. The scope should also determine the system boundaries, which should generally include the following: natural system boundaries, geographical boundaries, time boundaries, and technical system boundaries (production capital and personnel, and other product life cycles) (Baumann & Tillman, 2004). These should be considered in reference to the foreground and background system.

Since consumers can perceive product function differently, which can result in different behaviours and potential differences in the associated impact, three FUs were developed. They were developed and analysed based on examples and guidelines from previous LCAs on PSSs. The FUs take a user-perspective, but aim to measure consumer impact in different ways, not to be compared against another. These FUs offer different perspectives to the impact and impact potential of a PSS in comparison with a linear business model. By thinking about the function of a rental dress in three different ways, different consumer perceptions and behaviours are considered. The FUs and the associated RFs are described in detail in section 4.4.

III. Life cycle inventory (LCI)

The LCI includes the collection of all the inputs and outputs for each stage of the product life cycle. Inputs include materials and energy, and outputs can be other products, emissions, and waste. According to Baumann & Tillman (2004), the LCI should include: a) construction of a flow model of the technical system under investigation and in alignment with the determined system boundaries; b) data collection and documentation for all relevant activities and processes in the model; and c) calculation of the environmental loads of the system in reference to the FU (Baumann & Tillman, 2004).

Inventory data should be representative, meaning how well the data represents the true inventory of the process for which they are collected, for example regarding the technology, geography or time (European Commission - JRC - IES, 2010). Data should also be appropriate, meaning the extent that process data in the model represents the process of the system (European Commission - JRC - IES, 2010), which is determined when deciding to conduct an ALCA or CLCA. An ALCA should typically use average data and exclude marginal data[6], while a CLCA should use both types of data depending on the processes being modelled (Finnveden et al., 2009). The modelling approach determined in the goal and scope also guides how allocation should be addressed. An ALCA should partition through allocation by estimating "what share of the burdens of the multifunctional process belongs to", including the input materials and energy in the product under investigation (Ekvall, 2020, p. 12). Allocation can be determined based on function of the systems of analysis that are similar, such as mass, energy, or economic value. In CLCAs, system boundaries should be expanded to include the

[6] Average data can be understood as data representing "the average environmental burdens for producing a unit of the good and/or service in the system" and marginal as data representing "the effects of a small change in the output of goods and/or services from a system of environmental burdens of the system" (Finnveden et al., 2009, p. 3).

processes that will be affected by the change in flows from other affected life cycles of by-products or multi-functional processes or products (Ekvall, 2020).

The life cycle flows for a garment in the PSS was developed based on information from the case company, and the linear life cycle flow based on conventional consumption. Relevant process information was collected from various sources, primarily from literature of previously conducted life cycle assessments and reports detailing consumer information. Data was also collected from the behaviour survey and the case company. The technological and geographical representativeness of data is considered for all processes, which is specified in the next section, as well as in the table the activities and processes used from the database, which can be found in Appendix E.

The ecoinvent v3 database was used, as supplied by SimaPro. Ecoinvent offers six versions of datasets, and the "allocation, cut-off by classification, unit processes" dataset was selected and used. The allocation dataset was chosen as it is in alignment with the goal and attributional approach of the study. The cut-off classification uses data regarding the average supply of products allocated by the market value of products, similarly as the "allocation at the point of substitution model". However, the cut-off classification differs in that it does not credit primary producers with benefit for the provision of recycled materials, and the recycled materials bear impact only in the processing of the material (Ecoinvent, 2020; M. Goedkoop et al., 2016). Although, the "allocation at the point of substitution" is also suitable for an attributional approach, Ponsionen (2015) cautions that its complexity can calculate results that are not always suitable to the study. "Unit process" was selected, as this is more transparent by offering a clear link and traceability of inputs from upstream processes, whereas "system process" offers an aggregated dataset that is considered a black box because it does not offer further information regarding inputs or outputs of linked processes (M. Goedkoop et al., 2016). Allocation for impacts from production, retail distribution, laundry, and municipal incineration were based on the mass of the associated garments. Default allocation methods from the processes selected in the ecoinvent database are used.

IV. Life cycle impact assessment (LCIA)

The purpose of the LCIA is to help assess the results from the inventory analysis to understand the environmental consequences and their significance (Finnveden et al., 2009). The general impact categories are broadly summarised as resource use, human health, and ecological consequences (Baumann & Tillman, 2004) which are then divided into subcategories.

LCIA involves a few different steps. The first is the selection and identification of the categories for the environmental impacts relevant to the study, and classification which assigns the environmental loads from the LCI to their associated impact categories (Baumann & Tillman, 2004). The next step is characterisation, which summarises the extent of the impact from emissions and resource extractions in the common unit of the category indicator (Baumann & Tillman, 2004; Finnveden et al., 2009). The common unit for each category is often called characterisation factor (Finnveden et al., 2009) or equivalency factor (Baumann & Tillman, 2004). Characterisation results can be difficult to interpret because impact categories cannot be compared to one another, and the results do not show the overall magnitude of the impact (M. Goedkoop et al., 2016).

There are several LCIA methods that employ different characterisation methods. Characterisation methods can utilise a midpoint or endpoint approach. The endpoint indicator is defined as the area of protection, whereas the midpoint method is defined somewhere between the emission and the endpoint (Finnveden et al., 2009). The endpoint method provides indicators at the areas of protection, meaning the natural environment, human health, and resource availability (European Commission, 2011). Endpoint modelling can be reliable for some impact categories, for example, acidification and cancer effects, but is still developing for climate change in which a midpoint approach would select indicators earlier on (Finnveden et al., 2009). A midpoint approach integrates better the precautionary principle, whereas in the endpoint model, there is no consideration for impacts that cannot be modelled and are more unknown (Finnveden et al., 2009). Midpoint indicators have lower uncertainty, although endpoint indicators are easier to understand (M. Goedkoop et al., 2016).

LCIAs can include normalisation and weighting, but these are not mandatory. Normalisation relates the characterisation results to a reference value to make impact categories comparable and to express the magnitude of the environmental impacts from the analysed system (M. Goedkoop et al., 2016). Weighting assigns weights to the normalised indicator results to show the relative importance of the impact categories and establish a single score for the systems or product under analysis (European Commission - JRC - IES, 2010). Weighting is subjective and not based on natural-science since impact categories can be weighted on various factors (Baumann & Tillman, 2004). According to the ISO standards, weighting is not allowed for the comparative assertions (M. Goedkoop et al., 2016).

A midpoint approach was selected for the LCIA, and the ReCiPe Hierarchist midpoint method was selected after a literature review of LCIA methods. It's normalisation methods are based on a study by Sleeswijk et al. (2008), utilizing the population of EU25+3 of 464,036,294 citizens (PRé, 2019), in which normalised results are expressed as person equivalents, or the annual impact of an average European person in the year 2000 (M. Goedkoop et al., 2016; PRé, 2019). To determine relevant impact categories, LCAs on garment or other textiles were reviewed to understand the important impacts from an industry and research perspective that should be considered. Literature reviewed included: Farrant et al. (2010), Roos et al.(2015), Sandin et al. (2019), Watson & Weidemann (2019), Sandin & Peters (2018), and Piontek et al. (2020). This was taken into account in concurrence with the significant impact categories from the results. Results were normalised and following categories were analysed: freshwater ecotoxicity, marine ecotoxicity, human carcinogenic potential, and global warming potential.

V. Interpretation

The results from the LCIA should be interpreted and aligned with the goal and scope to deliver recommendations and/or conclusions. The interpretation involves two main parts: the identification of significant issues such as important findings or methodological choices, and the evaluation of results in order to establish confidence (Baumann & Tillman, 2004). Results can be presented in various ways, with the format determined by the character of the results, or by its analytical purpose (Baumann & Tillman, 2004). LCIA results are presented separately for each FU. The following analyses were conducted in the results:

- **Dominance analysis**: Conducted by analysing what life cycle stages in the analysed systems contribute the most to environmental impact categories. It also analysed how increased usage in both the linear and PSS BMs can reduce the share of the production impacts.
- **Sensitivity analysis**: Conducted by testing critical data and data variation, by altering the use intensity of garments in both the linear and PSS scenarios, as well as accounting for differentiation in transport modes.
- **Variation analysis**: Conducted by testing three different FUs, along with alternative scenarios within each.

4 A case study of a rental clothing BM and its environmental impacts

The case company is a B2C clothing library in Stockholm, where customers can rent formal and high-end dresses. Customers pay-per-use for dresses and can choose to rent dresses for 2,4,7, or 14 days. Most of the dresses that the company rents are second-hand, in which 60% of the dresses are procured through the company's own purchasing through second-hand shopping or over-stocks. About 40% of the dresses are from clients who rent out their own dresses. The company offers an online platform as well as a physical location, and laundry and repair are taken care of by the company. Customers can pick-up dresses from the store, or order online. Dresses are offered throughout Sweden, although the current customers live in the Stockholm area, and most choose to pick-up their dresses rather than order online.

Clients average 1.09 rentals per user from the time period stated previously. The company currently has 317 active dresses that are rented and owned by the company, and 163 actively rented dresses that belong to clients. Due to the large dress assortment and the relatively new market presence of the company, it is estimated that the average number of times a garment is currently rented is 2 times. However, some dresses have been rented many more times, with the top three dress rentals having been rented 17 times, 15 times, and 12 times. The company estimates that based on the quality and wear of the top-rented garments, that they could be worn between 5-15 more times.

The company began business in May 2018, and data used in the study is from its opening until February 2020. The company has a total of 856 clients and rents an average of about 50 dresses per month. In 2018, the company rented a total of 253 dresses, and in 2019, 616 dresses. The company expected to grow twice as much in 2020 compared to 2019, although this likely will change due to consequences from COVID-19.

4.1 Consumer purchasing and rental behaviour

This section provides a summary of the purchasing and rental behaviour of clients of the rental case company. It is based on the responses from the survey and data from the company. The summary provides a foundation for the reference flows in the scenarios modelled in the LCA.

4.1.1 Purchasing frequency and use intensity

The frequency of formal dress purchasing is shown in Figure 4-1, where the majority of respondents (61%) stated that they purchase formal dresses just for certain occasions. A weighted average was calculated based off of an assumption[7] made for the number of dresses purchased for certain occasions, estimating that 1.5 formal dresses are purchased annually per consumer.

[7] A multi-year scenario was built to estimate an annual number of purchased dresses for consumers who purchase "only for certain occasions". This scenario can be found in Appendix C: Supplementary information for LCI.

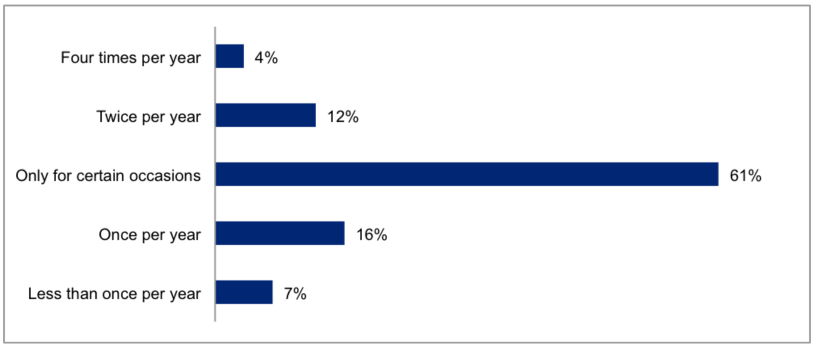

Figure 4-1. Annual consumer purchasing frequency for new formal dresses.

The majority of respondents (68%) stated that they wear their purchased formal dresses 3 times or less, with just 4% stating that they wear one formal dress more than 10 times. It is estimated that a consumer wears one formal dress 3.12 times, based on a weighted average calculated by taking the middle number of uses[8] for each response category.

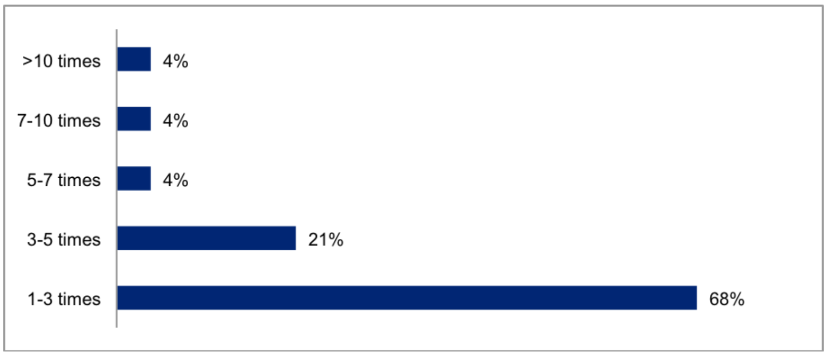

Figure 4-2.Wear occasions (use) of a purchased formal dress.

4.1.2 Laundry frequency

The survey results indicate that the majority of respondents (63%) only wash their dresses when it appears dirty, and quite rarely after every use. As the average number of times a garment is worn is 3.12 times, washing when it appears dirty was calculated to be 1.04 times (or every 3 uses), washing after every use as 3.12 times, and washing after every other use as 1.56 times (every 2 uses). This results in a weighted average of 1.72 wash cycles for every 3.12 wears.

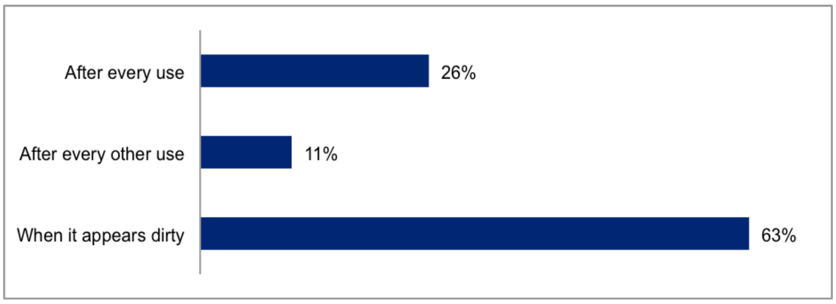

Figure 4-3. Frequency of consumer dress washing.

[8] 2 uses is used to represent the category '1-3 times', 4 uses to represent the category '3-5 times', 6 uses for '5-7 times', etc.

4.1.3 Transport

How consumers travel to rent clothing is important to understand since a PSS involves more consumer transportation than in an ownership business model. Consumers were asked of their primary and secondary transport modes in how they travel to the store to purchase items (Figure 4-4 A), and how they travel to the case company to rent (Figure 4-4 B). Consumers answered very similarly for both cases, with the metro (Stockholm tunnelbana) as the most popular form of transport as the primary mode (47% of respondents traveling to shop, and 54% of respondents traveling to the rental company with it). The bus is the most popular secondary form of transport (48% of respondents traveling to shop and 32% of respondents traveling to the rental company). Four transport scenarios were created as the most common forms of primary and secondary transport and are shown in Table 4-1.

Consumers were also asked how they planned their trip to the case company rental store, in which 55% of respondents stated they combine the visit to the rental store location with other errands, and 45% stated they make a point to just go to the rental store location.

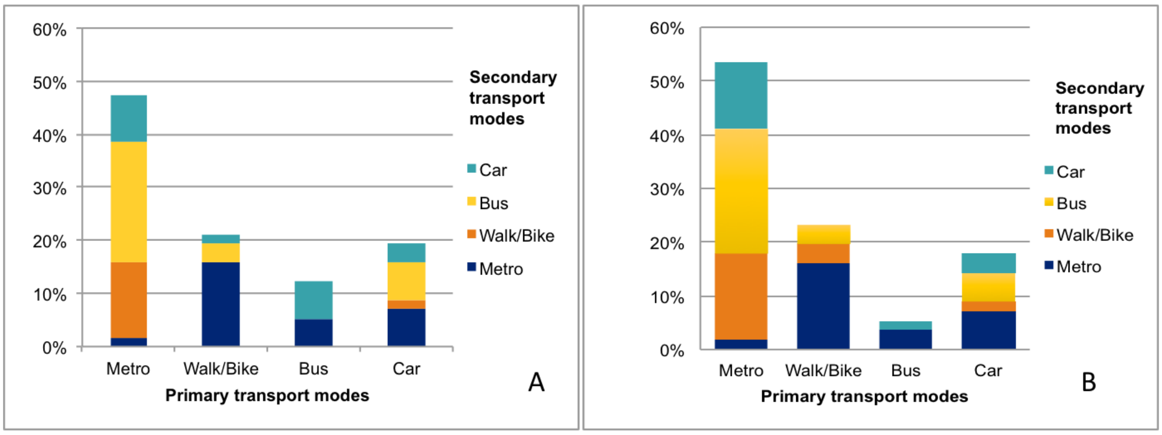

Figure 4-4.Primary and secondary transport modes for consumers to shopping areas (A), and to rental company location (B).

Table 4-1. Most popular travel modes

Transport Scenarios	Primary mode	Secondary mode
Scenario 1 (average)	Metro	Bus
Scenario 2	Metro	Walk
Scenario 3	Bike	Metro
Scenario 4	Car	Metro

4.1.4 Rental motivation and substitution behaviour

Consumers choose to rent dresses for different reasons, as shown in Figure 4-5. The primary motivator to rent for most respondents was to avoid having to purchase a dress (35% of respondents), followed by environmental concerns (21%). The most common secondary motivator to engage in rental was to wear unique dresses (33%), and the lowest motivator for the majority of respondents (72%) was having influence from peers to rent.

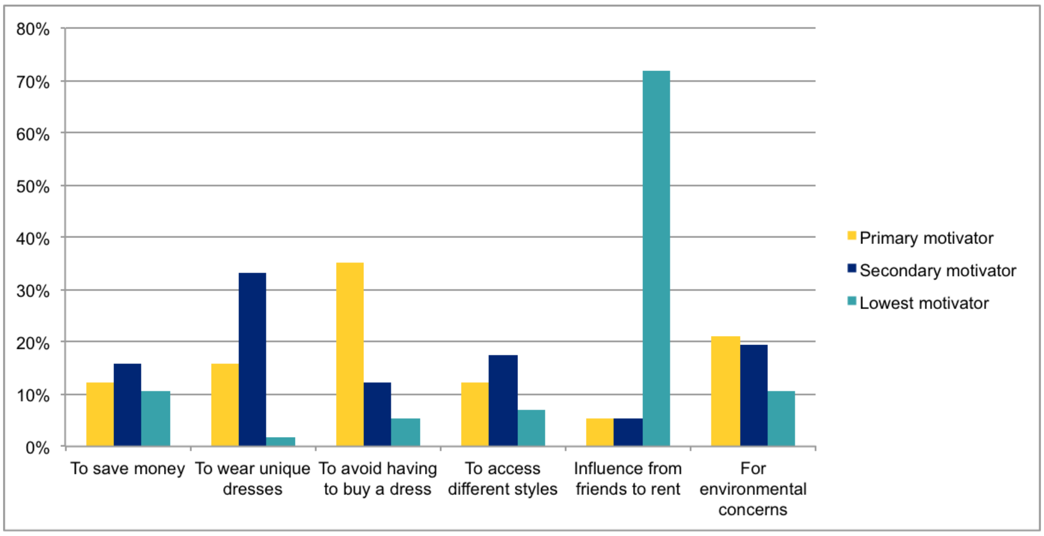

Figure 4-5. Ranked motivations for renting dresses.

When customers were asked how renting dresses from the case company affects their normal shopping behaviour, respondents selected a number on a scale from 0-10, with 0 representing no impact, to 10 as 100% substitution of rental dresses for conventionally purchased dresses. The spread is shown in Figure 4-6.

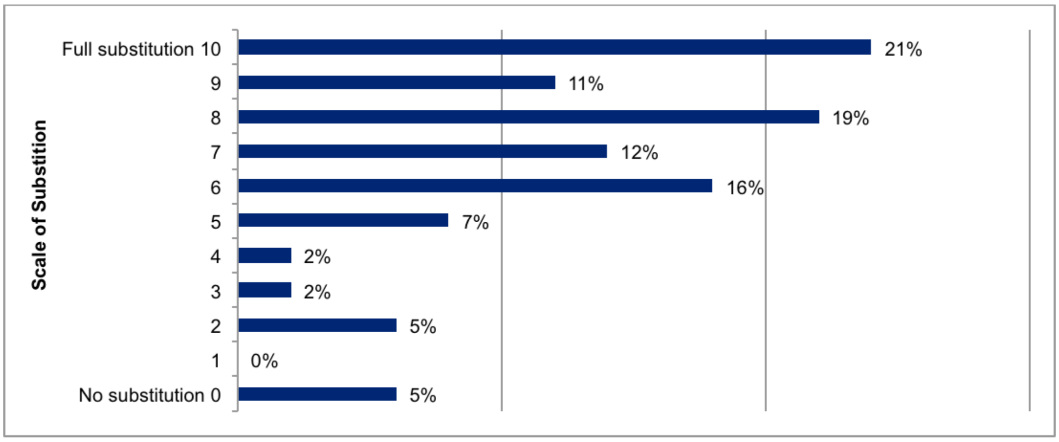

Figure 4-6. How dress rental affects normal purchasing behaviour.

A majority of the respondents indicated that they considered their participation in renting dresses as substitution for purchasing of dresses. Substitution here refers to the replacement rate (RR). The weighted average for respondent's reported replacement rate is 70%. This assumes that rental dresses substitute 70% of the need to purchase dresses.

Fifty-three percent of respondents stated that they still purchase dresses even though they rent. When respondents were given an open question inquiring the reasons why, the following reasons appeared to be the most common of why respondents felt they still needed to purchase formal dresses: the limited number of dresses available to rent, if consumers felt they wanted to wear a dress many times, and if dresses were well-priced to purchase. Many respondents commented that they purchase dresses because of a need to have casual or everyday dresses that would be worn more often, implying that the rental company fulfils a very specific niche of clothing for formal and special events.

Consumers were asked if they would want to rent more dresses if the case company would offer a membership fee rather than pay-per-use for their dresses. Seventy percent of respondents stated that they would not, with 40% stating they would rent more, with a weighted average of 3 more dresses per month. Of respondents who did indicate their interested in unlimited rentals, 88% of them said they would rent dresses as needed, not at the same time.

Consumers were also asked if they would be willing to rent other types of clothing such as a jacket or pair of jeans, in which 63% stated that they would be willing to rent a jacket or both items, although no respondents were interested in just renting jeans.

4.1.5 Consumer behaviour by type

Respondents were asked to identify a consumer shopping profile that they felt described their behaviour best. A description of consumer profiles can be found in Table 4-2, and respondents identification of themselves with the profiles in Figure 4-7.

Table 4-2. Consumer shopping types and characteristics

Consumer types	Characteristics
Influencer	Wants most updated wardrobe styles. Desires to stay updated with latest fashion trends and always have something different to wear.
Eco-friendly	Cares about the environment. Tries to buy from ethical and sustainable fashion brands, looks for sustainable alternatives.
Fitting-in	Wants to fit in and belong to a group. Buys similar style to friends, shops from the same places as peers.
Bargain	Seeks out deals. Shops sales, looks for cheaper alternatives and promotional offers.
Avoid	Tries to avoid clothes shopping. Shops for clothes only when needed or to replace something.
Stand-out	Wants to stand out from the crowd. Looks for unique clothing, seeks to customise their own style.

Source: Adapted from Ellen MacArthur Foundation (2017, p. 75)

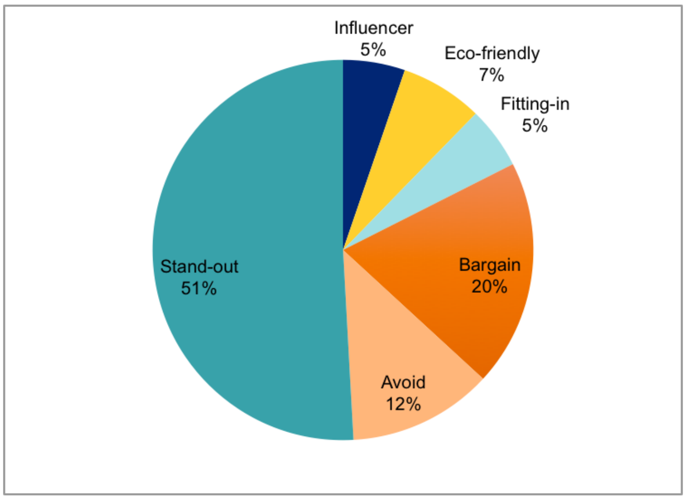

Figure 4-7. Consumer profiles.

When consumer profiles were assessed individually, there was some variation in the respondent's garment usage, purchases, and stated RR of rental dresses over purchased, as shown in Table 4-3. Although the use intensity and number of purchased dresses do not vary greatly, the RR varies quite a bit, with the lowest stated RR as 46.70% for influencer consumer profiles, and 90% RR for eco-friendly consumer profiles. Although the age group, education level and annual income were collected, the consumer profiles did not have any patterns in terms of demographic characteristics.

Table 4-3. Consumer profiles and behaviour variation

Consumer types	Number of times a garment is worn	Purchased dresses over 4 years	Replacement rate of rental dresses for purchased
Influencer	2	8	46.70%
Eco-friendly	5	5.5	90%
Fitting-in	2	5.3	80%
Bargain	3.1	6	59.10%
Avoid	3.4	6	62.90%
Stand-out	3.1	5.9	73.10%

4.2 A comparative LCA of consumption in a PSS vs linear BM

An overview of the life cycle stages of a dress in a linear business model vs. the case company's rental business model is shown in Figure 4-8. These stages and associated processes are described in further detail in the LCI in section 4.5.

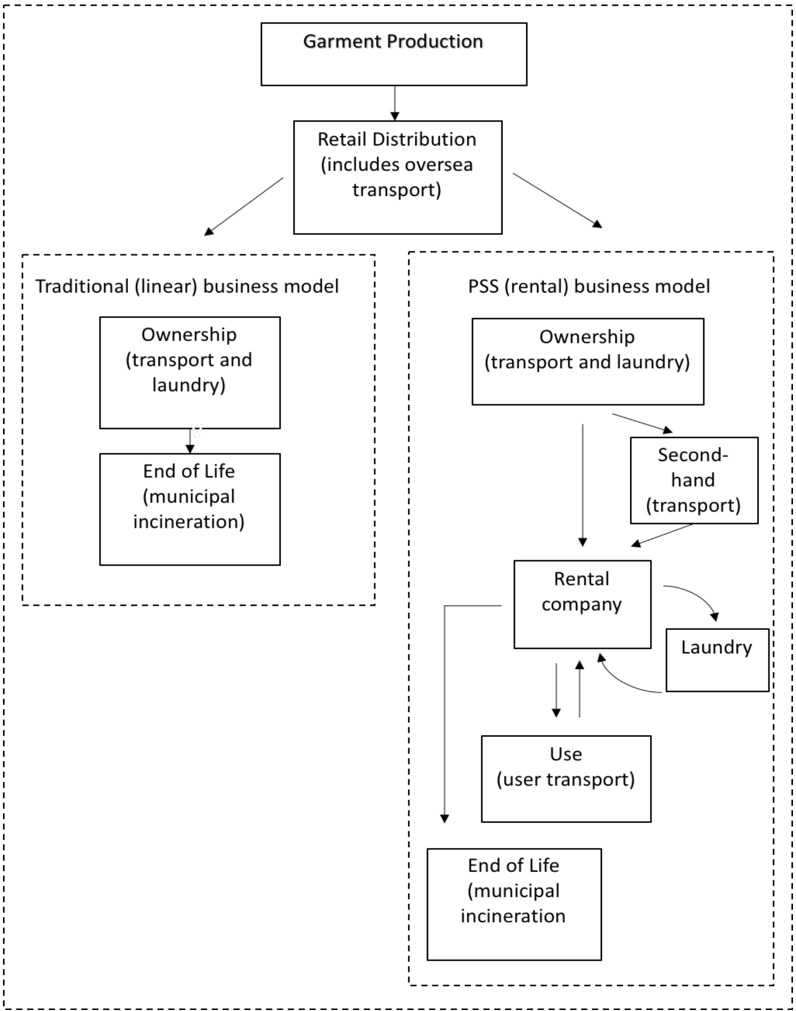

Figure 4-8. Life cycle of linear business model vs. rental case company.

