IIIEE Theses 2022:13

Environmental impact assessment of bike trailers

A comparative study of product-oriented and use-oriented product service systems using lifecycle assessment (LCA)

Isha Sen

Supervisors

Steven Kane Curtis

Ana Maria Arbelaez Velez

Thesis for the fulfilment of the
Master of Science in Environmental Management and Policy
Lund, Sweden, May 2022

Published in 2022 by IIIEE, Lund University, P.O. Box 196, 221 00 LUND, Sweden,

Tel: +46 222 00 00.Fax: +46 – 46 222 02 10, e-mail: iiiee@iiiee.lu.se.

ISSN 1401-9191

Acknowledgements

It is surreal to process that a roller coaster EMP journey of two years is coming to an end with this section. I have many people to thank, who made this journey possible and memorable.

Firstly, I want to thank my family- Mumma, Baba, for supporting me from the start to the end of this learning journey. Without their support, I would not have had the privilege to be here or achieved, what I have till now. I want to thank my support systems back home- dadu, dida, Rishabh and Sumaiya for making sure I was doing okay.

I want to extend my gratitude to the professors at IIIEE, who have supported me not just academically, but also morally- thank you Naoko, Bea, Lars, Åke, Håkan, Birgitta, Patricia and every one else I could not possibly mention here, for creating an extensive learning experience in the "insti-bubble". I do not have words enough to thank my supervisors- Steven and Ana, who have been my strongest support in the last 5 months. Thank you, Steven, for being a wonderful human-being, for checking up on me and for providing constructive feedback . Thank you, Ana, for being immensely patient and guiding me in my LCA learning process. I have both of you to thank for, for believing in me and guiding me throughout the process.

Thank you to the case company for giving me this interesting topic to research on and cooperate with all my data collection demands. Thank you, Magnus, for supervising me and giving me valuable insights. Kajsa, Charles, Thor, and everyone in the company for providing me inside perspective and support in my thesis and work. Thank you, Jack, for the professional and moral guidance.

I am thankful to my flatmates, Ines, Domenik, Hannah for taking care of me, especially during thesis, and making food and coffee for me and lending me your room as study space. Thank you for making sure I had the best spirits at home!

The last two years would not have been wonderful without my lovely 30 friends, my batchmates. You have been wonderful, and I am glad to know every one of you. Lastly and most importantly, I want to thank you, Martina and Seby for constantly supporting me and grounding me- for making sure I had a life outside academics – dinner, dancing or Kalmar's nation on tuesdays . Words fail me to describe the place both of you hold in my heart.

Abstract

Linear business models which focus on growth and profitability have been deemed to be destructive to the environment, leading to generation of vast volumes of waste and contributing to environmental impacts. As a solution to this problem, a system wide change in the form of circular economy has been proposed. Circular economy focuses on regeneration of materials, keeping resources in use as long possible, and implementation of new circular business models. However, the lack of evidence on its financial performance and sustainability benefits deters business to make the transition, hence upscaling circular business models has been observed to be slow. This research attempts to fill this gap by estimating the environmental impact of a bike trailer sold by Thule Group in Sweden, using life cycle assessment (LCA) and recommend a suitable circular business model for a bike trailer based on its environmental performance. The thesis aimed to quantify and compare the environmental impacts of three scenarios of Product Service System (PSS), an archetype of circular business model. These scenarios include two product-oriented PSS and one hypothetical use-oriented PSS, leasing, which were developed based on interviews with leasing companies and consultation within the case company. For the purpose of LCA, quantitative and qualitative data was collected from different departments within Thule Group. The results revealed that the leasing scenario performed 28-33% depending on the impact category better than the ownership scenario when the bike trailers are disposed after 6 years of use. However, if the trailers have a second use through sales in the second-hand market for 6 more years, the ownership scenario is preferable where it performs 25-32% better than the leasing scenario across the impact categories. The study provides key recommendations to the manufacturing companies and leasing companies to reduce their environmental impacts within their product and to transition away from linear business models.

Keywords: product-service system, life cycle assessment, bike trailer, circular business model, environmental impact evaluation

Executive Summary

Our natural resources, such as energy, water and raw material are limited. With the global middle class estimated to double in size to nearly 9 billion by 2050, it will drive the material consumption, costs, and price volatility with increasing resource scarcity. Additionally, this is anticipated to generate large volumes of waste streams and emissions contributing to the prevalent environment degradation stemming from unsustainable production. The current linear model of extracting materials for production, use and then dumping them is unsustainable, and has unfortunately dominated the global development pattern. Proposed as an alternative to the current linear economy, circular economy (CE) is deemed to promote a much-needed shift towards sustainable development and defined as "an industrial system that is restorative or regenerative by intention and design".

CE is conceptualised within business through business model innovation to a circular business model (CBM). Many CBMs exist but this thesis research scope down to a CBM archetype, product service systems (PSS) which is defined as a combination of product and service, that attempts to "deliver capability of the product rather than ownership". Although not circular by definition, PSS may support slowing of resource flows and reducing resource consumption and waste generation by integrating product and service offering to varying levels.

However, despite the significance of the transition to circularity, the uptake of CBM, and even PSS, has been observed to be slow, riddled with many institutional and organizational level barriers. Many studies recognize the lack of knowledge around the impacts of the PSS, in terms of environmental benefits due to the new business model. Indeed, as PSS are long term business models, thus, it is important for businesses to assess the impacts of the PSS before reconfiguring their existing business model.

Using the case study of a model of bike trailer offered by Thule Group, an outdoor sporting goods company based in Sweden, the thesis research aimed to recommend a suitable circular business model for bike trailers with improved environmental performance, by comparing the potential environmental impacts of various product-service system scenarios using lifecycle assessment (LCA): (1)the current baseline scenario of sales and provision of spare parts with disposal after 6 years of use ("ownership S1"); (2) baseline scenario of sales and spare parts provision with the product gaining a second life in the secondhand market in Sweden ("ownership S2"); (3) leasing of the product ("leasing scenario"). The first two scenario are categorized under "product-oriented PSS" and the third scenario as "use-oriented PSS".The following research questions (RQs) are formulated to help achieve the aim of the thesis.

RQ1: How do the environmental impacts of a bike trailer compare between the three PSS scenarios?

RQ2: What is the most suitable circular business model for a bike trailer from environmental performance perspective?

Research design methodology

The thesis focused on a single case study of a bike trailer under two product-oriented PSS scenario and one use-oriented PSS scenario for which LCA models were developed and their results were compared.

The qualitative data was collected in the form of meetings within the different departments of case company to understand the current business model, the technical product characteristics,

quality and modularity, spare parts production and the usage pattern of the product. Further, interview with a leasing companoes provided insights to model the hypothetical leasing scenario for the bike trailer. Additionally, quantitative data was collected through reviewing internal documents and meetings with representatives of different departments within Thule Group. This was complemented by secondary data collected through literature review and datasets from the ecoinvent database wherever primary data was unavailable for the purpose of conducting LCA. The data gathered was finally used to model the three PSS scenarios using the SimaPro software. Sensitivity analysis of identified uncertain variables, such as, total number of spare parts, user distance from the leasing hub, total assembly parts needed for refurbishment, total refurbishments in 12 years, lease cycles, and recycling rate of materials in the end of life (EOL) phase were tested.

Findings

RQ1: How do the environmental impacts of a bike trailer compare between the three PSS scenarios?

RQ1 was answered by comparing the LCA results between the three scenarios and outlining the reasons for the high impacts and the consequences on the total impacts were tested for the uncertain variables. The results revealed that the leasing scenario performed 28-33% depending on the impact category better than the ownership scenario when the bike trailers are disposed after 6 years of use. However, if the trailers have a second use through sales in the second-hand market for 6 more years, the ownership scenario is preferable where it performs 25-32% better than the leasing scenario across the impact categories. Moreover, several important parameters were identified at the level of phase, assembly parts and materials which were critical for the environmental performance of the bike trailer. The results showed that the production of bike trailer, particularly the main frame which is composed of nylon 6 with reinforced glass fiber, were the main contributing factors to the environmental impacts of the bike trailer. An important implication of the results is in the selection of material in the production of material, product design and decisions on reducing transportation emissions. Moreover, the results of the sensitivity analysis demonstrated that the increased refurbishing activity, which includes assembly parts production and its transportation from China to Sweden could considerably increase the impacts of the bike trailer under the leasing scenario. The product should hence be designed for durability for prolonging the lifespan of the assembly parts and reduce the need for refurbishing. Additionally, modular design of the product would ensure ease of maintenance, wherein the assembly parts are easily replaceable during refurbishing, foregoing the need for production of bigger assembly parts.

RQ2: What is the most suitable circular business model for a bike trailer from environmental performance perspective?

The author raises a flag of caution in taking the LCA results as a direct interpretation of an "suitable business model from environmental performance perspective." The decision makers should interpret the results in context of the study, meaning that along with the degree of uncertainty modelled in the LCA, the maturity of the market should be considered. For instance, if many bike trailers do not have a second life through second-hand sales, the results of ownership S2 are not valid. In a case where there is no second-hand sale of a bike trailer, the use-oriented PSS is preferable over product-oriented PSS. Ensuring that one bike trailer can provide service for more than 12 years without heavy maintenance needs can significantly decrease environmental impacts compared to ownership. However, as the sensitivity results indicate, increased intensity of maintenance through refurbishing could potentially increase the impacts more than the product-oriented PSS. Thus, caution must be exercised that the product under the use-oriented PSS should be designed for durability and requires the only little maintenance to maintain the functionality and safety characteristic of the product. Parallelly, if the leasing market does not have consumer acceptance, and consumers prefer short term rentals, increased maintenance activities might increase the impacts. These accompanying factors complicate the interpretation of LCA results presented in this thesis in answering RQ2 on "what is the most suitable circular business model for a bike trailer from environmental performance perspective?".

Conclusion and recommendations

The author concludes the thesis with recommendations to the bike trailer manufacturing and leasing companies based on the findings from the LCA and qualitative interviews with leasing companies

- Selection of materials in the production of bike trailer is critical. Reduce impacts from the production phase by using materials with lower environmental impact .
- Select suppliers closer to production and distribution facility to reduce impacts caused from transportation phase.
- Bike trailers should be designed with durability and modularity for ease of maintenance. While durable products reduce the need for maintenance, modular parts are easy to disassemble and repair. Also design modular parts enable disassembly for recycling.
- Design spare parts so that they are compatible with all bike trailer models. Further, designing them to ensure those parts will be used throughout many iterations of the product (for many years) will ensure limited risk of surplus while preparing spare parts inventory at the leasing model. Subsequently, accurate forecasting of the spare parts and preparing spare parts inventory by careful investigation of the repair needs would avoid purchase of spare on demand.
- Partner and collaborate with existing leasing companies for broader outreach.
- Develop leasing contract to include cost incurred by the customer if damaged beyond normal wear and tear to disincentivize need for refurbishment.
- Encourage consumers to lease the product for a longer time period to avoid frequent cleaning or repairing and to get faster payback on the capital cost of the product.
- Plan resource allocation for management of leasing service – customer support, logistics, repair, and cleaning personnel.
- Marketing of a new business model is crucial. Market to promote the new business model with focus on warranty of trust and quality, sustainability, and affordability.
- Develop infrastructure for end-of-life management of the trailers which are beyond repair. These include options for disassembly and remanufacturing or recycling.

The thesis research comprehensively generated knowledge on the environmental benefits of a use-oriented PSS over a product-oriented PSS, and critically reflected on the methodological choices and limitation and highlighted the important topics that could be studied in future to enhance this research.

Table of Contents

List of Figures

List of Tables

Abbreviations

CE- circular economy

BM- business model

CBM- circular business model

PSS – product-service system

CLCA – consequential life cycle assessment

ALCA- attributional 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

RF- reference flow

mPt- milli point

CTUe- Comparative Toxic Unit for ecosystems

PAF- potentially affected fraction of species

CTUh- Comparative Toxic Unit for humans

1 Introduction

1.1 Background

Our natural resources, such as energy, water and raw material are limited. With the global middle class estimated to double in size to nearly 9 billion by 2050, it will drive the material consumption, costs, and price volatility with increasing resource scarcity (EMF, 2013). Additionally, this is anticipated to generate large volumes of waste streams and emissions contributing to the prevalent environment degradation stemming from unsustainable production (EMF, 2013). The dominating "take-make-dispose" model or the linear economy is material and energy-intensive, thus raising concern over the environmental and economic issues arising from this system. The current linear model of extracting materials for production, use and then dumping them is unsustainable, and has unfortunately dominated the global development pattern, causing immense environmental harm (Frosch & Gallopoulos, 1989) and is expected to worsen with increased population growth and demand for goods. In view of this societal issue, a system-level redesign, through the emerging paradigm of circular economy (CE) to slow, narrow, and close the resource flow is presented as a solution (Nußholz, 2017). Proposed as an alternative to the current linear economy, CE is deemed to promote a much-needed shift towards sustainable development (Geissdoerfer et al., 2017). EMF (2015) conceptualizes and defines circular economy as "an industrial system that is restorative or regenerative by intention and design". The discourse around CE has increased in the EU in recent years, especially with the European Commission publishing "Closing the loop- An EU action plan for the Circular Economy" (European Commission, 2015). The European Union Green Deal puts priority to CE through this Circular Economy Action Plan wherein the "increasing product durability, reusability, upgradability, and repairability" are one of the key strategic areas for the promotion of CE (European Commission, 2020). Simultaneously, there has been a huge proliferation of policies at multi governance levels to adopt the CE principles (Urbinati et al., 2020). Additionally, within academia, research on CE has gained traction in the last 6 years, since 2015 (Goyal et al., 2021).

CE further places onus and accountability on the business to be part of the movement to combat climate crisis associated with resource depletion, waste and emissions. The conceptualisation of CE in business is through business model innovation to a circular business model (CBM)(Nußholz, 2017). It demands innovating not just within organizational operation but also throughout the value chain, with regards to the operations and stakeholder involvement (Manninen et al., 2018). From a business model innovation perspective, it is perceived that the transition to a suitable a CBM presents advantages to the businesses. They are in the form of cost and resource savings, competitive advantage through differentiation and creation of new value streams (Masi et al., 2017). Further, increased brand reputation as a "green brand" resulting from potential GHG emission reduction through circularity would be beneficial to the business due to growing sustainability awareness among consumers and stakeholders (Masi et al., 2017). CBMs are of various types or archetypes, including product service system (PSS), which is proposed as a solution to businesses to transition towards circularity and is the focus of this thesis.

1.2 Problem Definition

However, despite the significance of the transition to circularity, the uptake of CBM has been observed to be slow, riddled with many institutional and organizational level barriers (Guldmann & Huulgaard, 2020). Many studies recognize the lack of knowledge around the impacts of the CBM in terms of environmental reduction benefits and economic benefits hindering the transition to a new business model. This applies to the PSS which are indeed long term business models and need to be adequately assessed in terms of risks and benefits for their uptake (Lingegård, 2020). Studies in the same field have identified the need for quantitative studies to empirically examine the different business models and to validate the theories and models of CE (Reim et al., 2015); (Boehm & Thomas, 2013). Thus, in order to mitigate risks, it is crucial to analyze feasibility and benefits, in terms of environmental reductions in this context, to innovate the current business models of the companies (Lingegård, 2020).

CE strategies claim to improve economic and environmental performance of a company; however, they remain largely untested. As a result of this lacuna, lack of knowledge about long-term costs of implementing a CBM to ensure market demand, raises a concern over long term demand and cost structure of the new BM (Linder & Williander, 2017). Further, the environmental benefits of the new CBM are uncertain, which disincentivize businesses from investing (Das et al., 2022). Considering that the effectiveness of a CBM, in terms of environmental and economic performance depends on the context of the business, i.e., the market, size of the company, the sector of operation, it is not straightforward that all CBM contribute to sustainability (Manninen et al., 2018). Thus, it is important for businesses to assess the impacts of the CBM before reconfiguring their existing business model.

Furthermore, the selection of an appropriate PSS depending on the product characteristics (Nußholz, 2017) and the design of PSS itself is vital since it has significant impacts on the environmental performance of the product (Lingegård, 2020). Hence, this underlines the importance of appropriate business model selection and design. How does a business decide which business model is appropriate for them? One of the methods is making a business case of potential environmental benefits of the proposed new business model. Thus, considering the uncertainty around suitable business models, it becomes essential to forecast the potential environmental impacts of the new business model at an early stage, alongside economic assessment, in order to make a business case for investment into the new business model. Although it is clear from reviewing the existing literature on CBMs that it is equally important to conduct both environmental and economic assessment before implementing a CBM, the author decided to conduct only an in-depth environmental impact assessment evaluation in the thesis. However, the author asserts that an economic assessment is also needed, which should be investigated as future research.

Using the case study of a model of bike trailer offered by Thule Group, an outdoor sporting goods company based in Sweden, the thesis research evaluates the potential environmental impacts of a trailer under a use-oriented PSS model compared to product-oriented PSS model and in doing so, considering a total of three PSS scenarios. First, the study considers the existing scenario where the case company sells the product and offers spare parts for its maintenance. The second scenario is where the company sells the product to a user with provision of maintenance, which is then sold to a second family after use. Third, an additional scenario of leasing of the bike trailer is developed. These three scenarios are evaluated, compared and analyzed in terms of their environmental performance and interpreted based on LCA framework. The geographical scope is limited to Sweden.

1.3 Aim and Research Questions

The research objective is to recommend a suitable circular business model for bike trailers with improved environmental performance, by comparing the potential environmental impacts of various product-service system scenarios using lifecycle assessment (LCA): (1)the current baseline scenario of sales and provision of spare parts with disposal after 6 years of use (henceforth, "ownership S1"); (2) baseline scenario of sales and spare parts provision with the product gaining a second life in the secondhand market in Sweden (henceforth, "ownership S2"); (3) leasing of the product (henceforth, "leasing scenario"). Based on the PSS categories which Tukker (2004) formulates, the first two scenario are categorized under "product-oriented PSS" and the third scenario as "use-oriented PSS".

The objective will be achieved in three stages. Firstly, understanding the current business model of Thule Group. Secondly, by interviewing existing leasing companies in Sweden, a hypothetical leasing model for bike trailers offered by Thule will be developed. Lastly, using the LCA framework, the environment impacts of developed models and Thule's current business model will be compared and analyzed. The geographical scope is limited to Sweden.

The following research questions (RQs) are formulated to help achieve the aim of the thesis.

RQ1: How do the environmental impacts of a bike trailer compare between the three PSS scenarios?

RQ2: What is the most suitable circular business model for a bike trailer from environmental performance perspective?

RQ1 is evaluative in nature, whilst RQ2 is descriptive. Supported by an organizational perspective, the thesis will investigate the product, collect data and analysis to measure the environmental impacts of the bike trailer under the three scenarios.

1.4 Scope

The thesis focuses on a single case study of a bike trailer by Thule Group under two product-oriented PSS scenario and one use-oriented PSS scenario for which LCA models were developed and their results were compared. The study is valid for the geographical region of Sweden where the bike trailers are purchased and used. The production of the bike trailer takes place in China and the raw material is sourced in the same region, where the energy mix and transportation are specific to China. The final product is transported to Sweden for use via Netherlands wherein the transportation infrastructure of Europe is relevant.

The LCA compares a specific model of double-seater bike trailer under hypothetical use-oriented PSS (leasing) scenario to the baseline product-oriented PSS (ownership) scenarios. It considers the environmental impacts by prolonging the life of a bike trailer through repairing and intensifying the usage by leasing it multiple times in the leasing scenario. The spare parts demand and production is specific to the model of the bike trailer and so is the useful life as it can potentially seat two children. Moreover, the transportation distance of the consumers from the leasing hubs are also specific to the case study as 3 major cities of Sweden were selection as location for providing leasing and maintenance services.

Furthermore, the LCA data used ecoinvent database which have aggregated data over regions collected over specific time period. The quality of data used for modelling might not be representative of time of analysis and geography due to the data available in ecoinvent. As the assessment of the use-oriented PSS scenario is done before its implementation, the product system rely on many inputs in terms of services and products influences the data collection. To a certain extent, it is based on estimates, assumptions and secondary data from the ecoinvent database. While this might introduce uncertainty affecting the data quality, the best representative data and modelling approach was chosen to provide meaningful results.

While the problem of upscaling CBM in businesses include environmental and economic assessment and including social aspect would be interesting to study the sustainability of the business model, the thesis limits its focus on the environmental aspects. This is so, as evaluating environmental impacts demand in-depth investigation of the product under the system and the evaluation differs significantly from economic and social impact assessment. Moreover, the LCA considers company perspective, excluding the user perspective which does not measure if and how they travel to the hubs for pickup and delivery of the products. Thus, rebound effects are also not calculated. Furthermore, since allocation modelling approach is considered for the LCA, the consequences of replacing bike trailers under ownership with bike trailers under leasing scenario, and the subsequent structural changes on the background system are not captured.

1.5 Ethical considerations

The research used Thule Group as a case company to obtain quantitative and qualitative data to develop and evaluate business models. The research topic was developed in collaboration with them, which might have influenced the direction taken by the author in this thesis, compromising the generalizability and validity of the findings. However, the author ensured researcher honesty and integrity by supplementing findings through multiple sources (literature or qualitative interviews with other companies), thus achieving triangulation. Although Thule Group provides support in data collection, the thesis is not funded by them. A Non-Disclosure Agreement (NDA) was signed between the author and the case company for flagging any confidential information that may potentially be published in the public domain. As the evaluation was also based on hypothetical models, the probability of results of the research to harm the reputation of the case company or the interviewees was considered low. However, transparency in data collection and analysis ensured that their reputation was preserved. Further, the interviews conducted within and outside the case company were voluntary and their consent was asked before conducting the interviews. They participants of the interviews were briefed about the project and the manner in which their data will be used. Further, interviewers were anonymized. Information and data were handled on the author's password-protected personal computer and backed up online on OneDrive. The information will be deleted after 6 months of thesis submission. LCA was conducted on SimaPro on a computer provided by Lund University, which will be deleted from the computer as well.

1.6 Audience

The intended audience are LCA practitioners, and bike trailer manufacturing and leasing businesses. The results of this thesis are useful to support decision making for implementing a leasing use-oriented PSS for bike trailers or products similar to it, for example, strollers. The research will also be useful to the LCA practitioners intending to replicate methodology for evaluating and comparing different business models to extend the lifespan of a product. The research will contribute as empirical evidence of LCA as assessment tools for evaluating impacts of a CE strategy before it is implemented. The results will be relevant to the case company as a fact-based input to determine their CE strategies in future. Further, as a contribution to academia, the study will demonstrate LCA results in a new product category, namely, the bike trailer. In doing so, the study further develops the methodological approach to study the environmental impacts of various PSS contributing to the CE.

1.7 Disposition

The paper is structured as follows.

Chapter 1 provides the background and introduction of the problem which will be explored further. It sets stage for research by providing the aim of the thesis research, research questions, scope and limitations of the study.

Chapter 2 covers a brief literature review that introduces the concepts of circular economy, product-service systems and lifecycle thinking. It further describes the lifecycle assessment methodological framework and discusses its relevance for assessing product-service systems.

Chapter 3 presents the research design perspective and outlines methods for data collection and analysis

Chapter 4 introduces the case study and combines the LCA framework description and methodological choices made under this framework with respect to the case study context. It also develops a hypothetical leasing model which is used as an input to the LCA framework.

Chapter 5 presents the results of the LCA by comparing the environmental impacts between the three PSS scenarios for four impact categories. It further conducts sensitivity analysis on the results of the LCA

Chapter 6 interprets the results and discusses its implications, compares the results to previous studies and reflects on the methodological and data limitations

Chapter 7 concludes the thesis by providing recommendations to the intended audience and outlines areas for future research

2 Literature Review

The following section describes the concepts essential to building foundational knowledge for the purpose of this study, namely, the circular economy, product-service systems, and life cycle thinking.

2.1 Circular Economy

The concept of CE has evolved through many years since its conception and is positioned within the various schools of thought like Regenerative Design, Industrial Ecology, Cradle to Cradle, Biomimicry, Performance Economy, and the Blue Economy (Bocken et al., 2017; EMF, 2013). Many scholars have contributed to these schools of thought, from diverse disciplines, making it difficult to define and comprehend the term clearly. The most renowned is the definition frame by the Ellen MacArthur Foundation where Circular Economy as "an industrial economy that is restorative or regenerative by intention and design" (EMF, 2013). There is a consensus that CE represents an economic system that focuses on long-lasting design, reuse, recycling, and recovery of materials throughout the production, distribution, consumption, and end of life process (Urbinati et al., 2020). This system is aimed to increase resource efficiency and reduce resource inputs and waste, emissions, and energy leakage from the system (Manninen et al., 2018) through slowing, closing and narrowing material and energy flows (Geissdoerfer et al., 2017). The importance of CE can be corroborated by the growing movement towards transitioning from a linear to a circular model, with attention both from researchers, practitioners, and policymakers (Urbinati et al., 2020).

According to the Ellen MacArthur Foundation, the three principles of CE (1) designing out waste, (2) systems thinking and (3) modularity (EMF, 2013). Designing out waste implies designing the product to retain its value for a longer time without degrading its quality, i.e., through upgradation, reuse, recovery or recycling. This is in contrast with the products designed within linear economy, where the quality of the product is downgraded towards the end of its first life, making it unattractive or unfeasible for reuse or recycle (EMF, 2013). Further, the CE principle of systems thinking views elements as part of a system, wherein it influences and is influenced by other interlinked elements within the system. It further encourages innovation, keeping in mind the environmental and social consequences of business decisions. Especially for businesses, systems thinking encourages focusing on long term strategies and development of diversified value chain for reducing raw materials and energy cost over long time period, and guarantee stability in times of supply risk and fluctuating material cost owing to resource scarcity (EMF, 2013). These principles provide clear aims to the business who aspire to make a transition towards CE and these principles are achieved by CE strategies. Hofmann (2019) states that the CE strategies aim to keep the natural resources in use as long as possible to preserve their maximum value throughout their lifecycle.

