CHALMERS
UNIVERSITY OF TECHNOLOGY

Sustainability in Motion

A Business Model Life Cycle Assessment of Lending and Sales Business Models for Mobility Aids in the Dutch Market

Master's Thesis in Industrial Ecology

Cecilia Bohlin
Matilda Sandberg

DEPARTMENT OF TECHNOLOGY MANAGEMENT AND ECONOMICS
DIVISION OF ENVIRONMENTAL SYSTEMS ANALYSIS

CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2025
www.chalmers.se

Sustainability in Motion

A Business Model Life Cycle Assessment of Lending and Sales Business Models for Mobility Aids in the Dutch Market

Cecilia Bohlin
Matilda Sandberg

Department of Technology Management and Economics
Division of Environmental Systems Analysis
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2025

Sustainability in Motion
A Business Model Life Cycle Assessment of Lending and Sales Business Models for Mobility Aids in the Dutch Market
Cecilia Bohlin
Matilda Sandberg

Department of Technology Management and Economics
Chalmers University of Technology
SE-412 96 Gothenburg
Sweden
Telephone + 46 (0)31-772 1000

Gothenburg, Sweden 2025

Sustainability in Motion
A Business Model Life Cycle Assessment of Lending and Sales Business Models for Mobility Aids in the Dutch Market

Cecilia Bohlin
Matilda Sandberg

Department of Technology Management and Economics
Chalmers University of Technology

SUMMARY

In the European Union the industrial sector is one of the most significant contributors to global greenhouse gas emissions, highlighting the urgent need for more sustainable practices within the sector. Business model innovation, particularly models grounded in circular economy principles such as product-service systems, has emerged as a promising approach to decouple economic growth from environmental impact.

To assess the environmental impact of different business models this thesis has studied two business models in use today by a Dutch distributor of medical aids. The models analysed are a traditional linear sales model as well as a lending model. The models have been evaluated based on two products, a shower chair and a rollator.

To assess the sustainability of these models, the study applies the Business Model Life Cycle Assessment (BM-LCA) methodology. The method, which is built on the Life Cycle Assessment (LCA) methodology utilises the business model as the object of analyses, coupling monetary flows with environmental impact. The study also explores how the results can support improved sustainability practices for both the case company and other actors in the value chain.

The results indicate that the lending model generates significantly lower greenhouse gas emissions than the sales model, largely due to the reduced number of new products required. However, the findings also reveal that factors such as product pricing, delivery logistics, and user transport distance play a critical role in overall environmental performance of the business models. These parameters can influence outcomes to the extent that they may offset the relative benefits of one model over another.

In addition to the quantitative finding, the project also yielded valuable insights into the practical application of BM-LCA. It was found that the BM-LCA methodology can be used both to validate business model practices, as well as support strategic planning and adaptation of similar business models within the company. The method also facilitated cross-departmental collaboration and increased awareness of sustainability concepts, suggesting its potential as a platform for internal knowledge sharing. These observations underscore the broader strategic value of BM-LCA in guiding environmental management and scaling circular practices across different markets.

Keywords: business model life cycle assessment, life cycle assessment, circular economy, circular business models, business model assessment, product-service system

Acknowledgements.
We would like to sincerely thank the representatives from the case company and parent company for all their time, expertise and engagement. We would also like to thank our supervisor PhD Ana Carolina Bertassini and our examiner Professor Henrikke Bauman, for all their help and guidance. It has been a pleasure working with you.

Table of Contents

List of Figures

List of Tables

List of Abbreviations

Abbreviation	Definition	Page
BM-LCA	Business Model Life Cycle Assessment	1
PSS	Product-Service System	2
EPD	Environmental Product Decleration	2
LCA	Life Cycle Assessment	2
CE	Circular Economy	3
CEAP	Circular Economy Action Plan	3
LCI	Life Cycle Inventory	7
LCIA	Life Cycle Impact Assessment	7
EF	Environmental Footprint	15
GWP	Global Warming Potential	15
AP	Acidification Potential	15
ADP	Abiotic Depletion Potential	15

1. Introduction

Since the 1800s changes in human activity, primarily through the combustion of fossil fuels, have altered the world's climate. This has resulted in an increase of the average temperature around the world with 1.2 degrees Celsius (United Nations, n.d.). Under the Paris agreement, 196 parties agreed to keep the world's average temperature to well below 2 degrees Celsius above pre-industrial levels and to pursue efforts to keep the increase to a maximum of 1.5 degrees (UNFCCC, n.d.). To do this, actions need to be taken by all sectors in society. In the EU the biggest emitters are the energy, domestic transport and industry sector. With the industry sector responsible for 20.3% of the total emissions (European Parliament, 2024).