4.3 Goal of the LCA

The goal of the assessment is in alignment with the objectives of the thesis, of which is primarily to identify and compare the environmental impacts from cradle-to-grave of a shared dress in a rental clothing company vs. a dress consumed in a conventional (linear) business model in Sweden. Furthermore, it aims to understand how consumer behaviour may alter the environmental impacts. Shared dress in the study refers to a rented dress to be used by various users at different times, with the rental facilitated by a company. The dresses considered in the study are formal and special-occasion wear. This is an important distinction as consumer behaviour in regard to garment usage would differ with other types of clothing and would likely change the results.

The reason for carrying out this study is to understand what environmental implications rental clothing in a Swedish consumption context has compared to traditional ownership-based consumption, and to indicate what life cycle stages of the BMs have considerable impacts on the environmental consequences of a dress. The study is a comparative assertion and its results will be given to the case company and made publicly available as a master's thesis. The target audience are PSSs or similar companies, as well as researchers studying sustainable business models for alternative consumption. The objective is to better understand the environmental implications of different business models and the associated consumer behaviour to engage with them. It provides insights for a specific B2C business model context.

Since the data for garment-use and purchasing are case-specific, the results will differ for other garments and specific quantitative results should not be generalised to all clothing. Trends of the results however can be generalised, and these are discussed in section 6.1. Furthermore, the transport modelled relies heavily on public transport, and results will differ based on the location, for example in areas where public transport is not common nor reliable. The study is commissioned and performed by the author; no other organisations are involved with the decisions made in the study.

4.4 The scope

A user-oriented perspective is taken in the LCA, so the FUs must account for the resulting behaviour associated with the product and service use. Since consumers engage with clothing PSSs to rent clothes for different reasons, as shown in Figure 4-5 from the survey, it is important to understand the function that a rental dress provides in comparison to a purchased dress, and how different fulfilment of the function by the systems can change the environmental impact.

Different reasons to rent imply that consumption satisfies different needs. For example, some may be satisfied by the number of garments or number of different styles, such as respondents who stated their primary motivation to rent was to "wear unique dresses" or "to access different styles". Other consumers may have more satisfaction by the number of uses, or how many times a garment can be worn, such as consumers who stated their primary motivation to rent was to "avoid having to buy a dress", or "to save money", or "for environmental concerns". This is perhaps closer to the originally intended function of clothing. Therefore, three different FUs are suggested, and different scenarios for both the linear BM and PSS BM are analysed for each. The following FUs are analysed: "one average use", "consumer dress needs for 4 years" satisfied by the **number of dresses purchased** and "consumer dress needs for 4 years" satisfied by the number of **uses or wear occasions.** Two variations of the FU "consumer dress needs for 4 years" are modelled since the function of satisfaction can be provided in different ways. It should be understood that the FUs are not compared against another, they are used to understand and test different approaches to accounting for the impacts for garments in a PSS.

"One average use" is considered a narrow definition of the FU, whereas the other two FUs take a broader definition in that they consider a wider range of activities that include the potential for linear consumption to be displaced by shared consumption. Both definitions can be beneficial, as the narrow definition is better defined and has a higher degree of certainty. In contrast, the other FUs include more effects of consumer behaviour, but more assumptions have to be made and therefore there is more uncertainty. Different scenarios are modelled for the linear and PSS for each FU, which is described in Table 4-4. A total of 5 scenarios for the linear consumption system are modelled, with 9 scenarios for the PSS. Further details regarding the reference flows are described in section 4.5.

Table 4-4.Functional units (FUs) and descriptions

FU: **One average use of a formal dress**	
Linear Scenarios	PSS Scenarios
SL 1.1: One average use from cradle-to-grave where the total amount of wear occasions per garment is 3.12[9] times.	SPSS 1.1: One average use from cradle-to-grave where the total amount of rentals/users is 11 times[10].
SL 1.2: One average use from cradle-to-grave where the total amount of wear occasions per garment is 1 time.	SPSS 1.2: One average use from cradle-to-grave where the total amount of rentals/users is 2 times.
SL 1.3: One average use from cradle-to-grave where the total amount of wear occasions per garment is 11 times.	SPSS 1.3: One average use from cradle-to-grave where the total amount of rentals/users is 20 times.
FU: **4 years of consumer formal dress needs satisfied by purchasing**	
SL 2: Four years of dress purchasing (1.5 dresses per year) with an average use of 3.12 wears per garment.	SPSS 2.1: Four years of combined dress purchasing and rental with a 33%[11] replacement rate (RR) of purchased dresses and average users per rented garment as 11.
	SPSS 2.2: Four years of combined dress purchasing and rental with a 50% RR of purchased dresses and average users per rented garment as 11.
	SPSS 2.3: Four years of combined dress purchasing and rental with a 100% RR of purchased dresses and average users per rented garment as 11.
FU: **4 years of consumer formal dress needs satisfied by use**	
SL 3: Four years of dress use (4 dress occasions per year) with an average use of 3.12 wears per garment.	SPSS 3.1: Four years of dress use (4 dress occasions per year) with combine dress purchasing and rental with a 33% replacement rate (RR) of wear occasions, and assuming average users per rented garment as 11.
	SPSS 3.2: Four years of dress use (4 dress occasions per year) with combine dress purchasing and rental with a 50% RR of wear occasions, and assuming average users per rented garment as 11.
	SPSS 3.3: Four years of dress use (4 dress occasions per year) with combine dress purchasing and rental with a 100% RR of wear occasions, and assuming average users per rented garment as 11.

[9] This number is derived from the consumer survey and is described in "Use intensity" in section 4.5.3.

[10] This number is derived from case company data and is described in "Use intensity" in section 4.5.3.

[11] This percentage is derived from the purchasing behavior from the consumer survey with reference to the number of rentals per user from the case company, and is described in "Consumer purchasing and rental" in section 4.5.3.

4.4.1 System boundaries

The geographical boundaries in the use phase are specific to Stockholm, Sweden, since the consumption behaviour and usage likely differs in the capital city in comparison to other areas for a variety of reasons. Furthermore, the average transportation used is based on public transportation and specific to Stockholm since many consumers use the metro. However, the disposal through municipal incineration likely can be generalised to all of Sweden. Production data is not Swedish based, but is an electricity mix based off of data from 7 countries that dominated the Swedish importation of clothes between 2013-2017 (see Appendix D) based on the study by Sandin et al. (2019).

The time frame in assessment differs according to the FU. The time for the FU of "one average use" accounts for one wear occasion of a garment, where the time frame could be a few hours up to 12 hours and the associated impacts are considered the same because it is still one use. The time frame for the other two FUs is 4 years based on data from WRAP (2017). Four years refers to a dress's lifetime based on style obsolescence, not its technical durability. Since clothes are often discarded before the end of their technical life-time (Birtwistle & Moore, 2007), the length of life for the dresses is based on how long the dress could be considered to be a relevant style and continue to be used. WRAP (2017) assumes 3.62 years is the lifetime of a dress, and this study assumes 4 years to be the lifetime of formal dresses. This is because consumers may keep them for longer since they are conventionally more expensive, and that formal dress styles do not change as radically or quickly as everyday dresses in a fast fashion system.

Personnel needed for retail stores and the rental store, such as the transportation of employees to work are excluded. Lighting and heat needed for the physical stores are also excluded. Packaging for transoceanic shipment and retail distribution, as well as consumer distribution are excluded. Small details for garment such as zippers and buttons are also excluded from the study.

4.5 Life Cycle Inventory

The life cycle inventory includes data for processes and activities from cradle-to-grave for the linear business model and the rental business model. This section details the assumptions used to model the scenarios and justifies the use of particular data. Specific processes and details for the entire LCI can be found in Appendix D.

4.5.1 Production stages

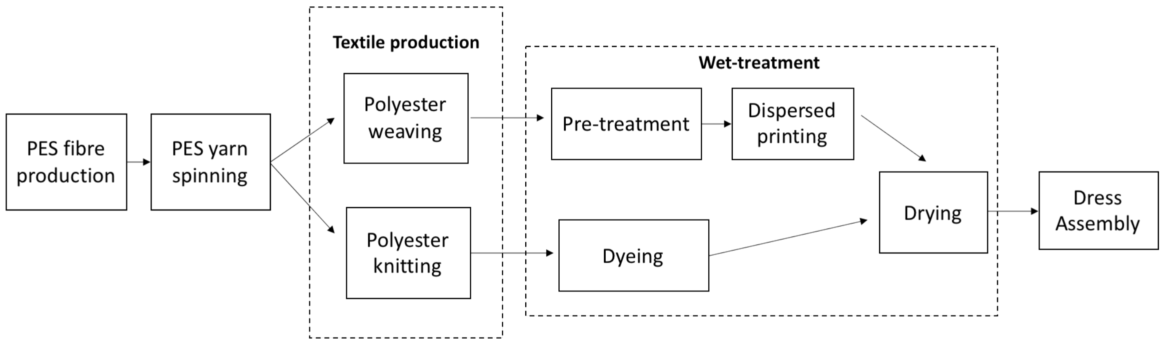

Figure 4-9. Polyester garment production process.

Source: Based on Roos et al. (2015) and Sandin et al. (2019).

The processes modelled for polyester dress production is shown in Figure 4-9. The same production processes were used in both the linear and PSS business model, as the case company offers rental of pre-used dresses and does not produce any dresses. Dress production data was taken from the life-cycle assessment of a polyester dress of 478 grams released by Mistra Future Fashion in two reports by Roos et al. (2015) and Sandin et al. (2019). The secondary data from Mistra Future Fashion was considered relevant, as most of the dresses from the case company are made of polyester. The top 3 dresses rented by the case company are made with a mix of materials including polyester, with two of the dresses consisting 100% of polyester. The top three dresses weigh around 500 grams. Therefore, the approximate dress sewing times for the garment type were assumed to be the same given the similar mass considering the weight of the dresses, and the general heavier nature of formal dresses. Buttons, zippers, and closure details or additional dress accessories are excluded as they are presumed to have insignificant effect due to their little relative mass to the garment. Table 4-5 shows the reference flows for the quantity of dresses needed to be produced.

Table 4-5. Product reference flows[12] for all modeled scenarios

<table>
<tr><td colspan="2">FU: One average use of a formal dress</td></tr>
<tr><td>Linear Scenarios</td><td>PSS Scenarios</td></tr>
<tr><td>SL 1.1: One purchased dress/3.12 total wear occasions</td><td>SPSS 1.1: One rented dress/11 total users</td></tr>
<tr><td>SL 1.2: One purchased dress/1 total wear occasion</td><td>SPSS 1.2: One rented dress/2 total users</td></tr>
<tr><td>SL 1.3: One purchased dress/11 total wear occasions</td><td>SPSS 1.3: One rented dress/20 total users</td></tr>
<tr><td colspan="2">FU: 4 years of consumer formal dress needs satisfied by purchasing</td></tr>
<tr><td rowspan="3">SL 2: 6 purchased dresses (1.5 dresses purchased yearly)</td><td>SPSS 2.1: 4 purchased dresses + (2 rental dresses/11 users)</td></tr>
<tr><td>SPSS 2.2: 3 purchased dresses + (3 rental dresses/11 users)</td></tr>
<tr><td>SPSS 2.3: 6 purchased dresses/11 users</td></tr>
<tr><td colspan="2">FU: 4 years of consumer formal dress needs satisfied by use</td></tr>
<tr><td rowspan="3">SL 3: 5.13 purchased dresses</td><td>SPSS 3.1: 3.43 purchased dresses + 5.28 rental dresses</td></tr>
<tr><td>SPSS 3.2: 2.56 purchased dresses + 8 rental dresses</td></tr>
<tr><td>SPSS 3.3: 16 rental dresses</td></tr>
</table>

4.5.2 Retail distribution and consumer purchasing

The distance and process data for transoceanic shipment of garments from production countries to retail stores in Sweden are based on data from the Mistra Future Fashion reports (Roos et al., 2015; Sandin et al., 2019). The garments are assumed to be transported from Asia to Europe by ship, and to retail stores by lorry. Resources needed for the retail store such as building infrastructure, heat and electricity, and transport for retail staff were excluded. The processes and quantities used for shipment can be found in Appendix D. The tonnes-kilometre (tkm) for the shipment found in the table refer to the mass of one garment modelled in production (477 g). Each modelled scenario is adjusted to reflect the change in mass of dresses needed and associated tkm, based on number of dresses needed from Table 4-5.

[12] Details for calculations and justification can be found in Appendix D: LCI processes from Ecoinvent database.

4.5.3 Use Phase (consumer purchasing, transport, laundry)

The use phase involves the purchasing of dresses by accounting for the material needed to produce the garments, the associated transport to purchase or rent, and the laundry activities associated with the use intensity.

Consumer purchasing and rental

Data to account for the impacts of consumer purchasing was dependent on the quantity of formal dresses purchased yearly, and the ability of rental dresses to substitute or displace normal purchasing behaviour. This is already summarised in Table 4-5. It should be noted that the number of purchases, as well as number of purchases per trip would likely be different for casual dresses. For example, Sandin et al. (2019) estimate that Swedes purchase 2.6 dress a year, based on Statistics Sweden's 2019 results. However, this data considers all dresses, and this study focuses specifically on formal dresses.

Different RRs are considered in two of the FUs since they account for a broader definition and therefore more activities in regard to consumer behaviour. Replacement rates are tested in the PSS scenarios, as shown in Table 4-6. The RR of rental for purchased dresses is based on a combination of company data and survey responses. A weighted average for the RR based on survey responses was calculated as 70% (see section 4.1.4). However, data from the case company shows that during the 26 months the company has been open, the average rental per user has been 1.09 rentals, or 0.5 dress rentals/year. As most users rent just one dress per rental, it assumed that one rental is equivalent to the usage of one dress. In projecting the same rental rate for four-year period (the time period of the FU), it is assumed that consumers rent 2 dresses during this time frame. If users are renting 2 dresses over a 4 year period, but consumers state a purchase need of 6 dresses over 4 years (1.5 dresses per year, see Figure 4-1), this means a 33% RR. This is a large contrast in comparison to the average stated RR by respondents to be 70%. Therefore, a 33% RR is tested, as well as a 50% and 100% replacement rate.

Table 4-6. Scenario replacement rates used to calculate reference flows for relevant FUs

FU: One average use of a formal dress	RR not relevant.
FU: 4 years of consumer formal dress needs satisfied by purchasing	SPSS 2.1: 33% RR of purchased dress
	SPSS 2.2: 50% RR of purchased dresses
	SPSS 2.3: 100% RR of purchased dresses
FU: 4 years of consumer formal dress needs satisfied by use	SPSS 3.1: 33% RR of wear occasions
	SPSS 3.2: 50% RR of wear occasions
	SPSS 3.3: 100% RR of wear occasions

Transport (Consumer and company)

Transport during the use phase in the linear business model scenarios involve consumer travel to the store and back home to purchase a garment. Transport in the PSS business model scenarios vary depending on the FU and reference flow, but generally include: a) transport for second-hand distribution of dresses to the rental company, b) travel for consumers to the rental store and back home for both pick-up and drop-off, c) company laundry transport for dresses from the store to the off-site laundry location and back, and d) consumer travel to the store and back to purchase a garment in addition to rental for some scenarios.

The PSS BM involves much more transportation activities than the linear BM. It includes additional transport from the first owner of the dress to be distributed to a second-hand or other type of similar store, and then to the case company's store. It was assumed that consumers travelled to a second-hand store to donate their garment, and that an employee from the case company travelled to pick-up the garment and take it to the store, based on company data where 60% of its inventory is procured through purchasing second-hand or overstock. The case company also washes their garments at two different off-site locations, meaning additional transport needed by the company. Public transport is stated to be used by the company, and an average of the two off-site location distances from the company was used.

The most popular transport mode combination was the use of the metro and the bus. This transport scenario was modelled as the average and used to model all transportation, unless noted otherwise. This decision was based off the survey and the data questionnaires. An additional three transport scenarios were created based off of the survey and are summarised in Table 4-1. These scenarios are used to test the impact of **consumer rental transport** in a sensitivity analysis.

Table 4-7. Transportation reference flows for all scenarios[13]

FU: **One average use of a formal dress**	
Linear Scenarios	PSS Scenarios
SL 1.1: 6.41 km for consumer purchasing transport	SPSS 1.1: 0.91 km for second-hand distribution 40 km for consumer rental transport 3.75 km for laundry transport
SL 1.2: 20 km for consumer purchasing transport	SPSS 1.2: 5 km for second-hand distribution 40 km for consumer rental transport 3.75 km for laundry transport
SL 1.3: 1.82 km for consumer purchasing transport	SPSS 1.3: 0.5 km for second-hand distribution 40 km for consumer rental transport 3.75 km for laundry transport
FU: **4 years of consumer formal dress needs satisfied by purchasing**	
SL 2: 120 km for consumer purchasing transport	SPSS 2.1: 80 km for consumer purchasing transport 1.82 km for second-hand distribution 80 km for consumer rental transport 7.5 km for laundry transport
	SPSS 2.2: 60 km for consumer purchasing transport 2.73 km for second-hand distribution 120 km for consumer rental transport 11.25 km for laundry transport
	SPSS 2.3: 5.45 km for second-hand distribution 240 km for consumer rental transport 22.5 km for laundry transport
FU: **4 years of consumer formal dress needs satisfied by use**	
SL 3: 102.6 km for consumer purchasing transport	SPSS 3.1: 68.6 for consumer purchasing transport 4.8 km for second-hand distribution 20 km* (5.28*2) trips to rental company= 211.2 km for consumer rental transport 3.75 km*5.28 dresses= 18 km for laundry transport

[13] Details for calculations and justification can be found in Appendix D: LCI processes from Ecoinvent database.

	SPSS 3.2: 51.2 for consumer purchasing transport 7.27 km for second-hand distribution 320 km for consumer rental transport 30 km for laundry transport
	SPSS 3.3: 14.55 km for second-hand distribution 640 km for consumer rental transport 60 km for laundry transport

Travel distance for consumer transport to shop was based on a combination of secondary data from literature with consideration for data collected from the author's survey. Granello et al. (2015) conducted a survey and found that the majority of respondents travelled between 2 – 15 km from their home to the store to purchase garments. Sandin et al. (2019) and Zamani et al. (2017) used this information and assumed a middle interval of 8.5 km to the store, 17 km round-trip. Piontek et al. (2019) assumed slightly higher transportation distance of 20 km round-trip. Based on the consumer survey, respondents indicated less than 30 minutes of transport time with the primary transport mode, and less than 30 minutes of transport with the secondary mode. It was assumed therefore that respondents spent 20 minutes of travel time with the primary mode, and 15 minutes traveling with the secondary mode. Travel times were converted to km by using the average speed of the Stockholm metro, 60 km/h (Trafikverket, personal communication, April 22, 2020). The speed limit in most streets in Stockholm are between 30-50 km/h (Trafikverket, personal communication, April 22, 2020), and 40 km/h was assumed the speed for a car without traffic. The speed of the bus was assumed at 30 km/h. Walking and biking speeds were based on time estimations using Google Maps. The resulting calculations of distances were then compared with the time frame and distance travelled from various areas in Stockholm to main shopping areas such as Drottningsgatan, and the case company location through use of Google Maps. The distance travelled was then adjusted to take in all three data sources, resulting in a round-trip distance of 20 km of the consumer to the store and home.

It was calculated that the primary mode of transport would take the consumer three-fourths of the distance, and the secondary mode of transport as the last quarter. The scenarios and time spent traveling were consistent for the transportation to the case company, and the transport of when consumers travelled to shop. More details regarding transport mode and processes used can be found in Table D3 in Appendix D: LCI processes from Ecoinvent database

Use intensity

The use intensity is understood and used in two different ways: the number of wear occasions for one **individual** in a FU, the number of wear occasions for a **garment** in a FU. Use intensity applied in the first way with an individual consumer perspective is used to calculate the number of wash and iron cycles for each scenario. For example, in the "one average use" FU, the use intensity for one consumer is one wear occasion, as implied in the FU's description. In the second FU, "4 years of consumer formal dress needs satisfied by purchasing", the use intensity is calculated based off of the average number of uses per garment, and the total number of garments purchased. In the FU, "4 years of consumer formal dress needs satisfied by use", the use intensity is hypothetical, and an assumption is made that a user needs a formal dress seasonally, or four times a year, indicating 16 wear occasions per FU. Details for the wear occasions can be found in Appendix C, Table 0-1 and 0-2. The number of wear occasions are not formally included in the reference flows, but the calculations of the wear occasions are necessary to calculate the number of wash and iron cycles.

Use intensity applied in the second way with a garment perspective indicates the total amount of times a garment is assumed to be worn. In a linear scenario, this means the total number of times a garment is used in its lifetime. Use intensity in this way is not used for the number of laundry cycles, it is used to divide the impacts of production or other activities by the number of total wear occasions or uses. The total number of uses for a purchased garment was calculated to be 3.12 uses/wear occasions, as indicated in Figure 4-2. This is lower than what was found in literature. Granello et al. (2015) conducted a survey that indicated that 58% of respondents use dresses 6-50 times a year. This is a very large disparity, but data from this study was included for all types of dresses. Zamani et al. (2017) assume 10 uses per dress, which is also a much higher assumption, but still considers all categories of dresses. 3.12 uses/dress is used as the average and is assumed suitable for formal dresses since it is perceived that there is less of a need for such attire. Furthermore, 51% of respondents stated that they associate their consumption behaviour with a "stand-out" consumer profile (see Table 4-2 and Figure 4-7), which indicates their desire to have unique clothing and more variation in style. This implies wearing the same garments a fewer amount of times. In linear scenarios, use intensity from a garment perspective means the total number of times one garment is used in its lifetime by the owner. The average assumed use intensity of 3.12 times is compared to the minimum amount of times a garment is assumed to be worn (1 use), and the highest amount (11 uses), as shown in SL 1.1, 1.2, and 1.3 in Table 4-4. In PSS scenarios, 11 users are assumed to be the average. This is because the rental company is relatively new, so the average rentals per garment is projected at a middle number between the currently low average (2 rentals per garment) and an average of the dresses with the highest amount of rentals and the projected maximum number of rentals for them (20 rentals per garment). This is shown in SPSS 1.1, SPSS 1.2, and SPSS 1.3 in Table 4-4. The total amount of uses and/or users is used to support calculation of other reference flows such as in production, transport, and end of life.

Laundry

The same characteristics for laundry loads are assumed for both consumers and the case company, since residential washing machines are used for both. The rental company's care of the garments seems to be a similar treatment to average consumer laundry, with the exception of increased washing cycles. Another differentiating factor for the case company laundry is that additional transport is needed in the rental scenario to wash garments, as specified above in the section on Transport (Consumer and company).

For consumer laundry habits, the survey results indicated that the majority of respondents only wash their dresses when it appears dirty, and quite rarely after every use (see Figure 4-3). Laundry cycles were calculated according to the number of times a garment is worn with the average stated washing behaviour by respondents. This results in a weighted average of 1.72 wash cycles for every 3.12 wears. This is consistent with the literature, as Granello et al. (2015) found that 34% of respondents used dresses 2-3 times before washing. This is supported by Sandin et al. (2019) who state that 4-5 uses are then the next most popular wash behaviour. The case company washes rented garments after every use, with an additional wash approximately every five wears. They attribute the extra wash due to a need when consumers come to try on dresses and may leave a makeup mark or odoron garments.

Since formal dresses require certain laundering care, a lower wash temperature and wash load was assumed in comparison to the average wash load with casual or everyday garments. According to a survey conducted by Presutto et al. (2007), 3 out of 4 consumers state they fill their washing machines to full capacity. However, Presutto et al. (2007) also found that 15% of respondents stated that the load of the laundry depends on the kind of garment. Since the study did not indicate what kind of laundry, it is assumed that formal washing dresses are washed in smaller loads and with other delicate pieces or washed alone in order to ensure that it is washed safely. This is supported by Pakula and Stamminger (2010) who note that delicate laundry loads are between 0.5-2 kg. Presutto et al. (2007) assumes that consumers who run a load with a small quantity to be about 1 kg, and that synthetic garments such as polyester are washed mostly at 30 ºC (Presutto et al., 2007). A 1 kg load of laundry in 30ºC is assumed in both the linear and PSS systems. Additional details regarding laundry can be found in Appendix D.

No garment drying is modelled in the process since dresses are air-dried by the company. This is assumed to be the same for consumers since these are formal dresses, in which most customers likely hang-dry to avoid damage. It was assumed also that drying rooms (torkrum) were not used, as heat could damage the dresses, and furthermore Roos et al. (2015) states that energy use in these types of rooms can vary greatly. However, ironing is modelled with every wash cycle, in which 10 minutes of ironing is assumed based off of company data and the dress mass.

Table 4-8. Wash and iron cycle reference flows[14]

FU: **One average use of a formal dress**	
Linear Scenarios	PSS Scenarios
SL 1.1: 0.55 wash and iron cycles	SPSS 1.1: 1.20 wash and iron cycles
SL 1.2: 0.55 wash and iron cycles	SPSS 1.2: 1.20 wash and iron cycles
SL 1.3: 0.55 wash and iron cycles	SPSS 1.3: 1.20 wash and iron cycles
FU: **4 years of consumer formal dress needs satisfied by purchasing**	
SL 2: 6.45 wash and iron cycles	SPSS 2.1: 4.3 wash and iron cycles for purchased dresses + 2.40 wash and iron cycles for rental dresses
	SPSS 2.2: 3.23 wash and iron cycles for purchased dresses + 3.60 wash and iron cycles for rental dresses
	SPSS 2.3: 7.2 wash and iron cycles for rental dresses
FU: **4 years of consumer formal dress needs satisfied by use**	
SL 3: 8.82 wash and iron cycles	SPSS 3.1: 5.91 wash and iron cycles for purchased dresses + 6.34 wash and iron cycles for rental dresses
	SPSS 3.2: 4.41 wash and iron cycles for purchased dresses + 9.60 wash and iron cycles for rental dresses
	SPSS 3.3: 19.20 wash and iron cycles

4.5.4 End of Life

The waste treatment method modelled for garments in both the linear and PSS system is municipal incineration in the Swedish context. This is a simplified end-of-life scenario but is considered accurate since most streams will eventually end up in incineration. According to Palm et al. (2014), only 20% of textiles put on the market in Sweden are separately collected post-consumer, and the remaining share likely ends up in incineration or landfill.

The processes and quantities used for shipment can be found in Appendix D: LCI processes from Ecoinvent database, and data is taken from Roos et al. (2015) and Sandin et al. (2019). The tonnes-kilometre (tkm) for the transportation of garments to a waste treatment facility shipment found in the table refer to the mass of one garment modelled in production (477 g). Each modelled scenario is adjusted to reflect the change in mass for number of garments going

[14] Details for calculations and justification can be found in Appendix D: LCI processes from Ecoinvent database.

to incineration, as well as the associated tkm, based on number of dresses needed from Table 4-5.