The three strategies of the circular economy are: 1) slowing resource flows; 2) narrowing resource flows; 3) closing resource flows. Whereas narrowing resource flows is associated with increasing efficiency of resource use per product within the production cycle (Bocken et al., 2016), closing resource flows deals with product recovery at the end of its lifecycle by converting waste into new forms of value for another production line (Nußholz, 2017). Slowing resource flow is specifically associated with increasing the life of the product by encouraging repair and maintenance, upgrade implementing the CE design principle for upgradability and durability (Bocken et al., 2016). Further, CBM which provides service for leasing or renting products than owning it through direct sales associated with linear BM foster product reuse and enhancing its use-intensity.

Within businesses, the implementation of the CE principles and strategies is through reconfiguration of business model (BM) elements to embed circularity (Nußholz, 2017) and requires changes within the organizational operation and its entire value chain, with respect to operations and stakeholder involvement (Manninen et al., 2018). Teece (2007) describes a business model (BM) as a simplified version of reality, capturing the mechanisms that a business employs to create value, deliver value, and captures value, essentially explaining how the business works (Magretta, 2002). This abstract concept is popularly represented using a Business Model Canvas (Osterwalder and Pigneur 2010). These elements of the BM are adjusted or innovated to encapsulate CE strategies of slowing, known as Circular Business Model (CBM), defined as a business model in which value is created from products by keeping them in use for as long as possible (Hofmann, 2019 ; Linder & Williander, 2017). CE is further proposed as a win-win-win solution contributing to the three dimensions of sustainable development, environmental, economic and social (Korhonen et al., 2018).

2.2 PSS

Among the different strategies to slow resource flows, the CBM archetype of product system services (PSS) has been widely promoted as a *pathway* for businesses to transition to CE (Moreno et al., 2016).

Product–service system (PSS) can be defined as consisting of “tangible products and intangible services designed and combined so that they jointly are capable of fulfilling specific customer needs” (Tukker, 2004). It is a combination of product and service, that attempts to “deliver capability of the product rather than ownership” (Bocken et al., 2016). It further attempts to create customer utility and generates value (Boehm & Thomas, 2013). Moreover, PSS offers means for businesses to transition towards CE, potentially reducing environmental impacts without compromising on economic performance. This thesis considers the definition of PSS by Tukker & Tischner (2006), which states that PSS are not inherently sustainable than the linear business models, but can only be considered so, if they reduce environmental impacts in comparison. Further the growing significance within the business community necessitates the need to investigate the impacts pre-implementation to reduce risks related to uncertainty of its sustainability contribution.

Tukker (2004) establishes that PSS can be classified into three broad categories, and each category provides service with varying environmental and economic characteristics. The first category is of ‘product-oriented service’, which primarily focuses on tangible product sales, along with provision of services like maintenance and repair or consultancy. This PSS is currently implemented within the case company, which offers repair services and spare parts for maintenance of the product over its lifespan. The second category is ‘use-oriented service’, where the product is still central to the business model, however, service provision is the main aim. The ownership of the product is retained by the producer, but the product function is made available to the users through schemes such as sharing, leasing or pooling. A hypothetical use-oriented PSS for the case company will be evaluated in this study. The last category of ‘result-oriented services’ wherein the functional result of a product is provided than the product itself through sales of service, for example, companies providing farmers a maximum harvest loss than selling (Tukker, 2004). Among many companies implementing PSS, Volvo’s car leasing through subscription scheme (*Care by Volvo I The All-Inclusive Car Subscription*, n.d.) and Adidas’s rental platform trial in France (Servantes, n.d.) illustrate the growing significance of PSS among various CBM alternatives.

Although not circular by definition, PSS may support slowing of resource flows (Bocken et al., 2016) and reducing resource consumption and waste generation (Kerdlap et al., 2021) by integrating product and service offering to varying levels. However, the ability of PSS to achieve sustainability, without compromising on economic performance, is dependent on many factors. Firstly, consumer values determine the success of a PSS implementation. The world is seeing a pervasive shift in the consumer behavior – a preference of access over ownership (EMF, 2013) – which is favorable for PSS implementation in a market which has consumer acceptance (Mont et al., 2006). Secondly, PSS design is of crucial importance, as it influences the sustainability performance (Tukker, 2004). Thirdly, it must be noted PSS is not suitable for all product types in terms of environmental impact reduction, and hence depend significantly on the product characteristics (Nußholz, 2017). Among many conditions suitable for using PSS, products with long lives are a good cases for this business model (Lingegård, 2020).

Thus, products such as bikes or strollers, which have long lives and have low frequency of use, are potentially suitable for PSS (Mont et al., 2006; Kerdlap et al., 2021). They can achieve material efficiency through intensifying use, prolonging life and maintenance and repair (Böckin et al., 2016). Further, strollers are widely used, and durable products with high recovery value at the end of their life (Kerdlap et al., 2021). Despite the long technical life of the product, the useful life of the strollers are significantly less due to its functionality, as it is used for the initial few years for babies (Mont et al., 2006). Further, Mont et al. (2006) posit that this discrepancy in the technical and use life leads to inefficiencies in resource consumption. Thus, the high reusability value of strollers makes it a suitable case for PSS as a business model. Specifically, this research will investigate one type of stroller, the bike trailer for children, which is hinged to the back of a bicycle. Like the stroller, the bike trailer serves the same function of transporting small children, with a useful life of only a few years. For these reasons, the bike trailer is a good case example for PSS. The illustration of the bike trailer under the three PSS scenarios are illustrated in Figure 2-1.

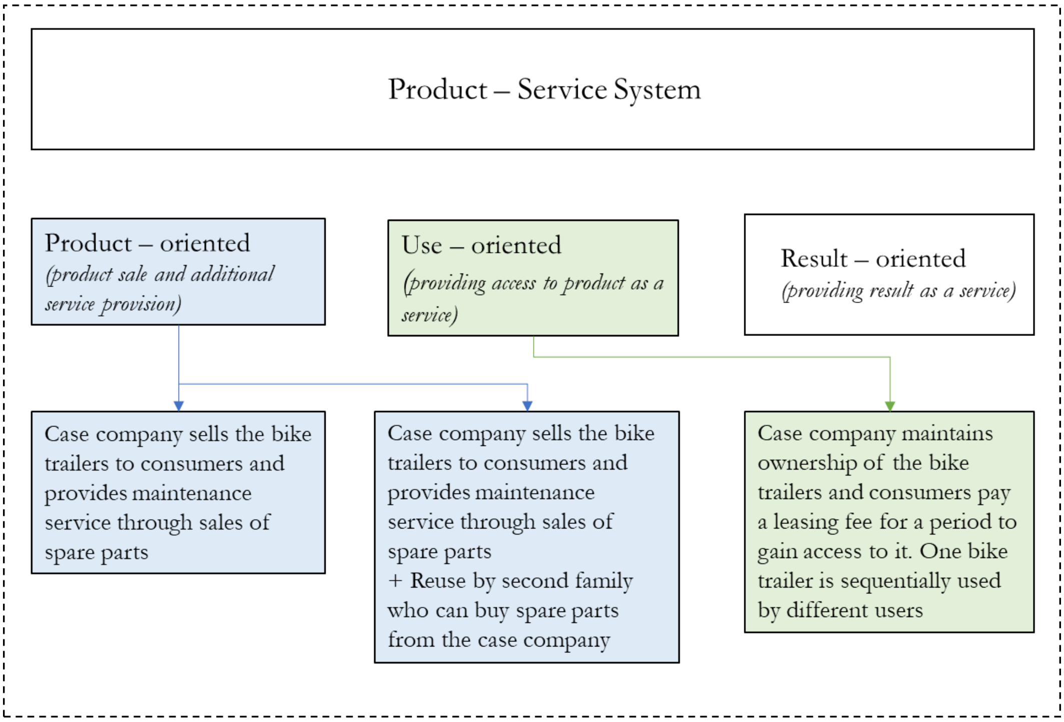

Figure 2-1:PSS categories and application to this study.

Source: Adapted from Tukker (2004)

2.3 Lifecycle thinking

With an increasing commitment towards environmental sustainability, lifecycle thinking considers the entire product lifecycle, from the extraction of raw materials to its end of life treatment, to reduce absolute impacts of the product (Mazzi, 2020). Lifecycle thinking provides a comprehensive analysis of all factors contributing to the impact of the product, allowing the identification of solutions for improving the overall performance of the entire system.

Lifecycle practices have evolved since they started in the 1960s with few companies in the United States and northern Europe conducting lifecycle studies to improve energy efficiency in packaging products. These isolated experiences which earlier focused on product flows have evolved to the development of standards and software in the 1990s to support lifecycle analysis (Mazzi, 2020). Since then, initiatives supporting lifecycle approaches have multiplied, gaining support from both government and the scientific community. In Europe, lifecycle thinking was promoted to support policy instruments like green public procurement and ecolabelling (EC, 2003). Now, improved methodological approaches in lifecycle thinking support decision making in several sectors to improve environmental, economic and social considerations (Mazzi, 2020). Due to growing public awareness of environmental issues and acknowledgement of sustainable development, the interest in studies and practices related to lifecycle thinking has increased (Hou et al., 2015), not just for the purpose of communication to stakeholders but also for internal system improvement to reduce environmental impacts. Lifecycle thinking extends to the concept of lifecycle assessment (LCA) which are outlined in the sections below.

2.4 Model operationalisation

Assessment frameworks in the literature are not sufficient, for example, there is a lack of coherence across assessment frameworks, there is limited methodological documentation, and there is little sector-specific knowledge for implementation. At the organizational level, many traditional tools for measuring GHG emissions are used to measure CE impacts within academia and practice (Kjaer et al., 2016), for example, input/output analysis, life cycle assessment, material flow analysis ,recycling efficiency rate, global reporting initiative, greenhouse gas indicators , and internal reporting guidelines (Das et al., 2022). Although these tools can be adapted to measure environmental impact of CBMs, they are not fully suited to address all aspects of circularity, and need to be researched further. Sassanelli et al. (2019) note that many studies fill this gap by creating their own adapted methods for environmental assessment from LCA, needing data and input from the organization under investigation (Pieroni et al., 2019). Furthermore, the ISO 14044:2006 standard on LCA state that a product can be defined as a good or a service. The definition thus makes LCA a suitable method for conducting assessment of a PSS (Kjaer et al., 2016).

However, using LCA in the context of PSS could be challenging, as it is typically applied on a single product system rather than a business model. Current LCA guidelines are inherently product-focused and do not deal explicitly with the complex characteristics of PSS (Kjaer et al., 2016). Kjaer et al. (2016) identifies three challenging areas to conducting LCA on PSS: 1) reference system 2) functional unit and 3)system boundary. Due to changes in the user behaviour and perceived of the PSS and the limited knowledge on the system, the implicit uncertainties and its dynamic nature makes it challenging to define an appropriate reference system and ensure equivalence in the functional unit definition. Moreover, PSS which pursue product lifetime extension through multiple lifecycles, such as leasing or renting, complicate allocation of impact between lifecycles.

As the success of PSS depends on consumer behaviour, this factor also makes it difficult to accurately predict its sustainability performance. The changes in consumer behaviour are difficult to quantify for the purpose of conducting an LCA, implying that assumptions regarding related factors need to be made (Kjaer et al., 2016). As a consequence of changes in consumption pattern and user needs, rebound effects are observed. Rebound effects are the "behavioral or other systemic response to a measure taken to reduce environmental impacts that offsets the effect of the measure"(Hertwich, 2008, p.86). As a result, the environmental benefit of any eco-strategy is either lower or negative. Although LCAs can address rebound effects, it depends on how the reference system is defined (Goedkoop, 1999). The changing consumption pattern is particularly important when the impacts of PSS before and after implementation are compared, the consumer behaviour might have changed (Goedkoop, 1999).

Moreover, lack of data, especially for assessment of a PSS before its implementation is a challenge. PSS is a complex system of a combination of product and services and rely on many inputs in terms of services, products, market and support systems and may extend to multiple product life cycles. The support systems are the newly developed network and partnership infrastructures (Reim et al., 2015) . These support systems influence the data collection, especially data related to user behaviour, and thus to a larger extent will have to be based on estimates, assumptions and secondary data (e.g., from LCA databases). While this might introduce uncertainty in the LCA model, choosing the best representative data and modelling approach, with detailed documentation should help provide meaningful results and opportunities for replication.

Additionally, deciding the scope of the LCA can be challenging since the LCA methodology does not prescribe guidance on it, or how the LCA processes differ with varying scopes (Goedkoop, 1999; Kjaer et al., 2016). Firstly, distinguishing foreground and background systems in a PSS can be difficult. Finnveden et al. (2009) notes that background processes have insignificant influence on the results of LCA, however distinction in the processes for PSS which depends on supporting systems is tricky. This introduces a risk of significant processes to be assessed with inaccuracy, adding to the uncertainty of the results (Kjaer et al., 2016) .This thereby challenges outlining the system boundary with completeness and consistency between the compared systems (Kjaer et al., 2016).In line with deciding the scope of the LCA, ISO 14044:2006 does not provide guidance on how a functional unit should be structured, but that it should be clearly defined and measurable. Thus, defining a strict functional unit for a PSS might not capture the consumer preferences and the reality adequately. Further, a functional unit for a comparative PSS needs to adequately capture reference flows of all the scenarios, which might be challenging. The functional unit must capture product and service functionality for a PSS, which are not easy to define (Kjaer et al., 2016) and can be challenging to define for a PSS evaluation (Goedkoop, 1999).

2.5 LCA framework

Lifecycle Assessment (LCA) provides a methodological framework to integrate lifecycle thinking into decision making and policy support (Hou et al., 2015), by assessing the potential environmental performance of a product from a lifecycle perspective. The assessment is determined by quantifying the emissions from the resource flows in the product lifecycle across various environmental impact categories. Furthermore, the comprehensive scope of LCA avoids the situation of problem shifting, from one lifecycle phase or region or environmental issue to another (Finnveden et al., 2009). LCAs are conducted based on the guidelines in the international standard of ISO 14040 and ISO 14044:2006. As established by these standards, an LCA study is performed in four phases, goal and scope definition, lifecycle inventory (LCI) analysis, lifecycle impact assessment (LCIA) and interpretation. The LCA process is shown in the Figure 2-2.

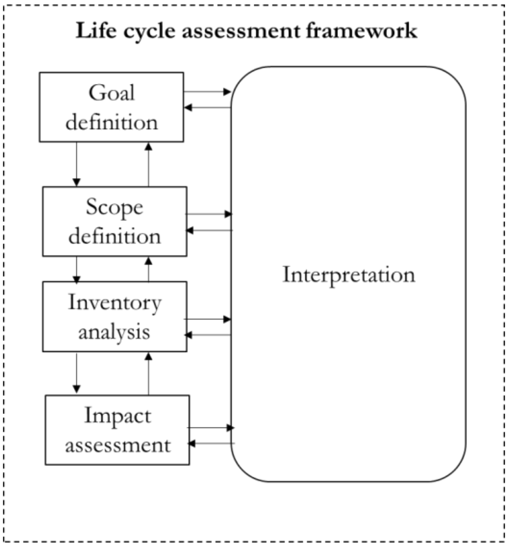

Figure 2-2:Framework for lifecycle assessment.

Source: Modified from ISO 14040:2006

The goal and scope define the reasons for conducting the study for an intended audience and the system boundaries within which the LCA will be conducted. This step also specifies the function of the product or service, in terms of quantitative and qualitative measure. The second phase concerns with compilation of data, in the form of inputs(resources) and outputs (emissions) over the product lifecycle with respect to the functional unit defined in the previous phase. The third phase, LCIA, aims to understand the environmental performance of the product across various impact categories. Finally, the results from the previous phase are interpreted in relation to goal and scope to suggest recommendations for fact-based decision making. Chapter 4 will describe these steps in detail along with the methodological choices considered.

2.6 Existing LCA Results

The literature review shows that LCA studies have been conducted for strollers under PSS (Kerdlap et al., 2021; Thorslund, 2019; Ang & Yifan, 2012), and also comparative LCA to use-oriented PSS (Kerdlap et al., 2021; Thorslund, 2019). Although bike trailer is a variation of a stroller, it should be noted it is different in its multifunctionality – to be used as a stroller, for jogging, or a trailer attached to a bike. This multifunctionality allows flexibility to the parent, built for durability for different terrains and weather conditions, and can seat children from 6 months to 5 years old, providing it a longer useful life than the stroller. Further, the availability of a double seater bike trailer can further increase its useful life. As Kerdlap et al. (2021)states that LCA of strollers or prams can be generalized to similar products with long use life and zero electricity usage during its use, LCAs on strollers are used to compare the results in the Chapter 6, to contextualize the results of this study.

As studies specific to bike trailers have not been conducted yet, the thesis will demonstrate LCA results in a new product category, namely, the bike trailer as a contribution to literature. In doing so, the study further develops the methodological approach to study the environmental and economic impacts of various PSS contributing to the CE. It also has practical relevance as a fact-based input to the case company to determine their CE strategies in future.

The Masters dissertation by Thorslund (2019) focused on this study focused on investigating the environmental, economic and social implications of a stroller under renting scheme using PSS and Service design framework. The quantitative analysis of this dissertation included a screening cradle to grave comparative LCA of the stroller under linear and PSS scenarios and GHG emissions are calculated based on ecoinvent data and compared. The functional unit is a stroller of weight 13 kgs and the includes cradle-to-gate analysis, with shipping of raw material from Asia, production within Europe for its use and its end-of-life phase which included 100% recycling of aluminum and steel and 100% waste incineration of remaining materials. According to the results, manufacturing of frame, consisting of aluminum had the largest GHG emissions over its lifecycle, followed by production of cotton in textile and finally emissions from plastic. However, this paper is not transparent regarding the LCIA method used for calculating the GHG emissions and does not provide details of the refurbishing activity. Further, transportation and EOL emissions are not explicit. Besides comparison of the emissions, this study was used as a reference to validate the hypothetical leasing model developed for the case company.

Mont et al. (2006) proposed PSS archetype of leasing for a stroller in 2006 based on a case study of pram producer in Sweden which was one of the top producers in the year 2000. Although an LCA was not conducted in this study, the process model for leasing of the stroller was detailed out, with respect to the product design changes and refurbishing needs in a leasing model, changes in the supply chain and potential barriers for the leasing model to work. The study further performed economic estimations of the leasing model. Regardless of the qualitative nature of the study, the potential environmental hotspots and points of improvements were indicated and the need for research was indicated, which this thesis attempts to answer. Moreover, the business model implications for a company leasing the stroller, considering the presence of the secondhand market, complemented the findings from the interviews.

Ang & Yifan (2012) study conducted a carbon footprint analysis on a packaged single stroller as a functional unit and done in accordance with PAS 2050. The stroller was a product of Bugaboo, a leading premium stroller manufacturing brand based in Netherlands, and can be likened to Thule Group. Considering a scope of cradle to grave analysis, the LCA includes the raw material extraction, manufacturing, distribution, use and disposal to landfill. However, as the geography of these lifecycle phases were not explicit in the study, only the overall material and phase relative contribution was compared to the results of this thesis. Besides primary data directly from the company, secondary databases such as Life-Cycle Inventory Database, CPM LCA Database and ELCD Database were chosen as the main databases and IPCC GWP conversion factors were used to obtain the characterised kgCO2e value for the inputs to the LCA. The results from this study revealed that raw material production phase accounted for most emissions in the product GHG emissions, with production of polyester fabric and Aluminium tube production as the biggest contributing materials.

Kerdlap et al. (2021) conducted a cradle-to-grave comparative analysis of a stroller under ownership and renting business models to serve all children born in Singapore over a period of 5 years. The functional unit used was the service provision of prams for 600000 child-years in Singapore; the child years defined as a combination of useful life of the stroller and number of children born in Singapore per year for 5 years. This study further considered scenarios for analysis for the ownership business model, wherein (1) the stroller is used for 3 years and disposed, (2) the stroller is used for 3 years and 50% of the manufactured strollers are passed onto second users, and (3) the stroller is used for 3 years, and all manufactured strollers are passed onto second users. These scenarios are compared to the renting scenario where the strollers are used for 6 years before disposing it off. The LCA assumes manufacturing in China, transportation to Singapore where use and maintenance involves light and heavy cleaning cycles and final disposal after 6 years to a waste-to-energy incineration plant in Singapore. The light cleaning includes washing the strollers with water and cleaning agents. Whereas the heavy cleaning included detaching the fabric from the stroller and cleaning with cleaning agent and drying in an electric dryer. Ecoinvent v3.6 was used for secondary data collection and ReCiPe2016 (H) midpoint method was selected for characterizing the different impact categories. Considering that the scope and LCIA methods differed from the choices made in this thesis, the overall impact contribution of manufacturing phase, which is common in terms of the geography of production, were compared. The results revealed highest impacts from the production phase, followed by cleaning and transportation of the stroller. Within production, plastic production and electricity had high contribution in few impact categories, while steel had higher impacts in the rest of impact categories. Besides comparing the production impacts, the assumptions in modelling the LCA in this study was compared to this thesis, along with referring to the leasing business model implications for the manufacturing companies, which were used to support findings from the interviews with leasing companies.

3 Research design, materials and methods

When designing a research project, it is important to start with the conceptual and technical design needed to accomplish the research objective. The conceptual design describes the research objective, the research questions, and a guiding research framework (which captures the scope of the research project). In contrast, the technical design articulates the strategies and methods use to collect and analyze the data. The content of the research is determined by the conceptual design, whilst the technical design considers how the content will be implemented. This study is structured on Verschuren et al. (2010) research design framework shown in Figure 3-1.

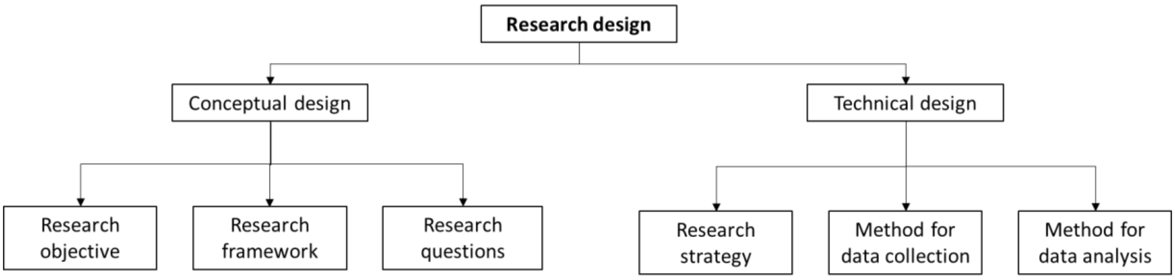

Figure 3-1:Research design framework.

Source: Adapted from Verschuren et al., (2010)

3.1 Conceptual design

The conceptual designs concerns a set of activities where the objective of the thesis, research framework, research questions are defined.

3.1.1 Research objective

The research objective is to recommend a suitable circular business model for bike trailers with improved environmental performance, by comparing the potential environmental impacts of various product-service system scenarios using lifecycle assessment (LCA): (1)the current baseline scenario of sales and provision of spare parts with disposal after 6 years of use (henceforth, “ownership S1”); (2) baseline scenario of sales and spare parts provision with the product gaining a second life in the secondhand market in Sweden (henceforth, “ownership S2”); (3) leasing of the product (henceforth, “leasing scenario”).

3.1.2 Research questions

The following research questions (RQs) are formulated to help achieve the aim of the thesis.

RQ1: How do the environmental impacts of a bike trailer compare between the three PSS scenarios?

RQ2: What is the most suitable circular business model for a bike trailer from environmental performance perspective?

3.1.3 Research framework

Verschuren et al. (2010) defines research framework as a schematic representation of the research objective, which presents interconnected phases of research in order to achieve the objective. As this thesis aims to recommend a suitable circular business model from an environmental performance perspective, a series of step are taken in order to reach the objective. In essence, a research framework represents the internal logic of a research project as displayed in **Error! Reference source not found.**. In the preliminary research phase, the literature review helped narrow the scope of the research and built a foundation for the type of data to be collected and helped develop conceptual frameworks within which research was conducted. The interviews further developed the hypothetical use-oriented PSS scenario. The conceptual framework, i.e, LCA, or the research perspective was used to analyse the research object, i.e, a phenomenon under study. The research object in this case is the bike trailer under the three PSS scenarios. Within the research perspective, the research object was evaluated to generate insights, or the "result of analysis". The results of the analyses were used to achieve the research objective. The framework is illustrated in Figure 3-2.

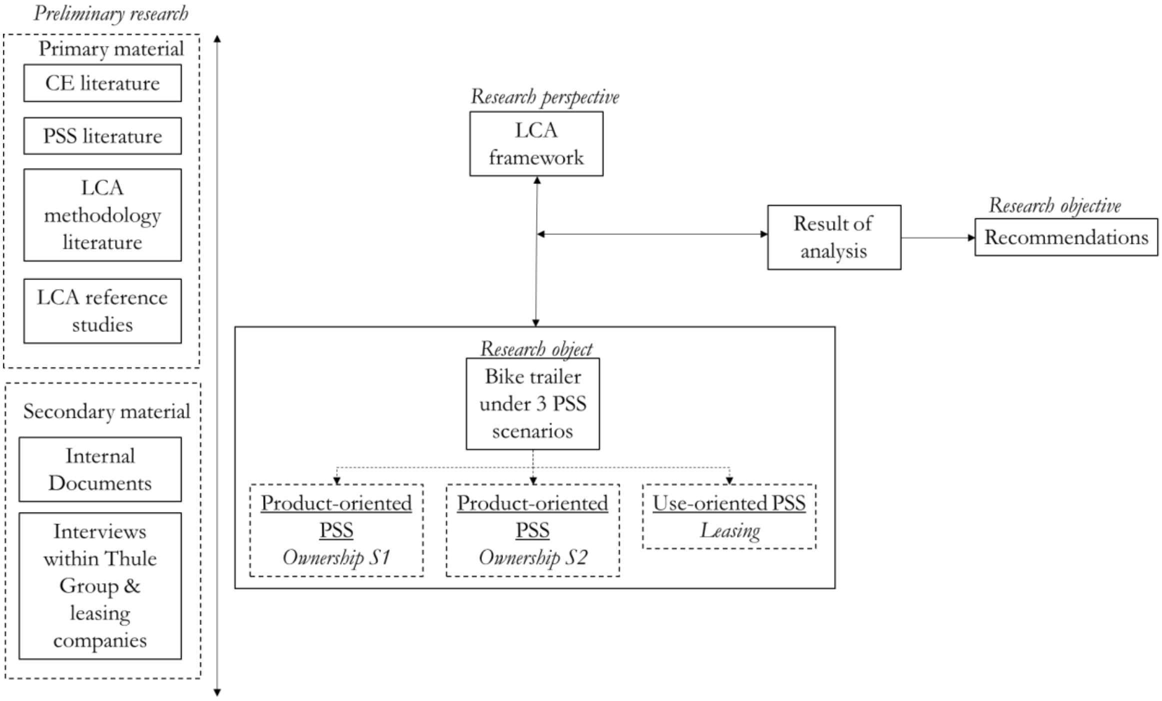

Figure 3-2: Research framework.