Table 4-9. Municipal incineration reference flows[15] for scenarios

<table>
<tr><td colspan="2">FU: One average use of a formal dress</td></tr>
<tr><td>Linear Scenarios</td><td>PSS Scenarios</td></tr>
<tr><td>SL 1.1:
0.15 kg of garments incinerated
0.005 tkm to incineration</td><td>SPSS 1.1:
0.04 kg of garments incinerated
0.001 tkm to incineration</td></tr>
<tr><td>SL 1.2:
0.48 kg of garments incinerated
0.01 tkm to incineration</td><td>SPSS 1.2:
0.24 kg of garments incinerated
0.007 tkm to incineration</td></tr>
<tr><td>SL 1.3: 0.04 kg of garments incinerated
0.001 tkm to incineration</td><td>SPSS 1.3: 0.02 kg of garments incinerated
0.0007 tkm to incineration</td></tr>
<tr><td colspan="2">FU: 4 years of consumer formal dress needs satisfied by purchasing</td></tr>
<tr><td rowspan="3">SL 2: 2.86 kg of garments incinerated
0.09 tkm to incineration</td><td>SPSS 2.1:
1.99 kg of garments incinerated
0.06 tkm to incineration</td></tr>
<tr><td>SPSS 2.2:
1.56 kg of garments incinerated
0.05 tkm to incineration</td></tr>
<tr><td>SPSS 2.3:
0.26 kg of garments incinerated
0.008 tkm to incineration</td></tr>
<tr><td colspan="2">FU: 4 years of consumer formal dress needs satisfied by use</td></tr>
<tr><td rowspan="3">SL 3: 2.45 kg of garments incinerated
0.07 tkm to incineration</td><td>SPSS 3.1:
1.87 kg of garments incinerated
0.06 tkm to incineration</td></tr>
<tr><td>SPSS 3.2:
1.57 kg of garments incinerated
0.05 tkm to incineration</td></tr>
<tr><td>SPSS 3.3:
0.69 kg of garments incinerated
0.02 tkm to incineration</td></tr>
</table>

[15] Details for calculations and justification can be found in Appendix D: LCI processes from Ecoinvent database.

5 Results: The life cycle impact assessment

The environmental impacts are presented for each functional unit, showing the comparison between the linear and PSS scenarios. It is presented first through the FU "one average use". It is then presented with the FU "the user dress needs for 4 years" satisfied by the **number of dresses purchased**, and lastly, as "the user dress needs for 4 years" satisfied by the number of **uses or wear occasions**. The scenarios cover the life cycle from cradle-to-grave, as explained in the LCI in section 4.5. The average data is tested against variations in use intensity, transport modes, and replacement rates (RR) of rental garments for purchased garments, in accordance with the proposed hypothetical models. This chapter focuses in detail on the results of the LCA, and is followed by a generalised summary of the findings in section 6.1.

The most significant impact categories out of the 18 mid-point indicator categories for all three functional units were freshwater ecotoxicity (FETP), marine ecotoxicity (METP), and human carcinogenic toxicity (HTPc). FETP, METP, and HTPc are analysed amongst the scenarios, along with the global warming potential (GWP). Significant impact categories are shown through normalised results, which is explained in section 3.3.4, section IV. The normalised results for the "one average use" FU are presented in Figure 5-1. The normalised results for the other functional units can be found in Appendix E. The full impact category names for the abbreviations in the figure below can also be found in Appendix E.

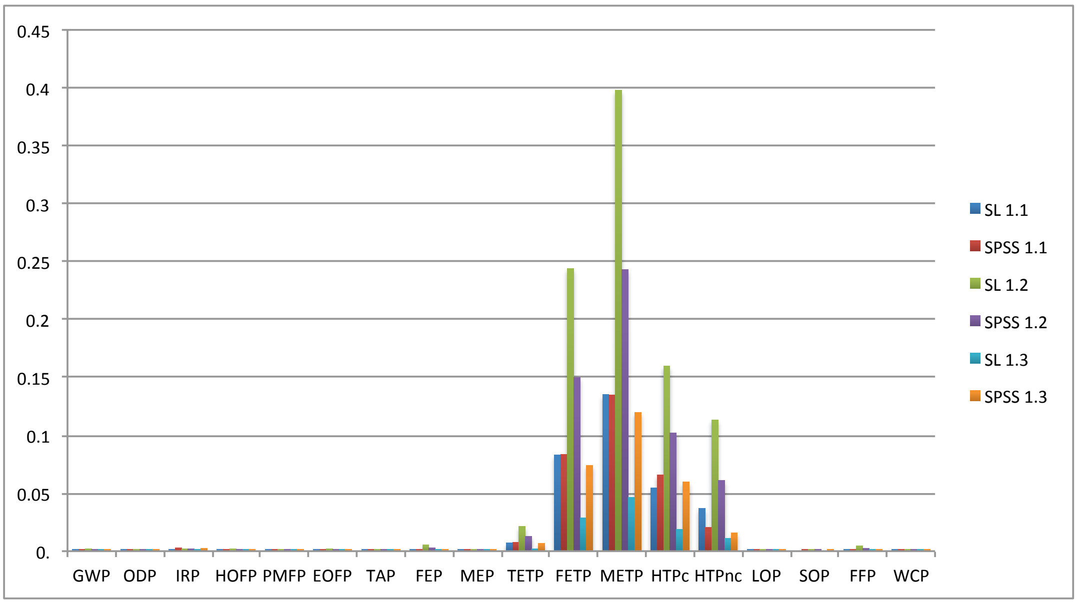

Figure 5-1. Normalised results for "one average use" scenarios.

5.1 Impact of one average use

This FU compares a few different scenarios, where the PSS system tests how differences in the number of total users for a garment change the impact of one average use, and the linear system tests differences in the total number of uses of the garment. The total number of uses is important to understand "one average use", because the increase in overall usage decreases the share of environmental burden from the production stages, as well the transoceanic shipment for retail distribution, and the consumer's trip to the store to purchase an item. The increased usage however does not impact the transport for rental, since 2 trips are still needed for every rental (pick-up and drop-off of the item). An overview of total use is shown in Table 5-1, and the specific reference flows for the scenarios can be found in section 4.5.

Table 5-1.One average use scenarios

One average use			
Linear Scenarios		PSS Scenarios	
SL 1.1 (Avg)	3.12 total uses	SPSS 1.1 (Avg)	11 users
SL 1.2 (low)	1 total use	SPSS 1.2 (low)	2 users
SL 1.3 (high)	11 total uses	SPSS 1.3 (high)	20 users

5.1.1 Significant impact categories

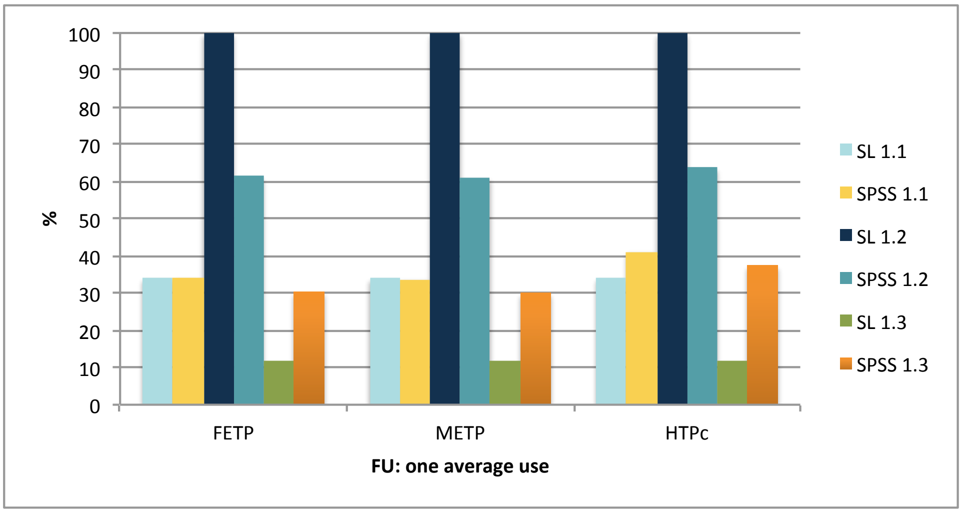

Figure 5-2. Characterisation results by percentage of impact of linear vs. rental scenarios for FETP, METP, and HTPc for "one average use". The highest scores of the category are set to 100% and other values set as a relative percent. Note that categories should not be compared to another in this figure, only comparison of scenarios within one impact category.

Freshwater ecotoxicity and marine ecotoxicity

Figure 5-2 shows that SPSS 1.3 has the lowest impact contribution to freshwater ecotoxicity potential compared to the other PSS scenarios. However, SL 1.3 contributes the lowest impact to this category overall, 20% less than from SPSS 1.3. Although SPSS 1.3 reduces the percentage of the impact from production by increasing the total number of users/rentals (see Figure 5-3), the high amount of transportation required for rental results in a higher impact contribution in this category than SL 1.3, which is the increased usage by one garment owner. Figure 5-2 shows that SL 1.2 has the highest impact in this category, resulting from the high impacts from production (see Figure 5-3). Although SPSS 1.2 has a low amount of total uses as well, it's impact in this category is 40% lower in this category than SL 1.2 despite increased transportation needs. SL 1.1 and SPSS 1.1 have relatively the same contribution to the category, and Figure 5-3 shows that the impact from S1.1 comes 70% from production, and the impact from SPSS 1.1 primarily from consumer transport for rental (50%). This indicates that the scenarios with the lower impact potential for freshwater ecotoxicity is where purchased dresses are used many times by garment owners themselves, followed by a high number of users to rent the same garment.

When alternative transportation modes are included (see Figure 5-5), SPSS 1.2 becomes the highest impact contributor to the category when using the T4 transportation scenario (see Table 4-1 for transport scenarios). All PSS scenarios with T4 were the highest contributors. SL

1.3 remains as the scenario with the lowest impact, followed by SPSS 1.3 T3, meaning that increased use by garment owners remains the least impactful for freshwater ecotoxicity, followed by high user rental when using public transportation (metro) in combination with walking. The is followed by SPSS 1.3 with average transportation (metro and bus), also confirming the benefit of high numbers of user rentals. However, this benefit changes when using high-impact transportation, as SPSS 1.3 T4 has a 75% higher impact in this category than SPSS 1.3 with average transportation. The rental scenarios that have a lower impact than the average linear scenario (SL 1.1) are SPSS 1.1 T2, SPSS 1.3, and SPSS 1.3 T2, meaning that average rental scenarios with 11 total users can have less impact than a purchased dress with average use of 3.12 wear occasions, despite increased transportation for the rental scenario, although only with the low-impact transportation modes such as use of the metro and walking. All PSS scenarios excluding T4 transport scenarios have a lower impact than the low use linear scenario (SL 1.2), indicating that all rental scenarios from low, mid, to high overall uses/rentals have a lower impact than low usage for a dress owner, if public transportation is used.

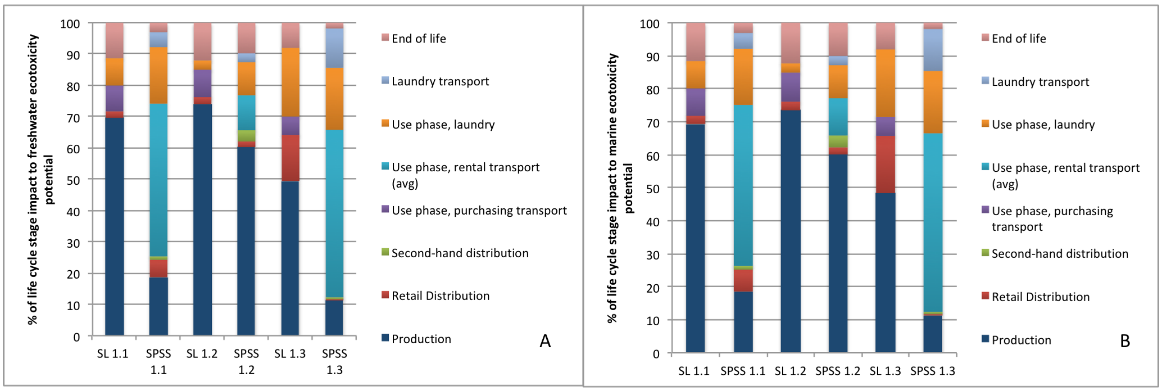

Figure 5-3. Life cycle stage contribution to the total impact for FETP (A) and METP (B), by percentage.

The impact contribution for the scenarios are very similar in percentage for marine ecotoxicity potential, as shown in *Figure 5-2,* with a similar share of life cycle stages contributing to the impact category, as shown in *Figure 5-3*. This indicates that the impact contribution for scenarios in freshwater ecotoxicity potential are reflected in the marine ecotoxicity potential, and life cycle stage contribution to the impact categories mirror this as well.

Human carcinogenic toxicity

The human carcinogenic toxicity potential was highest in SL 1.2, followed by SPSS 1.2, (see Figure 5-2), in which 81% and 63% of the impact are contributed from production (Figure 5-4). This is followed by SPSS 1.1 (with 17% impact contribution from production and 56% impact contribution from rental transportation), then SPSS 1.3 with 59% impact contribution from rental transportation. This indicates that rental transport is responsible for a large share of impact contribution to this category, meaning that increased use of a garment such as in SPSS 1.3, can increase the impact for human carcinogenic toxicity if increased use is associated with more transport. This is shown as SL 1.1, where a purchased garment worn with an average of 3.12 uses (76% of impact contribution from production), has lower impact than the rental scenario with increased users/rentals (SPSS 1.1, 1.2, and 1.3).

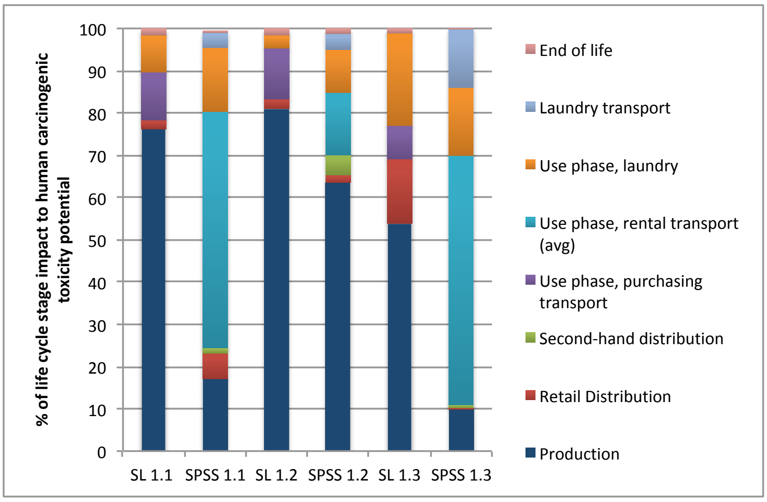

Figure 5-4. Life cycle stage contribution to the total impact for human carcinogenic toxicity potential, by percentage.

The variation for transport scenarios for HTPc shows that the PSS scenarios with T4 transport have the highest impact, followed by the low-use linear scenario (SL 1.2), then the low-use PSS scenarios (SPSS 1.2 with T2, T3, and the average transport scenario), as shown in Figure 5-5. This indicates that besides the high-impact transportation modes involving cars, production accounts for a higher impact in this category, as it contributes to 81% of the impact in SL 1.2, and 64% of the impact in SPSS 1.2 (Figure 5-4). SL 1.3 has the lowest impact, followed by SPSS 1.3 T2 and SPSS 1.3 T3, with nearly the same percentage contribution as SL 1.1. This indicates again that increased usage for garment owners has potentially the lowest, or nearly the same impact as high usage in a rental scenario when consumers use low-impact public transportation modes. Although high usage for rental scenarios greatly decrease the share of impacts resulting from production (see Figure 5-4), the increased share of rental transportation in this scenario contribute a greater impact than increased owner usage.

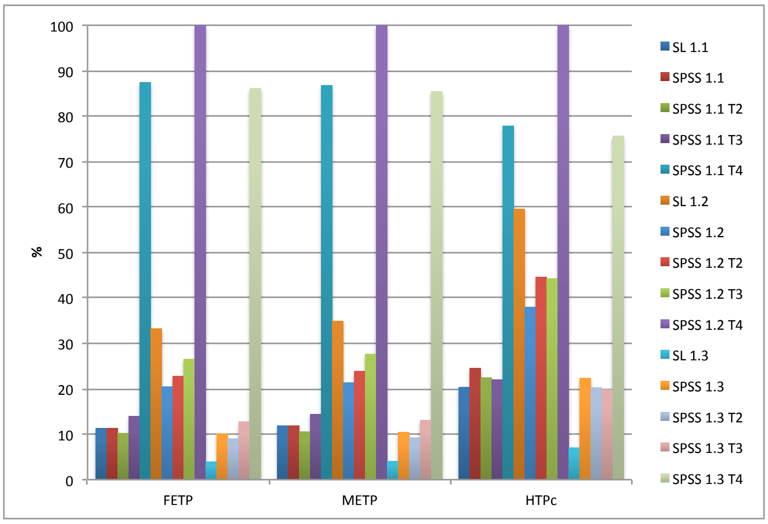

Figure 5-5. Characterisation results for significant categories with all scenarios for "one average use" with adjusted transportation scenarios for transportation associated with consumer rental transport. The highest scores of the category are set to 100% and other values set as a relative percent. Note that categories should not be compared to another in this figure, only comparison of scenarios within one impact category. No T indicates average transport with metro and bus, T2=metro and walking, T3=bike and metro, and T4=car and metro.

5.1.2 Global warming potential

While Figure 5-6 indicates that one average use in a PSS BM has a lower carbon footprint than the linear BM in the first two scenarios (SPSS 1.1 has a lower GWP than SL 1.1, and SPSS 1.2 is lower than SL 1.2), SPSS 1.2 has a higher carbon footprint than SL 1.1, indicating that increased use of owned garments in a linear scenario has a lower carbon footprint than renting clothes *if* garments are not rented or used enough times. This is also shown in SL 3.3 and SPSS 1.3, where the rental scenario shows a higher GWP despite having 20 users, whereas the linear scenario has 11 use occasions. This is due to the high amount of transport used in the PSS models based on the case company's activities (Figure 5-7). This indicates that the use intensification of garments already in ownership can offer greater savings in an individual's carbon footprint than engaging in rental clothing, depending on the rental scenario.

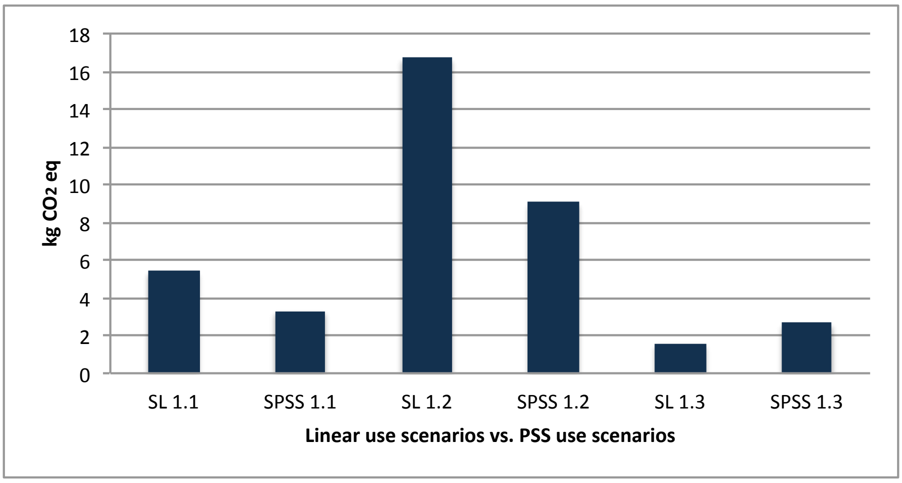

Figure 5-6. Global warming potential of "one average use" of three linear consumption scenarios (SL1.1,1.2,1.3) with three PSS consumption scenarios (SPSS 1.1,1.2,1.3) with total use/user variation.

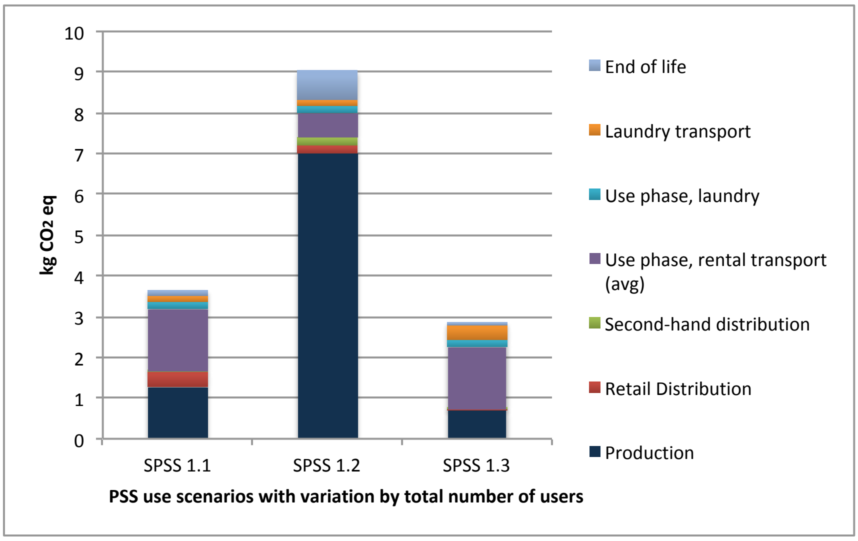

Figure 5-7.Comparison of carbon emissions in PSS consumption by life cycle stages, and variation of total use between scenarios. SPSS 1.1= 11 users, SPSS 1.2=2 users, SPSS 1.3=20 users.

Figure 5-8 shows different variations of transport modes, based on Table 4-1. The difference between the use of just public transportation and/or a combination of public transportation and walking/cycling is not surprising when comparing the impacts associated with the T4 scenario (combined car and metro transport). This is noteworthy, as when comparing linear to rental scenarios, rental business models should be in good proximity to consumers in order to encourage walking/biking and use of public transport, and to reduce overall impact from transport. Furthermore, rental business models should be in locations that do not incentivize driving. This is also shown in Figure 5-6 and Figure 5-7, which portrays how the carbon footprint of transport increases with increased users and rental while the share of the production impact decreases. Increasing the use for purchased garments also results in a reduced carbon footprint, as shown in Figure 5-9, as the share of production impact decreases with increased use.

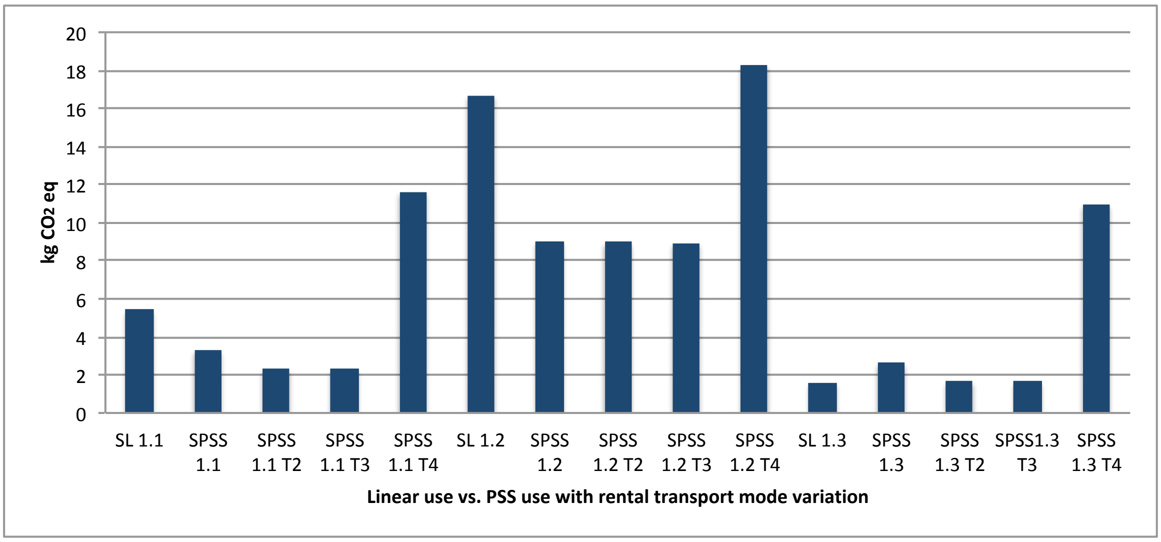

Figure 5-8.Global warming potential of "one average use" of three linear consumption scenarios with three PSS consumption scenarios with total use/user variation and transport adjustments for rental where no T indicates average transport with metro and bus, T2=metro and walking, T3=bike and metro, and T4=car and metro.

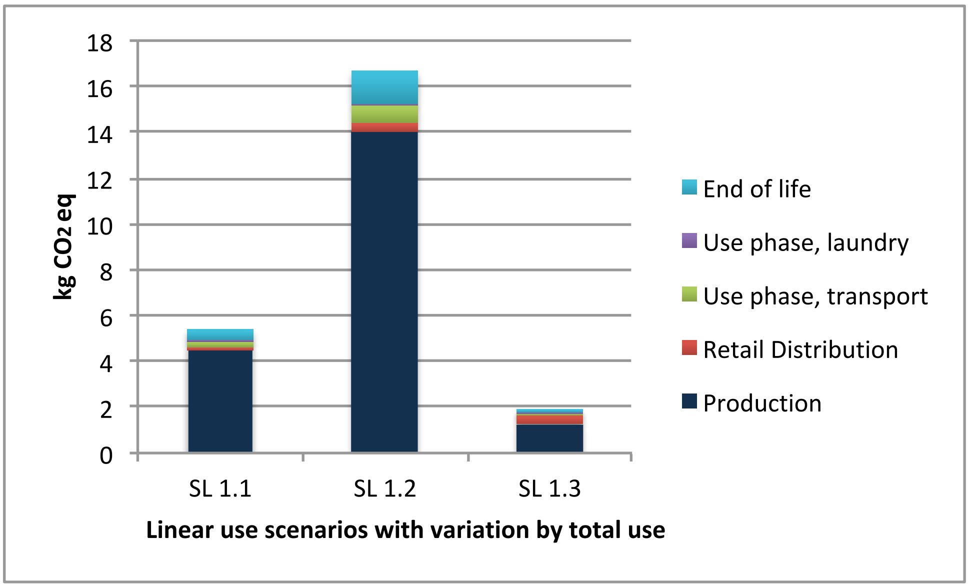

Figure 5-9. Comparison of carbon emissions in linear consumption by life cycle stages, and variation of total use between scenarios. SL 1.1= 3.12 total uses, SL 1.2=1 total use, SL 1.3=11 total uses.

5.2 Impact of individual dress consumption for 4 years

Consumers engage with clothing PSSs to rent clothes for different reasons, as shown in Figure 4-5 from the survey. Different reasons to rent imply that consumption satisfies different needs, and the impacts of consumer dress needs satisfied through purchasing are presented in this section.

5.2.1 Consumer dress satisfaction by purchasing

The impacts of **4 years of an individual consumer's dress purchasing satisfaction** are modelled in a few different scenarios comparing consumer engagement with the rental company vs. normal purchasing. Since rental clothing was not found to completely substitute ownership of dresses (see Figure 4-6), the PSS system also includes some purchased clothing, of which the reference flow was defined in Table 4-5. Replacement rates for rental dresses vs purchased dresses are tested against the linear system. An overview of the scenarios is provided in Table 5-2. Consumer purchase satisfaction scenarios

Table 5-2. Consumer purchase satisfaction scenarios

User dress satisfaction for four years: needs satisfied through purchasing			
Linear Scenarios		PSS Scenarios	
SL 1 (Avg)	Four years of dress purchasing (1.5 dresses per year) with an average use of 3.12 wears per garment.	SPSS 1.1 (Avg)	Four years of combined dress purchasing and rental with a **33%** replacement rate (RR) of purchased dresses and average users per rented garment as 11.
		SPSS 1.2	Four years of combined dress purchasing and rental with a **50%** replacement rate (RR) of purchased dresses and average users per rented garment as 11.
		SPSS 1.3 (high)	Four years of combined dress purchasing and rental with a **100%** replacement rate (RR) of purchased dresses and average users per rented garment as 11.

I. Significant impact categories

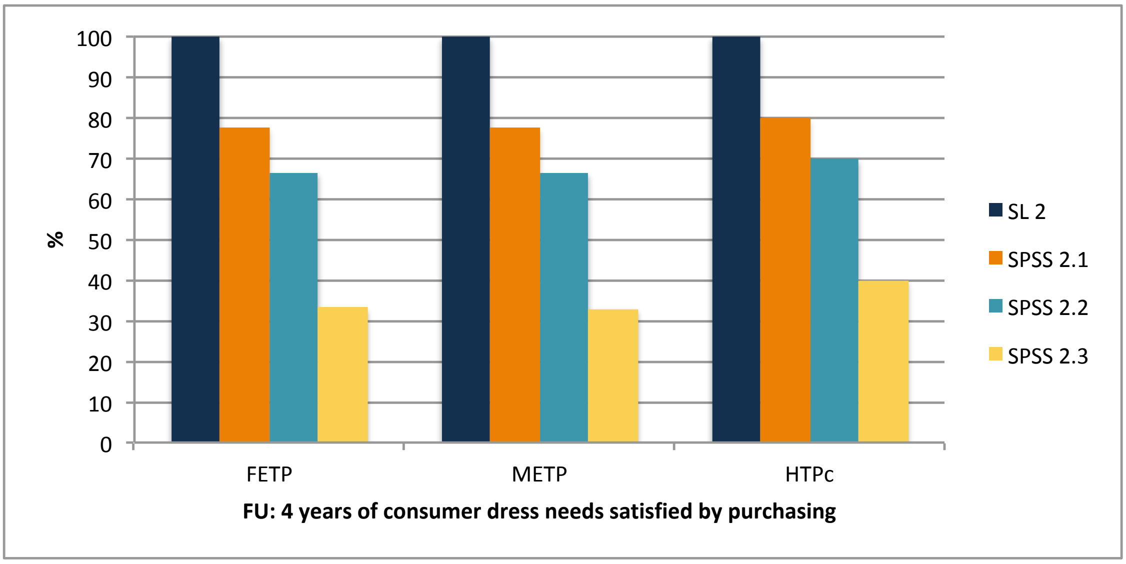

Figure 5-10. Characterisation results by percentage of impact of linear vs. rental scenarios for FETP, METP, and HTPc for "4 years of consumer needs by purchasing". The highest scores of the category are set to 100% and other values set as a relative percent. Note that categories should not be compared to another in this figure, only comparison of scenarios within one impact category.

Freshwater ecotoxicity and marine ecotoxicity

The linear scenario (SL 2) has the highest impact contribution to freshwater ecotoxicity potential (see Figure 5-10). With an increase in the replacement rate for purchasing, the impact associated with the PSS decreases, indicating the decrease with the associated need for production. This is also shown in Figure 5-11 where the percentage share of production in the overall impact to the category decreases from SL 2.1 to SPSS 2.3, meaning that the impact from transportation is less significant than production in this category. The impact for SPSS 2.3 is 67% less of the environmental impact of SL 2 for freshwater ecotoxicity, indicating the potential for full substitution for purchased dresses, as SPSS 2.2 is 44% less, and SPSS 2.1 is 33% less than the impact for the linear scenario (Figure 5-10).

For marine ecotoxicity, the percentage of impact contribution are nearly the same as freshwater ecotoxicity, as shown in Figure 5-10, where SL 2 has the largest impact and SPSS 2.3 as the lowest. The life cycle stage contribution to the overall impact to marine ecotoxicity is similar to that of freshwater ecotoxicity as well, and the percent contribution of life cycle stages to the overall impact for scenarios is shown in Figure 5-11.

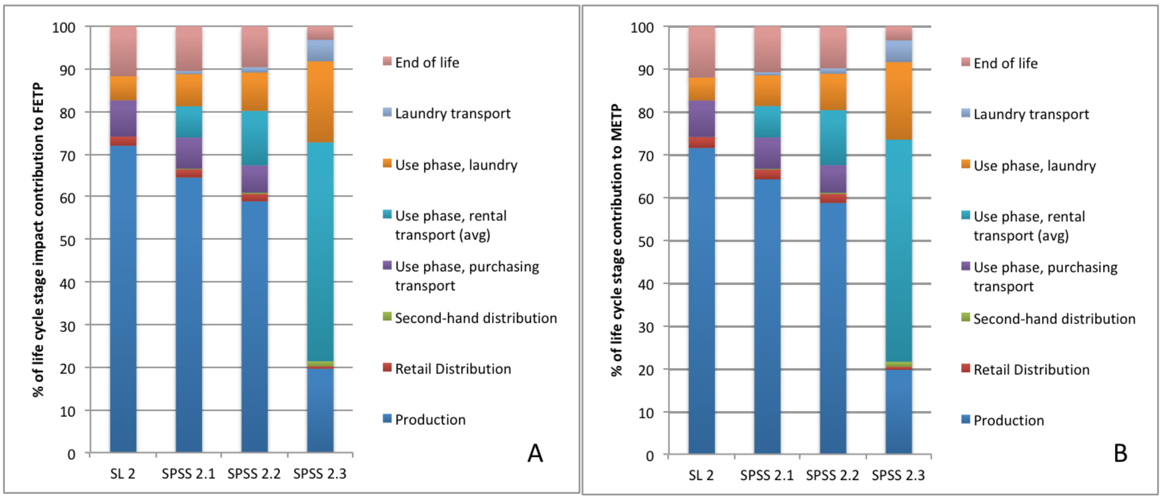

Figure 5-11. Life cycle stage contribution to the total impact for FETP (A) and METP (B), by percentage

Adjusted transportation scenarios (see Figure 5-13) shows that with high impact transportation scenarios such as T4, the benefit of a high replacement rate in SPSS 1.3 is negated and has a much larger impact for freshwater ecotoxicity and marine ecotoxicity, even more so than the linear scenario. Both these impact categories show that the linear scenario (SL 2) has around 60% less impact than rental scenarios with the high-impact transport scenario. However, in comparing the average or T2 or T3 scenarios, the SPSS 2.3 scenarios have nearly 30% less impact than the linear scenario (SL 2), indicating relatively the same impact for all the modelled public transportation mode combinations.

Human carcinogenic toxicity

The contribution for human carcinogenic toxicity shows that the linear scenario (SL 2.1) contributes the most impact to this category compared to the rental scenarios (Figure 5-10). This is followed by the PSS scenarios with the lowest replacement rates. The impact from SPSS 2.1 has 20% less impact for human carcinogenic toxicity than SL 2, with SPSS 2.2 having 30% less, and SPSS 2.3 with 100% replacement rate for purchased clothing with 60% less impact in this category than the linear scenario (SL 2). The decrease in impact to this category is associated with the decrease in the overall share of production impacts, as shown in Figure

5-12. In the adjusted transport scenarios for the human carcinogenic toxicity category, the T4 scenarios for even the highest replacement rate for SPSS becomes the highest impact contributors over SL 2, with SPSS 2.1 T4 having a 7% higher impact, SPSS 2.2 T4 with a 11% higher impact, and SPSS 2.3 T4 with a 21% higher impact for both freshwater ecotoxicity and marine ecotoxicity. All other transport scenarios for the PSS scenarios had a lower impact than the linear scenario, with the greatest difference between SPSS 2.2 and 2.3 having 25% less impact than SL 2 (see Figure 5-13).

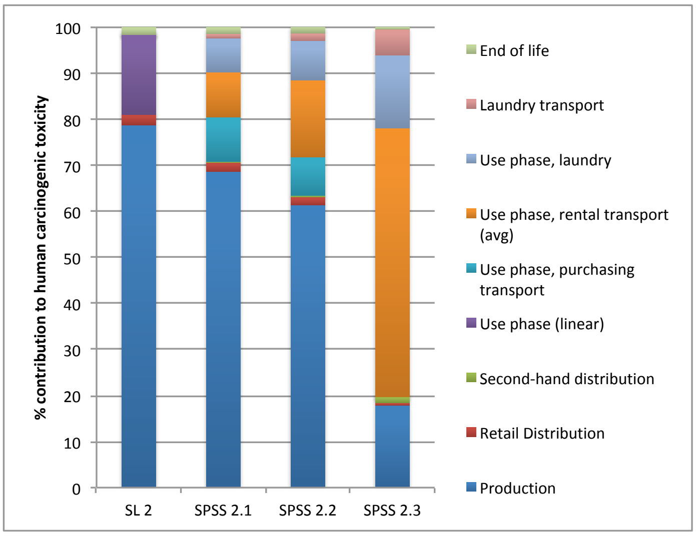

Figure 5-12. Life cycle stage contribution to the total impact for human carcinogenic toxicity potential, by percentage

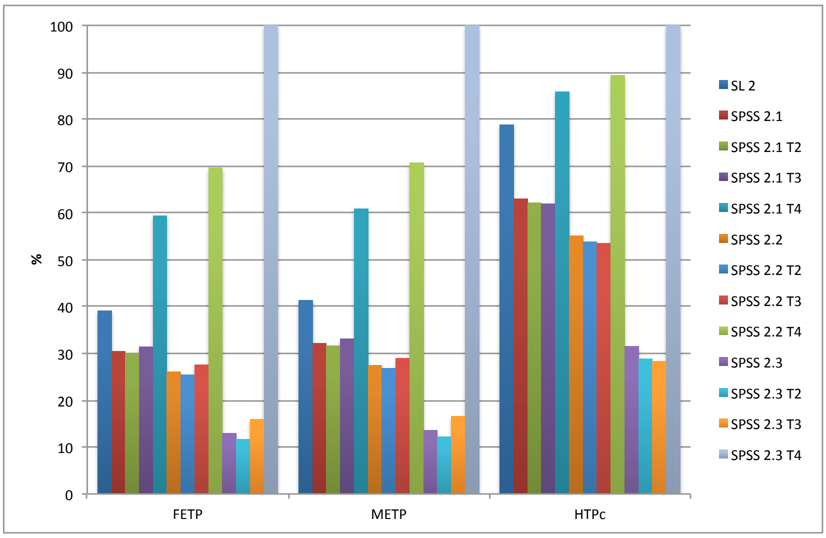

Figure 5-13. Characterisation results for significant categories with all scenarios for "4 years of consumers needs by purchasing", with adjusted transportation scenarios for transportation associated with consumer rental transport. The highest scores of the category are set to 100% and other values set as a relative percent. Note that categories should not be compared to another in this figure, only comparison of scenarios within one impact category.

II. Global warming potential

Figure 5-14 show a decrease in global warming potential with an increase in the replacement rate of rental clothes for purchased clothes, indicating that individual carbon savings can be

80% less if rental clothing substitutes 100% of the need to purchase. If rental clothing substitutes just half of purchasing needs, there is 40% savings, and if rental substitutes 33%, there is 27% savings in kg CO_2 eq per person.

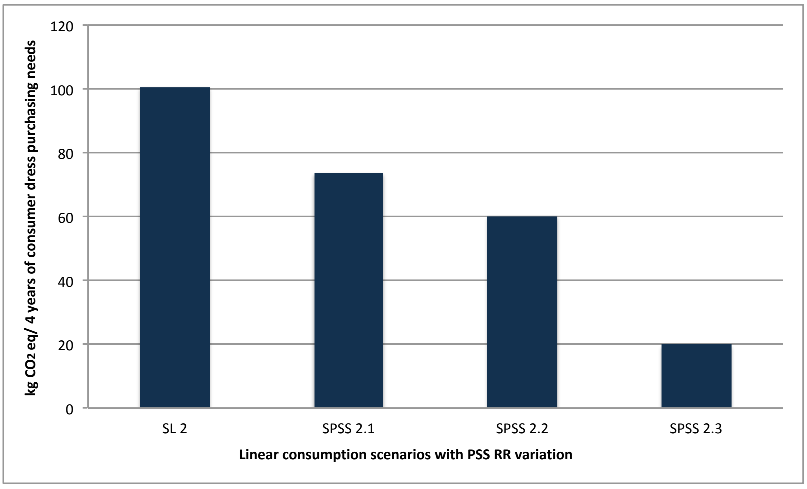

Figure 5-14. Global warming potential of a linear consumption scenario (SL) with a rental clothing consumption scenario of a 33% RR (SPSS 2.1), 50% RR (SPSS 2.2), and 100% RR (SPSS 2.3).

Transport scenarios are tested in Figure 5-15, which shows that the impact for the average transportation, and other public transportation methods with T2 and T3 have relatively the same GWP when comparing within the same scenario set. Despite changes with high-impact transportation, such as T4 scenarios, all rental scenarios have less impact towards GWP than the linear scenario (SL 2). SPSS 2.3 T4 with the 100% RR, even though having high-impact transportation, has 5% less impact contribution to GWP than SPSS 2.1 with average transport and 33% RR. It however has 10% higher impact than SPSS 2.2 with the 50% RR and average transport. This indicates that the use of high-impact transportation modes can have less impact if it is associated with a high replacement rate for purchased garments in comparison to low replacement rates, but there is a threshold where the impacts from transport overtake the impacts from decreased production, as we see with the SPSS 2.2 scenario.

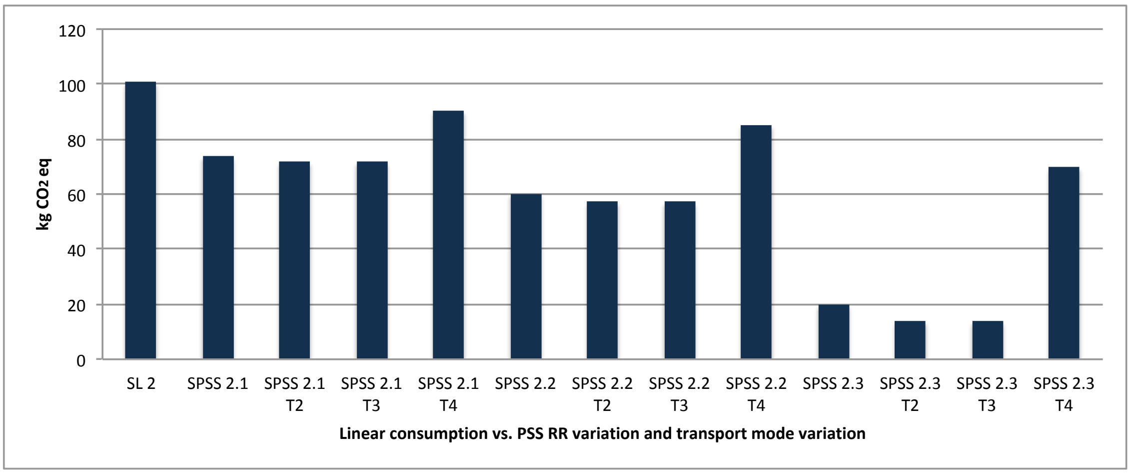

Figure 5-15.Global warming potential of a linear consumption scenario (SL) with a rental clothing consumption scenario of a 33% RR (SPSS 2.1), 50% RR (SPSS 2.2), and 100% RR (SPSS 2.3) and transport adjustments for rental where no T indicates average transport with metro and bus, T2=metro and walking, T3=bike and metro, and T4=car and metro.

5.2.2 Consumer dress satisfaction by use

The impacts for **4 years of an individual consumer's dress use satisfaction** is modelled in a few different scenarios comparing consumer engagement with the rental company vs. normal ownership and use. Similar scenarios are set up as in the previous section, however the RR is now applied to the number of **uses, or wear occasions** not the number of garments purchased. An overview of the scenarios is provided in Table 5-3.

Table 5-3. Consumer dress satisfaction by use scenarios

User dress satisfaction for four years: needs satisfied through use/wear occasions			
Linear Scenarios		PSS Scenarios	
SL 2 (Avg)	Four years of dress use (4 dress occasions per year) with an average use of 3.12 wears per garment.	SPSS 3.1	Four years of dress use (4 dress occasions per year) with combine dress purchasing and rental with a **33%** replacement rate (RR) of wear occasions, and assuming average users per rented garment as 11.
		SPSS 3.2	Four years of dress use (4 dress occasions per year) with combine dress purchasing and rental with a **50%** replacement rate (RR) of wear occasions, and assuming average users per rented garment as 11.
		SPSS 3.3	Four years of dress use (4 dress occasions per year) with combine dress purchasing and rental with a **100%** replacement rate (RR) of wear occasions, and assuming average users per rented garment as 11.

I. Significant impact categories

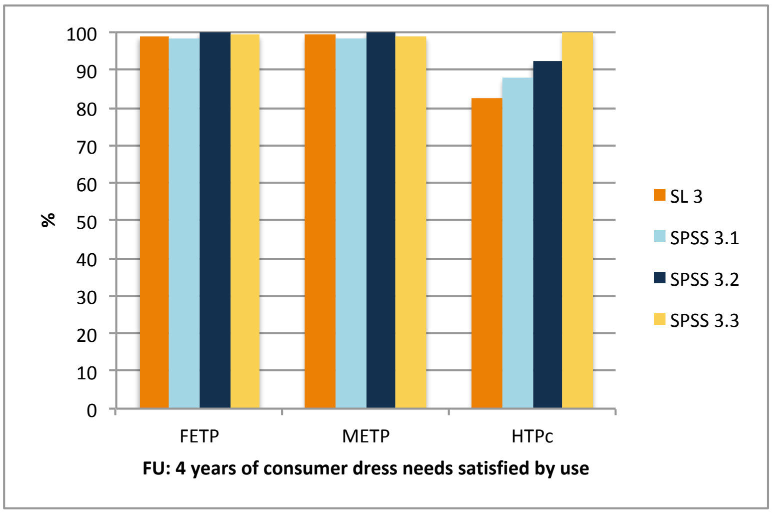

Figure 5-16. Characterisation results by percentage of impact of linear vs. rental scenarios for FETP, METP, and HTPc for "4 years of consumer dress needs by use". The highest scores of the category are set to 100% and other values set as a relative percent. Note that categories should not be compared to another in this figure, only comparison of scenarios within one impact category.

Freshwater and marine ecotoxicity

The freshwater ecotoxicity potential has very little difference between the scenarios, with SPSS 2.2 having less than a 2% higher impact than the linear scenario (SL 3) and rental scenario SPSS 3.1 (see Figure 5-16). It is just 1% higher than SPSS 3.3. SPSS 3.1 has the lowest impact, with a 33% replacement rate for the number of wear occasions for rental over purchased. This indicates that if consumers are using rental dresses to replace one use or wear occasion for clothing, then an increase in the number of uses from rental is not beneficial with increased transport, and with the need to purchase dresses. This is shown in SPSS 3.2 with a 50%

replacement rate for the number of uses, where an increase in the number of rental dresses used just once with combined purchasing has a higher impact. SPSS 3.3 with a 100% RR with 16 different rental occasions has a slightly lower impact than SPSS 3.2, indicated the potential benefit of just rental. A breakdown of contributing life cycle stages for freshwater ecotoxicity is shown in Figure 5-17. The percentages and differences are similar to that for marine ecotoxicity. Variations in the transport mode for freshwater and marine ecotoxicity show little difference across all rental transport variations, except notably in the T4 high impact scenario, as shown in Figure 5-19.

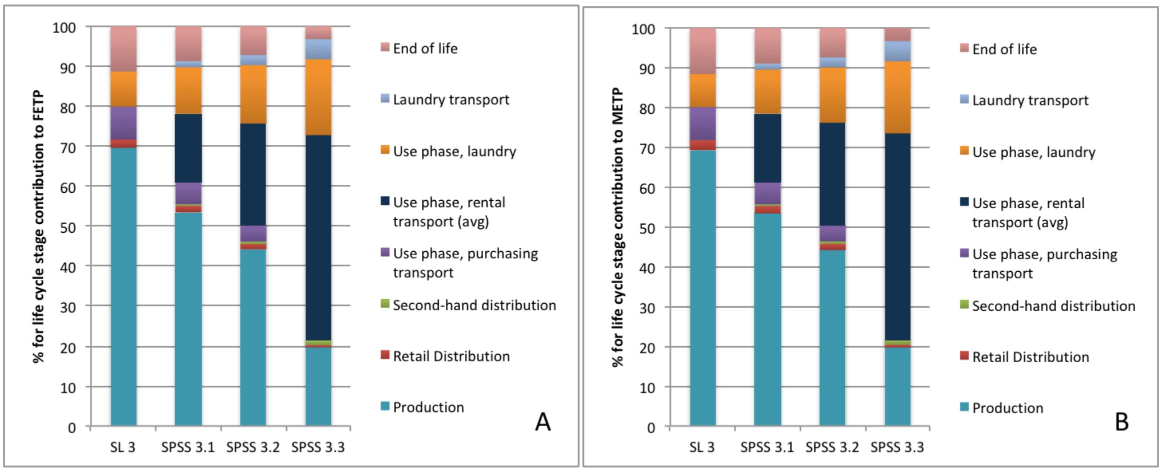

Figure 5-17. Life cycle stage contribution to the total impact for FETP (A), and METP (B), by percentage

Human carcinogenic toxicity

Figure 5-16 shows that SPSS 3.3 has the highest amount of impact contribution to human carcinogenic toxicity, with the linear scenario as the lowest (SL 3), with 18% less impact. As the impact increases with the increase in the replacement rate for use, this indicates that high transport associated with increased RR for rental contributes the most to human carcinogenic ecotoxicity potential, as shown in (Figure 5-18).When testing different transport scenarios, there is no significant variation in the results, with the exception of the high impact T4 scenarios.

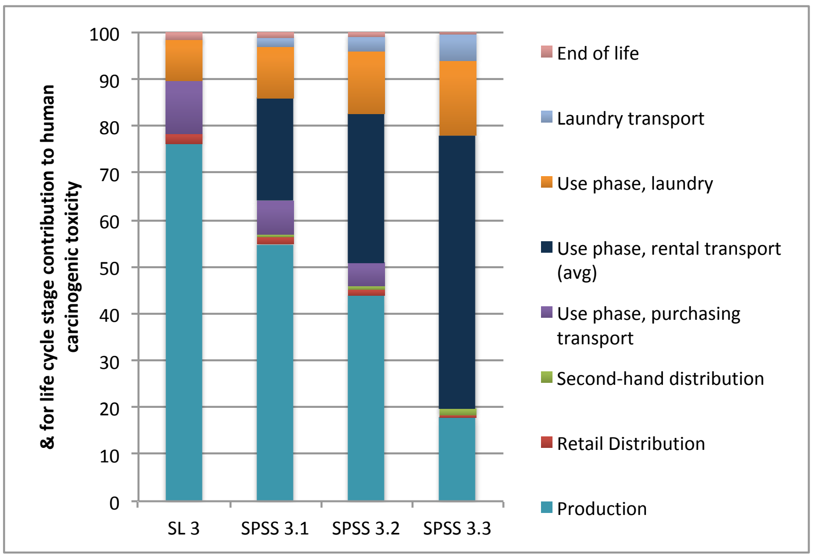

Figure 5-18. Life cycle stage contribution to the total impact for human carcinogenic toxicity, by percentage

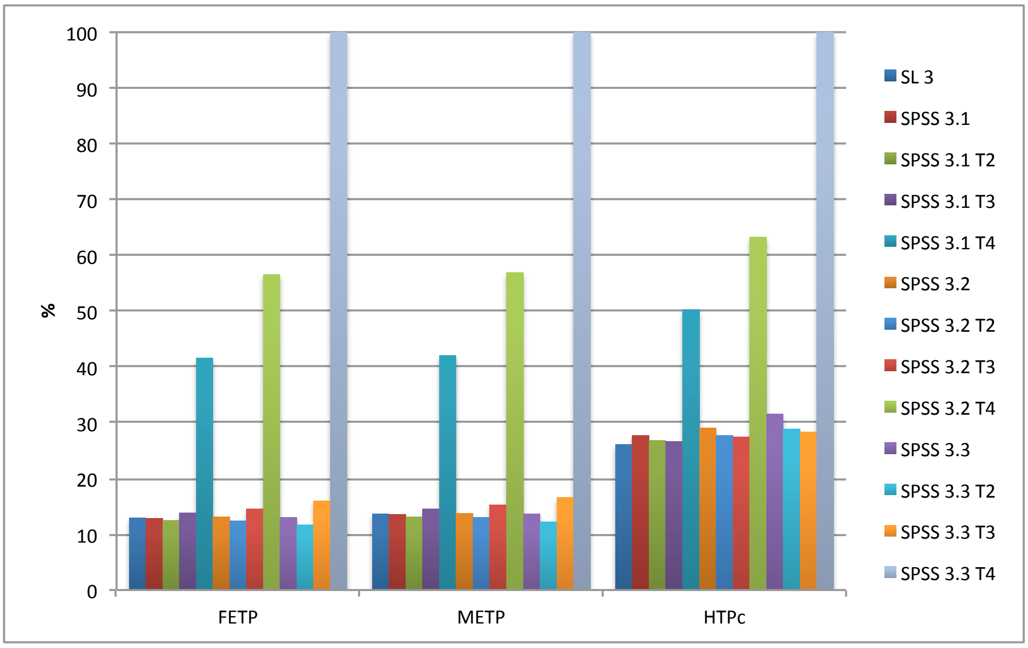

Figure 5-19. Characterisation results for significant categories with all scenarios for "4 years of consumer dress needs by use", with adjusted transportation scenarios for transportation associated with consumer rental transport. The highest scores of the category are set to 100% and other values set as a relative percent. Note that categories should not be compared to another in this figure, only comparison of scenarios within one impact category. No T indicates average transport with metro and bus, T2=metro and walking, T3=bike and metro, and T4=car and metro.

II. Global warming potential

The impacts towards GWP decrease with the increased replacement of wear occasions by rental dresses, as shown in Figure 5-20. Since transportation in the rental company is a large portion of the activity associated with rental due to the need for logistics and reverse logistics, Figure 5-21 indicates that that the renting of clothing can have higher impact towards GWP than linear consumption if consumers use high-impact transport modes, such as cars. Since the results of this figure are associated with RR for **use,** it is logical that the scenarios with higher RRs have a larger impact with the transport scenarios involving cars since more travel is associated with each use. It should be noted that this differs from Figure 5-15, as the RR for that functional unit is associated with rental replacement of **purchased garments.** It is important to understand that user satisfaction for consumption may be associated with how many times, or the use of a garment, or it could be associated with the number of certain types of garments that one has.