Source: Adapted from Verschuren et al. (2010)

3.2 Technical design

In order to realise the conceptual design, the technical design guides the process, which includes developing a research strategy or approach, identifying the research material and methods for data collection and data analysis.

3.2.1 Research strategy

Creswell & Creswell (2018) put forth that the selection of a research approach is crucial in planning the research. Research approaches are plans for research which detail the broad assumptions to the methods of data collection, analysis, and interpretation. The decisions on the assumptions in the study are guided by the philosophical worldview of the researcher Creswell & Creswell (2018). This research is guided by the pragmatic orientation of the researcher, which emphasises on problem-solving and make use of multiple methods to derive knowledge about the problem Creswell & Creswell (2018) .Verschuren et al., (2010) define five ways to conduct research to realise the objective of the thesis, also known as research strategy. These are - survey, experiment, case study, grounded theory, desk research. Further, there are three steps to identifying an appropriate research strategy. First , deliberating the type of investigation, whether it is "breadth" or "depth".

Second, if the study takes a quantitative or qualitative approach. Lastly if the researcher is driven by empirical research or desk research. Based on these steps, the research strategy was concluded to be of "depth" investigation, with the aim of conducting detailed investigation at a small scale, achieving depth of a context and reducing uncertainties. Further, the researcher's pragmatic philosophical orientation determined the quantitative research approach through empirical research. Based on these three decisions by the research, case study research design was considered to be an appropriate option to gain indepth insight into the research object of analysis confined in space and time (Verschuren et al., 2010). The research approach considered by the author in this study is shown in Table 1.

Table 1: Research approach for this study

Determinants	**Choices**
Breadth or Depth?	Depth
Quantiative or Qualitative	Quantitative
Empircal or Desk Research (Primary or Secondary Data)	Empirical

Case study perspective

A single case study as a research enquiry was conducted to collect and analyse data, providing empirical evidence on the existing theoretical concepts of CE . Yin(2014) defines case study as an "empirical enquiry to investigate a contemporary phenomenon in depth and within the real world-context." The rationale for selecting a case study was to retain a holistic real-world perspective, to include contextual conditions relevant to the case (Yin, 2014) and to gain an in-depth analysis of the research problem. One of the main reasons which alluded to the case study research enquiry to be suitable for the thesis is due to the nature of conducting an LCA. LCA requires context specific, geographically representative data and demands Firstly, the context specific nature of a LCA demanded specific data and intensive in-depth data generation, allowing capturing and highlighting any complexity. The case study results would be used further to generalise the findings, however it is omes with certain set of limitations, mainly related to the reliability and generalisability of the findings. These limitations can be mitigated and speak to the quality of the case study, as elaborated in Section "Case study quality".

Case study selection

The unit of analysis or the case was of a double seater bike trailer for children, Chariot Cross 2, manufactured by Thule Group. Thule Group is an outdoor sporting goods manufacturing company based in Sweden, which produces bike trailers, strollers, rooftop boxes, bike carriers, bags, among other equipment. The company has a strong name associated with high quality, safety and durability of the products. Thus, making their products attractive in the secondhand market for reuse. Thule Group has the highest market share in bike trailer sales in the Swedish market (Thule Group, 2022). Thus, the author selected a model of a trailer, which has the highest volume of sales among the different bike trailer offered by the company (Thule Group, 2022). This was considered representative of the range of bike trailers and used to generalise findings for this product category in Sweden.

Case study quality

The quality of the case study research design was be judged based on the following design tests, namely, construct validity, internal validity, and external validity and reliability (Yin, 2014).

Construct validity

This included identifying the correct operational measures for the concepts being studied. The construct validity in this study was increased by using multiple sources of evidence, by using existing literature, internal company documents, interviews with the project managers of different departments within the organization, interview with the CEO and external leasing companies in Sweden and Germany to establish context. The second tactic to enhance construct validity was to establish a chain of evidence, done by documenting the data collection, and analysis methods, thus establishing transparency in LCA methodology as well. The final tactic was getting the case study reviewed by key informants, done by the supervisor at the case company and the thesis supervisors at the IIIEE, Lund, Sweden.

Internal validity

Internal validity seeked to establish a causal relationship, particularly for explanatory or causal studies. This was done by employing the tactics of pattern matching and explanation building, conducted during the analysis phase of the study. Pattern matching entailed mapping the predicted patterns, based on literature to the empirical evidence. This was done by comparing literature on strollers and LCA on the same, with the case study**.** The second technique was explanation building, done during the analysis and interpretation phase within the LCA methodology to generate explanation to develop ideas for future research.

External validity and realibility

The extent to which the findings of the study can be generalised beyond the immediate study is defined by external validity. The form of research questions and its ability to transfer the case specific findings to general context play a significant role in enhancing external validity. As Yin (2014) notes that repeating the findings of a case study to a new setting requires good documentaiton of procedures and detailing the problem and developing through a case study's database. This research attemPts to achieve that by highlighting the rationale for any methodological choices taken by the author, in terms of modelling approaches, data collection, and analysis. Furthermore, by documenting the data sources, assumptions and estimations and transparently discussing them, allowed mitigation of limitations that arise from generalising the results of a case study.

3.2.2 Methods for data collection

After selecting the research strategy, the second step is deciding the type of data to be collected, and how and where to gather it (Verschuren et al., 2010). Data was collected using three methods: literature review, study of internal documents and interviews. Document analysis, literature review, online interviews, helped achieve a degree of triangulation using multiple data sources. The literature review on CE, CBM and PSS built the conceptual base for understanding the type of data which was needed to be collected and the guidance on modelling hypothetical scenarios. Additionally, the literature on LCA guided the quantitative assessment methodology in this study. The qualitative data was collected in the form of meetings within the case company to understand the current business model, the technical product characteristics, quality and modularity, spare parts production and the usage pattern of the product. Further, interview with a leasing companoes provided insights to model the hypothetical leasing scenario for the bike trailer. Additionally, quantitative data was collected through reviwing internal documents and meetings with managers of different departments within Thule Group. This was complemented by secondary data collected through literature review and datasets from the ecoinvent database wherever primary data was unavailable for the purpose of conducting LCA. The data gathered was finally used to model the three PSS scenarios using software SimaPro.

Literature review

The literature review for this study was conducted as shown in Figure 3. Firstly, keywords of "circular economy", "CBM" ,"PSS", "leasing", "renting", "stroller", "pram","bike trailer"and "LCA" were entered in search engines such as Google Scholar and Scopus based on the combination shown in process. Figure. Based on the initial set of papers selected, the author read the content of the articles. Further, using snowballing technique, other referenced papers were read and selected for analysis using the synthesis matrix, developed in MS Excel. The synthesis matrix helped in formulating themes and key concepts, particularly related to CE, PSS and strollers, leasing, lifecycle thinking and LCA of PSS. This process continued till a saturation was reached to answer the RQs. Although it should be noted that the literature review can never be fully saturated, implying that it is not possible to review all the relevant literature. However, the author defines saturation where the literature was overlapping and the information was sufficient to proceed with the next phase of data collection. The synthesised literature complemented the insights obtained from the interviews. Parallelly, literature review on LCA methodology, previous years IIIEE thesis on LCA and SimaPro software tutorial documents built understanding to conduct the evaluation. The findings from the literature review served as a basis for data collection from the case company and enhanced the knowledge through empirical evidence.

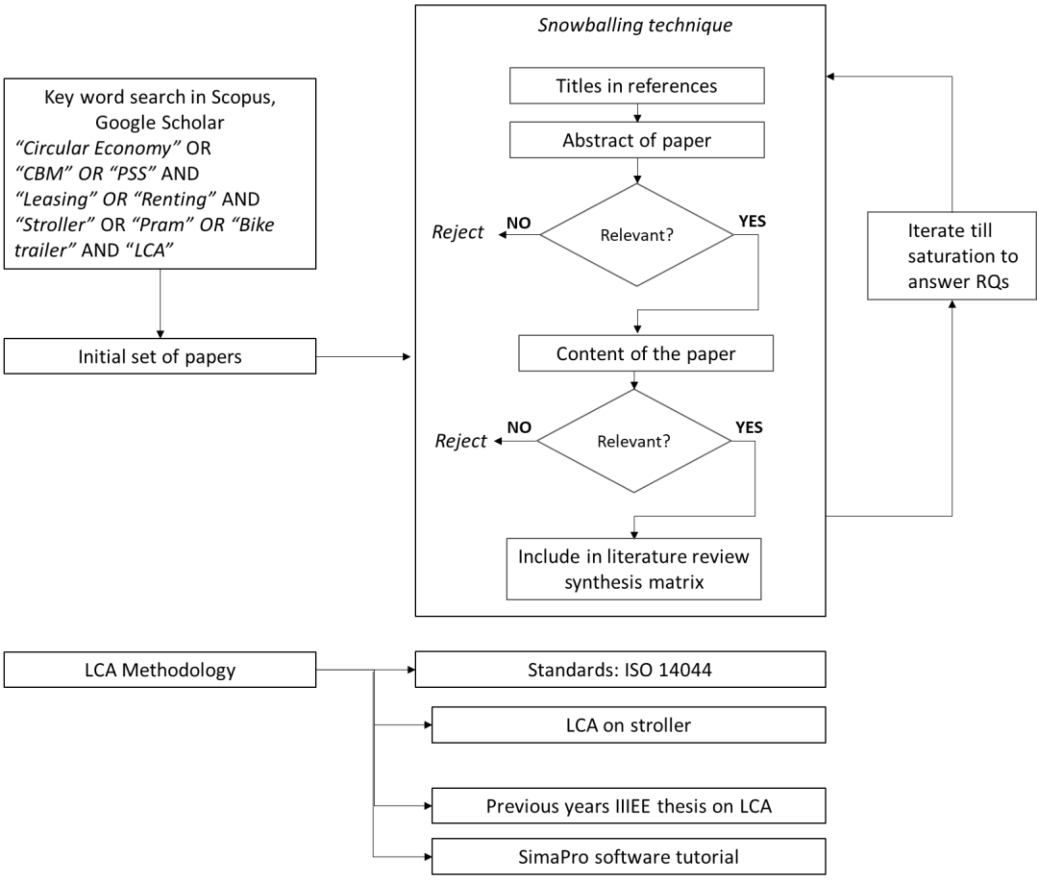

Figure 3-3:Literature review process.

Interviews

The interviews were conducted to gain both qualitative and quantitative understanding about the product system and leasing scenario. They took the form of a semi-structured interview, guided by close-ended questions on the product properties, and followed by open ended questions to understand the wider context of the product system. The interview process was concluded when it reached a point of saturation, and there was not new knowledge to be added to the data collection process in the defined framework.

- Qualitative and quantitative information about the bike trailer. This included speaking to project managers of relevant departments within the case company - design engineering, testing, spare parts team, quality assurance, customer support, store management, marketing, purchasing functions.

- Leasing scenario of the bike trailer and related findings from leasing to understand the wider context of renting or leasing of this product category. The questions were to gain knowledge on the presence of the leasing business model in the Swedish market, the usage of the bike trailer, leasing time, logistics, presence of secondhand market, marketing strategies, revenue model, maintenance needs and end of life of the product.

- Meetings with the CEO and International Product Manager (of bike trailers) within the case company to verify and validate the process models in three scenarios

An initial list of potential interviewees were provided by the author's contact at Thule Group, International Product Manager (of bike trailers). Through snowballing, the author contacted managers of other departments and contacts were provided for leasing companies which the case company partners with. The partnership is defined by Thule Group providing models of its bike trailers to these leasing companies operating in Sweden and Germany. Further, Thule on-site store and testing site visit at their facility deepend the understanding of the product.

Internal documents

Further, following the interviews, internal documents related to technical specifications, spare parts, quality issues, sales and customer feedback documents were provided by the interviewees which served as input to the LCA models.

3.2.3 Methods for data analysis

The interviews provided data which supplemented the results of the LCA. However, rigorous qualitative data analysis was not performed as the focus of the thesis was on quantitative assessment of the environmental impacts. This might have introduced few uncertainties and assumPtions, however, triangulation achieved through multiple sources attemPted to reduce this. For analysis of the quantitative data, the environmental impact analysis was done in line with the LCA framework, adhering to the ILCD guidelines. Further, sensitivity analysis of the uncertain variables of the LCA model was done on SimaPro, which was interpreted based on the knowledge of the literature reviewed.

4 Case study and lifecycle assessment methodology

This section starts with introducing the model of the bike trailer, Cross 2 by Thule Group, which is the unit of analysis in the LCA evaluation. Next, this section combines the description of the LCA framework which guided the environmental evaluation and the LCA methodological steps employed in the case study for better readability and understanding of the decision rationale.

4.1 Chariot Cross 2 bike trailer by Thule Group as a case study

4.1.1 Model selected for the LCA: Chariot Cross 2

The bike trailer model, Cross 2, a double seater bike trailer, weighing 14.5kgs and has a holding capacity of maximum 45 kgs is evaluated using LCA under the three scenarios. Further, Cross 2 offers a sitting height of 68cm. Cross 2 is considered representative of all the bike trailers sold by the company since it has the highest sales volume among all the bike trailers (Respondent 1). The product is designed for durability as Thule provides a warranty of 10 years for the main body (frame) of the trailer. In addition, the other parts have a warranty of a total of 5 years (Thule Group, n.d.). The different lifetimes make the product feasible for reuse or remanufacturing (Mont et al., 2006). Thus, the product differs from a conventional stroller due to its design for durability and longer useful life as it can seat two children, from 6 months to 4-5 years approximately (Thule Group, 2020; Respondent 1). The bike trailer can either be hitched to the back of a bike using arm hitch, see Figure 4-1 or may be used as a stroller.

Figure 4-1:Chariot Cross 2 bike trailer by Thule Group

4.1.2 Design of Chariot Cross 2 bike trailer

The trailer is made of main parts (also referred to as assembly or assembly parts hereafter), which are namely, frame, wheels, axle, arm hitch, strap, handlebar, body fabric and flag. The assembly is further composed of smaller components; however, this study addresses the components only at assembly level. Beside these, there are smaller components such as bolts or fasteners which are excluded from the scope this study due to their low weight. The deconstructed bike trailer with the assembly parts addressed in this research, is shown in the Figure 4-2.

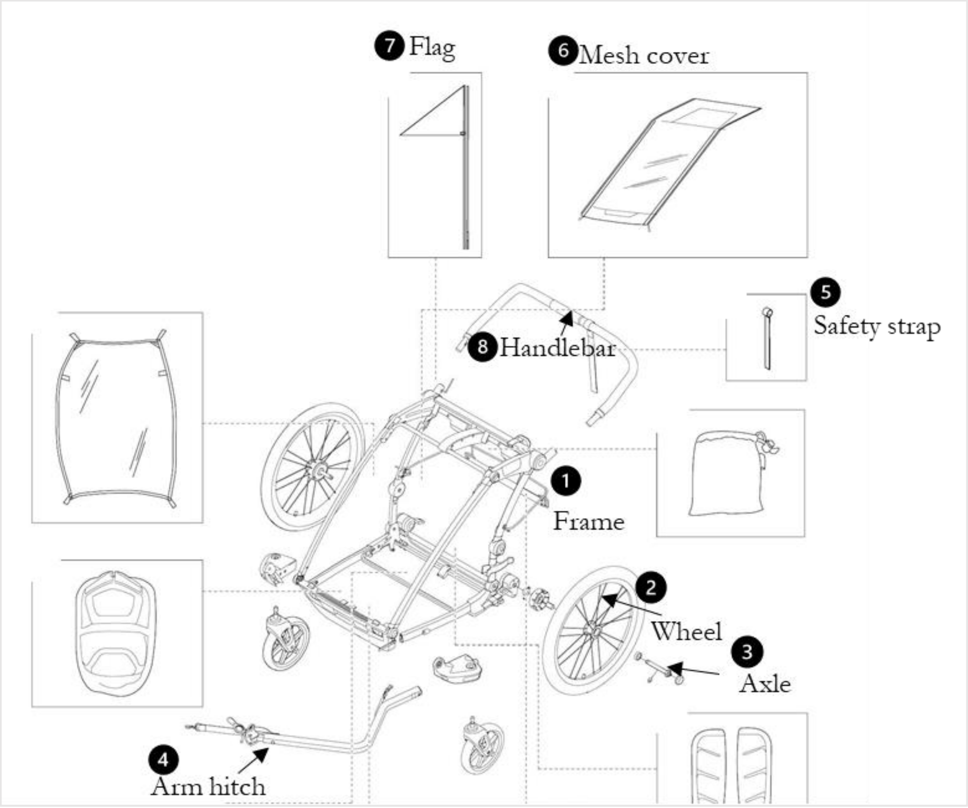

Figure 4-2: Deconstructed image of Chariot Cross 2

4.2 LCA

LCA was conducted based on guidelines in ILCD handbook (European Commission & Joint Research Center, 2010), and was modelled in the LCA software, SimaPro. This section details the methodological choices considered in this study within the LCA framework, including goal & scope, lifecycle inventory, lifecycle impact assessment and interpretation of results.

4.2.1 Goal

According to the ILCD guidelines (European Commission & Joint Research Center, 2010), the goal definition should cover six aspects, namely, intended application of the LCA study, the limitations of the study, decision context, the intended audience of the study, if the comparison will be disclosed to the public and the commissioner of the study. In line with aim of the thesis, the goal of this LCA was to compare the lifecycle environmental impacts of bike trailers under the current ownership versus its leasing scenario. The current ownership scenario, the baseline was further evaluated with two scenarios in mind, a bike trailer used by a family and then discarded (ownership scenario 1/S1) and the trailer has a second life through reuse from the secondhand market (ownership scenario 2/S2). The study is limited in its geographical boundaries by considering only the Swedish market.

ILCD guidelines stipulate determining the decision context for the goal of the study (European Commission & Joint Research Center, 2010). The decision context, in Figure 4-3, guided the methodological choices for LCA, i.e., deciding whether an attributional LCA (ALCA) or a consequential LCA (CLCA) modelling framework should be chosen (European Commission & Joint Research Center, 2010). This had implications on the decisions regarding choice of input data and the modeling of processes with multiple products (Ekvall, 2020). Ekvall (2020) describes ALCA as an approach which "describe the environmentally relevant physical flows to and from a life cycle and its subsystems". ALCA estimates what share of the global environmental burdens belong to the product (Ekvall, 2020). Whereas in CLCA, marginal data is used, and system boundaries expanded (Ekvall, 2004) to model the consequences of the system with relation background processes, such as production of materials, energy and transport (M. Goedkoop et al., 2016). In other words, CLCA generates information on the consequences of decisions in the system (Ekvall & Weidema, 2004).

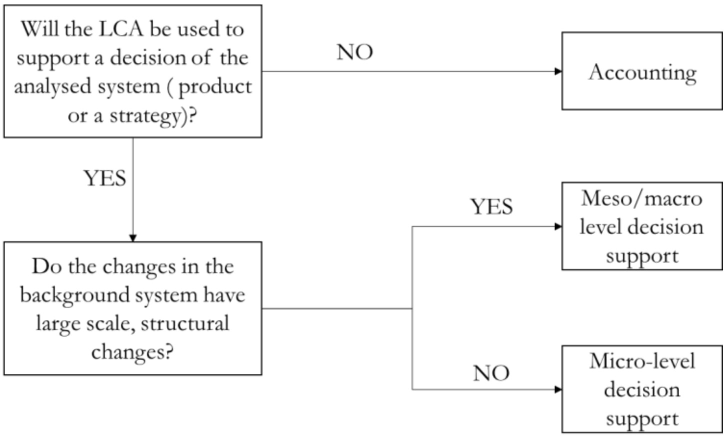

Figure 4-3: Decision context selection process.

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

Based on the framework in Figure 4-3, micro-level decision support was determined as the decision context as the comparison of the product under three PSS scenarios do not result into large structural changes. By taking an organizational perspective, the study is meant to act as a decision support in identifying the environmentally better business model for a bike trailer manufacturing or leasing organization. Contrastingly, CLCA deals with macro level decisions resulting in large structural changes (European Commission & Joint Research Center, 2010) which have extensive consequences on technology or others systems change. This alludes to either change in the production infrastructure or its decommission and occurs outside the system boundary of the system under study, but structurally affects other parts of the economy. Thus, ALCA was selected as the best approach.

Lastly, the study is part of the Masters thesis, which will be available in the public domain. It considers Thule Group as a case study company for an in-depth analysis. The extent of influence of the case company is on the finalization of the hypothetical business model. LCA of all the scenarios was performed based on the existing ISO standards.

4.2.2 Scope

In this step of the LCA methodology, the object of the LCA study, whether product or system, is identified and defined in line with the goal definition (Baumann & Tillman, 2004). In this context, the bike trailer and the repair service through provision of spare parts by the case company was studied. However, it expands the focus by also assessing the use phase, in particularly the usage time and handling of the product which determines the spare parts needed in its lifetime. However, the study makes broad assumption on the usage based on the qualitative interviews with the manufacturing and leasing companies in Sweden. It also does not account for the behavioral changes or the rebound effects of the users. Finally, this object of the LCA study defined the functional unit (FU).

Functional unit

The functional unit can be defined along the lines of "what", "how much", "how well", and "for how long" (European Commission & Joint Research Center, 2010). The FU of the LCA is the service provision of child mobility by bike trailers for 12 years. The use-intensity is considered to be travelling 6 km every day in a city terrain for all seasons in Sweden. The basis of assumption is that bike trailers are mostly used by parents to pick & drop off their kids to the day care center in a Swedish city, which is approximate of 3km (Respondent 2). The technical life is of the frame of the trailer is 10 years, based on the warranty provided by Thule (Thule Group, n.d.), but is assumed to be used by one family under the ownership model for 6 years. The scenarios are elaborated further in the next section, to elicit the author's assumptions approach.

System boundary

The scope also determined the system boundaries within which the LCA was conducted. It included considerations for the natural system boundary, geographical boundary, time boundary and technical system boundaries (Baumann & Tillman, 2004).

The system boundaries for this LCA are cradle to grave, including lifecycle phases of raw material extraction, manufacturing of bike trailer (hereafter combined under "production" phase) and spare parts production, packaging, transportation and distribution, use and maintenance including repairs and refurbishing, and disposal as shown in Figure 4-4 and Figure 4-5. The product is manufactured and packaged in China and transported to the Sweden for use via the distribution center in Netherlands. The use and disposal occur in Sweden. The transportation accounts for distance of material parts from the case company's sub-suppliers to suppliers within China, shipping to Sweden and distribution to Thule Group's stores (henceforth, hubs) within Sweden. Moreover, the scope excludes heating or cooling or electricity emissions from the store, capital goods, infrastructure and cleaning of bike trailer after every lease cycle in the leasing scenario.

Scenario setup

The scenarios for assessing the bike trailer were finalized based on literature review on stroller and its suitability as a PSS and interviews with the leasing companies and within Thule. The starting point for the research was three scenarios provided by Thule, (1) baseline scenario of ownership with sales of spare parts to retailers, considered as indirect maintenance (2) hypothetical ownership scenario with provision of direct maintenance services to consumers and (3) leasing or renting scenario. Through subsequent interviews, it was concluded that the bike trailers have a high secondhand sales value due to their high durability towards the end of a use life for a family. This was complemented by browsing of Swedish e-commerce website, blocket.se where multiple listings of the Chariot Cross 2 model were listed. Since an analysis of the secondhand market was out of scope of this study, the baseline was divided into two scenarios, (1) sales of product and spare parts and disposal after 6 years of use and (2) sales of product and spare parts and secondhand sale to another family which uses the product for 6 more years, with a cumulative total of 12 years. The third scenario was finalized as leasing since interviews with leasing companies indicated that short term rentals yielded losses for the companies compared to long time leases wherein the cost of the trailer is paid back over time. Thus, the leasing scenario with maximum three years of lease time for one family was finalized as the third scenario. The three scenarios which were considered for LCA have been detailed below. The data regarding the baseline scenarios were collected from within the company and its value chain, with assumptions of usage. The hypothetical leasing model was developed based on qualitative interviews with six leasing companies within Sweden and Germany. Acknowledging that the German market is different to

Sweden in terms of maturity of the leasing business models (Respondent 20, Respondent 16) only the product characteristics have been analyzed from the interviews with the German companies.

Baseline – Ownership Scenario 1

In this scenario, one trailer is assumed to be used for 6 years by a family and then discarded for municipal incineration. A double seater Chariot Cross 2 trailer has a maximum weight capacity of 45kg and allows a maximum sitting height of a child of 68cm. Based on this, it is assumed children between the age of 6 months to 5 years can ride in it. Considering a scenario where parents have twins, the trailer will be used for a maximum of 5 years. Alternatively, if assumed that parents have a child within 2 years of birth of their previous child, the trailer is assumed to be used for 7 years. An average of these two scenarios, i.e., 6 years, was derived to be one use-life of the Chariot Cross 2 trailer. This assumption will be followed in both the baseline scenarios. Centered around the FU, the reference flow (RF) and the flows of the system are decided. The RF to satisfy the function for this scenario are 2 bike trailers.