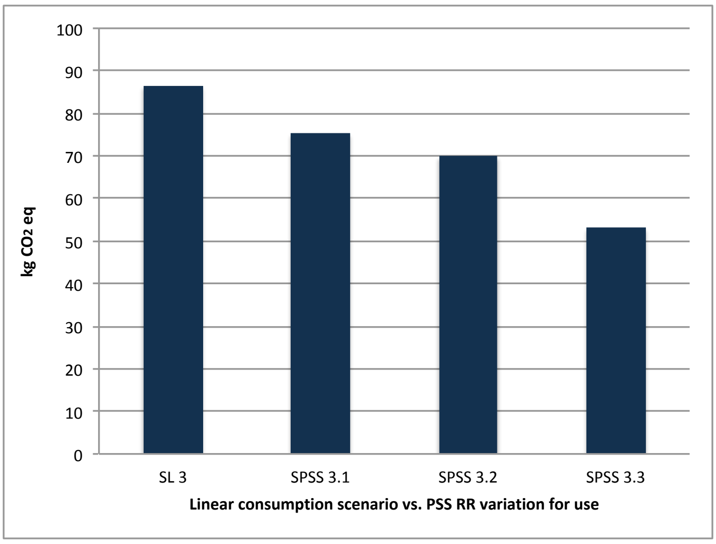

Figure 5-20.Global warming potential of a linear consumption scenario (SL) with a rental clothing consumption scenario of a 33% RR (SPSS 3.1), 50% RR (SPSS 3.2), and 100% RR (SPSS 3.3).

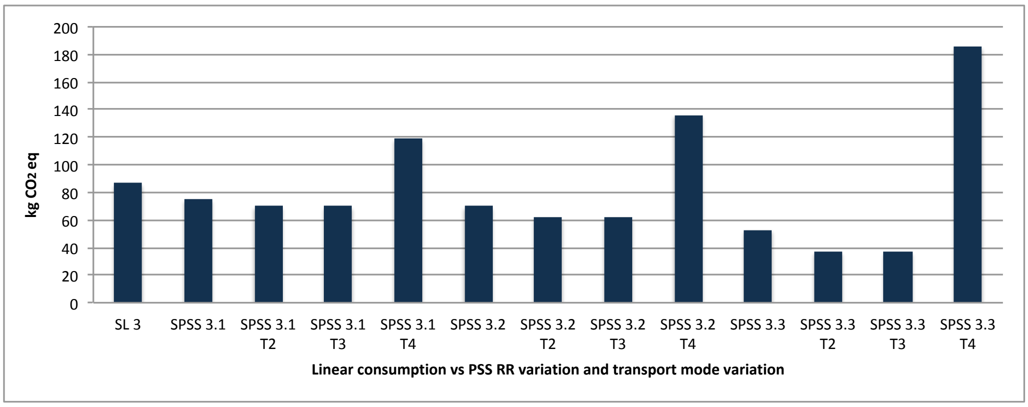

Figure 5-21.Global warming potential of a linear consumption scenario (SL) with a rental clothing consumption scenario of a 33% RR (SPSS 3.1), 50% RR (SPSS 3.2), and 100% RR (SPSS 3.3) and transport adjustments for rental where no T indicates average transport with metro and bus, T2= metro and walking, T3= bike and metro, and T4 = car and metro.

6 Discussion

6.1 Overview of findings

RQ1: What ways can the function of rental clothing be defined to assess the impacts in an LCA framework?

Although there are indications for why consumers choose to engage in PSSs, in particular rental clothing business models, it is not fully understood how consumers behave when doing so and how it affects their other consumption patterns. Since consumer behaviour can be reflected in different ways in how they consume and engage with products, three FUs were analysed. These FUs offer different perspectives to the impact and impact potential of a PSS in comparison with a linear business model.

The narrowly defined FU of "one average use" provides a somewhat simplistic, but a more concrete understanding of the impact associated with one use of a dress in a linear vs a rental scenario. This FU includes the cradle-to-grave life cycle stages for one dress, dividing certain activities or life cycle stages in the LCI, such as dress production, by the total number of uses or users in the scenario. It indicates the impacts for all processes necessary to facilitate one use of a dress whether purchased or rented and provides a micro-level perspective of the impacts. Although it factors in variations in the use intensity of a garment, the scope of the FU is limited since it does not consider how rental clothing can displace the production needed for clothing under ownership.

The other two FUs are more broadly defined, in which 4 years of consumer needs for a formal dress are analysed. One FU is where the needs are satisfied through a number of garments purchased, and the other where the needs are satisfied though the number of wear occasions or uses. These FUs include a replacement rate where rental dresses replace linear dresses to some degree either by the garment itself, or by the wear occasion. These more broadly defined FUs take a systems-thinking approach by considering the potential for rental systems to displace linear consumption systems on a specific product basis. However, rebound effects for purchasing of other type of products are not accounted for.

By thinking about the function of a rental dress in three different ways and in two different time frames, drivers for behaviour are considered that affect how rental systems can be used, which ultimately lead to variations in the results of the environmental outcomes.

RQ2: What are the environmental impacts of a rental dress company, and how do they compare to the impacts of dress consumption in a linear business model?

The analysed case study of a formal dress (ownership vs rental) was based on an example of a company in Stockholm. The analysis used three different FUs to ascertain the environmental implications from three different points of view, yielding different consumption scenarios. The most significant environmental impact categories consistent through all three functional units were freshwater ecotoxicity, marine ecotoxicity, and human carcinogenic toxicity. The scenarios and the results varied in each of the FUs. Summarising the total impact for one system in comparison to another, as well as stating which scenario is the most environmentally beneficial than the other is difficult. The ISO standards for LCAs stipulate that products in comparison should not be aggregated into a single score (European Commission - JRC - IES, 2010). Furthermore, a single score would not fully capture the disparity in the contribution of the impacts for different categories, which imply different issues and solutions to address them.

The variation in the impact by rental and linear scenarios throughout the different FUs indicate that the environmental savings potential for rental business models to replace linear business models are suitable where rental business models replace the need to purchase garments to a high degree. Furthermore, results suggest that the replacement of one use or wear occasion by one rental garment does not create environmental benefits due to the high transportation burden needed to facilitate one rental. Therefore, rental garments can be beneficial to replace the use of linear garments if rental garments are used multiple times in one rental period. This would require longer rental periods in order to provoke increased use.

Impact of one average use

The assessment of the FU "one average use" scenarios show that scenarios with increased use intensity, regardless of the linear or rental BM, have a lower environmental impact for freshwater and marine ecotoxicity compared with scenarios with low overall usage of garments. This is due to the decrease in the share of impacts from production by increased usage. However, the linear BM scenario with high-use intensity has 20% less impact contribution to these categories than the high-use intensity PSS scenario, indicating the potential environmental benefit of when consumers increase their usage of garments they already own.

Increased use intensity for the linear and rental scenarios also show a lower environmental impact for human carcinogenic toxicity, although the impact increases with increased transportation. This means that an average use intensity for both linear and rental business models can have a lower impact than high-use intensity rental scenarios, if the amount of uses are not too low, and if there is little rental transportation.

Lower GWP is also associated with an increased use intensity, with the average rental scenario having a lower impact than the average linear scenario. Low usage in the rental business model results in a higher GWP impact than the average linear scenario. The high-use scenario for the linear BM also has a lower impact than the high-use rental scenario, indicating again that use intensity is beneficial, if each use is not associated with increased transportation. Alteration of transportation modes show that high-impact transportation for consumer rental transport, such as the metro and car combined scenarios (T4), increase the impact for rental scenarios across all analysed categories to have a higher impact than the linear scenarios.

Impact of four years of consumer dress needs satisfied by purchasing

The FU focusing on "4 years of consumer dress needs satisfied by purchasing" indicated the most differential results between the scenarios, with the high RR in the rental scenario having the lowest impact contribution for all other analysed impact categories. All rental scenarios had lower impact contributions than the linear scenario. However, when testing transport mode variation, all rental scenarios with the high impact transportation mode (T4) had higher impact contributions than the linear scenario. The results from this functional unit indicate that when rental BMs substitute or replace the need to purchase garments, the environmental potential to reduce impact can be significant. However, this is only true when low-impact transportation modes are used, such as combined metro and bus, and metro and walking/cycling.

Impact of four years of consumer dress needs satisfied by use

The FU focusing on "4 years of consumer dress needs satisfied by use" had minimal changes in the impact across scenarios compared to the other functional units. The rental scenario with the 50% RR for wear occasions had the highest impact for freshwater and marine ecotoxicity, by just 2% over the linear scenario and the average rental scenario with the 33% RR. The replacement of the number of uses or wear occasions by renting garments has a high environmental impact due to the high amount of transport associated with the one use per rental. If rental garments were worn a few times in one rental, this could lower the impact.

However, it is uncommon in the case company to rent dresses for extended periods of time, which could encourage a higher use intensity per rental period. If consumers consider one rental garment to replace one use, then there is a lower impact associated with purchasing garments and wearing it more times rather than renting. At the same time, if consumers consider one rental garment to replace multiple uses that would be satisfied by a purchased dress, this would likely reduce the impact contribution by reducing the amount of transportation needed to facilitate use.

The 50% RR scenario also had a slightly higher impact than the 100% RR for wear occasions. It is noteworthy that the rental scenario with the 100% RR had a slightly lower impact than the 50% RR scenario, but slightly higher than the 33% RR scenario. This implies that the number of purchased garments and the amount of transportation needed to facilitate rental to satisfy wear occasions in the scenario with the mid-percentage replacement rate incurs greater impacts than either increased purchasing, or increased rental. This suggests a threshold between balancing the production burden and transportation burden.

For human carcinogenic toxicity, the rental scenario with the highest number of rentals contributes the most to this impact category, also indicating that increased transport associated with one use per rental results in more impactful consequences. The GWP potential decreases however with the increase in replacement rate for rentals over use, indicating the high GWP associated with production, and the relatively low carbon dependence of public transport. When comparing alternative transportation scenarios, the high-impact transport scenario with use of the car is higher than the linear and all other rental scenarios.

RQ2.1: **To what extent do user behaviour variations impact the result of an LCA on a clothing PSS?**

The environmental savings potential that a PSS can have is influenced heavily by how consumers choose to engage with rental BMs. This is shown in how many times consumers use garments, how they use rental to substitute or complement their purchasing or use needs, and how they choose to travel to rental store locations. These causal mechanisms were tested in the LCA were derived from the hypothetical models in chapter 3 that postulated their role in affecting the environmental outcome.

The hypothetical models were addressed in the LCA by creating various scenarios within each FU to perform a variation and sensitivity analysis, and test how they affected the results. The use intensity of garments in hypothetical model 1 was tested using the FU "one average use", where the linear and PSS scenarios were tested for low, average, and high use intensities. The RR for purchased dresses, and the RR for wear occasions in hypothetical model 2 was tested in both of the "4 years of consumer dress need" FUs, and hypothetical model 3 with variation in transport mode was tested in all three FUs.

Consumers' use intensity of garments is important both in the linear and PSS BM. Increased use intensity of clothes they already own or have purchased can significantly decrease the environmental impacts from production. Consumers can also increase their use intensity of garments in the same rental period to decrease their impact from transportation, as well as engage in more rentals, if they use low-impact transportation modes.

The RR of rental for purchased dresses plays an important role in discerning the environmental benefit of rental clothing. Users who rent solely in addition to normal purchasing are not creating any benefit, however as their engagement with rental reduces the need to purchase and produce products, the benefit of rental increases. The LCA, however, does not account for rebound effects, and it should be noted that use of rental scenarios may result in consumer savings which can be spent on other products and services that would result in a bigger impact.

Variation in transport modes was only modelled for the consumer transport to the rental store, and results between the high-impact transport and other transport modes were significant. Users who choose to take public transportation modes, such as the metro and bus combination, metro and walking, and cycling and metro scenarios can significantly reduce their impact and increase the environmental potential for clothing rental. Consumers who use high-impact transport such as cars, negate the benefit that a PSS could have and result in a higher impact than linear scenarios.

6.2 Significance and implications

6.2.1 Applicability and generalisation of the case study

This case study analysed a niche company offering rental formal dresses, a concept that is not new since rental formalwear has been around for several years, notably with the company, Rent the Runway in the US. Although this case study focuses on a specific product, the results are illustrative to interpret and map the environmental potential for other types of garments or products, as well as understand the type of infrastructure needed to support low-impact transport of products in PSSs.

The general low-use intensity and need for special-occasion wear suggests the potential to lower the impacts of production by increasing the overall usage of these types of garments. Although a decrease in garment production is beneficial, the associated transport needed to facilitate one garment rental creates a high impact that could reduce the PSS's potential for environmental impact savings. It is important that PSSs encourage increased use not only through multiple rentals, but also for one user to wear the same garment many times during the rental period. This could perhaps be facilitated by longer rentals, e.g. a few months rather than a few days or a week. However, this type of rental scenario will likely not work for special-occasion wear such as in the case company. If consumers are looking for unique garments for certain events, it renders the reuse of a garment as impractical by the same renter. However, longer rental time frames would be an important attribute for casual rental wear companies to have. Casual renting clothing could include anything from jeans to jackets, to more everyday clothing such as shirts. Longer rental time frames can also be applicable to PSSs offering other products where ownership can be wasteful and inconvenient, but where users may need a certain product for a slightly longer term, such as rental furniture to students.

Special-occasion wear rental companies can focus on securing locations that are central and require little or low-impact transportation, or find low-impact delivery services to facilitate forward and reverse logistics. For example, bike-delivery in cities with supportive cycling infrastructure. In locations with poor public transportation services and longer distances, such as in the US where cars are often necessary, PSSs may not be the most environmental option if consumers must facilitate the pick-up and drop-off. However, PSSs in more remote locations could opt to use more mainstream delivery methods to consumer homes, or alternatively set-up distribution and re-distribution networks. This for example could involve collaborations with small stores for multiple pick-up and drop-off locations, such as done with Wardrobe, a rental clothing company in New York that collaborates with local laundromats as part of its pick-up and drop-off network.

This case study offered perspective on how BMs can innovate their activities and services to influence positive consumer behaviour and reduce impact.

6.2.2 Business model implications

Although the impact of business model variations of PSSs was not explicitly addressed in the LCA, survey responses revealed that 70% of respondents would not be willing to rent more dresses if the case company would offer a membership with unlimited monthly rentals, instead of the current pay-per-use model. This would mean that membership-based rental models would not necessarily increase consumption, and perhaps could incentivise longer rental periods rather than just a few days, implying a decrease in the transportation burden with increased use.

However, the survey is specific to the case company and formal dresses, so the majority of respondents may not be interested in unlimited rentals because they do not have a need for the product, in comparison to casual rental wear or other products. Of respondents who did indicate interest in unlimited rentals, the majority stated that it would rent dresses as needed. Although this appears positive as it can be interpreted as curbed consumption, it implies increased transportation if consumers are taking multiple trips to rent dresses, rather than renting several dresses at the same time.

Short-term rental time frames may be attractive to customers for special occasion wear or formal wear; however, they decrease the environmental potential for PSSs by limiting the use intensity of garments. Business models that offer longer rental time frames may decrease the environmental impact of rental garments by motivating users to wear them longer. This also increases the potential for rental garments to substitute more purchased clothing. Furthermore, rental clothing companies must ensure to have an inventory that allow dresses to be used many times. Otherwise the addition of unused dresses in rental scenarios could increase the impact if companies have large inventories with little use. This would be a similar situation as consumers owning garments that they do not wear and let sit unused in their closets.

6.3 Methodology reflections

6.3.1 Survey limitations

The consumer survey provided an insight to a specific group of consumers in a capital city with high disposable income, which might not be representative of other cities in Sweden or other countries. Surveys are somewhat limited in collecting data about consumer behaviour, as respondents can indicate responses that they may not truly identify with but respond with what they feel is the best answer, or respond hypothetically. However, the data collected in the survey was compared to literature to check its adequacy and practicality when used to build the LCI.

The survey received 57 respondents, of the total 856 clients of the case company. This is not statistically representative, and the results of the survey may not adequately represent the behaviour of other clients. However, not all the company's clients are active. It is assumed that those who answered the survey are active clients, making the sample more representative. A survey with a broader range of consumers and products may show certain difference in behaviour, but it was beneficial that the survey results were specific to a niche product as it can provide a more detailed understanding rather than generalised data.

Although most survey questions were specific to formal dresses, some were more general and provided a further insight on consumers behaviour towards their renting motivations. The survey also gave insight to consumer's interest in renting other types of garments, as well as their engagement with rental if the case company's service pricing would change. It is acknowledged that the specific number of purchases and use intensity modelled in the LCA may not be applicable for other garments. However, the results still indicate a general understanding of use intensity and RR for purchasing that can be applied to other products.

6.3.2 Functional unit reflections and systemic implications

In interpreting the impacts for the three analysed FUs, the benefits of PSS are more apparent when considering the change in effect that renting dresses can have on consumption and the impact of production. This is shown in the "four-year" scoped FUs, while the "one average use" FU shows a limited perspective and benefit that a PSS may have.

As identified in the literature review, it is difficult to adequately define the core function of a system under LCA analysis, as primary functions of products and services are often accompanied with auxiliary functions. While it appears simple to select just one function, it must be ensured that this function is representative of the system(s) under analysis. For example, the function of clothing can easily be perceived as to be used/worn. However, when analyzing the "one average use" FU, the results for the linear vs. rental scenarios were mixed for many categories, as the need to facilitate use in the rental scenario required much more transportation. Although this FU appears representative, it does not fully capture the extended benefit that rental clothing can substitute the needs for purchased clothing. This makes the second FU more fitting, where rental garments substitute purchased garments to some degree over a four-year time period. By accounting for the behavior and use of a consumer for a larger time frame, and how the use of the rental system could displace the need for a linear system, the FU better showcases the benefits of a clothing PSS. However, this FU is rather specific to formal dresses, and does not consider the potential for rebound effects or consumers purchasing more of other products. The last FU of "four years of consumer purchasing needs satisfied by use," had very mixed results compared to the other two FUs. This is attributed to the high impacts from production being balanced by the high impacts from transportation in the rental scenarios, as one use in the rental scenario is associated with consumer rental transport.

The scope of the study was specifically on formal dress consumption. This does not, for example, account for how dress purchasing, or rental could incentivise other purchases, e.g. the potential indirect rebound effects of consumption. For example, the ability for consumers to wear dresses for cheaper through rental could incentivise them to buy other accessories, such as shoes that they previously could not afford, or buy more of something else. This is not accounted for in the LCA study, as it would require a more comprehensive behaviour study and would better be suited to consider in a consequential approach.

The LCA utilised a micro-level consumer-oriented perspective and took an attributional approach, following the recommendations for scope under Situation A as specified in Figure 3-3. In this regard, the consequences of the results perhaps do not appear significant. However, the impact could be magnified when assessing the potential of many individuals or entire business models, leading perhaps to large structural changes[16]. For example, the decreased need for garments would lead to a decreased need for production, perhaps resulting in a closure of

[16] "Structural changes" is a term used in the ILCD Handbook (2010), and is explained in 3.3.4.

garment or fibre production factories overseas. The implications from a rented polyester dress instead of a produced one could imply savings in fossil fuel extraction and lower contamination of wastewater by microfibers, while a rented cotton dress could imply reduced use of cropland, water-use, and chemicals. Consideration of broader consequences such as these would require a much more comprehensive FU and account for market consequences of entire rental systems replacing the current economy.

6.3.3 Choice of impact categories

Four impact categories were included in this study. Three categories that were shown as most significant (FETP, METP, HTPc), and GWP which was analysed in addition. Although these impact categories are perceived as relevant when consulting previous LCAs for garments, assessing all the impact categories would provide a more holistic overview of the impact of both systems.

Impact categories or indicators often reported in industrial assessment appear to not be the most significant impacts, as suggested by this study. For example, the company Reformation uses RefScale, a LCA tool to calculate the CO_2, water use, and waste footprints of their garments (2019). The Higg Material Sustainability Index (Higg MSI), created by the Sustainable Apparel Coalition and used commonly in the apparel industry, assesses four impact categories: global warming, eutrophication, water scarcity and abiotic resource depletion/fossil fuels (Watson 2019). This study analysed the commonly reported impact category of GWP, which showed positively for the rental scenarios. However, results were slightly more mixed with the significant categories, which are not typically assessed in the industry. It is important that industries assess broad impacts of production throughout various impact categories and justify the assessment of their chosen impact categories when creating products.

6.3.4 Data limitations and assumptions

"No matter how thorough the LCA practitioner, there will always be data gaps in LCIs" (Baumann & Tillman, 2004, p. 105). Data gaps in this case study were filled with the most suitable information found, and are disclosed in the LCI. It is important to discuss how the assumptions and estimates made affect the overall results.

Production data was based on secondary data provided by literature, and the material modelled (polyester) was consistent with the common material composition for dresses in the case company. The various impacts from different materials and fibres are not tested in this study, although the material used could affect the overall durability of garments, the number of washes required, and the potential for garments to be upcycled, and /or recycled. The material of garments also affects the upstream processes of extraction of resources to produce fibres. Modelling of a cotton dress instead of polyester could perhaps have had a larger water footprint, although this is not analysed in the study.

Consumer behaviour data was based on the survey, which reflects a very specific respondent group. Although the data was compared to literature, data was primarily used from the survey since the information was highly specific to formal dresses, while the literature generalised garments and all dresses. The consumer purchasing frequency was calculated based on consumer responses and assumptions of "certain occasion" frequency, as indicated in section 4.1.1. The purchasing frequency likely differs in different cities, as well as countries, where the number of dresses purchased could change based on the affordability of dresses in the region, the strength of the second-hand market, and the community atmosphere (if dresses are shared informally between family or friends). The change in purchasing frequency could then alter the environmental consequences of both systems under analysis. The average use intensity of purchased formal dresses in the survey was much lower than that found in literature, although this is attributed to the specific types of dresses that are rented in the case study, in comparison to generalised garments analysed in the literature review.

The laundry frequency was estimated based on the calculated weighted average of consumer responses and average number of uses from the survey. The laundry frequency may be slightly higher or lower for consumers perhaps than actual behaviour. A wash cycle was assumed to be a small load of 1 kg, in which the impact of one wash cycle is attributed to one dress, although dresses are half the load size at 0.477 kg. Since a dress must be washed no matter if there are other items to be washed with it, the burden was allocated to the dress. A wash cycle was also assumed to be filled with water to the average load of 3.4 kg, despite the washing of a smaller load. This likely increased the impact of laundry, however as laundry had a little significance compared to other life cycle stages, it assumed that these factors would not have changed the overall impact for the scenarios. Since garments are assumed to be washed at 30 ^{o} C due to the delicate nature and synthetic material of the dresses, this lowers the impact compared to the average 40 ^{o} C wash cycle used for many types of garments and casual wear. Garments are assumed to be air-dried so no heat for tumble dryers or heating rooms are modelled. The share of impact from laundry could change if consumers use higher impact washing machine programs, or tumble dry their laundry, however possible laundry behaviour variations are not included in the study. Laundry does not play a significant role in this study, but this may change if assessing the impact in other countries where the electricity mix might be considerably higher than that of Sweden.

Although variations in transport mode were tested, an average distance of 20 km (10 km to the store and 10 km back) for one trip were assumed for all scenarios. When considering the impact for rental transportation, smaller distances than the assumed average distance would have decreased the impact associated with rental scenarios, although it is unknown how large of a distance variation would be significant. Assumptions also had to be made in regard to the number of dresses accumulated at the same time by the case company in the second-hand redistribution process. The impact from transport could be much less if more dresses are collected at the same time, however there is no data on this. Three dresses collected at one time was assumed by the case company, although it could differ from 1-10 dresses. For consumer transport, the transport to purchase or rent a dress is often combined with other purposes or errands for a transport trip, as shown from the survey in section 4.1.3, in which the impact from transportation would be reduced if there were multiple reasons for a trip. However, this is not accounted for due to the complexity in allocating the burden of transport to multiple stops, and still 45% of respondents stated they make a point to go just to the rental store. However, 55% did state they go on multiple errands, which would decrease the share of impact coming from rental transportation and could likely change the overall environmental impact of a few scenarios. Although delivery for consumers is optional and offered by the case company, this was not modelled, as only 8 out of 856 consumers have chosen home delivery. The impact for laundry transport, although was shared for multiple dresses, contributed to an increase in rental scenarios, when transport was likely associated with employees coming to and from work daily, in which the burden should also be allocated in the system. However, employee transportation is not included in the modelled system, and so the burden was allocated entirely to laundry, as the trip is necessary regardless of whether the employee comes to or from work daily.

The EoL scenarios are highly simplified, and there is likely potential for a decrease in the overall impact of linear and rental scenarios if a more complex situation were modelled. In a linear scenario, it is likely that a formal dress in good condition is shared informally by being given to friends or family or sent to a second-hand store or redistribution store (as in the case for dresses procured by the case company). The increased use of a dress before its EoL would also help to decrease the share of impacts from production. In the PSS scenario, the case company has plans to donate their old dresses beyond repair to a company that uses old materials in new dresses. This is not accounted for in the EoL scenarios since the case company is quite new and has not done this yet, nor has data on how much material would be reused. The EoL scenario modelled also does not include credited heat or electricity from the incineration of waste in Sweden, as this goes beyond an attributional approach.

6.4 Critical reflections on results

The results of the LCA suggest a flag of caution for the promotion of PSSs as sustainable business models, as although it contains a resource-saving perspective, the impacts from other activities such as transport from forward and reverse logistics can have a significant impact on the overall environmental impact. Results suggest that the increased use intensity of purchased garments can have a lower environmental impact than increased intensity of use for rental garments, if rental is associated with an increase in transportation. This probes a broader societal question of whether the promotion of alternative consumption is enough to meet sustainability goals, or if society needs more radical change to slow consumption rather than change the direction of consumption. Slowing consumption could provide the increased use intensity that makes the production of garments significantly lower in the overall impact.

Increased usage also requires changing a system where styles become longer lasting and timeless, not just the materials themselves. This requires consumers to identify themselves with goods or garments they like, rather than what is signified by society or trends to identify themselves with. Slowing down consumption requires a deep societal and individual change where the apparel industry needs to shift in how clothes are designed and sold, and consumers must shift how they perceive and connect with material goods.

7 Conclusion

Acknowledging the need to change the current practices in the apparel industry, this thesis examined the potential of a clothing PSS by quantifying the environmental impacts of consumption in a rental clothing company in Stockholm and comparing it to a linear business model. The LCA study took a consumer perspective to understand the potential for rental clothing to displace purchased clothing. Consumer behaviour plays a key role in the overall impact of a PSS. How users decide to engage with rental BMs dictates the environmental savings potential that a PSS can have, as shown in how many times consumers wear garments, how they use rental to substitute their purchasing or use needs, as well as how consumers travel to rental store locations.

The LCA results indicate that the environmental savings potential for rental business models to replace linear business models are suitable when rental business models replace the need to purchase garments to a high degree. Results also suggest that the replacement of one use or wear occasion by one rental garment does not create environmental benefits due to the high transportation burden needed to facilitate one rental. Rental garments can be beneficial to replace use for linear garments if rental garments are used multiple times in one rental period.

As society begins to transition away from business-as-usual, and the fashion industry moves away from a take-make-dispose economy and towards circular strategies and sharing principles, it is important to not identify a blueprint of a business model as the most sustainable for all contexts. Business models with sustainability potential should be retrofit to each context and case, from the geographic location to the product and the consumer market. Business models such as PSSs do have potential when given the right conditions to cultivate, and PSSs can play an important role in shifting traditional consumption thinking and slowly dissolving the connection of consumers to ownership and products. Local municipalities and governments can increase the sustainability potential of such business models by developing supportive infrastructure and fostering an environment that encourages rental, as well as motivates consumers to act and think in ways with less environmental impact. Industry leaders can help to pave the way by honing their business models to provide choice architecture for consumers to behave sustainably.

7.1 Recommendations for practitioners

This research contributed to an understanding of various factors that play a role in the sustainability potential of PSSs both inside and outside of a business model's control. Therefore, recommendations are provided both to local governments as well as current and prospective businesses involved in product-service systems.

Recommendations to municipalities and local governments to support PSSs:

- Create robust public transportation, cycling, and walking infrastructure to encourage more sustainable consumer transportation.
- Create car free zones for shopping areas.
- Encourage central locations for companies offering rental or facilitating product sharing.

Recommendations to rental business leaders and companies:

- Incentivise consumers to increase their usage of a product per rental by increasing the rental time period to longer time frames that encourage a stewardship of garments.

- Centralise physical rental stores to minimise consumer travel distance and encourage the use of public transportation.
- Offer logistic services using bike-delivery or create a network of local distribution points.
- Offer services to consumers that provide them with a choice architecture to select the most sustainable alternative.
- Minimise the need for internal company logistics for product procurement and repair.

Business models such as PSSs can help transition society to alternative pathways of consumption, leading to more community-oriented businesses and business values designed around decreasing overall environmental impacts and reducing waste. However, business models striving to be sustainable cannot stop at shifting to service-oriented business offerings, businesses need to begin to strive for sufficiency and a decrease in total consumption. This research provides caution to defining all PSSs as sustainable business models, however it recognises the value and positive environmental potential that they could have in certain contexts, and advocates for more PSSs to help transition society away from linear business models.

7.2 Recommendations for further research

This research has contributed to the ideological development of methodology to understand the implications of consumer behaviour for the environmental impacts of alternative business models, and further provided quantitative evidence of the environmental impacts of PSSs in comparison to linear business models.

The role of consumer behaviour cannot be overlooked in assessing the impacts of business models, as shown in the results that consumer behaviour can significantly influence the environmental potential of both rental and linear scenarios. Further research could build off of the consumer profiles summarised in this research and assess the stereotypical consumption behaviour of each in an LCA. This could facilitate understanding of how certain consumer profiles may be better suited to engage in PSSs and would be beneficial to help PSSs find a target market that would also increase their environmental potential. Further research can also build off of the implications of the FUs to progress research desiring to quantify the impacts of shared and rented products. Insights from the results of the three FUs can help guide methodological approaches in terms of scope for what to include in LCAs of shared goods. It is suggested that social and economic benefits of PSSs are also explored to enhance the understanding of the sustainability outcomes and provide a more comprehensive picture.

PSSs are just the start of a shift to slower and more sustainable consumption, as it begins to incentivise consumers to rethink their mindset about products and how they are used. Business models that force consumers to think about how they use and interact with products can help to change current conventional consumption patterns and habits.

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Appendix A: Consumer survey

Dress Shopping & Renting	Klänning Shopping & Hyra
Thank you for participating in this survey! You are helping to contribute to research for a master's thesis at Lund University. The goal of this survey is to understand how customers use rental clothing services such as *the case company*. Data from this survey will be used in a life cycle assessment of a rental dress vs. a traditionally-used dress. By doing this survey, you will be entered into a raffle to win 500 SEK to rent a dress from *the case company.* Thank you for your time!	Tack för att du deltar i den här undersökningen! Genom att delta bidrar du till ett forskningsprojekt för en masteruppsats vid Lunds universitet. Målet med undersökningen är att förstå hur kunder använder klädhyrestjänster som *the case company*. Resultatet kommer att användas i en livscykelanalys där vi jämför miljöpåverkan av att hyra en klänning med miljöpåverkan av att köpa en klänning. Genom att delta i undersökningen så kommer du att vara med i utlottningen av ett presentkort värt 500 SEK som du kan använda till att hyra en klänning från *the case company*. Tack för din tid!
1. How often do you buy formal dresses? a. I buy dresses seasonally (4x a year) b. I buy dresses bi-annually (2x a year) c. I buy dresses once a year (1x a year) d. I buy a dress less than 1x a year e. I buy dresses only when needed for certain occasions	1. Hur ofta köper du högtidsklänningar? a. Jag köper klänningar säsongsvis (4x per år) b. Jag köper klänningar halvårsvis (2x per år) c. Jag köper klänningar en gång om året (1x per år) d. Jag köper en klänning mindre än 1x per år e. Jag köper klänningar endast när det behövs vid speciella tillfällen
2. How many times do you wear the same formal dress after you have purchased it? a. 1-3 times b. 3-5 times c. 5-7 times d. 7-10 times e. More than 10 times	2. Hur många gånger använder du samma högtidsklänning efter att du har köpt den? a. 1 - 3 gånger b. 3-5 gånger c. 5-7 gånger d. 7-10 gånger e. Mer än 10 gånger
3. How often do you wash and/or dry clean formal dresses? a. Every time that the dress is worn b. Every other time that the dress is worn c. When it seems dirty	3. Hur ofta tvättar du och / eller kemtvättar högtidsklänningar? a. Varje gång klänningen används b. Varannan gång klänningen används c. När den verkar smutsig
4. What best describes your shopping behaviour out of the categories below? Please select the one you identify best with. a. Bargain b. Stand-out	4. Vilken av de sex nedanstående kategorierna tycker du bäst beskriver vad som har störst inflytande över dina val när det gäller inköp av kläder? a. Prisjakt b. Unikhet

<table>
<tr><td>c. Avoid
d. Influencer
e. Fitting in
f. Eco-friendly</td><td>c. Undvika
d. Influencer
e. Passa in
f. Miljövänlig</td></tr>
<tr><td>5. Where do you usually purchase dresses from?
a. Online
b. Physical store
c. Second-hand
d. I avoid buying dresses and use what I have or borrow from friends</td><td>5. Var köper du vanligtvis högtidsklänningar?
a. Online
b. Fysiska butiker
c. Second-hand
d. Jag undviker att köpa klänningar och använder de jag redan har, eller lånar från vänner</td></tr>
<tr><td>6. How do you typically travel from home to the store to buy clothes?

<table>
<tr><td rowspan="4">What is the primary way you go to the store?</td><td rowspan="4">What is the secondary way you go to the store?</td><td>Car</td></tr>
<tr><td>Bus</td></tr>
<tr><td>Metro</td></tr>
<tr><td>Walk/bike</td></tr>
</table></td><td>6. Hur tar du dig vanligtvis till butiker för att köpa kläder?

<table>
<tr><td rowspan="4">Vilket är det primära sättet som du tar dig till butiken?</td><td rowspan="4">Vilket är det sekundära sättet som du tar dig till butiken?</td><td>Bil</td></tr>
<tr><td>Buss</td></tr>
<tr><td>Tunnelbana/Pendeltåg</td></tr>
<tr><td>Promenad/Cykel</td></tr>
</table></td></tr>
<tr><td>7. How long does it typically take you to go from home to a clothing store based on the primary and secondary transportation modes you selected from the previous question?

<table>
<tr><td></td><td><10 minutes</td><td><30 minutes</td><td><45 minutes</td><td>< 1hour</td></tr>
<tr><td>Car</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Bus</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Metro</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Walk/Bike</td><td></td><td></td><td></td><td></td></tr>
</table></td><td>7. Hur lång tid tar det för dig att ta dig till klädesbutiker med det primära och sekundära färdmedel som du svarat på föregående fråga?

<table>
<tr><td></td><td><10 minuter</td><td><30 minuter</td><td><45 minuter</td><td><1 timmar</td></tr>
<tr><td>Bil</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Bus</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Tunnelbana</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Promenad/Cykel</td><td></td><td></td><td></td><td></td></tr>
</table></td></tr>
<tr><td>8. Rank from 1 to 6, the main reason why you rent a dress from the case company. (1 is your top reason, and 6 is your lowest).

a. To save money
b. To wear unique dresses
c. To avoid having to buy a dress</td><td>8. Rangordna från 1 till 6, största anledningen till varför du hyr en klänning från the case company. (1 är högst prio, och 6 är lägst).

a. Spara pengar
b. Hitta unika klänningar
c. Slippa köpa en klänning</td></tr>
</table>

<table>
<tr>
<td>d. To have access to different dresses and styles
e. Influence from friends who also rent clothes
f. To reduce personal shopping for environmental concerns</td>
<td>d. Ha tillgång till olika klänningar och stilar
e. Inflytande från vänner som hyr klänningar
f. Minska konsumtionen för miljöns skull</td>
</tr>
<tr>
<td>9. How does renting a dress affect your normal dress shopping behaviour?
(sliding scale)

0 = Not at all (I rent dresses in addition to my usual purchasing)
10 = It 100% subsitutes my need to purchase a dress</td>
<td>9. Hur påverkas ditt normala köpbeteende av att hyra en klänning?
(sliding scale)

0 = Inte alls (jag hyr klänningar utöver mina normala klädinköp)
10 = Det ersätter till 100% mitt behov av att köpa en klänning</td>
</tr>
<tr>
<td>10. How do you receive your dress from the case company?
a. Pick-up in store
b. Delivery

11. If you pick up your dress, how do you get to the case company?

<table>
<tr><td rowspan="4">What is the primary way you go to the store</td><td rowspan="4">What is the secondary way you go to the store?</td><td>Car</td></tr>
<tr><td>Bus</td></tr>
<tr><td>Metro</td></tr>
<tr><td>Walk/bike</td></tr>
</table>

12. How long does it take you to go from home to a the case company based on the primary and secondary transportation modes you selected from the previous question?

<table>
<tr><td></td><td><10 minutes</td><td><30 minutes</td><td><45 minutes</td><td>< 1hour</td></tr>
<tr><td>Car</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Bus</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Metro</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Walk/Bike</td><td></td><td></td><td></td><td></td></tr>
</table>
</td>
<td>10. Hur hämtar du din klänning från the case company?
a. I butik
b. Leverans

11. Om du hämtar i butik, hur tar du dig till the case company?

<table>
<tr><td rowspan="4">Vilket är det primära sättet som du tar dig till butiken?</td><td rowspan="4">Vilket är det sekundära sättet som du tar dig till butiken?</td><td>Bil</td></tr>
<tr><td>Buss</td></tr>
<tr><td>Tunnelbana/Pendeltåg</td></tr>
<tr><td>Promenad/Cykel</td></tr>
</table>

12. Hur lång tid tar det för dig att ta dig till the case company med det primära och sekundära färdmedel som du svarat på föregående fråga?

<table>
<tr><td></td><td><10 minuter</td><td><30 minuter</td><td><45 minuter</td><td><1 timmar</td></tr>
<tr><td>Bil</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Bus</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Tunnelbana</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Promenad/Cykel</td><td></td><td></td><td></td><td></td></tr>
</table>
</td>
</tr>
</table>

<table>
<tr>
<td>13. How do you usually plan a visit to the case company?
a. I combine the visit to the case company with other errands.
I make a point to just go to the case company</td>
<td>13. Hur besöker du vanligtvis the case company butiken?
a. Jag kombinerar besök the case company med andra ärenden.
b. Jag besöker the case company när jag känner för det.</td>
</tr>
<tr>
<td>10. How do you receive your dress from the case company?
c. Pick-up in store
d. Delivery

14. How do you get to central Stockholm?
<table>
<tr><td rowspan="4">What is the primary way you go to the store</td><td rowspan="4">What is the secondary way you go to the store?</td><td>Car</td></tr>
<tr><td>Bus</td></tr>
<tr><td>Metro</td></tr>
<tr><td>Walk/bike</td></tr>
</table>

15. How long does it take you to go from home to a central Stockholm based on the primary and secondary transportation modes you selected from the previous question?
<table>
<tr><td></td><td><10 minutes</td><td><30 minutes</td><td><45 minutes</td><td>< 1hour</td></tr>
<tr><td>Car</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Bus</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Metro</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Walk/Bike</td><td></td><td></td><td></td><td></td></tr>
</table></td>
<td>10. Hur hämtar du din klänning från the case company?
c. I butik
d. Leverans

14. Hur tar du dig till centrala Stockholm?
<table>
<tr><td rowspan="4">Vilket är det primära sättet som du tar dig till butiken?</td><td rowspan="4">Vilket är det sekundära sättet som du tar dig till butiken?</td><td>Bil</td></tr>
<tr><td>Buss</td></tr>
<tr><td>Tunnelbana/Pendeltåg</td></tr>
<tr><td>Promenad/Cykel</td></tr>
</table>

15. Hur lång tid tar det för dig att ta dig till centrala Stockholm med det primära och sekundära färdmedel som du svarat på föregående fråga?
<table>
<tr><td></td><td><10 minuter</td><td><30 minuter</td><td><45 minuter</td><td><1 timmar</td></tr>
<tr><td>Bil</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Bus</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Tunnelbana</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Promenad/Cykel</td><td></td><td></td><td></td><td></td></tr>
</table></td>
</tr>
<tr>
<td>16. If the case company offered a flat rate membership (unlimited rentals per month), would you rent more dresses?
a. Yes
b. No

17. If yes, would you rent multiple dresses at one time, or go to the case company as needed?</td>
<td>16. Om the case company erbjöd ett fastpris-medlemskap (obegränsad antal klänningar per månad), skulle du då hyra fler klänningar?
a. Ja
b. Nej

17. Om ja, skulle du då hyra flera klänningar samtidigt från the case company eller hyra när det finns behov?</td>
</tr>
</table>

a. Multiple dresses at once b. Go rent as needed 18. How many more dresses would you rent? (sliding scale 1-5) 1=1 more dress 5 = 5 or more dresses	a. Flera klänningar på en gång b. Hyra vid behov 18. Hur många fler klänningar skulle du hyra? (sliding scale 1-5) 1=1 klänning 5 = 5 eller fler klänningar
19. Do you still buy dresses if you are also renting a dress(es)? If yes, why?	19. Köper du fortfarande klänningar om du också hyr klänningar? Om ja, varför?
20. Would you consider renting other types of clothing, such as a jacket or pair of jeans? a. Yes to both b. No to both c. Yes to jacket only d. Yes to jeans only	20. Skulle du överväga att hyra andra typer av kläder, till exempel en jacka eller ett par jeans? a. Ja till båda b. Nej till båda c. Ja bara till jacka d. Ja bara till jeans
21. What is your monthly income before taxes? a. 15,000 SEK - 20,000 SEK b. 21,000 SEK - 30,000 SEK c. 31,000 SEK - 40,000 SEK d. 41,000 SEK to 50,000 SEK e. >50,000 SEK	21. Vad är din månatliga lön före skatt? a. 15,000 SEK - 20,000 SEK b. 21,000 SEK - 30,000 SEK c. 31,000 SEK - 40,000 SEK d. 41,000 SEK - 50,000 SEK e. >50,000 SEK
22. Highest education level? a. High school b. Bachelor's degree c. Master's degree d. Doctoral degree	22. Högsta utbildningsnivå? a. Gymnasium b. Kandidatexamen c. Mastersexamen d. Doktorsexamen
23. Age? a. 18-25 b. 26-35 c. 35-45 d. 46-55 e. 55+	23. Ålder? a. 18-25 b. 26-35 c. 35-45 d. 46-55 e. 55+
Email address (In order to be entered into the raffle to win 500 SEK at *the case company*, you must enter your email address. You will only be contacted if you win and not for any other purposes.)	E-postadress (För att vara med i dragningen om att vinna 500 SEK till att hyra en klänning från *the case company*, så måste du ange din e-postadress. Du kommer bara att kontaktas om du vinner och inte i något annat syfte.)

Appendix B: General information collected from data questionnaires to the case company

Garment specific

- Top 3 rented dresses
- Material composition of top 3 dresses
- Dress mass
- Country of origin for production
- Most common dress material
- Average mass of dresses
- # of times dresses have been rented for top 3 garments
- # of times garments could likely be rented more
- # of washes per dress
- # of times of drying or dry cleaning/per dress
- # of times of ironing per dress
- Average # of rentals of top rented dress per month
- Average number of times that dresses are rented
- Average number of days dresses are rented

Activities

- Time frame of data collected
- Total rentals per year since opening
- Average rentals per month
- Number of transactions that are home delivered/picked-up
- How company received dresses for inventory
- Number of dresses collected for inventory at a time
- Number of actively rented dresses
- Laundry behaviour
    - Where are dresses washed
    - Wash load size
    - Wash temperature/wash program
    - Drying
    - Time spent ironing
    - Distance to laundry location, transport mode used
- End of life activities for garments

Users

- Average # of rented items per user
- Total # of users
- Typical rental period (time frame) for garments
- Average amount (SEK) spent per customer
- Highest number of times customer has rented
- Lowest number of times customer has rented
- Number of dresses per rental

Appendix C: Supplementary information for LCI

Purchasing frequency calculations

Table 0-1. Annual purchasing frequency for consumers who purchase "only for certain occasions", based off of assumptions derived from other responses

Year 1	0 dresses
Year 2	2 dresses
Year 3	1 dress
Year 4	3 dresses
Annual purchase frequency:	1.5 dresses

Table 0-2. Dress consumption over four-year functional unit, based off of Figure 4-1. Annual consumer purchasing frequency for new formal dresses

<table>
<tr><th colspan="3">Annual purchase frequency</th><th>4 year dress consumption (functional unit)</th></tr>
<tr><td colspan="3">Less than once per year</td><td>2 dresses</td></tr>
<tr><td colspan="3">Once per year</td><td>4 dresses</td></tr>
<tr><td rowspan="4">Only for certain occasions</td><td>Year 1</td><td>0 dresses</td><td rowspan="4">6 dresses*</td></tr>
<tr><td>Year 2</td><td>2 dresses</td></tr>
<tr><td>Year 3</td><td>1 dress</td></tr>
<tr><td>Year 4</td><td>3 dresses</td></tr>
<tr><td colspan="3">Twice per year</td><td>8 dresses</td></tr>
<tr><td colspan="3">Four times per year</td><td>16 dresses</td></tr>
</table>

** refers to Table 0-1.*

Life Cycle Inventory Calculations and Justification

Production

Table 0-3. Production reference flow calculations and justification

FU: **One average use of a formal dress**		
Linear Scenarios	PSS Scenarios	Justification
SL 1.1: One purchased dress/3.12 total wear occasions	SPSS 1.1: One rented dress/11 total users	1 dress required for one use, with the impact from production divided by the total number of uses in the linear scenarios, and the total number of users renting the garment in the PSS. One dress is modelled based on production of 477 g of polyester material. SL 1.1 and SPSS 1.1 have the "average" number of uses, based on survey data for the liner scenario, and based on data from the company for the PSS scenario. Since the rental company is relatively new, the average rentals per garment is projected at a middle number between the currently low average (2 rentals per garment) and an average of the dresses with the highest amount of rentals and the projected maximum number of rentals for them (20 rentals per garment. SL 1.2 and SPSS 1.2 use the lowest estimated number of uses and rentals. SL 1.3 and SPSS 1.3 use the highest estimated number of uses and rentals.
SL 1.2: One purchased dress/1 total wear occasion	SPSS 1.2: One rented dress/2 total users	
SL 1.3: One purchased dress/11 total wear occasions	SPSS 1.3: One rented dress/20 total users	
FU: **4 years of consumer formal dress needs satisfied by purchasing**		
SL 2: 6 purchased dresses (1.5 dresses purchased yearly)	SPSS 2.1: 4 purchased dresses + (2 rented dresses/11 users)	1.5 dresses are purchased yearly, meaning 6 dresses are consumed over a 4 year period (based off of the survey). Because the average rental per user is 1.09 rentals over 2.17 years (based off of the survey), 2 rentals are assumed over 4 years. 2 rented dresses/6 dresses is a 33% RR, this is applied to the number of garments rented/purchased for SPSS 2.1. The dresses that are rented are divided by the total number of users renting the garment in the PSS.
	SPSS 2.2: 3 purchased dresses + (3 rented dresses/11 users)	50% RR and the dresses that are rented are divided by the total number of users renting the garment in the PSS.
	SPSS 2.3: 6 rented dresses/11 users	100% RR and the dresses that are rented are divided by the total number of users renting the garment in the PSS.
FU: **4 years of consumer formal dress needs satisfied by use**		
SL 3: 16 wear occasions* (1 dress/ 3.12 wear occasions)= 5. 13 dresses	SPSS 3.1: 16 wear occasions* 33% = 5.28 wear occasions = **5.28 rental dresses/ 11 users** 16 wear occasions – 5.28 wear occasions = 10.72 wear occasions 10.72 wear occasions* (1 dress/3.12 wear occasions)=**3.43 purchased dresses**	For SL3, a total of 16 wear occasions are assumed for a four year period. Assuming one dress is worn 3.12 times (based off of the survey), the amount of purchased dresses is calculated. For SPSS 3.1, a 33% RR is also applied (as explained for SPSS 2.1). The RR is applied to the wear occasions or number of uses, instead of the number of garments purchased. It is assumed that a rented dress is worn once, and a purchased dress worn 3.12 times. A 33% RR means that 3.43 dresses are still purchased, and 5.28 dresses are rented. The rented dresses are divided by the

		total number of users renting the garment in the PSS.
	SPSS 3.2: 16 wear occasions* 50% = 8 wear occasions = 8 **rental dresses/ 11 users** 16 wear occasions – 8 wear occasions = 8 wear occasions 8 wear occasions* (1 dress/3.12 wear occasions)=**2.56 purchased dresses**	A 50% RR is applied to the wear occasions/uses. It is assumed that a rented dress is worn once, and a purchased dress worn 3.12 times. A 50% RR means that 2.56 dresses are still purchased, and 8 dresses are rented. The rented dresses are divided by the total number of users renting the garment in the PSS.
	SPSS 3.3: 16 wear occasions =**16 rental dresses/11 users**	A 100% RR is applied to the wear occasions/uses. It is assumed that a rented dress is worn once, that 16 wear occasions require 16 rentals. The rented dresses are divided by the total number of users renting the garment in the PSS.

Use intensity

Table 0-4. Wear occasions reference flow calculations and justification

FU: **One average use of a formal dress**		
Linear Scenarios	PSS Scenarios	Justification
SL 1.1: 1 wear occasion with a purchased dress	SPSS 1.1: 1 wear occasion with a rental dress	Since the functional sets the wear occasions, all scenarios have 1 wear occasion to represent one average use.
SL 1.2: 1 wear occasion with a purchased dress	SPSS 1.2: 1 wear occasion with a rental dress	
SL 1.3: 1 wear occasion with a purchased dress	SPSS 1.3: 1 wear occasion with a rental dress	
FU: **4 years of consumer formal dress needs satisfied by purchasing**		
SL 2: Year 1: (1.5 dresses*3.12 uses) Year 2: ((1.5 dresses* 3.12 uses)* (3/4)) Year 3: ((1.5 dresses* 3.12 uses)* (1/2)) Year 4: ((1.5 dresses* 3.12 uses)* (1/4)) **11.7 wear occasions**	SPSS 2.1: Year 1: (1 dress purchased*3.12 uses) + (0.5 rented dresses*1 use) Year 2: (1 dress purchased*3.12 uses)*(3/4) + (0.5 rented dresses*1 use) Year 3: (1 dresses* 3.12 uses)* (1/2)+ (0.5 rented dresses*1 use) Year 4: (1 dresses* 3.12 uses)* (1/4) + (0.5 rented dresses*1 use) = **7.8 wear occasions with purchased dresses + 2 wear occasions with rental dresses**	Based on the survey, consumers use dresses an average of 3.12 times. Because the FU is 4 years, and all of the dresses are not purchased at the same amount of time, the number of uses is determined based on the year they are bought. The dresses purchased the first year are utilised fully, but the dresses purchased the second year are only worn (3/4) of the years, dresses purchased the third year are only worn (2/4) of the years, dresses the last year worn (1/4) of the years so the use is adjusted accordingly. For the PSS, just one use is assumed per rental. The number of purchased dresses and rental dresses is based off of Table 0-3, utilizing the 33% RR for SPSS 2.1, 50% RR for SPSS 2.2, and 100% RR for SPSS 2.3.
	SPSS 2.2: Year 1: (0.75 dress purchased*3.12 uses) + (0.75 dresses*1 use) Year 2: (0.75 dress purchased*3.12 uses)*(3/4) + (0.75 dresses*1 use) Year 3: (0.75 dresses* 3.12 uses)* (1/2)+ (0.75 dresses*1 use) Year 4: (0.75 dresses* 3.12 uses)* (1/4) + (0.75 dresses*1 use) = **5.85 wear occasions with purchased dresses + 3 wear occasions with rental dresses**	

	SPSS 2.3: 6 wear occasions with rental dresses	
FU: **4 years of consumer formal dress needs satisfied by use**		
SL 3: 16 wear occasions	SPSS 3.1: 16 wear occasions* 33% = **5.28 wear occasions with rental dresses** 16 wear occasions – 5.28 wear occasions = **10.72 wear occasions with purchased dresses**	For SL3, a total of 16 wear occasions are assumed for a four year period. For SPSS 3.1, a 33% RR is applied (as explained in Table 0-3). The RR is applied to the wear occasions or number of uses, instead of the number of garments purchased. A 50% RR is applied for SPSS 3.2, and 100% RR for SPSS 3.3
	SPSS 3.2: 16 wear occasions* 50% = **8 wear occasions with rental dresses** 16 wear occasions – 8 wear occasions = **8 wear occasions with purchased dresses**	
	SPSS 3.3: **16 wear occasions with rental dresses**	

Transport

Table 0-5. Transport reference flow calculations and justification

FU: **One average use of a formal dress**		
Linear Scenarios	PSS Scenarios	Justification
SL 1.1: (20 km* 1 trip to the store) /3.12 uses=**6.41 km for consumer purchasing transport**	SPSS 1.1: (30 km/ 3 dresses)= 10 km/1 dress= 10 km/(11 rentals*1 dress)= 0.91 km/rental=**0.91 km for second-hand distribution** 20 km* 2 trips to rental company= **40 km for consumer rental transport** (15 km/ 2 wash cycles)*1.2 wash cycles = 9 km (9 km/1.2 wash cycle)*(1 wash cycle/2 dresses)= **3.75 km for laundry transport**	Consumer purchasing transport includes the distance for a consumer to go to the store and back home to purchase a dress. Consumer rental transport is considered the same distance, although each rental requires an additional trip in comparison to purchasing, since users must go back to return the dress. For second-hand distribution, transport is modelled for a dress to move from the first owner, to a second-hand store, to the rental company. It assumed that 3 dresses are transported at a time. The distance is then divided by the total number of rentals in order to get the distance for one rental. This is included just for the PSS scenarios, as it is an extension of the retail distribution for rental garments. Laundry transport is needed in the PSS scenarios, since the washing machines are offsite. 1 laundry transport trip (from store to laundry location and
SL 1.2: (20 km* 1 trip to the store) /1 use= **20 km for consumer purchasing transport**	SPSS 1.2: (30 km/ 3 dresses)= 10 km/1 dress= 10 km/(2 rentals*1 dress)= 5 km/rental=**5 km for second-hand distribution** 20 km* 2 trips to rental company =**40 km for consumer rental transport** (15 km/ 2 wash cycles)*1.2 wash cycles = 9 km (9 km/1.2 wash cycle)*(1 wash cycle/2 dresses)= **3.75 km for laundry transport**	
SL 1.3: (20 km* 1 trip to the store) /11 uses=**1.82 km for consumer purchasing transport**	SPSS 1.3: (30 km/ 3 dresses)= 10 km/1 dress= 10 km/(20 rentals*1 dress)= 0.5 km/rental=**0.5 km for second-hand distribution** 20 km* 2 trips to rental company =**40 km for consumer rental transport**	