Ownership Scenario 2

In this scenario, a trailer is used by the 1st family for 6 years and sold to the secondhand market online. The second family which buys this stroller secondhand is assumed to use it for 6 years. Since secondhand usage is difficult to estimate due to lack of data, 6 years has been considered as the maximum life. This scenario does not consider any refurbishing done to the bike trailer, and thus considering the wearability of the product, the product might be used for less than 6 years. This scenario is modelled on bold assumptions. Interviews within the case company, with the marketing team and the CEO, indicated a high demand for secondhand Chariot Cross 2 bike trailer. This was confirmed by evidence of total secondhand sales advertisement of this model on the Swedish website selling used products, blocket.se. However, the author is of the opinion that this number is not indicative of user acceptance of secondhand child products and future research is needed to solidify this scenario, as sales listing does not indicate if people are indeed buying the product. The RF for this scenario is 1 trailer. The combined process models for the two baseline scenarios are shown in Figure 4-4

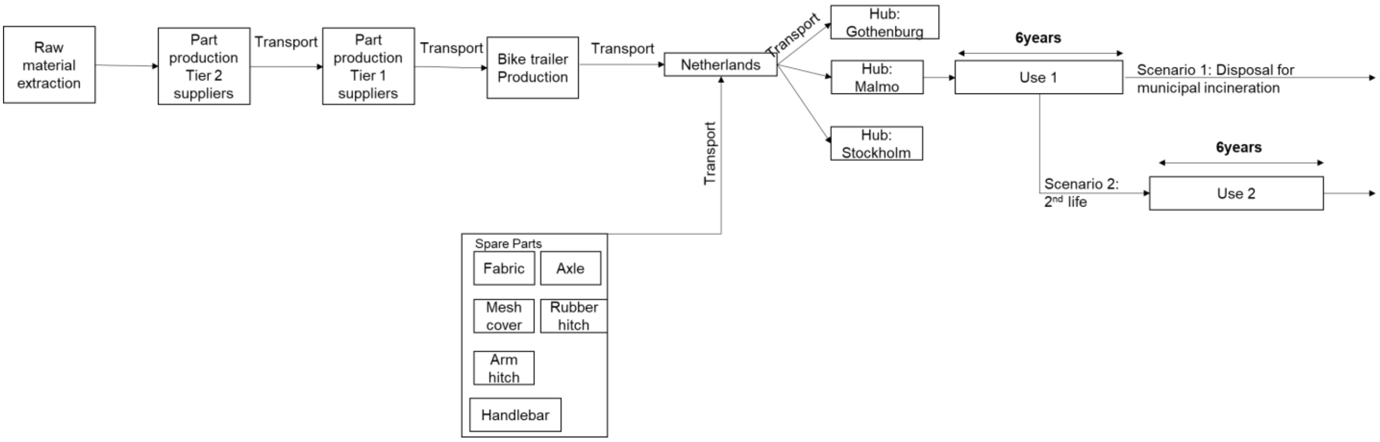

Figure 4-4: Ownership process model.

Source: Author

Leasing scenario

One of the main challenges to transition into PSS development is the creation of new business models (Wallin et al., 2013). The leasing scenario was developed from the interviews and presented using the elements of the business model canvas(BMC) , propositioned by (Nußholz, 2017). The BMC is based on nine building blocks representing key components as proposed by (Osterwalder and Pigneur 2010).

Table 2: Hypothetical leasing PSS scenario presented using Business Model Canvas. Source: Adapted from (Osterwalder and Pigneur 2010)

BMC component	**Variable**	**Leasing scenario or use-oriented PSS offering**
Value proposition (How is the value provided and to whom?)	Value for the customer (Products and services that create value for a specific customer segment)	The value for the customer in the leasing model is generated by reducing large initial investments, maintenance services and offerings of spare parts and accessories for a period of time decided by the customer. Product ownership is retained by the company after usage in the leasing period and option of insurance for theft and damage provided in this offering
	Customer segments (Groups of people or organizations a company aims to reach and provide service to)	The main customers are parents in Swedish who have children between the age of six months to five year old
	Customer relationships (Relationships established with the customer segments)	Considering that Thule has a strong presence in bike trailer category in the Swedish market, the extended relationship with customers by provision of maintenance service become vital
	Product/Service offered	Bike trailer leasing contract with maintenance service. Options of adding accessories to the contract
Value creation and delivery (How is the value provided?)	Key partners (Network of suppliers and partners that support the business model implementation)	Local delivery services like Post Nord for delivering trailers to customers
	Channels (The company's interface to reach their customer segments)	Leasing at the Thule hubs in Stockholm, Gothenburg or Malmö. The products can be pre-ordered from website

	Key resources (Assets required to offer the value to the customer segments)	Repair personnel at the store, competency to deal with leasing management
	Key activities (Activities involved in offering and delivering the value)	Marketing of leasing business, repairing, logistics, customer service
Value capture	Cost structure (Costs incurred when operating a business model)	Monthly payment for a minimum leasing contract of 3 years. Monthly leasing cost is decided on the basis of the market price of the product and with payback period of 3 years. The basis of the payback is decided on the pricing offered by different leasing companies interviewed and their yardstick of payback period.
	Revenue streams (Revenue a company generates from each customer segment)	The revenue is a continuous payment over time from the leasing contract. In cases of damage or theft of the trailer under the leasing period of a consumer, repair cost or loss of business cost is paid by the consumer

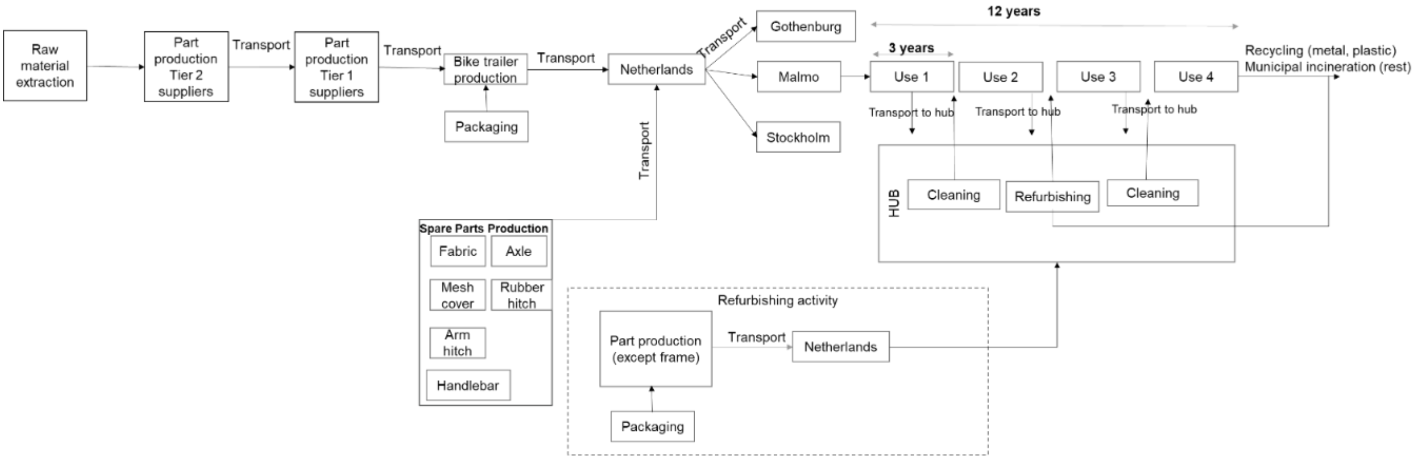

Figure 4-5: Leasing scenario process flow.

Source: Author

In the leasing scenario, the RF is considered as 1 trailer which is leased multiple times over the time period of 12 years. It is assumed that the user leases the trailer for 3 years and send it back to the hub. The transportation between the hub and the user for receiving and sending trailer are considered using local logistics carriers like Post Nord after each leasing period. Cleaning and repairing activity take place after each cycle to ensure that the product is as good as new. This is in consideration that users are particularly cautious about the safety and hygiene aspect of the child products and demand the best quality (ref- interviews, Mont). Further, the interviews indicted that in order to limit any major damage to the bike trailer during the leasing phase, the contract should levy damage fee from the users, if the damage includes bent frame or fabric tear. This has implications on fewer spare parts needed for repair service. The trailer is refurbished every 6 years, by replacing every assembly with new parts except for the main frame to maintain the quality of the product. Towards the end of its life, the trailer is assumed to be dismantled at the hub and sorted for recycling and municipal incineration. The process flow is illustrated in the Figure 4-5. The process flow for the purpose of LCA calculation was developed based on internal consultation within Thule Group with the International Product Manager (of bike trailers) and the CEO. The FU and the RF of all scenarios are summarized in this table below.

Table 3: FU and RF of three PSS scenarios

Scenario	FU	RF or total bike trailers manufactured
Ownership s1	A trailer providing child mobility for 12 years	2
Ownership s2		1
Leasing		1

4.2.3 Lifecycle Inventory (LCI)

In this step, inputs and outputs for each stage of the product lifecycle are modelled. The inputs could be in the form of materials, energy and outputs could be other products, emissions or waste. Baumann & Tillman (2004) stipulate that LCI step of the LCA methodology should begin with constructing a flow model of the technical system in line with the system boundaries, collect data and document them for the relevant activities and processes in the model and finally calculate the environmental loads of the system in reference. In the data collection phase, the inventory data should be representative of the time, geography or technology of the data (European Commission - JRC - IES, 2010). Further, based on the modelling approach determined in the goal and scope specification of this study, i.e., ALCA for this study, guides the allocation type. Ekvall (2020) argues that ALCA should partition through by estimating the share of the burden the multifunctional process belongs to. This also includes consideration of allocation for material and energy in the product in focus. Allocation can be determined based on mass, energy or economic value and in this study, mass allocation was selected for all multifunctional processes. The datasets were considered with "allocation, cut-off by classification, unit processes", in alignment with the goal and scope of the study. This section outlines the lifecycle phase process flows and the underlying assumptions and calculations used by the author to model the scenarios for conducting LCA

Raw material extraction and manufacturing

In this study, the bike trailers are manufactured in China, packaged and transported to Sweden for distribution and sales. Each bike trailer has a total weight of 15.34 kg. This study considers assembly level breakdown as it considers spare parts provision and refurbishing within the scope of LCA. The material composition for the top assembly components of the product is illustrated in Table 8 in the Appendix. Further, this phase also includes production waste processing, which entails calculating the impacts of the waste materials in the production line. The system boundary includes the emissions from the manufacturing of these materials wasted in the production line as this volume wasted is extracted as a resource and transported to the supplier as input to the bike trailer, however, is wasted due to inefficiencies in the production process.

The spare parts production and production of the trailer is considered to done on the same production line, meaning it takes place only once in this LCA. The type of spare parts required, and its number is estimated based on spare parts sales per unit trailer from year 2020 to 2021 and extrapolated to 12 years. It must be noted that the same number of forecasted spare parts have been assumed for the leasing scenario as well, however this number might increase depending on the usage of the trailer. Based on interviews, the author flags caution that handlebar and mesh cover are more susceptible to usage related damage, increasing their production demand.

Within the category of spare parts, components with low weight, such as bolts and screws have been considered out of scope and only considers the assembly level components as spare parts. This includes manufacturing of mesh cover, handlebar and wheels. Further, the electricity used for direct manufacturing of this product is 2.68 kWh per product as provided by the suppliers. Based on mass allocation, the electricity for spare parts production is computed. Finally, after production, the product is packaged consisting of textile, paperboard, plastic packaging and instruction kit, as shown in Table 9in the Appendix. The packaging weight is calculated as 5.34 kg, totaling the product weight to 20.88 kgs. The datasets used to model this phase in SimaPro can be found in Appendix, Table 14. Further the estimation and data sources used for the unit processes in this phase are detailed in Table 12, found the Appendix. This packaged product is transported from China to Sweden.

Transportation

The transportation of this product considers the transportation of material parts from sub-suppliers to suppliers within China to Netherlands, where the distribution center of Thule is located. From the distribution center, the product is transported to the Thule stores in Sweden (henceforth hubs), which are selected through consultation with the company as the three major Swedish cities, Malmö, Gothenburg and Stockholm. The product reaches the hubs through various modes of transports over long distances which are summarized in Table 21, Appendix. The tonne-kilometer (tkm) has been calculated as a product of distance and total product weight, 20.88 kg. The assumptions and estimations used for data calculation in this phase is detailed in the Appendix Table 21.

Use and Maintenance

In the ownership scenarios, the use is assumed to be 6 years for a family, wherein which they take care of the maintenance and cleaning of the bike trailer. Additionally, this is mirrored in the secondhand usage in ownership S2. The secondhand usage is considered a maximum of 6 years as well. It must be taken into account that this is a broad assumption and considering the age of the product, the trailer might be used for a shorter period. It is notable that the product is designed for usage in rough terrain and cold weather conditions as that of Sweden, thus the maintenance is generally limited to cleaning of mud from hard and soft parts, such as fabric. Cleaning activities have not been considered within the system boundary in all scenarios since it is limited to hand or manual cleaning as the fabric cannot be removed by the user for washing in a machine. Additionally, the maintenance phase also considers use of spare parts damaged by wear and tear or production defect. The spare parts produced in the previous phase are used in this phase, their amount and type calculated based on sales data from 2020 to 2021 and their demand is extrapolated for the next 12 years. The spare parts required for a bike trailer is considered to be consistent in all three scenarios.

Alternatively, in the leasing scenario, the bike trailer is to be cleaned after every use cycle. The use cycle has been assumed to be four in a period of 12 years, meaning that the bike trailer is leased four times for a leasing period of 3 years each. This assumption is rooted in the literature which states that strollers are used by a family for three years. Further, this finding is compounded by interviews with the leasing companies who have assigned a maximum leasing contract of 3 years. As new companies, since they are in their experimentation phase, the author recommends future research to solidify this assumption. Additionally, it is assumed that the bike trailer is refurbished after 6 years. Mont et al. (2006)state that a stroller refurbishing should consider only parts which need to be replaced, such as fabric. However, this study considers the most optimistic number and replaces all parts of the trailer but keeps the frame intact. The Chariot Cross 2 model of the bike trailer has a 10-year guarantee for frame, whereas for the rest it is provided as 5 years. The warranty period is taken as an indicator of the durability of the parts (Singh et al., 2019). Deriving from the warranty period, the author justifies that the frame, largely composed of aluminum and plastic, will be durable and functional even after 6 years of use, whereas other components will need to be replaced after this time to make the product look as good as new and in a good working condition. The refurbishing activity includes production of all parts except frame, packaging of these parts and transportation to the hubs in Sweden, as shown in the process flow in Figure 4-6.

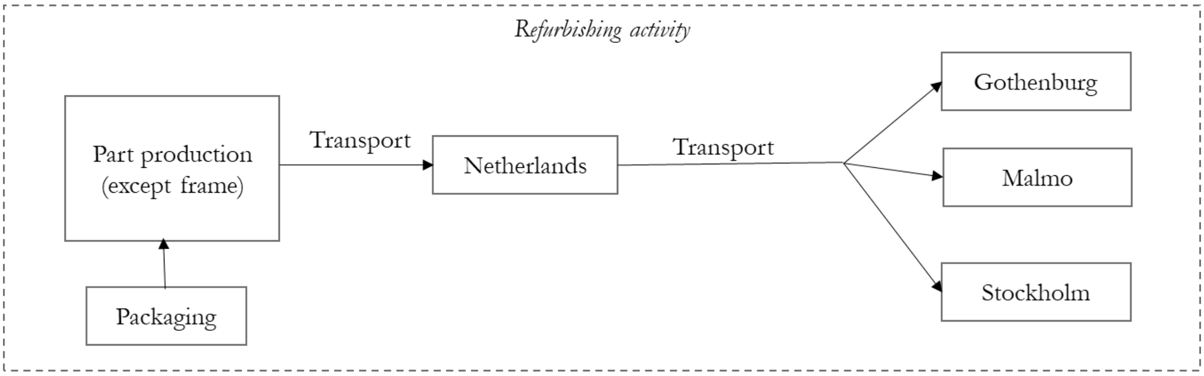

Figure 4-6: Refurbishing process model

Source: Author

End of life

In all three scenarios, the trailer is assumed to be disassembled for recycling metal and plastic components with 100% recycling rate. This constitutes 90% of the product weight. The remaining 10% are sent for municipal incineration. A ready-made Swedish municipal incineration waste scenario in SimaPro has been used for calculating impacts for this 10% weight. This is a very simplified waste scenario as the knowledge around how the product is disposed was not known to the interviewees. Conversely, this waste scenario can only be considered optimistic for the two ownership scenarios as it is not expected for the users to disassemble the product and sorting for recycling. Thus, the author is of the opinion that future research is needed to track the disposal of the product under the three scenarios.

4.2.4 Lifecycle Impact Assessment (LCIA)

Life cycle impact assessment (LCIA) supports the interpretation of LCA studies by translating emissions and resource extractions into a limited number of environmental impact scores. According to ISO 14040 standard, LCIA is carried out in five steps:

- Selection of impact categories, category indicators and characterization models: In this step, the impacts are identified and selected in alignment with the goal and scope of the study, along with the models of cause-effect chains and their endpoints (Baumann & Tillman, 2004)
- Classification, which includes assigning inventory data to the impact categories

- Characterization, meaning calculation and quantifying the environmental impacts per category to represent the cause-effect chains. This is done by multiplying inventory data with a characterization factor.
- Normalization is an optional step which is relating the characterization results to a reference value, which is generally the total impacts of the category in a region. The characterization results are multiplied by a normalization factor to give a unitless value. This is an optional step and more meaningful to use to gain an understanding of the magnitude of environmental impacts caused by a system in focus (Baumann & Tillman, 2004)
- Weighing, which is also an optional step which allows comparison between different impact categories by multiplying normalization results with weighting factors. The methods for generating weighting factors are value-based and dependent on the application of LCA results, for example, on monetarization, targets, panel-decision, etc. (Baumann & Tillman, 2004). However, since quantification are value based., the ISO standards do not allow weighing in public studies

Although normalization and weighing are optional, it can facilitate interpretation of LCA results and better communication to decision and policy makers. The results after characterization are commonly expressed in different metrics, making comparison between impact categories difficult, thus the last two optional steps allow comparison and identification of relevant impacts by analyzing the characterized profile as a whole (Hauschild et al., 2013).

Impact categories are presented at two levels, as midpoint and endpoint indicators. Characterization factors at the mid-point level are located in the cause-impact pathway, near the area of protection. A cluster of category endpoints of recognizable value to society is referred to as an 'area of protection', for example human health, natural resources, the natural environment and the man-made environment. The areas of protection are denoted as human health, ecosystem quality and resource scarcity. Conversely, the end point indicators reflect the damage at these areas of protection. The mid-point indicators have a stronger relation to the environmental flow and have lower levels of uncertainty in results, whereas the end point indicators are aggregated and easier to interpret and communicate in terms of relevance of the environmental flows (Baumann & Tillman, 2004).

Within the LCA literature, there exist many ready-made LCIA methods wherein the environmental impact assessment procedure is packaged together. The author employed ILCD 2011 Midpoint+ method available in SimaPro. Released by European Commission, Joint Research Center in 2012, this is updated version of a LCIA methodology developed based on a comprehensive review of best existing practices for Characterization models and supports the correct use of Characterization factors for impacts assessment (Hauschild et al., 2013). Developed for European context, this method uses indicators only for midpoint indicators and provides normalisation and weighting factors. The normalisation factors are provided for the average European citizen (EU 27) based on domestic inventories in the year 2010 (Benini et al., 2014). While the weighting factors, which receive the same weight in the baseline approach. The author selected this method as weighting factors were presented for the midpoint category, which allowed comparison of the impact categories, to be able to display and discuss the most significant categories in this thesis (European Commission & Joint Research Center, 2012).

4.2.5 Interpretation

The final step of the LCA methodology is interpretation of results to draw conclusions and give recommendations (Baumann & Tillman, 2004). In line with the goal and scope of the study and the intended audience, the results are interpreted along the following steps according to the ISO standards.

- Identification of significant issues, for example, critical methodological choices or important environmental findings
- Evaluating the completeness, sensitivity and consistency tests
- Drawing conclusions and giving recommendations

These steps were performed in SimaPro software and are expounded in the next Chapter.

5 Findings

This section briefly discusses the context of the leasing business model of bike trailers in Sweden, founded on six interviews. This is followed by discussion of results from the LCA.

5.1 Leasing market in Sweden

The interviews with the leasing companies provided insights into the growing leasing market in Sweden and Germany, the usage of the bike trailer and the maintenance requirements needed in this mode. The interview questions, along with the interview list can be found in Appendix, Table 7. The interviews indicated that the leasing market for bike trailers in Sweden is growing with demand due to the highly durable offering of the product. The multifunctionality of using it as a bike trailer and stroller and the option to detach the trailer from the bike offers the users flexibility to select trailers. However, despite the attractiveness of the bike trailers, the high purchasing cost is driving the users to lease it. Leasing of the trailer allows accessibility and affordability through payments in installment and the maintenance service of the trailer is a responsibility of the leasing companies. It was also found that secondhand sales are also a cheaper alternative to buying firsthand, however the comparable cost to new trailers and the lack of trust in the quality of the child product, and ease of maintenance are major drivers of secondhand market to leasing. Although literature suggests the child products like strollers have high hedonic value, and parents are extremely careful with leasing products for their children that might come with safety or hygiene risks (Mont et al., 2006), the two interviewees in Germany were positive on the high growth of the leasing of trailers and the favorable response of parents to the reuse value of the product. Similarly, Sweden is also showing rising positive acceptance of the leasing of child products, such as the bike trailer.

5.2 Results from LCA

Based on the modelling in SimaPro, LCA was performed and results of the three scenarios were compared and analyzed. ILCD 2011 Midpoint+ method was used to conduct the impact assessment. To begin with, comparison of three scenarios based on their aggregate weighted results are presented, followed by weighted comparison of the total impacts of the selected impact categories. The weighting values for this method, measured in single score unit milli points (mPt) are based on EC-JRC Global, equal weighting category of ILCD 2011 Midpoint+ method (European Commission & Joint Research Center, 2012) offered by SimaPro. Although the ISO standards stipulate that aggregation in to single score through weighting for comparison between different products is not allowed (European Commission & Joint Research Center, 2010). the author selects this method as only one product is compared under different scenarios for the same FU to select the impact categories to present in this study as 16 impact categories cannot be presented. Lastly, this section analyses the impact of each scenarios for the selected impact categories in detail using their characterization values as ISO standards state that a single weighted score does not capture the contribution of impacts for different categories as they mean different solutions and issues are needed to address them (European Commission & Joint Research Center, 2010). This section is followed by the last step of LCA methodology, Interpretation, wherein, uncertainty and sensitivity is analyzed. The lifecycle covers cradle to grave analysis for all three scenarios.

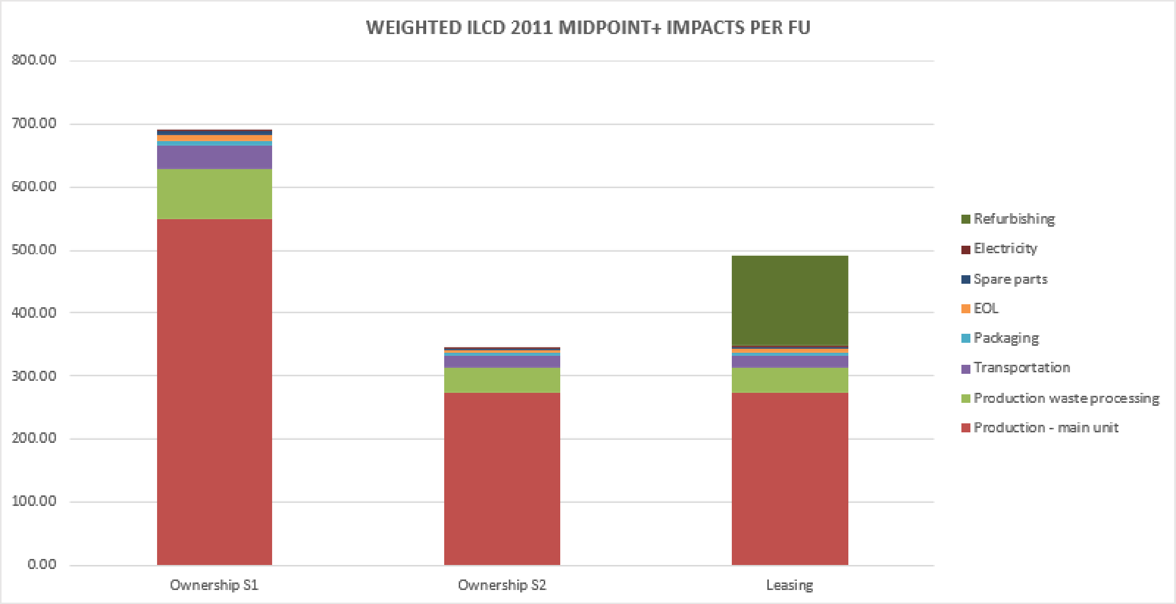

Figure 5-1: Aggregated weighted scores of 3 PSS scenarios. Weighted values based on ILCD 2011 midpoint+: EC-JRC global, equal weighting

The ownership S2 results in overall reduction of aggregated impacts per FU (as shown in Fig xx) and across all impact categories, approximately 50% less than ownership S1 and 30% lower than leasing scenario. This reduction is mainly due to production of one bike trailer in this scenario compared to ownership S1. Impacts from the leasing scenario have the second lowest reduction potential, contributing to 29% lower than the ownership S1. The impacts increase compared to ownership S2 due to the need for refurbishing of the trailer. The contribution of each phase for selected impact categories are detailed in Section 5.2.2.

5.2.1 Environmental impacts by category

The content of this section broadly answers RQ1 which questions how the environmental impacts compare between the three PSS scenarios. The analysis of the inventory and the subsequent impact assessment of the three scenarios performed using SimaPro yielded environmental impacts shown in Figure 5-2.

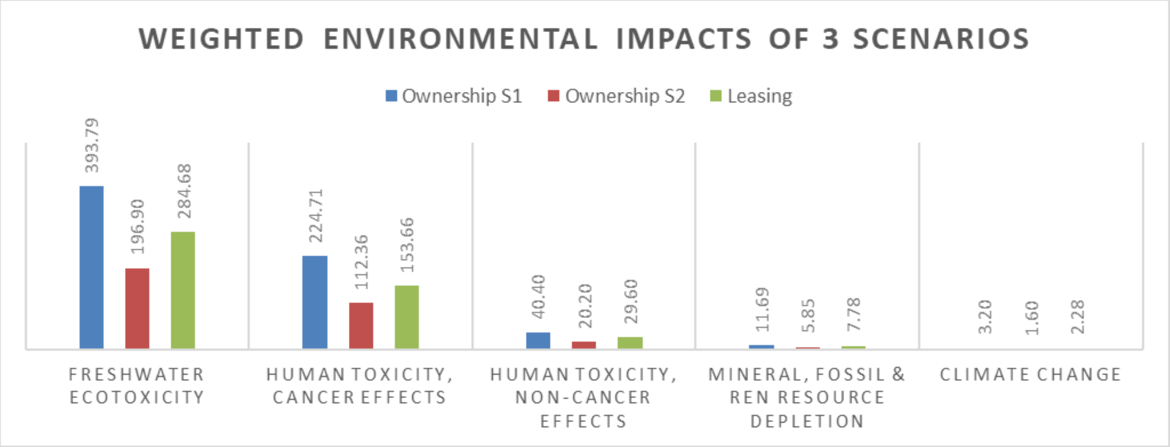

Figure 5-2: Contribution of 3 PSS scenarios to freshwater ecotoxicity, human toxicity, mineral, fossil and renewable resource depletion and Climate Change. Weighted values based on ILCD 2011 midpoint+: EC-JRC global, equal weighting

This figure shows the weighted potential environmental impacts values organized in the descending order of impacts (from left to right). Out of the 16 mid-point impact categories provided by the ILCD 2011 Midpoint method, only five were considered "significant" to be presented in this section. The values for all 16 impacts categories can be found in Table 23 in Appendix. The author defines the term" significance" based on two criteria, the top contributing impacts and the relevant impacts to be displayed from a manufacturing business perspective. The categories- freshwater ecotoxicity, human toxicity (cancer effects), human toxicity (non-cancer effects), mineral fossil and renewable resource are presented as they showed the highest impacts among all categories based on their weighted scores. Climate change is presented since this has been prioritized in corporate action for sustainability like Science Based Targets.

Consistently over these five impact categories, ownership S2 resulted in lowest impacts, followed by the leasing scenario and lastly ownership S1. The next section compares the three scenarios within each of these five impact categories based on their characterization values and details the contribution of lifecycle phases within it.

5.2.2 Phase contribution to environmental impacts for three scenarios per FU

Freshwater ecotoxicity

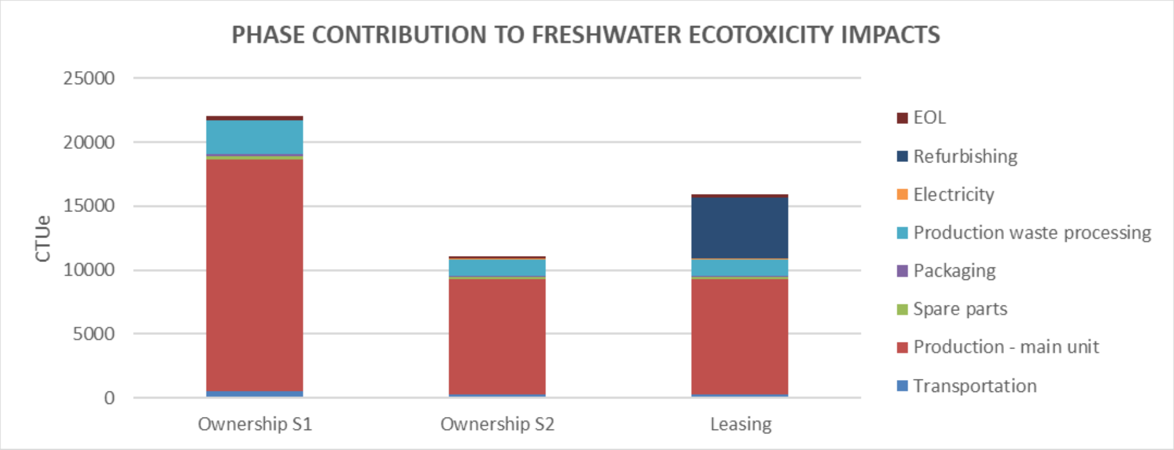

Figure 5-3:Contribution of PSS scenarios to Freshwater ecotoxicity; Characterization based on ILCD 2011midpoint+ method

"Freshwater ecotoxicity potential is captured in Comparative Toxic Unit for ecosystems (CTUe), expressing an estimate of the potentially affected fraction of species (PAF) integrated over time and volume per unit mass of a chemical emitted (PAF m3 year/kg)" (European Commission & Joint Research Center, 2010).

In all scenarios, the production phase, which included production waste processing, refurbishing and transportation accounted for the highest impacts. In both ownership S1 and ownership S2, bike trailer production was the highest contributor to freshwater ecotoxicity potential, responsible for nearly 82% of the impacts. This differs in the leasing scenario where the production of the trailer is only around 57% of the total emissions. As shown in Figure 5-3, the absolute production value of ownership S2 and leasing is significantly lower than ownership s1, by 50% and 28% respectively, since only one bike trailer is produced to satisfy the FU in these two scenarios compared to two bike trailers in ownership s1. Parallelly, the refurbishing activity in the leasing scenario accounts for 30% of the total impact. The main reason for refurbishing having high impacts is that apart from production of the frame assembly of the bike trailer, refurbishing activity includes production and transportation of all assembly parts from China to Sweden. Collectively, the production and refurbishing activity in the leasing scenario accounts for 87% of the emissions, which are comparable to the production contribution in the ownership scenarios. Further, the transportation phase contributes to nearly 2% of the total freshwater ecotoxicity impacts in both ownership scenarios. While considering the increase in transportation activity in the leasing scenario from the leasing hubs to the users, the impacts are slightly lower than the transportation in the ownership scenarios by 0.73%. This signals that the transportation of the product from China to Sweden has drastically higher impacts than the transportation of trailers within Sweden from the designated hubs to the users, indicating potential reduction in transport emissions through organizational decisions.

Human toxicity (cancer and non-cancer effects)

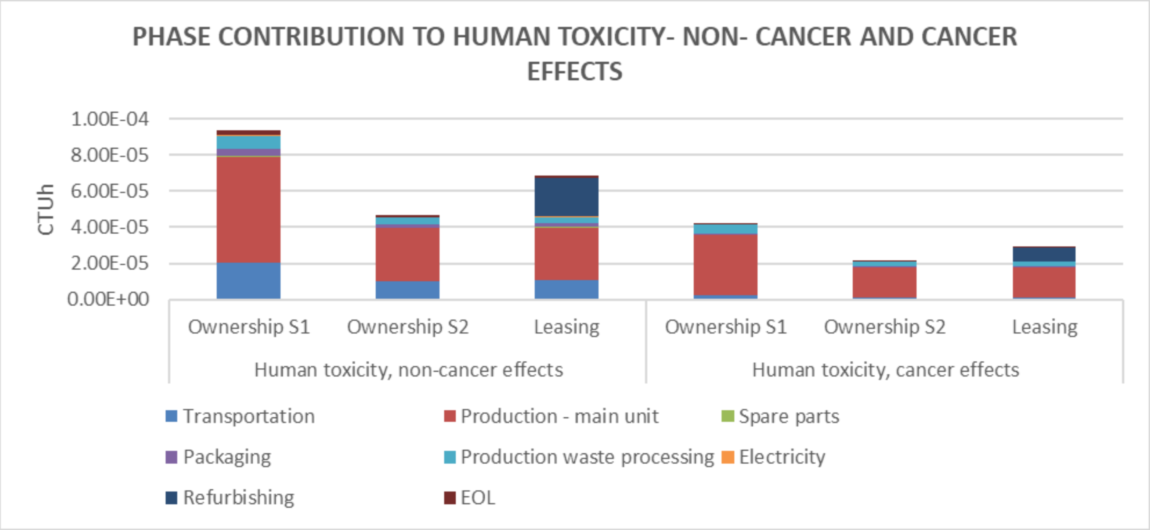

Figure 5-4:Contribution of PSS scenarios to Human toxicity - non-cancer and cancer potential; Characterization based on ILCD 2011midpoint+ method

"Human toxicity, both cancer and non-cancer effects are measure in Comparative Toxic Unit for humans (CTUh), expressing the estimated increase in morbidity in the total human population per unit mass of a chemical emitted (cases per kilogram)" (European Commission & Joint Research Center, 2010). These two categories have thus been presented together in this section as they are measured in the same units and follow the same pattern of impact contribution from the lifecycle phases in the three scenarios. The human toxicity (cancer-effects) potential impacts are consistently 56% lower than the human toxicity (non-cancer effects) potential across the three scenarios. Thus, the author chooses to conduct detailed analysis of human ecotoxicity (non-cancer effects) in this section, which would also be applicable to human ecotoxicity (cancer effects).

Ownership S2 and leasing scenarios contributed 50% and 32% lower than ownership S1 to this impact category. Similar to freshwater toxicity potential, the production phase has the highest impact in all three categories, amounting to 62% and 43% in the ownership scenarios and leasing scenario respectively. However, the absolute CTUh values of the production phase impacts are 50% lower in ownership S2 compared to ownership s1. This is due to production of only one bike trailer per FU in ownership S2, as established earlier. The production impacts in leasing scenario are 20% lower than ownership s1 since production of frame is avoided in the refurbishing phase which is the biggest contributor in the production phase. Alternatively, the refurbishing impacts of the leasing scenario are high, amounting to 31% of the total product impacts. This is the case since refurbishing includes transportation emissions of the parts, which as indicated increases the impacts in this environmental impact category. Furthermore, transportation phase also has significant impacts on the human toxicity potential (non-cancer effects), accounting for 22% and 15% in both ownership scenarios and leasing scenarios respectively. Like freshwater toxicity, the transportation distance and the mode of transportation determine the magnitude of impacts within this phase.

Mineral, fossil and renewable resource depletion

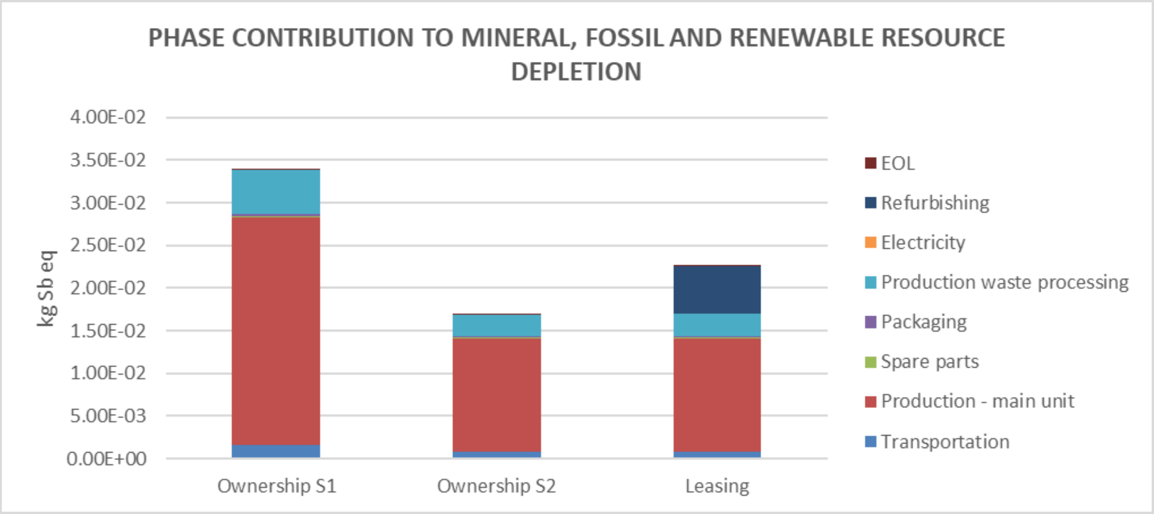

Figure 5-5: Contribution of PSS scenarios to Mineral, fossil and renewable resource depletion; Characterization based on ILCD 2011midpoint+ method

This impact category has the third highest impact among all categories based on the weighted single scores. Following the trends of freshwater and human toxicity potential, ownership S2 has the least impacts on this category, followed by leasing scenario and ownership S1 scenario. They amount to 50% less in ownership S2 compared to ownership S1 and 25% less compared to leasing scenario. Parallelly, the leasing scenario impacts are 33% less than ownership S1 impacts. Moreover, the production and production waste processing at the factory level are the highest contributors in ownership scenarios, amounting to 79% and 15% respectively. Alternatively, in leasing scenario production contributes to 59%, production waste processing contributes to 12%, while refurbishing contributes to 25%. It is interesting to note that the potential impact for this impact category is more from the production phase, including production waste processing . Transportation impact is considerably low compared to other impact categories, amounting to nearly 5% of product emissions over its lifecycle in three scenarios. It can be concluded that the production phase impacts need to be reduced for reducing the mineral, fossil and renewable resource depletion potential impacts.

Climate Change

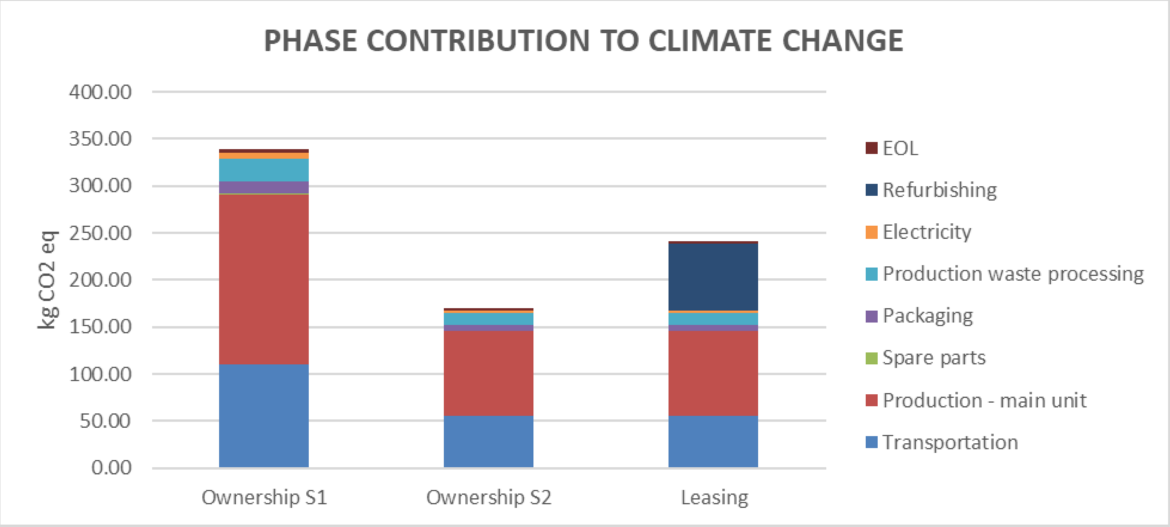

Figure 5-6: Contribution of PSS scenarios to Climate Change; Characterization based on ILCD 2011midpoint+ method

The climate change impact category is captured in Global Warming Potential (GWP), that calculates the radiative forcing over a time horizon of 100 years (European Commission & Joint Research Center, 2010). Figure 5-6indicates the GWP performance of the ownership S2 is better than the leasing and ownership s1. Compared to ownership s1, the ownership S2 contributes 50% less and the leasing scenario 29% less relative to it, indicating that production of two bike trailers and production of frame assembly among other assembly components of the trailer are the main reasons for the higher carbon footprint. The production GWP impacts in the ownership scenarios result to 53% impacts for the product lifecycle, whereas it accounts for 37% in the leasing scenario. Conversely, the refurbishing activity in leasing accounts for 30%. The results indicate that the production of a bike trailer significantly reduces the impact in the leasing scenario, however the refurbishing activity, which is the second highest emission intensive phase, determines the total production impacts. This means that the number of refurbishes in a span of 12 years considered or the total parts used to conduct refurbishing play a significant role in determining the total GWP impacts of the leasing scenario. The Figure 5-7 below elicit the GWP contribution of the assembly parts in the production phase and further display the GWP contribution of the materials in this phase.

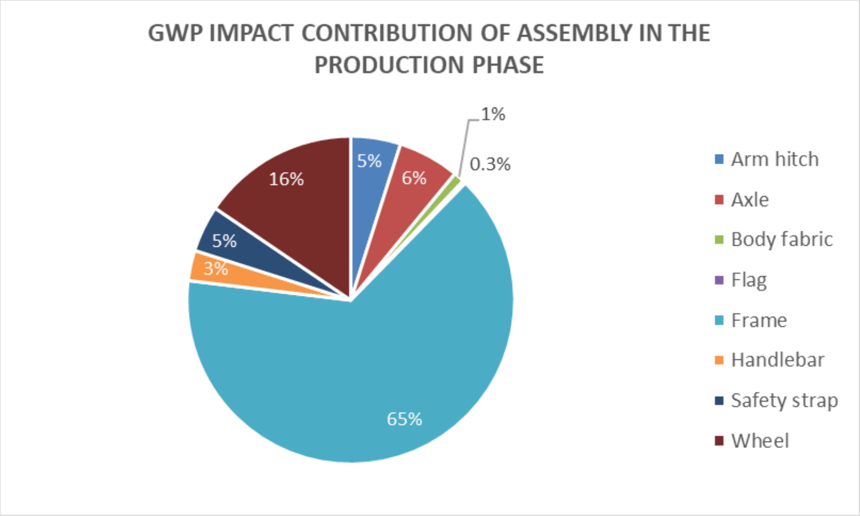

Figure 5-7: GWP contribution of assembly parts in the production phase

Table 4: GWP contribution of materials in Chariot Cross 2 bike trailer

Unit	kg CO2 - eq	%Emissions of total materials
Aluminum	36.9	41%
Steel	2.636	3%
Copper	0.181	0%
Plastic	47.78	53%
Rubber	1.31	1%
Fabric	1.639	2%
Total	90.3	100%

The results in Figure 5-7 indicate that the refurbishing activity has lower emissions, since the frame production is not included, which emits 65% of total production impacts. This is because of its material composition, wherein Aluminum and plastic (mainly composed of nylon 6 with glass fiber) have significant GWP impacts, accounting 41% and 53% respectively for the production impacts. Since the production values are the same for all three scenarios, the materials have the same contribution per bike trailer in all scenarios. The GWP contribution of all materials are shown in Table 4

Furthermore, the transportation activity is the second highest contributor to GWP in the ownership scenarios, amounting to 33% of the impacts. Conversely, in the leasing scenario it accounts for 23%. The transportation division is further elicited in Table 5. This categorization might be useful to the case company in planning logistics to be able to reduce the impacts, with sub-suppliers to suppliers accounting for most of the transport emissions. It should be noted that the hub to user distance considers four round trips in 12 years, for a user located 100km from the hub. The change in the location of user from the hub and the total leasing cycles might impact the total product emissions, which will be further verified in the sensitivity analysis in the next section.

Table 5: GWP contribution of transportation phase

Transport classification in the leasing scenario	
Flow	**% Contribution to transport GWP**
Sub-suppliers to Suppliers	96%
Supplier to Thule	3%
Thule distribution center to hubs	0.1%
Hubs to User (roundtrip per FU)	1%

5.3 Sensitivity Analysis

The results of the LCA are dependent on large number of estimations and assumptions. In order to investigate their extent of impact on the total environmental impacts, a sensitivity analysis was performed. The uncertain variables in each phase, which were estimated based on qualitative interviews were put up for the sensitivity test. Based on parameter changes for each variable, as shown in Table 6, the aggregated weighted scores were calculated and the changes with respect to the impacts in the ownership and leasing scenarios were captured.

Table 6: Sensitivity analysis of uncertain variables in three PSS scenarios

Phase	**Variable**	**How was the parameter changed**	**% Impact change in ownership**	**% Impact change in leasing**
Production	Total number of spare parts	10% increase	0.1%	0.2%
Use	Transport distance of user from hub	10 % increase	0%	0%
	Total assembly parts needed for refurbishment	Only fabric replaced	0%	-29%
	Total refurbishments needed	2	0%	30%
	Lease cycles	10% increase	0%	0%
	Lease cycles	8	0%	0.2%

EOL	Recycling rate	Changing recycling rate to 80% in metals and 50% in plastic (Netherlands waste scenario in SimaPro)	0%	0%

In the production phase, there were uncertainties on how many total spare parts are required per FU for a bike trailer in ownership and leasing scenarios. In the study, the estimation was done based on the spare parts sold in two years (2020-2021) at Thule, however this isn't sufficient timeframe of analysis to arrive at an accurate data. The second phase of changes were considered with usage in the use-phase were regarded as highly uncertain due to high degree of assumptions employed for determining user behavior in the hypothetical leasing model. This included testing the user distance to the hub, the assembly parts needed in the refurbishing cycle, total number of refurbishments needed and the average leasing cycle by the user. The user distance and the leasing cycle was increased by 10% and tested for sensitivity. On the other hand, for refurbishing only the production and transportation of fabric was considered to be part of the refurbishment of the bike trailer. A study by Mont et al (2006) on LCA of strollers considered replacement of all fabric in the product as part of refurbishment due to their shorter lifetime compared to other parts, in their leasing model proposition. This same study further put forth that one stroller could "in theory serve at least 8 users" (Mont et al., 2006). Thus, 8 leasing cycles were considered for this test. Lastly, two refurbishment activities, without altering the assembly parts in the leasing scenario was tested for sensitivity.

The final uncertainty is in the recovery of materials in the end of life of the bike trailer, wherein the 80% metal recycling and 50% mixed plastic waste recycling is considered. The numbers were assigned based on Netherlands waste scenario provided by SimaPro software which has comparable recycling rates due to the mixed composition of the materials in the product. The original scenario considered 100% recycling rate. The description of this scenario is in Appendix.

The total weighted impacts of the bike trailer with respect to the ownership and leasing scenarios are illustrated in Figure 5-8.

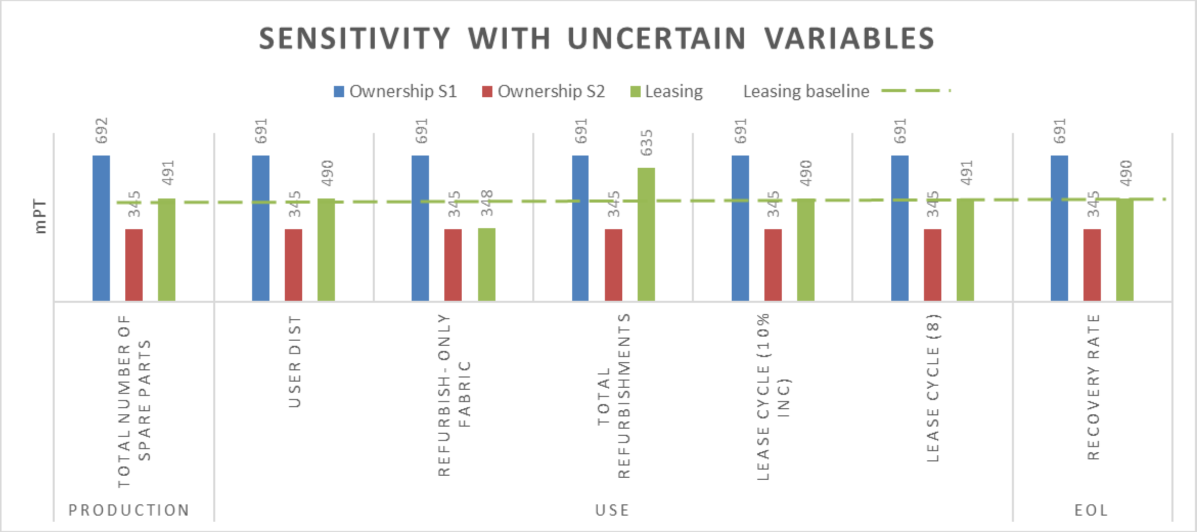

Figure 5-8: Sensitivity analysis of uncertain variables in the model

The results from the sensitivity analysis show that the changes in variables barely change the total impacts in the ownership scenario. Thus, one dashed line denoting the weighted impacts from leasing scenario, i.e., 490 mPt is shown in the figure above. Additionally, both ownership scenarios are displayed to compare the impacts between different scenarios for changes in the variables. The effect of altering refurbishing material, i.e., only fabric, and the total refurbishments have significant impact on the results. Considering fabric is changed once in 12 years as part of refurbishment activity, the leasing impact is comparable to the ownership S2 scenario, as it reduces the impacts from the leasing baseline by 29%. This changes the total emissions of the bike trailer under leasing where it is comparable to ownership S2, nearly 1% lower. Whereas compared to ownership S1, the total emissions in the leasing scenario were nearly 50% lower by altering the assembly part which needs to be replaced in the refurbishing cycle.

Secondly, by carrying out two refurbishment cycles in 12 years, instead of one as done in the original leasing scenario, increases the leasing impact by 30%. The results show that the impacts in the leasing scenario was comparable to ownership S1, around 8% lower, and 46% higher than ownership S2. Here, the refurbishing activity involved replacing all assembly parts in the bike trailer except the frame. These two variables drastically alter the impacts of the leasing scenario as it has implications on the number of assembly parts which need to be produced. As established in the sections above, the production phase of the bike trailer has the biggest impact over its lifecycle. Thus, further investigation is needed on the usage of the product in the leasing scenario, which will determine the intensity and frequency of repair, thus detailing the number of spare parts which need to be produced per FU. The rest of the variables were found to have insignificant effect on the total environmental of the scenarios

5.4 Summary

Based on a case study of a bike trailer manufactured by Thule Group, an LCA was conducted to see how the environmental impacts of a bike trailer change under three scenarios, (1) sales of a bike trailer which is used by a family for 6 years and disposed, also known as "ownership S1", (2) sales of a bike trailer which is used for 6 years and sold to secondhand market and used by a family for 6 more years before disposing, defined as "ownership S2" and lastly (3) leasing of a bike trailer for multiple uses in 12 years, known as "leasing".