	(15 km/ 2 wash cycles)*1.2 wash cycles = 9 km (9 km/1.2 wash cycle)*(1 wash cycle/2 dresses)= **3.75 km for laundry transport**	back) is assumed to be 15 km. The distance is calculated by the average distance of the two offsite laundry locations. It is assumed that 2 wash cycles are done for every trip, and that 1 wash cycle includes 2 dresses for each trip. 1.2 wash cycles are required for every rental dress use (see Table 0-6).
FU: **4 years of consumer formal dress needs satisfied by purchasing**		
SL 2: 20 km * 6 trips to the store =**120 km for consumer purchasing transport**	SPSS 2.1: 20 km * 4 trips to the store=**80 km for consumer purchasing transport** (30 km/ 3 dresses)= 10 km/1 dress= 10 km/(11 rentals*1 dress)= 0.91 km/rental (0.91 km/rental)*2 rentals = **1.82 km for second-hand distribution** 20 km* 4 trips to rental company= **80 km for consumer rental transport** (3.75 km/dress)*2 dresses **= 7.5 km for laundry transport**	Consumer purchasing transport includes the distance for a consumer to go to the store and back home to purchase a dress. Consumer rental transport is considered the same distance, although each rental requires an additional trip in comparison to purchasing, since users must go back to return the dress. In the PSS scenarios, SPSS 2.1 and SPSS 2.2 both have purchasing and rental transport, since rental replaces purchasing by 33% and 50% in these scenarios. For second-hand distribution, transport is modelled for a dress to move from the first owner, to a second-hand store, to the rental company. It assumed that 3 dresses are transported at a time. The distance is then divided by the total number of rentals(users) in order to get the distance for one rental. This distance is then multiplied by the number of consumer rentals for the scenario. This is included just for the PSS scenarios, as it is an extension of the retail distribution for rental garments. Laundry transport is needed in the PSS scenarios, since the washing machines are offsite. Laundry transport is needed in the PSS scenarios, since the washing machines are off-site. 1 laundry transport trip (from store to laundry location and back) is assumed to be 15 km. It is assumed that 2 wash cycles are done for every trip, and that 1 wash cycle includes 2 dresses. 1.2 wash cycles are required for
	SPSS 2.2: 20 km * 3 trips to the store=**60 km for consumer purchasing transport** 0.91 km/rental*3 rentals= **2.73 km for second-hand distribution** 20 km* 6 trips to rental company= **120 km for consumer rental transport** (3.75 km/dress)*3 dresses=**11.25 km for laundry transport**	
	SPSS 2.3: (0.91 km/rental) * 6 rentals = **5.45 km for second-hand distribution** 20 km* 12 trips to rental company= **240 km for consumer rental transport** 3.75 km*6 dresses= **22.5 km for laundry transport**	

		every rental dress use (see Table 0-6). Based on this, 3.75 km are travelled for laundry transport per dress.
FU: **4 years of consumer formal dress needs satisfied by use**		
SL 3: 20 km* 5.13 trips to the store= **102.6 km for consumer purchasing transport**	SPSS 3.1: 20 km * 3.43 trips to the store= **68.6 for consumer purchasing transport** (30 km/ 3 dresses)= 10 km/1 dress= 10 km/(11 rentals*1 dress)= 0.91 km/rental * 5.28 rentals = **4.8 km for second-hand distribution** 20 km* (5.28*2) trips to rental company= **211.2 km for consumer rental transport** 3.75 km*5.28 dresses= **18 km for laundry transport**	Consumer purchasing transport includes the distance for a consumer to go to the store and back home to purchase a dress. Consumer rental transport is considered the same distance, although each rental requires an additional trip in comparison to purchasing, since users must go back to return the dress. In the PSS scenarios, SPSS 3.1 and SPSS 3.2 both have purchasing and rental transport, since rental replaces use of purchased garments by 33% and 50% in these scenarios. For second-hand distribution, transport is modelled for a dress to move from the first owner, to a second-hand store, to the rental company. It assumed that 3 dresses are transported at a time. The distance is then divided by the total number of rentals(users) in order to get the distance for one rental. This distance is then multiplied by the number of consumer rentals for the scenario. This is included just for the PSS scenarios, as it is an extension of the retail distribution for rental garments. Laundry transport is needed in the PSS scenarios, since the washing machines are offsite. Laundry transport is needed in the PSS scenarios, since the washing machines are off-site. 1 laundry transport trip (from store to laundry location and back) is assumed to be 15 km. It is assumed that 2 wash cycles are done for every trip, and that 1 wash cycle includes 2 dresses. 1.2 wash cycles are required for every rental dress use (see Table 0-6). Based on this, 3.75 km are travelled for laundry transport per dress.
	SPSS 3.2: 20 km * 2.56 trips to the store= **51.2 for consumer purchasing transport** 0.91 km/rental * 8 rentals = **7.27 km for second-hand distribution** 20 km* 16 trips to rental company= **320 km for consumer rental transport** 3.75 km*8 dresses**= 30 km for laundry transport**	
	SPSS 3.3: 0.91 km/rental * 16 rentals = **14.55 km for second-hand distribution** 20 km*32 trips to rental company=**640 km for consumer rental transport** 3.75 km*16 dresses**= 60 km for laundry transport**	

Laundry

Table 0-6. Laundry reference flow calculations and justification

<table>
<tr><td colspan="3">FU: One average use of a formal dress</td></tr>
<tr><td>Linear Scenarios</td><td>PSS Scenarios</td><td>Justification</td></tr>
<tr><td>SL 1.1:
1.72 wash and iron cycles/3.12 uses= 0.55 wash and iron cycles for one use</td><td>SPSS 1.1:
1 wash and iron cycle + (1 wash and iron cycle/ 5 uses) = 1.20 wash and iron cycles for one use</td><td rowspan="3">In the linear scenarios, 1.72 wash and iron cycles are assumed for every 3.12 uses (based on survey). This is adjusted to the 1 use.
In the PSS, dresses are washed after every use and additionally every fifth use.</td></tr>
<tr><td>SL 1.2: 0.55 wash and iron cycles</td><td>SPSS 1.2: 1.20 wash and iron cycles</td></tr>
<tr><td>SL 1.3: 0.55 wash and iron cycles</td><td>SPSS 1.3: 1.20 wash and iron cycles</td></tr>
<tr><td colspan="3">FU: 4 years of consumer formal dress needs satisfied by purchasing</td></tr>
<tr><td rowspan="3">SL 2: (1.72 wash and iron cycles/3.12 uses)* 11.7 uses = 6.45 wash and iron cycles</td><td>SPSS 2.1:
(1.72 wash and iron cycles/3.12 uses)*7.8 uses with purchased dresses = 4.30 wash and iron cycles for purchased dresses
2 wash and iron cycles + (2 wash and iron cycles/ 5 uses)= 2.40 wash and iron cycles for rental dresses</td><td rowspan="3">In the linear scenario, the ratio of 1.72 wash and iron cycle to 3.12 uses is used and multiplied by the total number of uses/wear occasions of the consumer, based on the number of wear occasions calculated in Table 0-4.
In the PSS, dresses are washed after every use and additionally every fifth use.

Although the same information is used to model laundry cycles for consumers and the company, they are differentiated since the company wash cycles must include transport from the rental location to the laundry location.</td></tr>
<tr><td>SPSS 2.2:
(1.72 wash and iron cycles/3.12 uses)*5.85 uses with purchased dresses = 3.23 wash and iron cycles for purchased dresses
3 wash and iron cycles + (3 wash and iron cycles/ 5 uses)= 3.60 wash and iron cycles for rental dresses</td></tr>
<tr><td>SPSS 2.3: 6 wash and iron cycles + (6 wash and iron cycles/ 5 uses)=7.20 wash and iron cycles</td></tr>
<tr><td colspan="3">FU: 4 years of consumer formal dress needs satisfied by use</td></tr>
<tr><td rowspan="3">SL 3: 2: (1.72 wash and iron cycles/3.12 uses)* 16 uses = 8.82 wash and iron cycles</td><td>SPSS 3.1: (1.72 wash and iron cycles/3.12 uses)*10.72 uses with purchased dresses = 5.91 wash and iron cycles for purchased dresses
5.28 wash and iron cycles + (5.28 wash and iron cycles/ 5 uses)= 6.34 wash and iron cycles for rental dresses</td><td rowspan="3">In the linear scenario, the ratio of 1.72 wash and iron cycle to 3.12 uses is used and multiplied by the total number of uses/wear occasions of the consumer, based on the number of wear occasions calculated in Table 0-4.
In the PSS, dresses are washed after every use and additionally every fifth use.

Although the same information is used to model laundry cycles for consumers and the company, they are differentiated since the company wash cycles must include transport from the rental location to the laundry location.</td></tr>
<tr><td>SPSS 3.2: 1.72 wash and iron cycles/3.12 uses)*8 uses with purchased dresses = 4.41 wash and iron cycles for purchased dresses
8 wash and iron cycles + (8 wash and iron cycles/ 5 uses)= 9.60 wash and iron cycles for rental dresses</td></tr>
<tr><td>SPSS 3.3: 16 wash and iron cycles + (16 wash and iron cycles/ 5 uses)=19.20 wash and iron cycles</td></tr>
</table>

EoL

Table 0-7. Municipal incineration reference flow calculations and justification

FU: **One average use of a formal dress**		
Linear Scenarios	PSS Scenarios	Justification
SL 1.1: 0.477 kg/3.12 uses=**0.15 kg of garments incinerated** (0.03 tkm/1 kg)*0.15 kg=**0.005 tkm to incineration**	SPSS 1.1: 0.477 kg/11 users=**0.04 kg of garments incinerated** (0.03 tkm/1 kg)*0.04 kg= **0.001 tkm to incineration**	One dress with a mass of 0.477 kg is used, which is divided by the number of total uses/users of the garment to calculate the burden for just one use of the dress (the FU) in incineration. This mass is used to calculate the tkm for the garment to travel to a waste treatment facility for incineration.
SL 1.2: 0.477 kg/1 uses=**0.48 kg of garments incinerated** (0.03 tkm/1 kg)*0.48 kg=**0.01 tkm to incineration**	SPSS 1.2: 0.477 kg/1 user=**0.24 kg of garments incinerated** (0.03 tkm/1 kg)*0.24 kg= **0.007 tkm to incineration**	
SL 1.3: 0.477 kg/11 uses=**0.04 kg of garments incinerated** (0.03 tkm/1 kg)*0.04 kg=**0.001 tkm to incineration**	SPSS 1.3: 0.477 kg/20 users=**0.02 kg of garments incinerated** (0.03 tkm/1 kg)*0.02 kg= **0.0007 tkm to incineration**	
FU: **4 years of consumer formal dress needs satisfied by purchasing**		
SL 2: 0.477 kg*6 dresses = **2.86 kg of garments incinerated** (0.03 tkm/1 kg)*2.86 kg = **0.09 tkm to incineration**	SPSS 2.1: (0.477 kg*4 purchased dresses)+((0.477 kg*2 rented dresses)/11 users) = **1.99 kg of garments incinerated** (0.03 tkm/1 kg)*1.99 kg = 0.06 tkm to incineration	The number of dresses consumed (based on Table 0-3) in the four year period is multiplied by the mass of the dress modelled in production. In the PSS scenarios, the mass of the rented dresses are divided by the number of users of the garment to allocate the share of the burden for incineration for the rental dresses. Although it is assumed that dresses are not all purchased or rented at the beginning of the FU (the start of the 4 years), the impact from incineration for all dresses are taken into account.
	SPSS 2.2: (0.477 kg*3 purchased dresses)+((0.477 kg*3 rented dresses)/11 users) = **1.56 kg of garments incinerated** (0.03 tkm/1 kg)*1.56 kg = **0.05 tkm to incineration**	
	SPSS 2.3: (0.477 kg*6 rented dresses)/11 users = **0.26 kg of garments incinerated** (0.03 tkm/1 kg)*0.26 kg = **0.008 tkm to incineration**	
FU: **4 years of consumer formal dress needs satisfied by use**		
SL 3: 2 0.477 kg*5.13 dresses = **2.45 kg of garments incinerated** (0.03 tkm/1 kg)*2.45 kg = **0.07 tkm to incineration**	SPSS 3.1: (0.477 kg*3.43 purchased dresses)+((0.477 kg*5.28 rented dresses)/11 users) = **1.87 kg of garments incinerated** (0.03 tkm/1 kg)*1.87 kg = **0.06 tkm to incineration**	The number of dresses consumed (based on Table 0-3) in the four year period is multiplied by the mass of the dress modelled in production. In the PSS scenarios, the mass of the rented dresses are divided by the number of users of the garment to allocate the
	SPSS 3.2:	

	(0.477 kg*2.56 purchased dresses)+((0.477 kg*8 rented dresses)/11 users) = **1.57 kg of garments incinerated** (0.03 tkm/1 kg)*1.57 kg = **0.05 tkm to incineration**	share of the burden for incineration for the rental dresses. Although it is assumed that dresses are not all purchased or rented at the beginning of the FU (the start of the 4 years), the impact from incineration for all dresses are taken into account.
	SPSS 3.3: (0.477 kg*16 rented dresses)/11 users = **0.69 kg of garments incinerated** (0.03 tkm/1 kg)*0.69 kg = **0.02 tkm to incineration**	

Appendix D: LCI processes from Ecoinvent database

Table D1: Production (based on production for mass of a 477 g dress)
The entirety of data from this table is based off of the studies by Roos et al. (2015) and Sandin et al. (2019).

Material/ Ecoinvent Process (Allocation, cut-off)	**Amount**	**Unit**
PES fibre production		
Materials		
Polyethylene terephthalate, granulate, amorphous (RER); transformation	0.5934	kg
Lubricating oil (RER); market	0.005934	kg
Toluene diisocynate (RoW); market	0.00011868	kg
Antimony (GLO); market	0.00011868	kg
Energy		
Electricity medium voltage (CN); market	0.8901	kWh
Heat, central or small-scale, other than natural gas (ROW) light fuel oil, at boiler 100kW, non-modulating; transformation	1.30548	MJ
Emissions to air		
Terepthalate, dimethyl	0.00005934	kg
Output		
PES fibres (to PES yarn spinning process)	0.5934	kg
PES yarn spinning		
Material		
Lubricating oil (RER); market	0.0009448	kg
PES fibres (from PES fibre production)	0.5934525	kg
Energy		
Production electricity mix (See Table D1.1)	2.2439	kWh
Waste		
Waste textile, solid (ROW); market	0.0029525	kg
Output		
PES yarn (to polyester knitting process and polyester weaing process)	0.5905	kg
Polyester knitting		
Material		
PES yarn (from PES yarn spinning)	0.13695048	kg
Lubricating oil (RER); market	0.01349	kg
Electricity		
Production electricity mix (See Table D1.1)	0.044517	kWh
Waste		

Waste textile, soiled (RoW), treatment of municipal incineration; market	0.00205048	kg
Output		
Knit polyester tricot (to Wet-treatment, dyeing process)	0.1349	kg
Polyester weaving		
Material		
PES yarn (from PES yarn spinning)	0.1555	kg
Acrylic acid; market	0.007675	kg
Electricity/heat		
Production electricity mix (See Table C1.1)	1.27405	kWh
Waste/emissions		
Air emissions from acylic acid	0.007675	kg
Water emissions from acrylic acid	0.007675	kg
Waste textile, soiled (RoW), treatment of municipal incineration	0.002	kg
Output		
Polyester weave (to Wet-treatment, pre-treatment process)	0.1535	kg
Wet-treatment, Dyeing		
Resources		
Water, river	0.02231	m3
Knit polyester tricot (from polyester knitting)	0.286	kg
Material/fuels		
Ammonium sulfate, as N (GLO); market	0.00286	kg
Aniline (RoW); market	0.0143	kg
Production detergent, see Table D1.2	0.02145	kg
Acrylic acid (RoW) ; market	0.00572	kg
Ethylene glycol monoethyl ether (RoW); market	0.00429	kg
Formic acid (RoW); market	0.00429	kg
Hydrogen peroxide, without water, in 50% solution state (RoW); market	0.00429	kg
Reducing agent, see Table D1.3	0.00143	kg
Phosphoric acid, industrial grade, without water, in 85% solution state (GLO); market	0.00572	kg
Soda ash, dense (GLO); market	0.006435	kg
Sodium hydroxide, without water, in 50% solution state (GLO); market	0.00143	kg
Production softener, see Table D1.4	0.0572	kg
Wetting, penetrating agent for synthetics, see Table D1.5	0.00286	kg
Energy		

Production electricity mix (See Table D1.1)	0.2002	kWh
Heat, central or small-scale, other than natural gas, light fuel oil, at boiler 100kW, non-modulating; transformation	8.58	MJ
Emissions to air		
Remazol black B	0.0004719	kg
Acetic acid	0.000000286	kg
Emissions to water		
Isobutyl acrylate	0.0000053625	kg
Formaldehyde	11/08/2020 13:40:000.0000000446875	kg
Alcohol ethoxylate	0.0000182325	kg
Glyphosate	0.00001287	kg
Sodium	0.0000572	kg
Carbonate	0.00002145	kg
Diethylene glycol	0.00001287	kg
Ammonium ion	0.00000715	kg
Sulfate	0.00000715	kg
Alkylbenzenesulfonic acid, sodium salt c10-c13	0.00002574	kg
Remazol black B	0.0000715	kg
Acetic acid	0.00000858	kg
Sodium hydroxide	0.0000715	kg
Sulfite	0.00003575	kg
Fatty acids as C	0.000160875	kg
N,n' - dimethylacetamide	0.000160875	kg
Waste to treatment		
Sludge from pulp and paper production (CH) treatment of, sanitary landfill; transformation	0.143	kg
Output		
Dyed PES tricot (to Wet-treatment, drying for PES tricot)	0.286	kg
Wet-treatment, Pre-treatment		
Resources		
Water, river	0.017904	m3
Material/fuels		
Polyester weave (from polyester weaving)	0.2984	kg
Acrylic acid (RoW); market	0.01492	kg
Lubricant, see Table D1.6	0.001492	kg
Phosphoric acid, industrial grade, without water, in 85% solution state (GLO); market	0.001492	kg

Electricity/heat		
Production electricity mix (See Table D1.1)	0.2089	kWh
Heat, central or small-scale, other than natural gas (RoW), heat production, light fuel oil, at boiler 100kW, non-modulating (CH); transformation	8.952	MJ
Emissions to water		
Isobutyl acrylate	0.000005595	kg
Alcohol ethoxylate	0.000003357	kg
Glyphosphate	0.000013428	kg
COD, Chemical Oxygen Demand	0.00005968	kg
Formaldehyde	0.000000046625	kg
Waste to treatment		
Sludge from pulp and paper production (CH) treatment of, sanitary landfill; transformation	0.1492	kg
Output		
Pre-treated polyester weave (to Wet-treatment dispersed printing process)	0.2984	kg
Wet-treatment, Dispersed printing		
Resources		
Water, river	0.000080568	m3
Materials		
Pre-treated polyester weave (from Wet-treatment, pre-treatment)	0.2984	kg
1-propanol (GLO); market	0.031332	kg
Acrylic dispersion, without water, in 65% solution state (RoW) without water in 65% solution state; market	0.008952	kg
Aniline (RoW); market	0.04924	kg
Acrylic acid (RoW); market	0.002984	kg
Formic acid (RoW); market	0.001492	kg
Reducing agent, see Table D1.3	0.002984	kg
Sodium hydroxide, without water, in 50% solution state (GLO); market	0.002984	kg
Production softener, see Table D1.4	0.04476	kg
Electricity/heat		
Production electricity mix (See Table D1.1)	0.0334208	kWh
Heat, central or small-scale, other than natural as, light fuel oil, at boiler 100kW, non-modulating; transformation	0.567	MJ
Emissions to air		
CI Remazol black B	0.00049236	kg
Acetic acid	0.0000001492	kg
Emissions to water		

Isobutyl acrylate	0.00016785	kg
CI Remazol black B	0.000049236	kg
Formaldehyde	0.000000046625	kg
Alcohol ethoxylate	0.000002238	kg
Sodium	0.00001492	kg
Sulfite	0.00001492	kg
Sodium hydroxide	0.00002984	kg
Acetic acid	0.000004476	kg
Fatty acids as C	0.00003357	kg
N,n'-dimethylacetamide	0.00003357	kg
Waste to treatment		
Sludge from pulp and paper production (CH) treatment of, sanitary landfill; transformation	0.1492	kg
Output		
Dispersed printed PES weave (to Wet-treatment, drying for dispersed printed PES weave)	0.2984	kg
Wet-treatment, drying for dyed PES tricot		
Dyed polyester tricot (from Wet-treatment, dyeing)	0.286	kg
Production electricity mix (See Table D1.1)	0.2288	kWh
Heat, central or small-scale, other than natural gas (RoW) light fuel oil, at boiler 100kW, non-modulating; transformation	2.288	MJ
Output		
Dried polyester tricot (to dress assembly)	0.286	kg
Wet-treatment, drying for dispersed printed PES weave		
Dispersed printed PES weave (to Wet-treatment, drying for dispersed printed PES weave)	0.2984	kg
Production electricity mix (See Table D1.1)	0.2387	kWh
Heat, central or small-scale, other than natural gas (RoW) light fuel oil, at boiler 100kW, non-modulating; transformation	2.387	MJ
Output		
Dried polyester weave (to dress assembly)	0.2984	kg
Dress assembly		
Tap water (RER); market	0.169812	kg
Dried polyester tricot (from wet-treatment)	0.286	kg
Dried polyester weave (from wet-treatment)	0.2984	kg
Cotton fibre (GLO); market	0.00167	kg
Electricity/heat		
Production electricity mix (See Table D1.1)	2.46132	kWh
Heat, central or small-scale, natural gas (GLO); market	0.060102	MJ

Waste		
Waste textile, soiled (CH) municipal incineration; transformation	0.10907	kg
Output		
Assembled dress (to retail distribution process, Table D2)	0.477	kg

Table D1.1 Production electricity mix (China, Bangladesh, Turkey, India, Pakistan, Vietnam, Cambodia) As this table also corresponds with the table regarding production, the entirety of data from this table is based off of the studies by Roos et al. (2015) and Sandin et al. (2019).	
Material/ Ecoinvent Process (Allocation, cut-off)	Share of electricity mix
Electricity, medium voltage (CN); market	55.8%
Electricity, medium voltage (BD); market	17.8%
Electricity, medium voltage (TR); market	12.6%
Electricity, medium voltage (PK); market	3%
Electricity, medium voltage (VN); market	2.6%
Electricity, medium voltage (KH); market	2.1%
Electricity, medium voltage (IN); market	6.10%

Table D1.2 Production detergent (used in Wet-treatment, dyeing process) As this table also corresponds with the table regarding production, the entirety of data from this table is based off of the studies by Roos et al. (2015) and Sandin et al. (2019).		
Material/ Ecoinvent Process (Allocation, cut-off)	Amount	Unit
Acrylic acid (RoW); market	0.1	kg
Dimethyl sulfate (RoW); market	0.005	kg
Ethoxylated alcohol (AE3);market	0.1	kg
Walter, ultrapure (GLO); market	0.5	kg
Output		
Production detergent	1	kg

Table D1.3 Reducing Agent (used in Wet-treatment, dyeing process and Wet treatment, dispersed printing process) As this table also corresponds with the table regarding production, the entirety of data from this table is based off of the studies by Roos et al. (2015) and Sandin et al. (2019).		
Material/ Ecoinvent Process (Allocation, cut-off)	Amount	Unit
Calcium carbonate, precipitated (RoW); market	0.02	kg
Sodium dithionite, anhydrous (RoW); market	0.9	kg
Sodium sulfite (RoW); market	0.08	kg
Output		
Reducing agent	1	kg

Table D1.4 Production softener (used in Wet-treatment, dyeing process and Wet treatment, dispersed printing process) As this table also corresponds with the table regarding production, the entirety of data from this table is based off of the studies by Roos et al. (2015) and Sandin et al. (2019).

Material/ Ecoinvent Process (Allocation, cut-off)	Amount	Unit
Diethanolamine (GLO); market	0.03	kg
Stearic acid (GLO); market	0.2	kg
Water, ultrapure (GLO); market	0.77	kg
Output		
Production softener	1	kg

Table D1.5 Wetting, penetrating agent for synthetics (used in Wet-treatment, dyeing process) As this table also corresponds with the table regarding production, the entirety of data from this table is based off of the studies by Roos et al. (2015) and Sandin et al. (2019).		
Material/ Ecoinvent Process (Allocation, cut-off)	Amount	Unit
Fatty alcohol (GLO); market	0.5	kg
Maleic anhydride (GLO); market	0.15	kg
Water, ultrapure (GLO); market	0.35	kg
Output		
Wetting, penetrating agent	1	kg

Table D1.6 Lubricant (used in Wet-treatment, pre-treatment process) As this table also corresponds with the table regarding production, the entirety of data from this table is based off of the studies by Roos et al. (2015) and Sandin et al. (2019).		
Material/ Ecoinvent Process (Allocation, cut-off)	Amount	Unit
Acrylic acid (RoW);market	0.1	kg
Polyacrylamide (GLO); market	0.2	kg
Water, ultrapure (GLO); market	0.7	kg
Output		
Wetting, penetrating agent	1	kg

Table D2: Distribution and retail The entirety of data from this table is based off of the studies by Roos et al. (2015) and Sandin et al. (2019).		
PES fibre production		
Material/ Ecoinvent Process (Allocation, cut-off)	Amount	Unit
Materials		
Assembled dress	0.477	kg
Transport, freight, sea, transoceanic ship (GLO); market	9.0058	tkm
Transport, freight, lorry 16-32 metric ton, euro 6 (RER); market	1.3595	tkm
Transport, freight, lorry 3.5-7.5 metric tone, euro 6 (RER); market	0.1526	tkm

Table D3: Transport Processes
Transport

Material/ Ecoinvent Process (Allocation, cut-off)	Amount
Materials	
Average transport by metro and bus	
1. Transport, tram (SE)	The primary transport mode (1) was assumed to be used for 75% of the distance travelled per trip, and the secondary transport mode (2) for 25% of the distance travelled. Distances can be found in Table 4-7. Transportation reference flows for all scenariosand Table 0-5.
2.Transport, regular bus (CH)	
Transport scenario 2	
1.Transport, tram (SE)	The primary transport mode (1) was assumed to be used for 75% of the distance travelled per trip, and the secondary transport mode (2) for 25% of the distance travelled. Distances can be found in Table 4-7 and Table 0-5.
2.Walking (nothing modelled)	
Transport scenario 3	
1.Transport, passenger, bicycle (GLO)	The primary transport mode (1) was assumed to be used for 75% of the distance travelled per trip, and the secondary transport mode (2) for 25% of the distance travelled. Distances can be found in Table 4-7 and Table 0-5.
2.Transport, tram (SE)	
Transport scenario 4	
1.Transport, passenger car, Euro 4 and 5 mix	The primary transport mode (1) was assumed to be used for 75% of the distance travelled per trip, and the secondary transport mode (2) for 25% of the distance travelled. Distances can be found in in Table 4-7 and Table 0-5.
2.Transport, tram (SE) electricity mix	
Comments	
The dataset "Transport, tram" from the Ecoinvent database was used as a proxy for the metro, with the electricity source modified to the Swedish electricity mix. Although most Stockholm metro trains supply energy back to the grid when breaking (SL, personal communication, April 23, 2020), this was not accounted for. "Transport, regular bus (CH)" was used as a proxy for the Swedish bus that uses diesel fuel. This is because of the lack of data available in the database to create the unique Stockholm fuel blend for buses (51% on biodiesel from canola plants and 13% from hydro-treated vegetable oil (HVO), and 21% from Ethanol (ED95) (SL, personal communication, April 23, 2020). A dataset for car transport was created through a mix of Euro 4 and Euro 5 emission standards for passenger cars. This datasets used in the mix were taken from Ecoinvent and incorporated a mix of vehicle sizes and fuel type. This was determined based on a report from Sjödin et al. (2018) stating that Euro 5 emission vehicles were the most abundant among diesel cars in Spain, Sweden, Switzerland, and the UK between 2011 and 2017. Euro 5 cars made up 39% of diesel passenger car set among these countries, with Euro 4 cars as 33% of diesel passenger cars just in Sweden (p. 7). The petrol passenger cars most commonly had Euro 4 emission standards, therefore a dataset was created using the mixed datasets of Euro 4 and Euro 5 emissions standards for passenger cars.	

Table D4: Laundry **One wash cycle and ironing session per garment is assumed to be the same for laundry in the linear and the PSS model, since the case company utilizes residential washing machines.** Data is based off of Roos et al. (2015) , Beton et al. (2014), Granello et al. (2015), Presutto et al. (2007), Pakula and Stamminger (2015), Sandin et al. (2019), as well data received and calculated from the consumer survey and data questionnaires to the case company.		
One wash cycle		
Material/ Ecoinvent Process (Allocation, cut-off)	Amount	Unit

One wash cycle/laundry load		
Tap water (RER); market	13.6	kg
Detergent (see Table D4.1)	41.1	g
Electricity, low voltage (SE); market	0.13	kWh
Waste		
Wastewater, from residence (RoW)	13.6	l
Ironing for one dress		
Electricity, low voltage (SE); market	0.27	kWh
Comment		
One wash cycle is assumed to be a 1 kg load at 30 ºC. Beton et al. (2014) assume that an average washing temperature of 32.9 ºC results in 0.13 kwH/kg. Detergent use is calculated as 41.1 g per kg of load washed, according to Beton et al. (2014). It is also assumed that 46.3 liters of water are consumed for an average laundry load of 3.4 kg (Beton et al., 2014; Presutto et al., 2007), and that most washing machines have sensors to distribute the proper amount of water per load, as well as electricity need since 2005 (Presutto et al., 2007). However, considering an average load is about 3.4 kg/cycle with most washing machine capabilities at 6 kg (Beton et al., 2014), the amount of water is adjusted for the average load despite the likelihood of a much smaller load of 1 kg. This is justified due to the lack of certainty whether there is a minimum load and water input for a wash cycle. Ironing is modelled assuming 10 minutes of ironing for a 477 g dress.		

Table D4.1 Detergent (used in laundry)
The entirety of data from this table is based off of the studies by Roos et al. (2015) and Beton et al. (2014). Note that the quantities for each material in detergent is to produce 0.887 kg of detergent, but 41.1 g of detergent is used per laundry cycle of 1 kg.

Material/ Ecoinvent Process (Allocation, cut-off)	Amount	Unit
Ethoxylated alcohol production (AE11), palm oil (RER); transformation	0.02	kg
Ethoxylated alcohol production, petrochemical (AE7) (RoW); transformation	0.04	kg
LAS-pc (alkylbenzene sulfonate, linear, petrochemical) (RER); transformation	0.078	kg
Acetic acid, without water, in 98% solution state (RER); transformation	0.052	kg
Layered sodium silicate, SKS-6, powder (RER); transformation	0.03	kg
Zeolite, powder (RER)	0.201	kg
Sodium percarbonate, powder (RER); transformation	0.170	kg
Sodium perborate, monohydrate, powder (RER); transformation	0.087	kg
Sodium perborate, tetrahydrate, powder (RER); transformation	0.115	kg
Antifoam S1.2-3522 (not found in database and not modelled)	0.5%	
FWA DAS-1 (not found in database and not modelled)	0.2%	
Polyacrylate (not found in database and not modelled)	4%	
Protease (not found in database and not modelled)	1.4%	
Sodium persulfate (GLO); transformation	0.004	kg

Water, ultrapure (RoW); transformation	0.142	kg
Emissions		
Carbon dioxide	0.12	kg
Carbon monoxide	0.000053	kg
Sulfur oxides	0.00062	
Nitrogen oxides	0.00029	
Hydrocarbons	0.00097	
BOD	0.000043	
COD	0.000090	
Output		
Detergent (for consumer and company laundry)	0.887	kg

Table D5: End of Life		
Municipal incineration		
Material/ Ecoinvent Process (Allocation, cut-off)	Amount	Unit
Transport, freight, lorry 3.5-7.5 metric tons, euro5 (RER); market	0.0143	tkm
Waste polyethylene (CH), treatment of, municipal incineration	0.477	kg

Appendix E: Supplementary results

LCIA Midpoint category abbreviations

Table 1-1. LCIA midpoint categories from ReCiPe method

Impact category	Abbreviation	Unit
Global warming	GWP	kg CO2 eq
Stratospheric ozone depletion	ODP	kg CFC11 eq
Ionizing radiation	IRP	kBq Co-60 eq
Ozone formation, Human health	HOFP	kg NOx eq
Fine particulate matter formation	PMFP	kg PM2.5 eq
Ozone formation, Terrestrial ecosystems	EOFP	kg NOx eq
Terrestrial acidification	TAP	kg SO2 eq
Freshwater eutrophication	FEP	kg P eq
Marine eutrophication	MEP	kg N eq
Terrestrial ecotoxicity	TETP	kg 1,4-DCB
Freshwater ecotoxicity	FETP	kg 1,4-DCB
Marine ecotoxicity	METP	kg 1,4-DCB
Human carcinogenic toxicity	HTPc	kg 1,4-DCB
Human non-carcinogenic toxicity	HTPnc	kg 1,4-DCB
Land use	LOP	m2a crop eq
Mineral resource scarcity	SOP	kg Cu eq
Fossil resource scarcity	FFP	kg oil eq
Water consumption	WCP	m3

Normalised results for "4 years of consumer needs" FUs

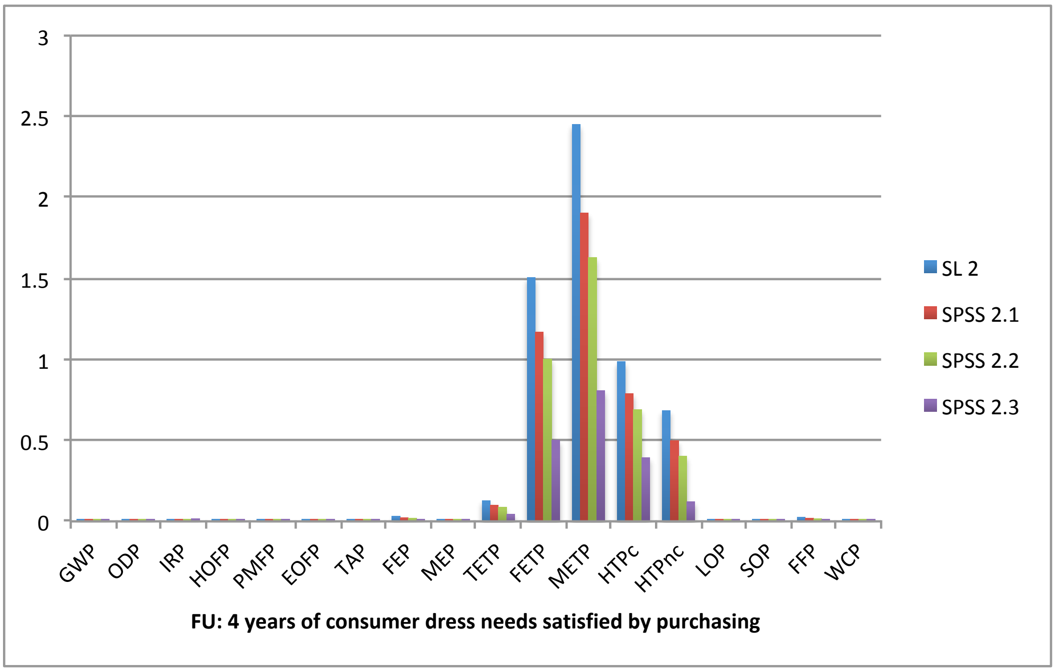

Figure 0-1. Normalised results for 4 years of consumer dress needs satisfied by purchasing

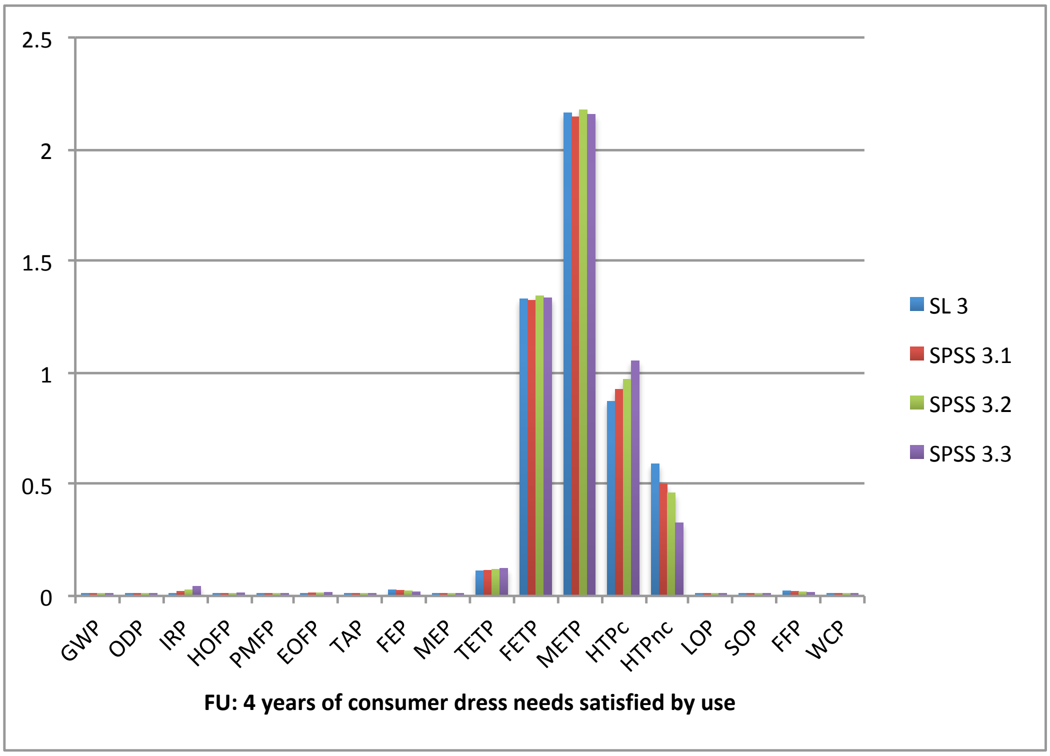

Figure 0-2. Normalised results for 4 years of consumer dress needs satisfied by use

Characterisation results for "one average use" FU

Table 1-2. Characterisation results for "one average use" scenarios

Impact category	Unit	SL 1.1	SPSS 1.1	SL 1.2	SPSS 1.2	SL 13	SPSS 1.3
GWP	kg CO2 eq	5.405473309	3.31651138	16.69362366	9.043935919	1.591035694	2.652500869
ODP	kg CFC11 eq	3.10881E-06	1.93084E-06	9.55528E-06	5.20653E-06	9.30449E-07	1.55154E-06
IRP	kBq Co-60 eq	0.337005214	1.309392514	0.886177523	0.933813655	0.151431539	1.286454399
HOFP	kg NOx eq	0.012516267	0.01844684	0.03863585	0.024664433	0.003690062	0.017012261
PMFP	kg PM2.5 eq	0.008042251	0.005657466	0.02479186	0.013703392	0.002382303	0.004678727
EOFP	kg NOx eq	0.012855396	0.019300021	0.039682616	0.025450236	0.003790071	0.017829932
TAP	kg SO2 eq	0.016109417	0.012943204	0.049528565	0.028003481	0.004816579	0.01100478
FEP	kg P eq	0.001152187	0.000769402	0.003494002	0.001946226	0.000360852	0.000631788
MEP	kg N eq	0.001007428	0.000421686	0.003039349	0.001616464	0.000320811	0.00029979
TETP	kg 1,4-DCB	7.317413151	7.960590314	22.03269483	13.41004874	2.344895612	7.123904463
FETP	kg 1,4-DCB	0.102067664	0.102380384	0.299508674	0.183919008	0.035349345	0.091032087
METP	kg 1,4-DCB	0.13948347	0.139042584	0.410664152	0.251064341	0.047847395	0.123455559
HTPc	kg 1,4-DCB	0.150908785	0.182411046	0.442736958	0.282398428	0.052295609	0.165931704
HTPnc	kg 1,4-DCB	5.501899435	3.060877706	16.91524193	9.088584671	1.645157493	2.385993917
LOP	m2a crop eq	0.077181227	0.148612334	0.223789949	0.163317321	0.027639911	0.140845346
SOP	kg Cu eq	0.006674706	0.013528626	0.01884659	0.014332212	0.002561642	0.012889599
FFP	kg oil eq	1.434878715	0.943693255	4.426764835	2.422870438	0.423874908	0.768266514
WCP	m3	0.042251437	0.046523195	0.124061782	0.077515247	0.014606478	0.041860784

Table 1-3. Characterisation results for "one average use" scenarios with transportation variation

Impact category	Unit	SPSS 1.1 T2	SPSS 1.1 T3	SPSS 1.1 T4	SPSS 1.2 T2	SPSS 1.2 T3	SPSS 1.2 T4	SPSS 1.3 T2	SPSS 1.3 T3	SPSS 1.3 T4
GWP	kg CO2 eq	2.323347983	2.303186913	11.61848751	8.964666117	8.944505065	18.2598057	1.659337478	1.639176409	10.95447702
ODP	kg CFC11 eq	1.55496E-06	1.33132E-06	5.87438E-06	5.34868E-06	5.12503E-06	9.6681E-06	1.17566E-06	9.52016E-07	5.49508E-06
IRP	kBq Co-60 eq	1.275398443	0.650124792	0.874808413	1.504562787	0.879289128	1.103972746	1.252460363	0.627186702	0.851870317
HOFP	kg NOx eq	0.008256702	0.006902448	0.028302486	0.022602303	0.021248049	0.042648087	0.006822123	0.005467868	0.026867906
PMFP	kg PM2.5 eq	0.003802144	0.003781426	0.01434234	0.013591136	0.013570418	0.024131332	0.002823405	0.002802687	0.013363601
EOFP	kg NOx eq	0.008976251	0.007272774	0.02966271	0.023676841	0.021973364	0.0443633	0.007506162	0.005802685	0.028192621
TAP	kg SO2 eq	0.008168103	0.007880963	0.031832709	0.02755512	0.02726798	0.051219726	0.006229679	0.005942539	0.029894285
FEP	kg P eq	0.000722252	0.000657931	0.002541057	0.00209864	0.002034319	0.003917445	0.000584638	0.000520317	0.002403443
MEP	kg N eq	0.000415394	0.000405558	0.000528758	0.001634638	0.001624801	0.001748001	0.000293499	0.000283662	0.000406862
TETP	kg 1,4-DCB	6.412358766	5.253862242	44.92355057	14.77999266	13.62149611	53.29118463	5.57567296	4.417176405	44.08686475
FETP	kg 1,4-DCB	0.092073731	0.125845734	0.787137428	0.205570134	0.239342137	0.900633834	0.080725435	0.114497438	0.775789132
METP	kg 1,4-DCB	0.124665686	0.169117178	1.019754351	0.280554423	0.325005916	1.175643094	0.109078662	0.153530154	1.004167328
HTPc	kg 1,4-DCB	0.166907561	0.163826388	0.578282926	0.331712165	0.328630993	0.743087531	0.150428219	0.147347046	0.561803585
HTPnc	kg 1,4-DCB	2.884425331	3.626902647	11.29206863	9.634591844	10.37706916	18.04223518	2.209541551	2.95201886	10.61718485
LOP	m2a crop eq	0.11870956	0.083299176	0.291136873	0.196370072	0.160959688	0.368797385	0.110942573	0.075532189	0.283369886
SOP	kg Cu eq	0.012192472	0.012069832	0.060878328	0.018581794	0.018459154	0.06726765	0.011553445	0.011430806	0.060239302
FFP	kg oil eq	0.606911656	0.612349883	3.629980003	2.361484344	2.36692257	5.384552698	0.431484917	0.436923144	3.454553269
WCP	m3	0.043703874	0.031057828	0.065806681	0.090332334	0.077686288	0.11243514	0.039041464	0.026395418	0.06114427

Characterisation results for "4 years of dress needs satisfied by purchasing" FU

Table 1-4. Characterisation results for "4 years of dress needs by purchasing" scenarios

Impact category	Unit	SL 2	SPSS 2.1	SPSS 2.2	SPSS 2.3
GWP	kg CO2 eq	100.6230864	73.71823129	60.26583561	19.89235064
ODP	kg CFC11 eq	5.77196E-05	4.23432E-05	3.4655E-05	1.15812E-05
IRP	kBq Co-60 eq	5.761436118	6.459804403	6.808989302	7.855982267
HOFP	kg NOx eq	0.232931472	0.19218764	0.171815768	0.110664996
PMFP	kg PM2.5 eq	0.149558192	0.111025016	0.091758456	0.033934793
EOFP	kg NOx eq	0.239242522	0.198101506	0.177531044	0.115783631
TAP	kg SO2 eq	0.299142732	0.225323974	0.188414659	0.077639196
FEP	kg P eq	0.021235153	0.015696227	0.012926768	0.004615018
MEP	kg N eq	0.018515301	0.0131875	0.0105236	0.002528918
TETP	kg 1,4-DCB	134.3411195	105.4856059	91.05812061	47.75466583
FETP	kg 1,4-DCB	1.84798565	1.436803586	1.231213307	0.614163523
METP	kg 1,4-DCB	2.529927852	1.9647756	1.682200648	0.834092375
HTPc	kg 1,4-DCB	2.731974579	2.186213103	1.913333346	1.094289252
HTPnc	kg 1,4-DCB	102.1658136	74.23552185	60.27040232	18.35849072
LOP	m2a crop eq	1.388490907	1.222917485	1.140131674	0.8915826
SOP	kg Cu eq	0.118399143	0.105992619	0.099789451	0.081164141
FFP	kg oil eq	26.6952708	19.6850618	16.17996811	5.660376495
WCP	m3	0.76524356	0.603230215	0.522223636	0.279089734

Table 1-5. Characterisation results for "4 years of dress needs by purchasing" scenarios with transport variation

Impact category	Unit	SPSS 2.1 T2	SPSS 2.1 T3	SPSS 2.1 T4	SPSS 2.2 T2	SPSS 2.2 T3	SPSS 2.2 T4	SPSS 2.3 T2	SPSS 2.3 T3	SPSS 2.3 T4
GWP	kg CO2 eq	71.73190422	71.69158231	90.32218337	57.28634525	57.22586214	85.17176419	13.93337026	13.81240385	69.70420742
ODP	kg CFC11 eq	4.15914E-05	4.11442E-05	5.02303E-05	3.35274E-05	3.28565E-05	4.64857E-05	9.32595E-06	7.98407E-06	3.52425E-05
IRP	kBq Co-60 eq	6.391816353	5.14126904	5.59063628	6.707007132	4.831186166	5.505236957	7.652017842	3.900375934	5.248477661
HOFP	kg NOx eq	0.171807363	0.169098855	0.21189893	0.141245353	0.137182591	0.201382704	0.049524168	0.041398642	0.169798868
PMFP	kg PM2.5 eq	0.107314373	0.107272936	0.128394765	0.086192491	0.086130336	0.11781308	0.022802863	0.022678553	0.086044039
EOFP	kg NOx eq	0.177453964	0.174047012	0.218826883	0.146559732	0.141449303	0.208619111	0.053841008	0.043620149	0.177959764
TAP	kg SO2 eq	0.215773771	0.215199493	0.263102984	0.174089355	0.173227936	0.245083175	0.04898859	0.047265751	0.190976226
FEP	kg P eq	0.015601927	0.015473285	0.019239536	0.012785318	0.012592355	0.018241732	0.004332119	0.003946192	0.015244947
MEP	kg N eq	0.013174916	0.013155243	0.013401643	0.010504724	0.010475215	0.010844815	0.002491167	0.002432149	0.003171348
TETP	kg 1,4-DCB	102.3891423	100.0721497	179.4115258	86.41342559	82.9379363	201.9470017	38.46527654	31.5142974	269.5324274
FETP	kg 1,4-DCB	1.416190273	1.483734285	2.806317656	1.200293341	1.301609355	3.285484449	0.552323603	0.754955622	4.722705784
METP	kg 1,4-DCB	1.936021794	2.024924787	3.726199112	1.639069944	1.772424427	4.324335964	0.747830984	1.014539937	6.118362979
HTPc	kg 1,4-DCB	2.155206126	2.149043792	2.977956857	1.866822885	1.857579371	3.100949002	1.001268345	0.982781308	3.469520536
HTPnc	kg 1,4-DCB	73.88261694	75.36757172	90.69790336	59.74104505	61.96847712	84.96397514	17.29977647	21.75464036	67.74563628
LOP	m2a crop eq	1.163111937	1.092291171	1.507966563	1.050423351	0.944192202	1.567705298	0.712165957	0.499703653	1.746729836
SOP	kg Cu eq	0.103320311	0.103075032	0.200692023	0.09578099	0.09541307	0.24183856	0.073147217	0.072411378	0.365262355
FFP	kg oil eq	19.01149847	19.02237505	25.05763515	15.16962324	15.18593796	24.23882832	3.639686903	3.672316261	21.77809698
WCP	m3	0.597591575	0.572299483	0.641797187	0.513765674	0.475827537	0.580074095	0.262173812	0.186297535	0.394790649

Characterisation results for "4 years of dress needs satisfied by use" FU

Table 1-6. Characterisation results for "4 years of dress needs by use" scenarios

Impact category	Unit	SL 3	SPSS 3.1	SPSS 3.2	SPSS 3.3
GWP	kg CO2 eq	86.48811284	75.30306842	69.90525742	53.06539593
ODP	kg CFC11 eq	4.97412E-05	4.34105E-05	4.0426E-05	3.08942E-05
IRP	kBq Co-60 eq	5.392044796	10.39747388	13.29561934	20.9500636
HOFP	kg NOx eq	0.200260521	0.230728167	0.248014929	0.295149252
PMFP	kg PM2.5 eq	0.128676759	0.115801441	0.10982388	0.090521056
EOFP	kg NOx eq	0.205686568	0.238830208	0.257561774	0.308800044
TAP	kg SO2 eq	0.257752046	0.240334232	0.23297312	0.207094039
FEP	kg P eq	0.018435117	0.016348812	0.015448787	0.012310681
MEP	kg N eq	0.01611898	0.01297303	0.011511323	0.006747264
TETP	kg 1,4-DCB	117.0791106	119.853339	122.8251947	127.370227
FETP	kg 1,4-DCB	1.633092173	1.622867182	1.649870082	1.638099599
METP	kg 1,4-DCB	2.231748375	2.213854468	2.246703249	2.224699863
HTPc	kg 1,4-DCB	2.414551818	2.56192935	2.68774078	2.918587937
HTPnc	kg 1,4-DCB	88.03098493	74.96390719	68.69148171	48.97537255
LOP	m2a crop eq	1.234900739	1.598712076	1.819162927	2.377787998
SOP	kg Cu eq	0.106795431	0.141568864	0.163117338	0.216457073
FFP	kg oil eq	22.95819758	20.31857828	19.06633352	15.09939764
WCP	m3	0.676026564	0.69352243	0.716050063	0.744375472

Table 1-7. Characterisation results for "4 years of dress needs by use" scenarios with transport variation

Impact category	Unit	SPSS 3.1 T2	SPSS 3.1 T3	SPSS 3.1 T4	SPSS 3.2 T2	SPSS 3.2 T3	SPSS 3.2 T4	SPSS 3.3 T2	SPSS 3.3 T3	SPSS 3.3 T4
GWP	kg CO2 eq	70.05916559	69.95271521	119.1375023	61.95995016	61.79866167	136.3210663	37.17478159	36.85220447	185.897014
ODP	kg CFC11 eq	4.14258E-05	4.0245E-05	6.42324E-05	3.7419E-05	3.56298E-05	7.19743E-05	2.48801E-05	2.13018E-05	9.39908E-05
IRP	kBq Co-60 eq	10.21798521	6.916540338	8.102869836	13.02366688	8.021477534	9.818946576	20.40615847	10.40178005	13.99671799
HOFP	kg NOx eq	0.176924238	0.169773775	0.282765974	0.166493824	0.15565979	0.326860091	0.132107044	0.110438975	0.452839577
PMFP	kg PM2.5 eq	0.106005343	0.10589595	0.161657578	0.094981307	0.09481556	0.179302876	0.06083591	0.060504416	0.229479048
EOFP	kg NOx eq	0.184320699	0.175326344	0.293545205	0.174971609	0.161343798	0.340463285	0.143619715	0.116364092	0.474603066
TAP	kg SO2 eq	0.215121698	0.2136056	0.340070819	0.194772312	0.192475193	0.38408916	0.130692422	0.126098185	0.509326119
FEP	kg P eq	0.01609986	0.015760245	0.025703149	0.015071588	0.014557019	0.029622025	0.011556283	0.010527145	0.040657158
MEP	kg N eq	0.012939809	0.012887873	0.013538369	0.011460988	0.011382297	0.012367896	0.006646594	0.006489212	0.008460411
TETP	kg 1,4-DCB	111.6786765	105.5618147	315.0177678	110.4393426	101.17137	418.5288748	102.5985222	84.06257784	718.7775912
FETP	kg 1,4-DCB	1.568448054	1.746764234	5.238384361	1.567416864	1.837592882	7.127926403	1.473193148	2.013545198	12.5942123
METP	kg 1,4-DCB	2.137944447	2.372648329	6.864012585	2.131688072	2.487299999	9.292397352	1.994669489	2.705893362	16.31608814
HTPc	kg 1,4-DCB	2.480070958	2.463802369	4.652132892	2.563712908	2.539063527	5.854715791	2.670532183	2.621233419	9.252538027
HTPnc	kg 1,4-DCB	74.03223876	77.95251901	118.4245951	67.27986288	73.21968129	134.5410088	46.15213454	58.0317716	180.6744274
LOP	m2a crop eq	1.440825432	1.253858604	2.351241647	1.579940742	1.296657667	2.959359237	1.899343618	1.332777474	4.658180629
SOP	kg Cu eq	0.134513973	0.133866434	0.391575292	0.152428108	0.151446989	0.541914952	0.195078611	0.193116373	0.974052311
FFP	kg oil eq	18.54037136	18.56908527	34.50217224	16.37208078	16.4155866	40.55662751	9.71089206	9.797903681	58.07998561
WCP	m3	0.678636419	0.611865295	0.795339233	0.693495501	0.592327132	0.87031795	0.699266346	0.496929608	1.052911246