The results revealed that the leasing scenario performed 28-33% depending on the impact category better than the ownership scenario when the bike trailers are disposed after 6 years of use. However, if the trailers have a second use through sales in the second-hand market for 6 more years, the ownership scenario is preferable where it performs 25-32% better than the leasing scenario across the impact categories. This is so because only one bike trailer is produced without any refurbishing needs to satisfy consumer needs in a time frame of 12 years. While the leasing scenario has environmental impacts higher than ownership S2, the leasing scenario is deemed to reduce the environmental impacts over the product lifecycle compared to the ownership scenario under the condition that it is disposed after 6 years of use. Although production phase is the biggest contributor to the impacts for all three scenarios, the refurbishing phase contributes significantly to the leasing scenario, contributing to approximately 30% for all impact categories, thus increasing its emissions compared to ownership S2. The results from the sensitivity analysis show that determining what needs to be replaced in the refurbishing phase plays a crucial role in the overall impacts of the bike trailer under leasing scenario. Mont et al (2006) suggest that replacing fabric in a durable product like stroller in the refurbishing activity can prolong the life of the product. The sensitivity analysis showed that replacing only the fabric during refurbishing, resulted in decrease of the environmental impacts by 29% and was comparable to the ownership S2. This indicated that designing a durable product could significantly reduce refurbishing needs, thus making leasing scenario the environmentally best option among the given scenarios. In line with this argument, the number of times refurbishments are needed also change the impacts of the leasing scenario substantially, increasing the impacts by 30% if the product is refurbished twice in 12 years.

The study also investigated the production and transportation impacts in all categories, indicating that manufacture of the frame and transportation within China and from China to Sweden were the main reasons for the high impacts.

6 Discussion

This section first answers the RQs presented in this study by reflecting on the new insights from the interviews which complement the LCA findings. This is followed by discussing the results in relation with earlier LCAs on similar products and discussing the methodological limitations of the study. The section concludes with discussing the generalizability of the study.

The research objective was to recommend a suitable circular business model for bike trailers with improved environmental performance, by comparing the potential environmental impacts of various product-service system scenarios using LCA. While the LCA results informed RQ1, placing these findings in context based on the insights from the interviews, aided in answering RQ2. The reflections from the interviews helped in interpreting the results from RQ1, which is answered in Section 5.4. The study does not provide conclusive answers to RQ2; however, it answers what is the *conditionally* best circular business model for a bike trailer. While the need for further investigation is discussed later, the following sub sections answer the RQ2. It further improves the understanding of the leasing business model for a bike trailer, by explaining its implications on the product design, logistics, and business model implications. The subsection concludes by briefly discussing the assumptions considered in modelling the ownership S2, and the need for research to reduce the uncertainties in the baseline and make it a fair comparison while evaluating and comparing it environmental impacts.

6.1 What is the most suitable circular business model for a bike trailer from environmental performance perspective?

Leasing should be preferred if the alternative is owning the bike trailer and disposing it after 6 years of use. However, if the pram is sold to a secondhand market and used in addition for 6 more years, then ownership is recommended. The results from the LCA conclude the same, wherein ownership S1 had greater impacts than leasing. This is especially so, regardless of considering the replacement of all assembly parts once in 12 years, the leasing scenario nonetheless reduces the environmental impacts compared to the ownership S1 by 29%. The principal reason for emission reduction in the leasing scenario is due to the production of only one bike trailer which is to be used for 12 years compared to producing 2 bike trailers in ownership S1. Moreover, the production of frame of the bike trailer, which is composed of Nylon 6 with glass fiber and Aluminum, collectively accounting for 94% of production emissions, increases the impact of the trailer significantly. Considering that this study does not consider the production of frame in the refurbishing phase, the impacts of leasing are thus lower than ownership S1. However, it should be noted that increasing the need to refurbish to be able to lease the bike trailers in "nearly-new" condition, meaning ensuring safety, functionality, and hygiene aspects of the trailer, might exceed the impacts of the trailers more than the ownership S1. The analysis of the results presented that refurbishing the bike trailer twice within 12 years would increase the impact of the trailer and make the ownership S1 preferable. This has implications for designing the trailer for durability for reducing refurbishing needs and bringing down the need for replacing all the assembly parts after 6 years of usage.

6.1.1 Product design implications

The findings from the interviews within the case company and leasing companies which also lease other child products, such as strollers from other companies, indicate that the bike trailer is already designed to endure the harsher Swedish winter climate and designed to be durable which reduces the spare parts needs compared to the existing strollers in the Swedish market. According to these interviews, the assembly parts more vulnerable to damage through usage are the fabric which is physically accessible by a child while being seated inside the trailer. One instance from the meeting with the technical team at the case company indicated that the mesh cover, which is a mesh-like fabric made of Nylon 6- glass fiber enforced, can have dirt stuck in and might need washing. Thus, a removable mesh cover would ensure that the user can wash the cover during the lease time, reducing the burden or potential replacing of the cover. Furthermore, literature and interviews indicate that modular design to easily replace smaller parts than the entire assembly can ensure lowering production impacts and bring down the total impacts of the trailer being leased. Further, it enables easy repairability and for disassembling at the end of life for either remanufacturing or recycling.

6.1.2 Logistics considerations

The leasing companies mentioned that keeping spare parts inventory for different model and products is hard to forecast to be able to maintain an inventory, and thus needs to be ordered on demand from the product manufacturers (Respondent 16, Respondent 20), leading to an increase in transportation emissions. Conversely, for a manufacturing company to reconfigure their business model to lease their products from their stores, spare part needs can be forecasted from historic data and an inventory can be maintained, reducing the on-demand supply of spare parts from suppliers. In future, the manufacturing companies can find pathways in reduction of logistics emissions by owning their logistics fleet and integrating pickup and delivery routes (Respondent 15, Respondent 20). This could also ensure quicker access to the products (Tukker, 2004). One of the challenges in current delivery and pick up of trailers using local logistics carrier after end of leasing cycle is the packaging which cannot be reused multiple times as the bike trailer. Every new leasing transport would require new packaging frequently since ensuring safe delivery without damage is crucial. Evaluation of how the emissions change with increasing packaging production and its transportation needs to be undertaken. The interviews indicated that currently consumers in Sweden prefer short term rentals during vacation. Further investigation is needed into the repairing needs for long term leasing considering the unpredictability increases with increased usage

6.1.3 End of life management

Bike trailer leasing would ensure that the bike trailers are fully utilized before being disposed (Respondent 15, Respondent 17, Respondent 18, Respondent 19, Respondent 20, Respondent 21; Kerdlap et al., 2021) . The life span of the trailer could increase through multiple repairs; however an evaluation needs to be conducted to test till what extent repairing and refurbishment can be done by not increasing the environmental impacts more than the ownership S1. Further, as the leasing model retains ownership of the bike trailer, the trailer can be disassembled and internally recycled or sold to other companies (Mont et al., 2006), thus improving the end of life management of the trailer.

6.1.4 The secondhand market

The interviews also revealed that many bike trailers gain second life through sales in the secondhand market in Sweden. As the bike trailer is durable after 6 years of useful life, it is still in a good condition to be used and thus an ownership scenario was created considering the secondhand market. The LCA results showed that in this case where one bike trailer is used for a total of 12 years in this ownership scenario, ownership S2, the trailer would have the lowest impacts. This is the case since only a bike trailer is produced for a period of 12 years and no refurbishments are done either by the first owner or the second, except replacing small spare parts such as mesh cover, safety strap, wheel replacement. Although the impacts from this scenario showed to have the lowest impacts, 50% less than ownership S1 and 30% less than the leasing scenario, there were considerable areas of uncertainty while modelling it for the purpose of the study. Mont et al. (2006) and the interviews suggest that it cannot be determined if all bike trailer owners will be able to find a secondhand user. Although a popular secondhand sales website in

Sweden, blocket.se, displayed the presence of many bike trailers, this was not indicative of the presence of the secondhand market for the trailer. Hence, more investigation is needed to determine this, which was considered out of the scope of this study. Furthermore, the interviews suggest that there is a lack of trust by parents for a child product on the safety and hygiene aspects of a used trailer sold online. In contrast, the leasing model, wherein the leasing companies or the manufacturers are responsible for the maintenance of the products can reassure them. Thus, despite of the ownership S2 being environmentally superior to the other studied options, the penetration of 2nd hand market in Sweden is unclear. Furthermore, there is a degree of uncertainty on how long a secondhand bought bike trailer will be used by the second family. The product was assumed to be good to use after 6 years of first use, however since refurbishing was not considered in ownership S2, as it is the responsibility of the user, the actual useful life of the secondhand model might be lower than 6 years. This could potentially increase the impacts from the bike trailer under ownership S2. Therefore, if it is not guaranteed that the bike trailer will get a second life and be used for at least 12 years, it should be leased to have a lower environmental impact.

6.1.5 Business model implications for bike trailer manufacturing companies

The child products, particularly strollers and bike trailers, which have a long technical life but shorter useful life are suitable products for a PSS model, such as leasing (Tukker, 2004). The interviews with the leasing companies in Sweden and in Germany indicated that it is a growing market with leasing trailers moving from short term leasing type during vacation to long term leasing. Since the interviewing companies are less than a year old, the longer leasing duration was not established however they indicated that their market research dictates that leasing of child products is a growing interest. Mont et al. (2006) indicate that maintenance and reconditioning services increase customer retention and thus, create competitive advantage for the stroller (or bike trailer in this case) manufacturing companies. This could further allow them access to the secondhand market, gaining access to new consumer segments who cannot offer firsthand premium cost of the trailer in the first place.

It is imperative for a leasing company to ensure that the safety and functionality of the trailer is guaranteed through reconditioning, as parents are wary of used child products (Mont et al., 2006; Respondent 17, Respondent 19, Respondent 21). Further, the cost of the leasing the trailer should be less than owning it within the same period of time, in order to give the consumers an incentive to buy at an affordable price, besides guaranteed function and service (Respondent 15, Respondent 17, Respondent 20, Respondent 19, Respondent 21). However, it must be noted that smaller consumer base, shorter leasing time and thus, frequent need for cleaning between every lease cycle might not be profitable for the manufacturing company and not give payback in the estimated time frame. Therefore, an economic evaluation should be conducted to support the feasibility of implementing the new CBM. The interviews further indicate that premium brand products, such as Thule, are a symbol of the social status but are inaccessible to many due to their high upfront cost (Respondent 20). The feature of payment as per need will open a new market segment. The cost of leasing prams should be lower than the cost of owning a pram, especially when transaction costs are included. Finally, customers do not need to store the trailers or spend time and efforts selling them on the second-hand market after using them.

6.2 Comparing results of life cycle assessment

In this section, the results are discussed against previous findings of LCA studies on strollers, which are considered proxy products for a bike trailer in this study, as studies specific to bike trailers have not been conducted in academia. (Ang & Yifan, 2012 ; Thorslund, 2019; Kerdlap et al., 2021; Mont et al., 2006) which have compared the bike trailers under different CBM scenarios, the discussion examines the similarities and differences in the results in the context of the case study and identifies the underlying parameters which influence the results. However, it should be noted that the studies are not directly comparable due to the different contexts in which the studies were performed. The context includes different scopes, the way the functional unit is defined, the data and assumptions selected and the selection of impact categories and methods. Based on the brief description of the previous studies in Section 2.6, this section will draw the similarities and differences in the results of the LCA studies. Such a comparison shows that the choices a business makes with regards to material, product design, production location, the usage and end of life treatment of treatment have direct impacts on the environmental performance of the products analyzed. Furthermore, such a comparison also shows methodologically the diversity of results across the products analyzed, suggesting that data availability and researcher assumptions are important factors, which requires transparency and caution among others when interpreting results

6.2.1 Production

One common conclusion to previous LCA studies on strollers is that the production phase is the biggest contributor to the environmental impacts across the entire lifecycle. Overall the production impacts of the LCA in this study, which account for the highest impacts of the bike trailer over the entire lifecycle, are comparable to (Kerdlap et al., 2021; Thorslund, 2019; Ang & Yifan, 2012). However, since the material composition is different in these studies, the comparison at the material level will not be valid. While the thesis results show that plastic, particularly nylon 6- glass fiber reinforced and Aluminum are the main reasons for the high impact, the other studies indicate Aluminum, steel and plastic have high impacts, depending on their mass in the material. In contrast, the fabric of the bike trailer, which was composed of polypropylene and polyester in the case considered in the thesis, had very insignificant aggregated impacts compared to Ang & Yifan (2012) which used polyester fabric and Thorslund (2019) selecting cotton fabric accounted for one of the highest contributions to the total stroller impacts. As ILCD 2011 midpoint+ was selected, it didn't allow for the comparison of absolute impact numbers within the impact categories to the reference papers.

6.2.2 Transportation

While transportation was the second-highest contributor to the aggregated environmental impacts in the ownership scenarios, it resulted mostly from the impacts of transporting material from the sub-supplier to the supplier of bike trailer parts in the production country, China. While this has implications for the case company to select suppliers based on the distance, Mont et al. (2006) and Kerdlap et al. (2021)indicate that the distance to transport bike trailers from the leasing companies could potentially increase the total product impacts. This was tested in the thesis where while conducting the sensitivity analysis, the user distance was changed by 10% and resulted in insignificant changes compared to the total impacts of the trailer. The author analyses that the decision in leasing products from three big cities in Sweden, namely, Malmö, Gothenburg and Stockholm than delivering the products to consumers within Sweden from one distribution center played a role in reducing the transport emissions.

6.2.3 Use and maintenance

Although Mont et al. (2006) flag caution that the provision of spare parts for refurbishment might increase the environmental impacts in the stroller, this study measures the extent to which production of spare parts concerns the repairability of the bike trailer. Considering that a bike trailer has longer durability and resistance to wear and tear than the traditional stroller, the impacts are significantly reduced compared to refurbishing a stroller for leasing purposes. The other reference studies do not consider refurbishment within their system boundaries, thus direct comparison cannot be made.

6.2.4 End of life

As the case company did not have any data on the EOL of the bike trailer after selling them to their customers, due to the nature of the ownership model, and the existing leasing business models have not operated in the market to experience EOL of the trailers, the author assumed simplified scenario with 100% recycling of metals and plastic and the rest is sent for waste incineration in the Swedish market. The datasets were provided in SimaPro. Moreover, a sensitivity analysis was conducted with a Netherlands waste scenario with 80% metal recycling rate, 50% plastic recycling and the rest into incineration to see change in total impacts of the product. The waste scenario of incineration in Sweden however does not include for credited heat or electricity from the process, as it goes beyond the attributional approach. Although the aggregated weighted values did not change significantly with the modified EOL scenario in the sensitivity analysis, the effect on the individual impact categories may be different which should be researched in future. (Kerdlap et al., 2021)considered incineration of the product, 10% energy recovery, in their study based on national statistics of Singapore, whereas other studies assumed their EOL scenarios, facing the data challenges similar to this study. Ang & Yifan (2012) assumed that the product is landfilled after use, whereas the other reference studies are not explicit with their choices. This scenario can be enhanced with primary data collection as part of future research.

6.3 Critical methodological reflection

In this section, the reflections and possible limitations are presented of the life cycle assessment of the bike trailer. The limitations correspond to the choices in the method of data collection, the modelling approach, impacts covered in this study and the quality of data. Based on the results and the methodological choices, the applicability and generalisability of the study to other contexts is discussed.

6.3.1 Data collection methods

In this thesis, the quantitative and qualitative data was collected through consultation with different departments within the case company and interviews with the bike trailer leasing companies in Sweden and Germany. Overall, this provided sufficient data to construct the three scenarios used in this study; however, there was no data collected directly from consumers. Thus, some assumptions or estimations were made based on interviewee data as well as existing literature. With more time and resources, future research may wish to include consumer perspectives through interviews or surveys to form a more accurate profile of user preferences and behaviour and reduce uncertainties in the model.

6.3.2 Defining scope

The study took ALCA modelling approach, which captured the environmental burden of the product under the three PSS scenarios. However, taking this choice also implied that the impacts of the services on the background system were not captured, for instance impacts on market and potentially capturing the rebound effects. CLCA modelling approach would have been suitable to capture the consequences which would have perhaps magnified the impacts of the bike trailer. For instance, less demand of bike trailer would lead to decreased production, impacting the suppliers economically. Conversely, this might reduce resource extraction of virgin materials and benefit the system. These effects can be analysed in consequential modelling, but the FU needs to designed more comprehensively, accounting for market changes of replacing linear economy with circular economy (European Commission & Joint Research Center, 2010). However, as ALCA is more established (Ekvall, 2020) and the complexity to model CLCA , it was deemed as the appropriate choice for this study. However, this opens opportunities for future environmental evaluation using CLCA. Moreover, the FU for this study was defined to capture the product and service offering of a PSS and to render it comparable to other scenarios. In doing so, the author deduced the usage period as 12 years, based on the rationale mentioned in Section 4.2.1. However, it is possible to use the bike trailer for more than 6 years and 12 years in the ownership and leasing scenarios, respectively. This was a crucial variable to assess under the sensitivity analysis, however the design of the FU for a PSS meant creating a new FU with new usage periods. Thus, modifying the definition of a representative FU for PSS comparison could capture varying usage periods of the bike trailer. Moreover, the scope excludes heating or cooling or electricity emissions from the store, capital goods, infrastructure and cleaning of bike trailer after every lease cycle in the leasing scenario.

6.3.3 Data limitations and assumPtions

There were certain data gaps in the LCA model, arising from lack of data available through consultations with the case company and the interviews conducted. The author used best representative data and rationale for assumptions which are outlined here. However, these data gaps influence the results of the LCA which are discussed here.

The PSS scenarios to be compared were developed on the basis of initial collaboration with the case company. The appropriateness of evaluating the product under the leasing scenario was verified and validated through literature (Kjaer et al., 2016; Mont et al., 2006). The scenarios were modified to include second-hand sales based on the insights from the interviews. Although only three PSS scenarios were compared, bike trailer is probably compatible with other PSS scenarios and might provide better environmental performance. This could be explored in future research.

Ownership S1	**Ownership S2**	**Leasing**	**General**
-A family uses the bike trailer for 6 years - The trailer is disposed after 6 years	-Second family uses the trailer for 6 years - total use of a bike trailer is 12 years, after which it is disposed	- A family leases the trailer for 3 years -Refurbishment is carried out once after 6 years of leasing a trailer - Refurbishment activity includes replacing of all assembly parts except the frame - Leasing hubs are located in 3 major cities of Sweden - Stockholm, Malmö, Gothenburg - User distance from the leasing hub is 100 km - A trailer can be used for a total of 12 years	- EOL management includes 100% recycling of metals and plastic. The rest is incinerated as municipal waste in the Swedish waste incineration scenario.

One assumption in the ownership scenarios was that the bike trailer is used for 6 years by the first family and additionally 6 years by the second family through secondhand sales. Based on maximum carrying capacity and the sitting height of the trailer, i.e., 45 kg and 68 cm respectively, it was assumed that children between the age of 6 months to 5 years can ride in it. Considering a scenario where parents have twins, it is assumed that the trailer would be used for a maximum of 5 years. Alternatively, if assumed that parents have a child within 2 years of birth of their first child, the trailer is assumed to be used for 7 years. An average of these two scenarios, i.e., 6 years, was derived to be one use-life of the Chariot Cross 2 trailer in the ownership scenarios. This could however change if the double seated trailer is used for other purposes, such as for cargo or carrying pets (Respondent 19). Thus, only one scenario of usage, for carrying children was assumed to be the purpose of the trailer, however the use life could extend beyond 6 years if the users utilize the trailer as a cargo, which is dependent on the choice of the users. Alternatively, in the leasing scenario, 3 years is assumed to be the maximum leasing time for a user, accommodating 4 users in 12 years' time. This assumption was made based on the use life of the trailer for one child and the maximum leasing time stipulated in the leasing contracts of the companies interviewed. Acknowledging that the leasing could be either short term rentals, ranging from daily to weekly to a month, mid-term, i.e., less than 6 months or long term, the cleaning and repairing requirements could increase, resulting in higher demand of spare parts or higher transaction costs in maintenance. Altering the useful life in all scenarios could potentially change the environmental impacts and have bearing on the economic impacts if the product needs frequent maintenance to be made durable beyond 6 years, which need to be investigated in future.

Furthermore, the total number of refurbishments considered and the assembly parts which need to be produced, transported, and replaced in this activity is the most optimistic value. The interviews with the testing department within the case company indicated that the sturdiness of the product will potentially not require replacements of all parts, but since this has not been tested, the warranty provided for the assembly parts was considered as a proxy of their technical life (Singh et al., 2019). The frame has a total warranty of 10 years, and the rest of the products for 5 years, thus justified replacing all parts except frame after two complete leasing cycles, i.e., 6 years. The sensitivity analysis revealed that reducing the total assembly parts for refurbishment could drastically decrease the impacts of the bike trailer, whereas increasing the frequency of refurbishment proves to be environmentally detrimental than the ownership S1.

The delivery of the bike trailers and their pickup after every leasing cycle is done by the local delivery service, for example, Post Nord. The study assumes that the maximum delivery distance from the hubs or stores is 100 km. Although, a sensitivity analysis by increasing the distance by 10% did not result into significant impact changes of the trailer, the impacts could potentially change if scenarios of the user travels multiple number of times for picking up the bike trailer or for maintenance. However, as the results show that this transportation distance has trivial contribution to the total impacts of the trailer, thus the overall impact of the trailer is likely to not increase drastically from the current values.

Finally, the EOL scenario of the bike trailer were highly simplified, where recyclable materials in the bike trailer, i.e., Aluminum, steel and plastic were assumed to undergo recycling with 100% recycling rate. Whereas the remaining parts of the trailer were forwarded for waste incineration in Swedish market. In reality, the users might not disassemble the different assembly parts of the bike trailer as they are bolted together, and the trailer might either end in landfill or waste incineration. As the EOL of the trailer was not tracked by the case company or the leasing companies, this waste scenario was modelled and put up for sensitivity test where 80% metals are recovered, and 50% plastic is recovered. This was modelled on the basis of Netherlands waste scenario as provided by SimaPro.

6.3.4 Impact categories

The author decided to present the results in four impact categories based on the highest impact category calculated from the aggregated weighted scores based on ILCD 2011 midpoint+ method. As previous LCA studies on strollers did not consider the same method for calculation, the decision on the categories to display was taken at the author's discretion. While the weighted scores were considered to compare and select the categories to display, the differences within the impacts are not fully captured and aggregation runs the risk of overlooking the key impact categories. Consecutively, displaying all sixteen impact categories based on their Characterization values would have illustrated a more accurate portrait of the extent of impacts of the bike trailer.

6.4 Generalisability

This thesis evaluated the impacts of a bike trailer under ownership and leasing scenarios. Although the thesis focuses on a niche product, the results can be extended to other products with similar product characteristics as the bike trailer. This implies that products which have no emissions in their use life and have a shorter useful life than the product lifespan, such as other child products. Moreover, the hypothetical leasing model developed through consultation can also be replicated for these products. However, while generalizing the results, the business model should consider the functionality of the similar products and how long the user needs it. For example, household tools such as screwdrivers and hammers are preferable for short term rentals (Husqvarna AB, n.d.) whereas child products can be leased for a longer time. This has implications on the frequency of maintenance, the cleaning and personnel cost and the payback period of the original investment of the product (Respondent 1).

The impact results in this thesis were presented showing scenario comparison, phase contribution including material and assembly contribution to the impacts, and comparison between different impact categories within ILCD 2011 Midpoint+ impact assessment method. The presentation of data in different formats allow for businesses to make decisions on how they could reduce environmental impacts. Additionally, the results of this LCA showed trends similar to LCA studies (Kerdlap et al., 2021; Thorslund, 2019) conducted on strollers, that the leasing model resulted in lower impacts than ownership models under certain conditions. Moreover, investigating the phase contribution in detail, it was concluded in this thesis and other reference studies (Kerdlap et al., 2021; Thorslund, 2019; Ang & Yifan, 2012) that production of the bike trailer is the biggest contributor to the impacts.

While this study indicated durable design of the product and modular design reduces refurbishing needs and thus reduces impacts, it also signals that product that require frequent maintenance and refurbishments could potentially increase the environmental impacts of the product. Consequently, similar studies also show that transportation and intensive cleaning activities can increase impacts of the product significantly. While this study examines one specific case, the results are comparable with previous studies of similar products. For example, this study uses similar approaches by (Kerdlap et al., 2021). Furthermore, this thesis provides a thorough overview of the methods, case context, data, and assumptions, which may help future researchers to replicate research of bike trailers in different contexts, or different products in similar contexts.

7 Conclusion

The thesis research aimed to serve the objective to recommend a suitable circular business model for bike trailers with improved environmental performance, by comparing the potential environmental impacts of various product-service system scenarios: (1)the current baseline scenario of sales and provision of spare parts with disposal after 6 years of use (2) baseline scenario of sales and spare parts provision with the product gaining a second life in the secondhand market in Sweden (3) leasing of the product. This thesis explored the following research questions:

RQ1: How do the environmental impacts of a bike trailer compare between the three PSS scenarios?

RQ2: What is the most suitable circular business model for a bike trailer from environmental performance perspective?

RQ1 was answered by comparing the LCA results between the three scenarios and outlining the reasons for the high impacts and the consequences on the total impacts were tested for the uncertain variables. The results revealed that the leasing scenario performed 28-33% depending on the impact category better than the ownership scenario when the bike trailers are disposed after 6 years of use. However, if the trailers have a second use through sales in the second-hand market for 6 more years, the ownership scenario is preferable where it performs 25-32% better than the leasing scenario across the impact categories. Moreover, several important parameters were identified at the level of phase, assembly parts and materials which were critical for the environmental performance of the bike trailer. The results showed that the production of bike trailer, particularly the main frame which is composed of nylon 6 with reinforced glass fiber, were the main contributing factors to the environmental impacts of the bike trailer. An important implication of the results is in the selection of material in the production of material, product design and decisions on reducing transportation emissions. Moreover, the results of the sensitivity analysis demonstrated that the increased refurbishing activity, which includes assembly parts production and its transportation from China to Sweden could considerably increase the impacts of the bike trailer under the leasing scenario. The product should hence be designed for durability for prolonging the lifespan of the assembly parts and reduce the need for refurbishing. Additionally, modular design of the product would ensure ease of maintenance, wherein the assembly parts are easily replaceable during refurbishing, foregoing the need for production of bigger assembly parts.

The author, however, raises a flag of caution in interpreting the LCA results as a direct interpretation of an "suitable business model from environmental performance perspective". The decision makers should interpret the results in context of the study, meaning that along with the degree of uncertainty modelled in the LCA, the maturity of the market should be considered. For instance, if a majority of bike trailers do not have a second life through second-hand sales, the results of ownership S2 are not valid. Moreover, in a case where there is no second-hand sale of a bike trailer, the use-oriented PSS is preferable over product-oriented PSS. Ensuring that one bike trailer can provide service for more than 12 years without heavy maintenance needs can significantly decrease environmental impacts compared to ownership. However, as the sensitivity results indicate, increased intensity of maintenance through refurbishing could potentially increase the impacts more than the product-oriented PSS. Thus, caution must be exercised that the product under the use-oriented PSS should be designed for durability and requires the only little maintenance to maintain the functionality and safety characteristic of the product. Parallelly, if the leasing market does not have consumer acceptance, and consumers prefer short term rentals, increased maintenance activities might increase the impacts. These accompanying factors complicate the interpretation of LCA results presented in this thesis in answering RQ2 on "what is the most suitable circular business model for a bike trailer from environmental performance perspective?".

7.1 Recommendations to manufacturing companies

The author provides recommendations to the bike trailer manufacturing and leasing companies based on the findings from the LCA and qualitative interviews with leasing companies

- The selection of materials in the production of bike trailer is critical. Reduce impacts from the production phase by using materials with lower environmental impact
- Select suppliers closer to production and distribution facility to reduce impacts caused from transportation phase
- Bike trailers should be designed with durability and modularity for ease of maintenance. While durable products reduce the need for maintenance, modular parts are easy to disassemble and repair. Also design modular parts enable disassembly for recycling.
- Design spare parts so that they are compatible with all bike trailer models. Further, designing them to ensure those parts will be used throughout many iterations of the product (for many years) will ensure limited risk of surplus while preparing spare parts inventory at the leasing model. Subsequently, accurate forecasting of the spare parts and preparing spare parts inventory by careful investigation of the repair needs would avoid purchase of spare on demand.
- Partner and collaborate with existing leasing companies for broader outreach
- Develop leasing contract to include cost incurred by the customer if damaged beyond normal wear and tear to disincentivize need for refurbishment
- Encourage consumers to lease the product for a longer time period to avoid frequent cleaning or repairing and to get faster payback on the capital cost of the product
- Planning resource allocation for management of leasing service – customer support, logistics, repair and cleaning personnel
- Marketing to promote the new business model with focus on guarantee of trust and quality, sustainability and affordability
- Develop infrastructure for end-of-life management of the trailers which are beyond repair. These include options for disassembly and remanufacturing or recycling

7.2 Significance of the thesis

The findings are mostly aligned with the previous LCA studies on strollers, which have analyzed them at a product level and compared to the leasing or rental scenarios. Although few differences could be identified which could be attributed to the modelling decisions made, this thesis goes beyond these studies by including the refurbishment of trailer and estimating spare parts needs for repairing. By doing so, it highlights the importance and sensitivity of the maintenance activities in significantly increasing overall impacts of the bike trailer.

The contribution of this study lies in conducting environmental impact assessment for a new product category, bike trailer, which is more durable and have longer use life than the conventional strollers. Thus, by transparently outlining the assumptions and estimations, this study provides the LCA practitioners, manufacturing companies and leasing companies opportunities to improve or modify the results to help assess a potential CBM and provide important insights on what to consider when replicating the LCA for similar products. Further, for the leasing companies which are already implementing this business model, the insights into the hotspots in the model and the potential means of reducing impact within their scope through forecasting and bulk ordering spare parts, optimize logistics planning to decrease impacts from delivering the products could be useful.

The research demonstrated that the LCA provided an appropriate methodological framework to integrate lifecycle thinking into evaluating the environmental impacts over the entire lifecycle of the product under the three PSS scenarios. However, using LCA in the context of PSS was challenging. This was reflected in the way the challenges in the way the reference system, FU and the system boundaries were defined. The FU was designed to capture the usage time but to introduced inflexibility to set it for sensitivity testing. Moreover, LCA does not fully capture the dynamic nature of PSS, wherein the consumption practices may change. Further defining system boundaries to include rebound effects or the consequences of change of services on the background system becomes crucial. This has implications on future research to develop guidelines for using LCA for evaluating a PSS. Furthermore, due to the hypothetical nature of the use-oriented PSS scenario and hence the lack of data availability to model the LCA, introduced a degree of uncertainty as the author had to consider the best representative data to provide meaningful results.

7.3 Recommendations for future research

Although the thesis research comprehensively evaluates the environmental impacts of the bike trailer under the three PSS scenarios, there are important topics that could be studied in future to enhance this research. This thesis started with defining the problem of upscaling CBM in the businesses due to lack of environmental and economic feasibility assessment before implementation of the new CBM. This study partially supported the upscaling challenge by conducting an environmental assessment of a CBM archetype, a use-oriented PSS of a bike trailer, and compared it to two scenarios of product-oriented PSS of a bike trailer using LCA. However, the environmental assessment was a narrower scope considered by the author and thus, economic assessment needs to be conducted to make a business case for transition to CE through implementation of a CBM. It will be of great value to explore tradeoffs between the environmental impacts and cost performance for future study. Further, inclusion and evaluation of the social impact assessment would be useful to speak to the sustainability of the business models.

It would be helpful to address the uncertainties of usage of the bike trailer under leasing through a sensitivity analysis. This includes the manner in which the bike trailer is used and the variation in lease cycles, which determine the which parts need to be repaired and the frequency of repair. An investigation into the usage pattern as future research and modelling the LCA to incorporate rebound effect would be useful. Further, a comprehensive data of the transportation distance of the users from the leasing store would provide accurate estimation of the impacts from the transportation phase This thesis therefore generates knowledge on the environmental benefits of a use-oriented PSS over a product-oriented PSS and provides direction for future research.

8 Bibliography

Ang, Y., & Yifan, L. (2012). Carbon Footprint Analysis for Baby Strollers. *Chinese Journal of Population Resources and Environment*, *10*(4), 16–21. https://doi.org/10.1080/10042857.2012.10685103

Bocken, N. M. P., de Pauw, I., Bakker, C., & van der Grinten, B. (2016). Product design and business model strategies for a circular economy. *Journal of Industrial and Production Engineering*, *33*(5), 308–320. https://doi.org/10.1080/21681015.2016.1172124

Bocken, N. M. P., Olivetti, E. A., Cullen, J. M., Potting, J., & Lifset, R. (2017). Taking the Circularity to the Next Level: A Special Issue on the Circular Economy: Taking Circularity to the Next Level. *Journal of Industrial Ecology*, *21*(3), 476–482. https://doi.org/10.1111/jiec.12606

Böckin, D., Willskytt, S., & Tillman, A. et al. (n.d.). *What makes solutions within the manufacturing industry resource efficient?* 19.

Boehm, M., & Thomas, O. (2013). Looking beyond the rim of one's teacup: A multidisciplinary literature review of Product-Service Systems in Information Systems, Business Management, and Engineering & Design. *Journal of Cleaner Production*, *51*, 245–260. https://doi.org/10.1016/j.jclepro.2013.01.019

Care by Volvo I The all-inclusive car subscription. (n.d.). Retrieved January 28, 2022, from https://www.volvocars.com/us/care-by-volvo/

Das, A., Konietzko, J., & Bocken, N. (2022). How do companies measure and forecast environmental impacts when experimenting with circular business models? *Sustainable Production and Consumption*, *29*, 273–285. https://doi.org/10.1016/j.spc.2021.10.009

Ekvall, T. (2020). Attributional and Consequential Life Cycle Assessment. In M. José Bastante-Ceca, J. Luis Fuentes-Bargues, L. Hufnagel, F.-C. Mihai, & C. Iatu (Eds.), *Sustainability Assessment at the 21st century*. IntechOpen. https://doi.org/10.5772/intechopen.89202

Ekvall, T., & Weidema, B. P. (2004). System boundaries and input data in consequential life cycle inventory analysis. *The International Journal of Life Cycle Assessment*, *9*(3), 161–171. https://doi.org/10.1007/BF02994190

EMF. (2013). *Towards the circular economy*. Ellen MacArthur Foundation. Cowes, Isle of Wight, UK. https://ellenmacarthurfoundation.org/towards-the-circular-economy-vol-1-an-economic-and-business-rationale-for-an

EMF. (2015). *Towards a circular economy: Business rationale for an accelerated transition*. Ellen MacArthur Foundation. Cowes, Isle of Wight, UK. https://emf.thirdlight.com/link/ip2fh05h21it-6nvypm/@/preview/1?o

European Commission & Joint Research Center. (2010). *ILCD handbook: General guide for life cycle assessment: detailed guidance*. Publications Office of the European Union. http://lct.jrc.ec.europa.eu/pdf-directory/ILCD-Handbook-General-guide-for-LCA-DETAIL-online-12March2010.pdf

Finnveden, G., Hauschild, M. Z., Ekvall, T., Guinée, J., Heijungs, R., Hellweg, S., Koehler, A., Pennington, D., & Suh, S. (2009). Recent developments in Life Cycle Assessment. *Journal of Environmental Management*, *91*(1), 1–21. https://doi.org/10.1016/j.jenvman.2009.06.018

Frosch, R.A. and Gallopoulos, N.E. (1989) Strategies for Manufacturing. Scientific American, 261, 144-152. https://doi.org/10.1038/scientificamerican0989-144

Geissdoerfer, M., Savaget, P., Bocken, N. M. P., & Hultink, E. J. (2017). The Circular Economy – A new sustainability paradigm? *Journal of Cleaner Production*, *143*, 757–768. https://doi.org/10.1016/j.jclepro.2016.12.048

Goedkoop, M. J. (1999). *Product Service systems, Ecological and Economic Basics*. 132.

Goyal, S., Chauhan, S., & Mishra, P. (2021). Circular economy research: A bibliometric analysis (2000–2019) and future research insights. *Journal of Cleaner Production*, *287*, 125011. https://doi.org/10.1016/j.jclepro.2020.125011

Guldmann, E., & Huulgaard, R. D. (2020). Barriers to circular business model innovation: A multiple-case study. *Journal of Cleaner Production*, *243*, 118160. https://doi.org/10.1016/j.jclepro.2019.118160

Hauschild, M. Z., Goedkoop, M., Guinée, J., Heijungs, R., Huijbregts, M., Jolliet, O., Margni, M., De Schryver, A., Humbert, S., Laurent, A., Sala, S., & Pant, R. (2013). Identifying best existing practice for characterization modeling in life cycle impact assessment. *The International Journal of Life Cycle Assessment*, *18*(3), 683–697. https://doi.org/10.1007/s11367-012-0489-5

Hertwich, E. G. (2008). Consumption and the Rebound Effect: An Industrial Ecology Perspective. *Journal of Industrial Ecology*, *9*(1–2), 85–98. https://doi.org/10.1162/1088198054084635

Hofmann, F. (2019). Circular business models: Business approach as driver or obstructer of sustainability transitions? *Journal of Cleaner Production*, *224*, 361–374. https://doi.org/10.1016/j.jclepro.2019.03.115

Hou, Q., Mao, G., Zhao, L., Du, H., & Zuo, J. (2015). Mapping the scientific research on life cycle assessment: A bibliometric analysis. *The International Journal of Life Cycle Assessment*, *20*(4), 541–555. https://doi.org/10.1007/s11367-015-0846-2

Kerdlap, P., Gheewala, S. H., & Ramakrishna, S. (2021). To Rent or Not to Rent: A Question of Circular Prams from a Life Cycle Perspective. *Sustainable Production and Consumption*, *26*, 331–342. https://doi.org/10.1016/j.spc.2020.10.008

Kjaer, L. L., Pagoropoulos, A., Schmidt, J. H., & McAloone, T. C. (2016). Challenges when evaluating Product/Service-Systems through Life Cycle Assessment. *Journal of Cleaner Production*, *120*, 95–104. https://doi.org/10.1016/j.jclepro.2016.01.048

Korhonen, J., Honkasalo, A., & Seppälä, J. (2018). Circular Economy: The Concept and its Limitations. *Ecological Economics*, *143*, 37–46. https://doi.org/10.1016/j.ecolecon.2017.06.041

Linder, M., & Williander, M. (2017). Circular Business Model Innovation: Inherent Uncertainties: Circular Business Model Innovation. *Business Strategy and the Environment*, *26*(2), 182–196. https://doi.org/10.1002/bse.1906

Lingegård, S. (2020). Product service systems: Business models towards a circular economy. In M. Brandão, D. Lazarevic, & G. Finnveden, *Handbook of the Circular Economy* (pp. 61–73). Edward Elgar Publishing. https://doi.org/10.4337/9781788972727.00013

Magretta, J. (2002, May 1). Why Business Models Matter. *Harvard Business Review*. https://hbr.org/2002/05/why-business-models-matter

Manninen, K., Koskela, S., Antikainen, R., Bocken, N., Dahlbo, H., & Aminoff, A. (2018). Do circular economy business models capture intended environmental value propositions? *Journal of Cleaner Production*, *171*, 413–422. https://doi.org/10.1016/j.jclepro.2017.10.003

Masi, D., Day, S., & Godsell, J. (2017). Supply Chain Configurations in the Circular Economy: A Systematic Literature Review. *Sustainability*, *9*(9), 1602. https://doi.org/10.3390/su9091602

Mazzi, A. (2020). Introduction. Life cycle thinking. In *Life Cycle Sustainability Assessment for Decision-Making* (pp. 1–19). Elsevier. https://doi.org/10.1016/B978-0-12-818355-7.00001-4

Mont, O., Dalhammar, C., & Jacobsson, N. (2006). A new business model for baby prams based on leasing and product remanufacturing. *Journal of Cleaner Production*, *14*(17), 1509–1518. https://doi.org/10.1016/j.jclepro.2006.01.024

Moreno, M., De los Rios, C., Rowe, Z., & Charnley, F. (2016). A Conceptual Framework for Circular Design. *Sustainability*, *8*(9), 937. https://doi.org/10.3390/su8090937

Nußholz, J. (2017). Circular Business Models: Defining a Concept and Framing an Emerging Research Field. *Sustainability*, *9*(10), 1810. https://doi.org/10.3390/su9101810

Osterwalder, A., Pigneur, Y., & Tucci, C. L. (2005). Clarifying Business Models: Origins, Present, and Future of the Concept. *Communications of the Association for Information Systems*, *16*. https://doi.org/10.17705/1CAIS.01601

Pieroni, M. P. P., McAloone, T. C., & Pigosso, D. C. A. (2019). Business model innovation for circular economy and sustainability: A review of approaches. *Journal of Cleaner Production*, *215*, 198–216. https://doi.org/10.1016/j.jclepro.2019.01.036

Reim, W., Parida, V., & Örtqvist, D. (2015). Product–Service Systems (PSS) business models and tactics – a systematic literature review. *Journal of Cleaner Production*, *97*, 61–75. https://doi.org/10.1016/j.jclepro.2014.07.003

Sassanelli, C., Rosa, P., Rocca, R., & Terzi, S. (2019). Circular economy performance assessment methods: A systematic literature review. *Journal of Cleaner Production*, *229*, 440–453. https://doi.org/10.1016/j.jclepro.2019.05.019

Servantes, I. (n.d.). *Adidas' outdoor division will test out a new rental program*. Input. Retrieved February 14, 2022, from https://www.inputmag.com/style/adidas-outdoor-division-will-test-out-a-new-rental-program

Singh, J., Cooper, T., Cole, C., Gnanapragasam, A., & Shapley, M. (2019). Evaluating approaches to resource management in consumer product sectors—An overview of global practices. *Journal of Cleaner Production*, *224*, 218–237. https://doi.org/10.1016/j.jclepro.2019.03.203

Teece, D. J. (2007). Explicating dynamic capabilities: The nature and microfoundations of (sustainable) enterprise performance. *Strategic Management Journal*, *28*(13), 1319–1350. https://doi.org/10.1002/smj.640

Tukker, A. (2004). Eight types of product–service system: Eight ways to sustainability? Experiences from SusProNet. *Business Strategy and the Environment*, *13*(4), 246–260. https://doi.org/10.1002/bse.414

Tukker, A., & Tischner, U. (2006). Product-services as a research field: Past, present and future. Reflections from a decade of research. *Journal of Cleaner Production*, *14*(17), 1552–1556. https://doi.org/10.1016/j.jclepro.2006.01.022

Urbinati, A., Rosa, P., Sassanelli, C., Chiaroni, D., & Terzi, S. (2020). Circular business models in the European manufacturing industry: A multiple case study analysis. *Journal of Cleaner Production*, *274*, 122964. https://doi.org/10.1016/j.jclepro.2020.122964

Verschuren, P., Doorewaard, H., & Mellion, M. J. (2010). *Designing a research project* (2nd ed. / rev. and ed. by M.J. Mellion). Eleven International Pub.

Wallin, J., Chirumalla, K., & Thompson, A. (2013). Developing PSS Concepts from Traditional Product Sales Situation: The Use of Business Model Canvas. In H. Meier (Ed.), *Product-Service Integration for Sustainable Solutions* (pp. 263–274). Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-642-30820-8_23

Appendix A: Interviews

Table 7: List of interviewees

#	Organization	Position	Type of communication	Relevance for thesis
1	Thule Group	CEO	In-person meeting	Supervisor, informant on overview of current business model, finalization of hypothetical leasing business model
2	Thule Group	International product manager	In-person meeting	Consultation, point of contact, information overview on bike trailers
3	Thule Group	Quality Manager Warranty	Online meeting	Spare parts estimation
4	Thule Group	Senior Test Engineer, Bike trailer	In-person meeting	Durability and repairability of different assembly parts, on-site observation
5	Thule Group	Quality Warranty Specialist	Email communication	Common quality issues faced by customers and underlying reason
6	Thule Group	Store manager	In-person meeting	Product characteristics, frequent repairing claims
7	Thule Group	Customer Service Manager	Online meeting	Spare parts sales
8	Thule Group	Marketing manager	Online meeting	Contacts to leasing companies Thule sends its products to
9	Thule Group	Chief Technical Engineer Soft Goods	Online meeting	Fabric process for LCA input
10	Thule Group	Chief Engineer Multi-sport & Bike Trailers	Online meeting	Bill of materials of Cross 2
11	Thule Group	Sales	Online meeting	Contacts to leasing companies Thule sends its products to
12	Thule Group	Purchasing Analyst	Online meeting	Spare parts forecasting and purchasing
13	Thule Group	Manager, Supplier Quality	Online meeting	Quality issue claims from consumers
14	Thule Group	Senior Test Engineer	Online meeting	Testing standards for a bike trailer

Interview on leasing model				
15	Lund University, Sweden	Professor, Division of Packaging Logistics Department of Design Sciences	Online meeting	Challenges with logistics and reuse packaging
16	Bikey bike	Anonymous	Online meeting	Leasing model information
17	Strolley	Anonymous	Online meeting	Leasing model information
18	Åre Barnvagen	Anonymous	Email communication	Information on vacation leasing/ short term rental
19	Parently	Founder	Online meeting	Leasing model information
20	Nomadi	Co-founder	Online meeting	Leasing model information
21	Leasing company in Sweden	Anonymous	Online meeting	Leasing model information

Interview questions to the leasing companies

1. Business mode presence
    a. How long have you been renting out the bike trailers? When did you start the company and how has it progressed? Have you faced any challenges? What has been easy?
    b. Popularity of renting out the bike trailers compared to other products?
    c. What is your revenue model?
    d. Any partnerships?
2. Repair
    a. Which parts of a bike trailer need repairing the most?
    b. Who repairs it?
    c. How do you forecast/ decide the spare parts inventory?
    d. How many trailers do you have in your inventory?
    e. How do you get the repair parts?
    f. What activities are involved after the cleaning cycle?
        i. Where do you clean? How many personnel are needed ?
3. Transport
    a. How do you deliver the product? How do you get it back?
    b. How long does a delivery take from the date of order?
4. Usage
    a. What is the condition of the trailer after the user returns the trailer? How do users use it?
    b. Which parts need frequent repairs? Which parts are lost by the customer?
    c. What are the acceptable conditions for renting out used bike trailer?

   d. How long is the average renting of bike trailer? How many rents for shorter frame compared to longer time frame?
   e. Perception of renting child products? Why do they opt for renting in the first place?
   f. What is the perception of secondhand buy vs leasing for a limited time?

5. EOL
   a. What happens to the EOL of the trailer?

Appendix B: Calculated data from the case company

Table 8:: Material composition in Assembly parts

#	Assembly	Aluminium (kg)	Copper (kg)	Fabric (kg)	Plastic (kg)	Rubber (kg)	Steel (kg)	Zinc (kg)	Total weight (kg)
	TOTAL	9.33	0.08	0.34	10.58	3.75	3.85	0.04	15.34
1	Frame	3.34	0.00	0.08	3.86	0.01	1.09	0.02	8.38
2	Wheel	0.77	0.04	0.00	0.93	1.87	0.63	0.00	4.24
3	Axle	0.37	0.00	0.00	0.35	0.00	0.06	0.00	0.77
4	Arm hitch	0.49	0.00	0.02	0.07	0.00	0.07	0.00	0.65
5	Safety strap	0.00	0.00	0.00	0.28	0.00	0.29	0.00	0.57
6	Handlebar	0.26	0.00	0.00	0.22	0.00	0.01	0.00	0.49
7	Fabric	0.00	0.00	0.16	0.04	0.00	0.00	0.00	0.20

Table 9: Material composition in packaging

Material	**Weight (kg)**
Textile packaging	0.15
Paperboard packaging	4.5
Plastic packaging	0.57
Instructions and Repair kit	0.32
Total	5.54

Table 10: Transportation data input

Scenarios	Geography	Transport Mode	Kilometre	tkm
Ownership S1 Ownership S2 Leasing	China	Air freight	4400	91.87
	China	Road freight	27007	563.92

	China to Europe	Ocean cargo	19492	407.00
	Europe	Inland waterways	198	4.13
	Europe	Road freight	1090	22.76
Leasing (user to the hub roundtrip)	Europe	Road freight	215	4.48

Table 11:Calculated spare parts based on Sales data

Spare parts per year for 1 unit of bike trailer	
Arm hitch	0.475
Wheel	0.04
Rubber hitch strap	0.02
Flag	0.02
Handlebar	0.005
Weather cover	0.005
Mesh cover	0.002

Appendix C: Data used in LCI

A. Assumptions and estimations

Table 12: Production phase data source and estimation

Unit processes	Data source	Estimation method	Scenarios applicable to
Material production	Bill of material for weight & material of the assembly. Material type & emissions from ecoinvent database	Materials were categorized into major assemblies and their weights were calculated from the BOM for this product	Ownership S1 Ownership S2 Leasing
Energy	Data provided by suppliers. Based total units produced, electricity need per unit is calculated.		Ownership S1 Ownership S2 Leasing
Packaging	Supplier data		Ownership S1 Ownership S2 Leasing
Spare Parts	Sales data (2020-2021), Interview within Thule to determine the damage reasons (functionality or usage)	Total Cross 2 sales number taken from the internal sales data. Spare parts count calculated from spare parts sales to customer per year from 2020-2021. Spare parts per unit Cross 2 per year calculated	Ownership S1 Ownership S2 Leasing
Spare parts-Material production	BOM for spare parts & materials	Mass allocation	Ownership S1 Ownership S2 Leasing
Spare parts-Energy	Supplier data	Mass allocation	Ownership S1 Ownership S2 Leasing
Spare parts-Packaging	Supplier data	Mass allocation	Ownership S1 Ownership S2 Leasing

Table 13: Transportation phase data sources and estimation

Unit processes	Data source	Estimation method	Scenarios
Spare parts-Transport	Derived from supplier data for Cross 2	Mass allocation	Ownership S1 Ownership S2 Leasing
Transport (sub suppliers to suppliers)	Logistics data from Thule docs for the LCA which was conducted earlier	Weight of the product * kilometer / tonne	Ownership S1 Ownership S2 Leasing

Transport (suppliers to Thule DC)	Logistics data from Thule docs for the LCA which was conducted earlier	Weight of the product * kilometer / tonne	Ownership S1 Ownership S2 Leasing
Transport (Thule DC to hubs in SE)	Internal consultation yielded basing store hubs in three major cities of Sweden. Google maps for distance calculation. Transportation mode assumed to be road freight	3 major cities (Malmo, Stockholm, Gothenburg) where Thule stores are located considered hubs and distance taken from Google maps for road transport.	Leasing
Transport (Hubs to users)	Users travel to the store to collect the trailer	100km assumed to be the maximum user distance	Leasing

B. Inventory

Table 14: Ecoinvent data for assembly part - frame

#	Frame	Ecoinvent data set used	Qty (kg) for 1 unit
1	Aluminum	Aluminum alloy, AlMg3 {GLO}| market for | Cut-off, U	3.3
2	Nylon 6	Nylon 6, glass-filled {RoW}| market for nylon 6, glass-filled | Cut-off, U	3.32
3	POM	Polypropylene, granulate {GLO}| market for | Cut-off, U	0.3
4	ABS	Acrylonitrile-butadiene-styrene copolymer {GLO}| market for | Cut-off, U	0.03
5	PP	Polycarbonate {GLO}| market for | Cut-off, U	0.3
6	PC	Polyethylene, high density, granulate {GLO}| market for | Cut-off, U	0.05
7	PE	Polyethylene, high density, granulate {GLO}| market for | Cut-off, U	0.006
8	Injection molding	Injection molding {GLO}| market for | Cut-off, U	4.006
9	Copper	Copper {GLO}| market for | Cut-off, U	0.0014
10	Steel, low alloyed	Steel, low-alloyed {GLO}| market for | Cut-off, U	1.078
11	Stainless steel	Steel, chromium steel 18/8 {GLO}| market for | Cut-off, U	0.0088
12	Non-woven PP	Textile, non-woven polypropylene {GLO}| market for textile, non-woven polypropylene | Cut-off, U	0.01

13	Non woven PE	Textile, non-woven polyester {GLO}| market for textile, non woven polyester | Cut-off, U	0.06
14	Weaving, synthetic fiber	Weaving, synthetic fiber {GLO}| market for weaving, synthetic fiber | Cut-off, U	0.07

Table 15:Ecoinvent data for assembly part - arm hitch

#	**Arm hitch**	**Ecoinvent data set used**	**Qty (kg) for 1 unit**
1	Aluminum	Aluminum alloy, AlMg3 {GLO}| market for | Cut-off, U	0.486
1	Copper	Copper {GLO}| market for | Cut-off, U	0.002
1	Low alloyed steel	Steel, low-alloyed {GLO}| market for | Cut-off, U	0.069
2	TPU	Polyurethane, flexible foam {RoW}| market for polyurethane, flexible foam | Cut-off, U	0.045
3	Nylon 6	Nylon 6, glass-filled {RoW}| market for nylon 6, glass-filled | Cut-off, U	0.069
4	Fabric	Textile, non-woven polyester {GLO}| market for textile, non woven polyester | Cut-off, U	0.02

Table 16:Ecoinvent data for assembly part -handlebar

#	**Handlebar**	**Ecoinvent data set used**	**Qty (kg) for 1 unit**
1	Aluminum	Polyethylene, high density, granulate {GLO}| market for | Cut-off, U	0.262
2	Steel	Steel, low-alloyed {GLO}| market for | Cut-off, U	0.005
3	ABS	Acrylonitrile-butadiene-styrene copolymer {GLO}| market for | Cut-off, U	0.039
4	PVC foam	Polyvinylchloride, bulk polymerized {GLO}| market for | Cut-off, U	0.182

Table 17:Ecoinvent data for assembly part - axle

#	**Axle**	**Ecoinvent data set used**	**Qty (kg) for 1 unit**

1	Aluminum	Aluminum alloy, AlMg3 {GLO}| market for | Cut-off, U	0.365
2	Steel	Steel, low-alloyed {GLO}| market for | Cut-off, U	0.059
3	PA6GF	Nylon 6, glass-filled {RoW}| market for nylon 6, glass-filled | Cut-off, U	0.263
4	POM	Polycarbonate {GLO}| market for | Cut-off, U	0.0252
5	TPU40GF	Polyurethane, rigid foam {RoW}| market for polyurethane, rigid foam | Cut-off, U	0.049
6	PC	Polycarbonate {GLO}| market for | Cut-off, U	0.011
7	Injection molding	Injection molding {GLO}| market for | Cut-off, U	0.3482

Table 18:Ecoinvent data for assembly part - wheel

#	**Wheel**	**Ecoinvent data set used**	**Qty (kg) for 1 unit**
1	Aluminum	Aluminum alloy, AlMg3 {GLO}| market for | Cut-off, U	0.77
2	Copper	Copper {GLO}| market for | Cut-off, U	0.036
3	Low alloyed steel	Steel, low-alloyed {GLO}| market for | Cut-off, U	0.445
4	Stainless steel	Steel, chromium steel 18/8 {GLO}| market for | Cut-off, U	0.184
5	PA6GF30	Nylon 6, glass-filled {RoW}| market for nylon 6, glass-filled | Cut-off, U	0.841
6	EVA	Ethylene vinyl acetate copolymer {RER}| market for ethylene vinyl acetate copolymer | Cut-off, U	0.086
7	LDPE	Polyethylene, low density, granulate {GLO}| market for | Cut-off, U	0.005
8	EPDM	Synthetic rubber {GLO}| market for | Cut-off, U	1.871

Table 19: Ecoinvent data for assembly part - body fabric

#	**Body fabric**	**Ecoinvent data set used**	**Qty (kg) for 1 unit**

1	Polypropylene	Textile, non-woven polypropylene {GLO}| market for textile, non woven polypropylene | Cut-off, U	0.036
2	Polyester	Textile, non-woven polyester {GLO}| market for textile, non woven polyester | Cut-off, U	0.161
3	Weaving, synthetic fiber	Weaving, synthetic fiber {GLO}| market for weaving, synthetic fiber | Cut-off, U	0.197

Table 20: Ecoinvent data for packaging

	Packaging		**Qty (kg) for 1 unit**
1	Paperboard packaging	Corrugated board box {RER}| market for corrugated board box | Cut-off, U	4.5
2	Plastic packaging	Polyethylene, low density, granulate {GLO}| market for | Cut-off, U	0.57
3	Instructions & repair kit/ Paper packaging	Paper, woodfree, uncoated {RER}| market for | Cut-off, U	0.32

Table 21:Ecoinvent data for transport

#	**Flow**	**Transport**		**km**	**tkm**
1	sub supplier to supplier	Air freight	Transport, freight, aircraft, medium haul {GLO}| market for transport, freight, aircraft, medium haul | Cut-off, U	4400	91.87
2	sub supplier to supplier	Truck (China)	Transport, freight, lorry >32 metric ton, euro4 {RoW}| market for transport, freight, lorry >32 metric ton, EURO4 | Cut-off, U	26807.4	559.74
3	Supplier to company	Truck (China)	Transport, freight, lorry >32 metric ton, euro4 {RoW}| market for transport, freight, lorry >32 metric ton, EURO4 | Cut-off, U	200	4.18

4	Supplier to company	Truck (EUR)	Transport, freight, lorry >32 metric ton, euro5 {RER}| market for transport, freight, lorry >32 metric ton, EURO5 | Cut-off, U	15	0.31
5	Supplier to company	Ocean shipping	Transport, freight, sea, container ship {GLO}| market for transport, freight, sea, container ship | Cut-off, U	19492.3	407.00
6	Supplier to company	Inland waterways	Transport, freight, inland waterways, barge {RER}| market for transport, freight, inland waterways, barge | Cut-off, U	198	4.13
7	Company to customers	Truck (EUR)	Transport, freight, lorry >32 metric ton, euro5 {RER}| market for transport, freight, lorry >32 metric ton, EURO5 | Cut-off, U	1090	22.76

C. Description of Netherlands waste scenario used for sensitivity in this study. Source: SimaPro documentation

- Description: Waste (waste scenario) {NL}| treatment of waste | Cut-off, U, considers all waste types in the Netherlands
- Input: Materials/fuels,
- Output: Electricity/heat

Table 22: Separated waste from the waste scenario of Netherlands. Source: SimaPro

Dataset	**Process**	**Allocation**	**Recycling rate**
Core board (waste treatment) {GLO}|	recycling of core board	Cut-off, U Cardboard	94,8%
Paper (waste treatment) {GLO}	recycling of paper	Cut-off, U Packaging paper	91.8%
Packaging glass, white (waste treatment) {GLO}	recycling of packaging glass, white	Cut-off, U Glass	86.6%
Steel and iron (waste treatment) {GLO}	recycling of steel and iron	Cut-off, U Ferro metals	86.6%
Aluminum (waste treatment) {GLO}| |	recycling of Aluminum	Cut-off, U Aluminum	38.4%
Mixed plastics (waste treatment) {GLO}| |	recycling of mixed plastics	Cut-off, U Plastics	38.4%

PE (waste treatment) {GLO}| |	recycling of PE	Cut-off, U PE	38.4%
PET (waste treatment) {GLO}	recycling of PET	Cut-off, U PET	38.4%
PP (waste treatment) {GLO}| |	recycling of PP	Cut-off, U PP	38.4%
PS (waste treatment) {GLO}| |	recycling of PS	Cut-off, U PS	38.4%
PVC (waste treatment) {GLO}| |	recycling of PVC	Cut-off, U PVC	38.4%
Paper (waste treatment) {GLO}| |	recycling of paper	Cut-off, U Paper	94.8%
Paper (waste treatment) {GLO}| |	recycling of paper	Cut-off, U Newspaper 94,8	94.8%
Biowaste {CH}| |	treatment of biowaste, industrial composting	Cut-off, U Compost	48%
remaining Curb side collection (waste scenario) {NL}| |	treatment of waste	Cut-off, U	100%

Appendix D: LCA results, tables and figures

Table 23:Total weighted ILCD 2011 midpoint+ impact category score

Impact category	**Unit**	**Ownership S1**	**Ownership S2**	**Leasing**
Total	mPt	690.95	345.48	490.31
Freshwater ecotoxicity	mPt	393.79	196.90	284.68
Human toxicity, cancer effects	mPt	224.71	112.36	153.66
Human toxicity, non-cancer effects	mPt	40.40	20.20	29.60
Mineral, fossil & ren resource depletion	mPt	11.69	5.85	7.78
Ionizing radiation HH	mPt	5.02	2.51	3.61
Particulate matter	mPt	3.56	1.78	2.48
Climate change	mPt	3.20	1.60	2.28
Acidification	mPt	2.27	1.13	1.64
Photochemical ozone formation	mPt	2.07	1.03	1.52
Terrestrial eutrophication	mPt	1.95	0.98	1.43
Marine eutrophication	mPt	1.04	0.52	0.76
Freshwater eutrophication	mPt	0.73	0.37	0.51
Water resource depletion	mPt	0.35	0.17	0.23
Ozone depletion	mPt	0.15	0.08	0.12
Land use	mPt	0.01	0.00	0.01
Ionizing radiation E (interim)	mPt	0.00	0.00	0.00

Table 24: Characterization factors of the ILCD 2011 midpoint+ method

ILCD 2011 midpoint+ Impact Categories	**Unit**
Climate change	kg CO_2 eq.
Ozone depletion	kg CFC-11 eq.
Human toxicity, cancer effects	CTUh
Human toxicity, non-cancer effects	CTUh
Particulate matter/Respiratory inorganics	kg PM2.5 eq.
Ionizing radiation, human health	kBq U^{235} eq. (to air)
Photochemical ozone formation, human health	kg NMVOC eq.
Acidification	mol H+ eq.
Eutrophication terrestrial	mol N eq.
Eutrophication freshwater	kg P eq.
Eutrophication marine	kg N eq.
Land use	kg C deficit
Ecotoxicity freshwater	CTUe
Resource depletion water	m^3 water eq.
Resource depletion, mineral, fossils and renewables	kg Sb eq.

Table 25: Characterization values of three scenarios for Freshwater toxicity potential

Impact category	**Freshwater ecotoxicity (CTUe)**		
Phases	**Ownership S1**	**Ownership S2**	**Leasing**
Transportation	548.48	274.24	280.05
Production - main unit	18079.29	9039.64	9039.64
Spare parts	253.76	126.88	126.88

Packaging	171.50	85.75	85.75
Production waste processing	2657.78	1328.89	1328.89
Electricity	30.64	15.32	15.32
Refurbishing	0.00	0.00	4830.14
EOL	349.18	174.59	263.11
Total	**22090.63**	**11045.31**	**15969.79**

Table 26:Characterization values of three scenarios for Human toxicity potential (cancer and non-cancer effects)

Impact category	**Human toxicity, non-cancer effects**			**Human toxicity, cancer effects**		
Phases	**Ownership S1**	**Ownership S2**	**Leasing**	**Ownership S1**	**Ownership S2**	**Leasing**
Transportation	2.05E-05	1.02E-05	1.04E-05	2.06E-06	1.03E-06	1.05E-06
Production - main unit	5.86E-05	2.93E-05	2.93E-05	3.38E-05	1.69E-05	1.69E-05
Spare parts	7.29E-07	3.65E-07	3.65E-07	2.42E-07	1.21E-07	1.21E-07
Packaging	3.79E-06	1.90E-06	1.90E-06	6.22E-07	3.11E-07	3.11E-07
Production waste processing	7.08E-06	3.54E-06	3.54E-06	4.71E-06	2.35E-06	2.35E-06
Electricity	8.10E-07	4.05E-07	4.05E-07	2.23E-07	1.12E-07	1.12E-07
Refurbishing	0.00	0.00	2.14E-05	0.00	0.00	7.64E-06
EOL	2.49E-06	1.25E-06	1.52E-06	1.61E-07	8.05E-08	1.08E-07
Total	**9.39E-05**	**4.70E-05**	**6.88E-05**	**4.18E-05**	**2.09E-05**	**2.86E-05**

Table 27: Characterization values of three scenarios for mineral fossil and renewable resource depletion

Impact category	**Mineral, fossil & ren resource depletion (kg Sb eq)**		
Phases	**Ownership S1**	**Ownership S2**	**Leasing**
Transportation	1.56E-03	7.81E-04	7.97E-04
Production - main unit	2.67E-02	1.33E-02	1.33E-02
Spare parts	1.99E-04	9.93E-05	9.93E-05
Packaging	2.09E-04	1.04E-04	1.04E-04
Production waste processing	5.19E-03	2.60E-03	2.60E-03
Electricity	8.91E-06	4.46E-06	4.46E-06
Refurbishing	0.00E+00	0.00E+00	5.58E-03
EOL	3.25E-06	1.63E-06	2.38E-06

Climate change

Table 28: Characterization values of three scenarios for Climate change potential

Impact category	**Climate Change (kg CO2 eq)**		
Phases	**Ownership S1**	**Ownership S2**	**Leasing**
Transportation	110.60	55.30	55.30
Production - main unit	180.70	90.35	90.35
Spare parts	1.23	0.62	0.62
Packaging	11.82	5.91	5.91
Production waste processing	25.07	12.53	12.53
Electricity	5.30	2.65	2.65
Refurbishing	0.00	0.00	71.32
EOL	4.30	**2.15**	2.80

Table 29:Assembly contribution to production phase

Assembly	GWP in the production phase
Arm hitch	4.45
Axle	5.47
Body fabric	0.96
Flag	0.27
Frame	58.34
Handlebar	2.71
Safety strap	4.13
Wheel	14.02
Total	90.35

Table 30:Material contribution to production phase

Unit	**kg CO2 - eq**	**%**
Aluminum	36.9	41%
Steel	2.636	3%
Copper	0.181	0%
Plastic	47.78	53%
Rubber	1.31	1%
Fabric	1.639	2%
Total	90.3	100%

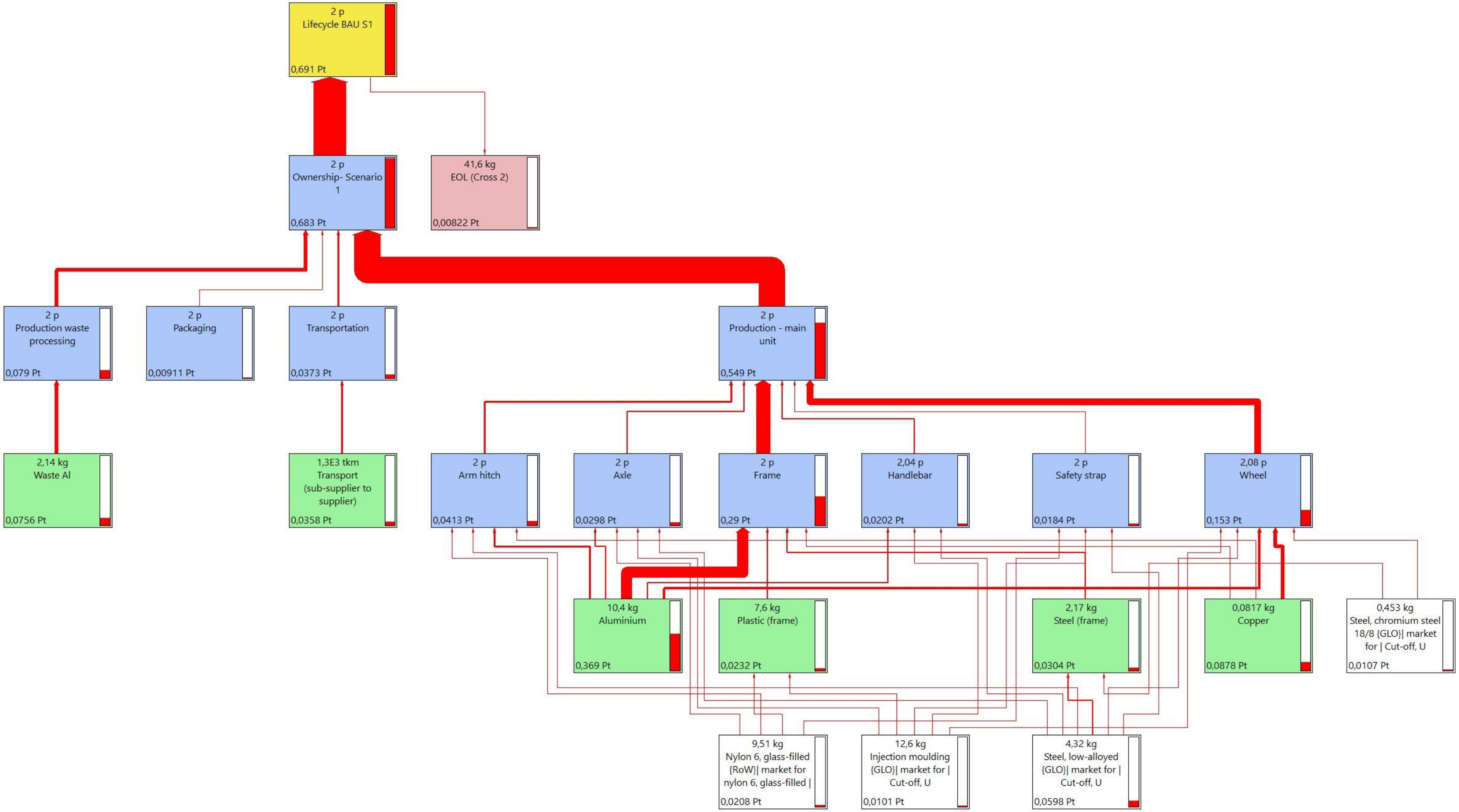

Figure 9: Network diagram of ownership S1. Top contributing processes are displayed here. Single weighted scores are displayed as flows

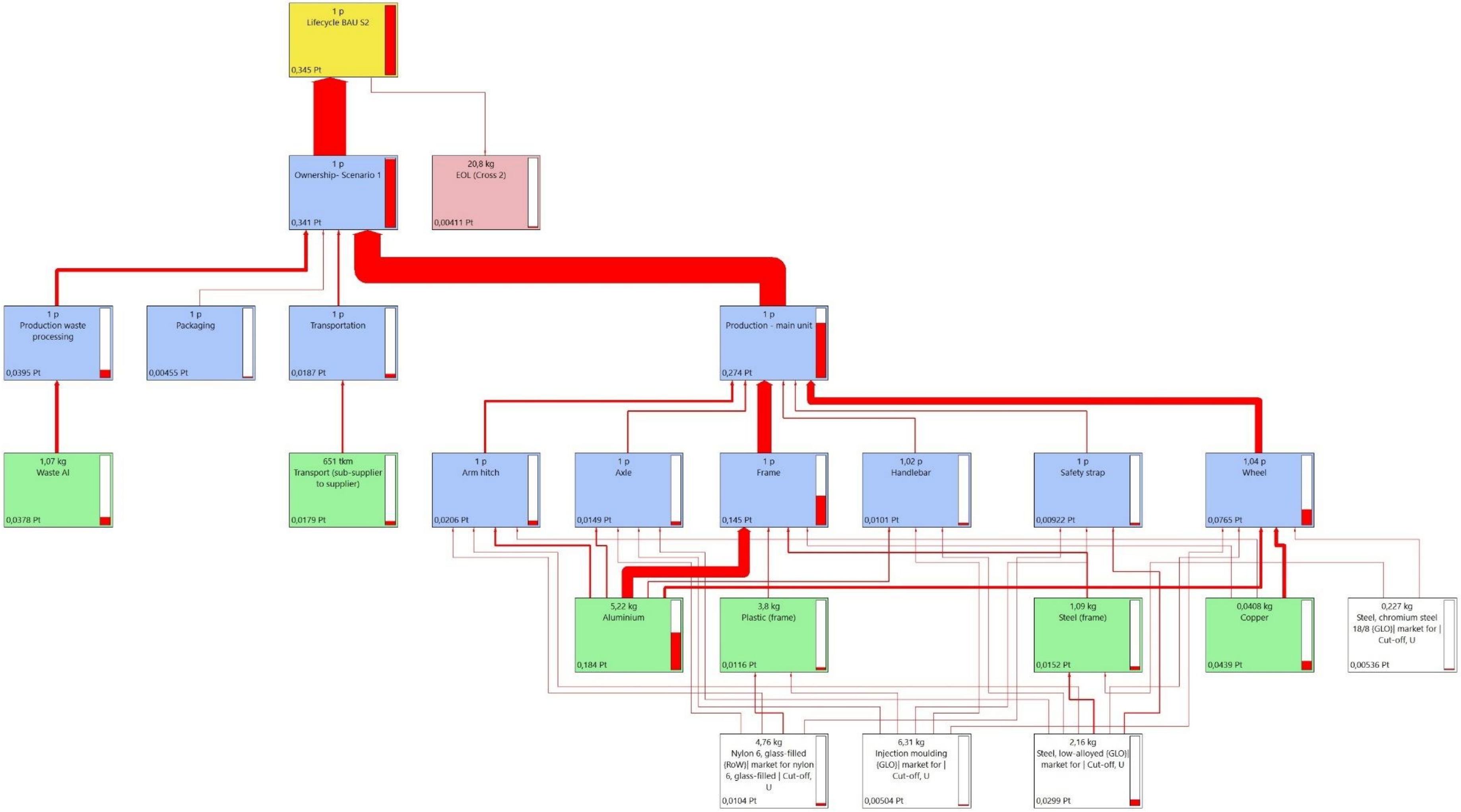

Figure 10:: Network diagram of ownership S2. Top contributing processes are displayed here. Single weighted scores are displayed as flows

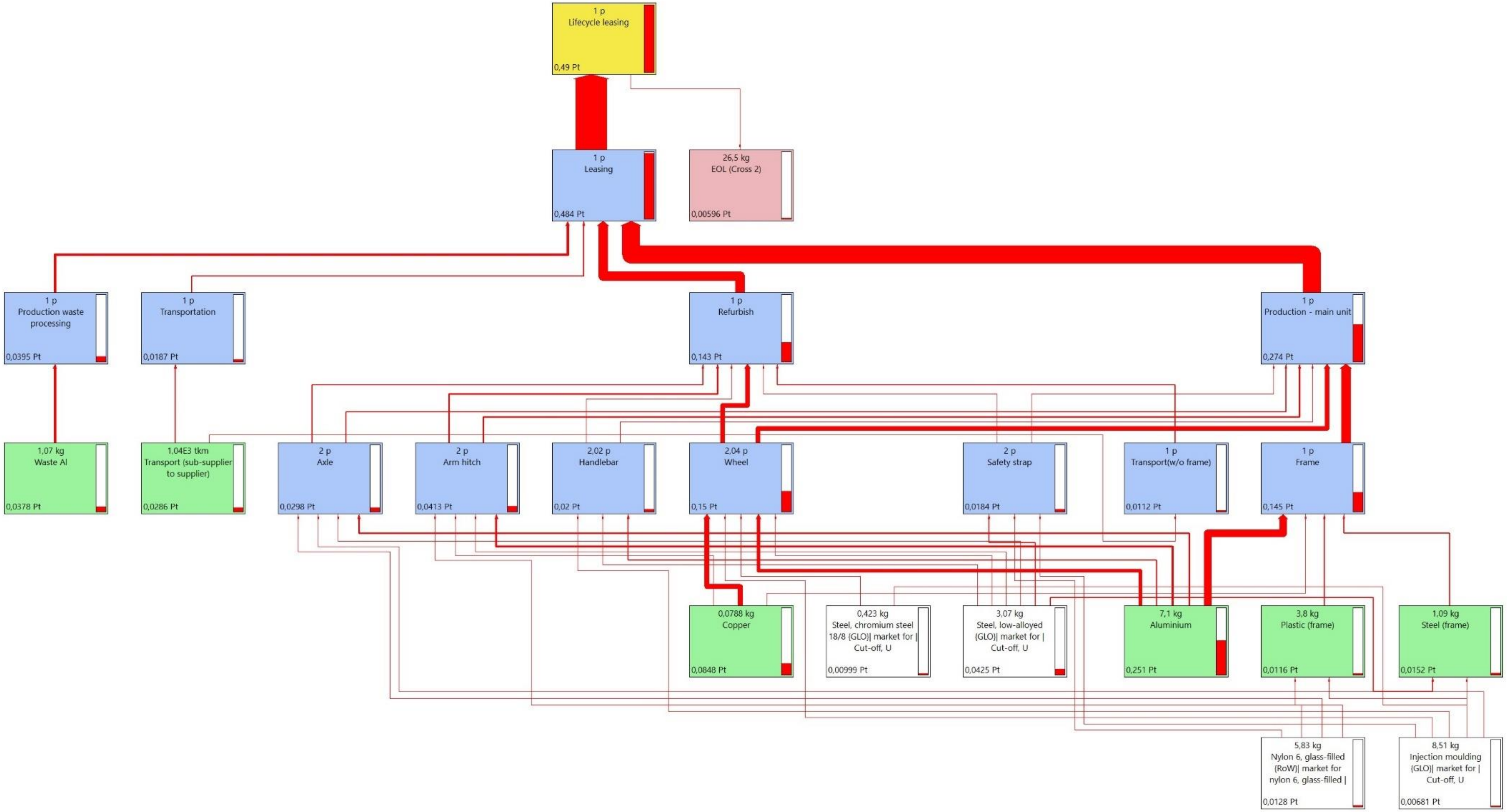

Figure 11:: Network diagram of leasing. Top contributing processes are displayed here. Single weighted scores are displayed as flows