One way for the industrial sector to limit their contribution to climate change is through adopting more sustainable business models, aiming to decouple a firm's resource use from its economic growth. These models are often grounded in circular economy principles, emphasizing the extension of product lifespans, reuse of materials, and the transition from ownership to access-based consumption (Bocken et.al., 2014). Research shows that integrating sustainability early in a company’s business plan has the possibility to radically improve both a company’s environmental and social performance. It is estimated that moving to more sustainable business models could potentially reduce companies' environmental impact by up to 90% (Bocken, 2023).

One company that aims to incorporate circular business models as part of their environmental management strategy is a Swedish company that acquires businesses in the European healthcare sector. This project will focus on one of their subsidiary companies, a distributor of mobility aids and other assistive equipment operating in the Netherlands. The Dutch subsidiary currently employs several business models, providing access to its products through sales, loans, and rentals to a variety of clients, including private individuals, nursing homes, and home care providers.

While business strategies such as lending and rental show promise in reducing environmental impacts, a significant research gap remains in how to assess the sustainability of such a model. Most existing approaches evaluating the environmental impacts of business models lack the incorporation of real company specific data about the operations in practice (Bocken, 2023). In response to this gap, the Business Model Life Cycle Assessment (BM-LCA) methodology has emerged in recent years. Although being built around the life cycle assessment methodology, it utilizes the business model, instead of a product or service, as the basis of analysis. It aims to integrate financial data, such as costs and revenues, with environmental impacts, making it possible to assess the business as a whole (Böckin et al., 2022).

1.1. Aim

The aim of this study is to assess and compare the environmental performance of a product-service system (PSS) and a linear sales business model within a Dutch case company. The case company has several different business models in place today, but the ones that will be analysed in this project are their traditional linear sales as well as their PSS lending model. Two products will be analysed, a shower chair and a rollator. The assessment and comparison will be carried out through the application of the BM-LCA method.

The project also aims to identify possible improvements in the business models and to evaluate how the results of the study can be used by the case company and the parent company.

The project aims to answer the following research questions:

- Which business model has the lowest environmental impact when coupled with a financial perspective?
- How does the choice of product influence the environmental impact of a business model?
- Can any environmental or economic hotspots be identified within the business models? How can they be mitigated?
- How can the results of the BM-LCA help implement sustainable business practices used by the case company and other subsidiary companies owned by the parent company?

1.2. Limitations

The project will be limited to two products, a shower chair produced by a Swedish manufacturer and a rollator produced by a Norwegian manufacturer. These products are evaluated within the business models that they are currently part of at the case company in the Dutch market. Specifically, the study only focuses on two models. A lending business model in which the case company retains ownership of the product and a traditional linear sales model, where ownership is transferred to the customer. The rollator was only studied for one of the models, namely the linear sale model, while the shower chair was evaluated for both.

The financial data considered in the project will be assessed for one year and is limited to the Dutch company's business network within the Netherlands. In contrast, the environmental assessment covers the entire life cycle of the product (cradle-to-grave). However, due to limited access to manufacturer specific data, the environmental impacts from material extraction and production are based on secondary data sources. For the rollator an environmental product declaration (EPD) was used, whereas for the shower chair an internal life cycle assessment (LCA) performed by the manufacturer was used.

2. Theoretical Background

This section provides the theoretical foundation for the study by outlining key concepts and frameworks relevant to the project.

2.1. Circular Economy Concept and Policies

The purpose of circular economy (CE) is to minimize resource use, waste and emissions by keeping materials and products in use for as long as possible. This is usual done through focusing on slowing and closing resource loops, primarily through strategies such as reusing, repairing and recycling resources (Bocken, 2023). Circular economy is commonly contrasted with linear economy, where the flow of resources moves linearly from extraction through manufacturing, use, to disposal. This model is increasingly viewed as unsustainable in the long run due to finite natural resources and its associated environmental impacts (Meadows et al., 1972). The two models therefore differ fundamentally in their treatment of material flows, with the circular economy promoting a cradle-to-cradle approach in contrast to the more classical cradle-to-grave perspective that characterizes a traditional linear economy (Bocken et. al., 2016).

Europe is today one of the world's largest importers of materials and the economy currently predominantly functions on a linear take-create-dispose resource model. This has led to significant waste streams, where often still viable resources get lost. Only about 5% of the raw material value is recaptured in Europe after the first use. It is also estimated that Europe currently uses 1.5-2 times more resources than can be regenerated naturally (Ellen McArthur Foundation, 2015). The European commission has specified that a transition to a circular economy will be needed to reduce pressures on natural resources (European Commission, 2020.). The new Circular Economy Action Plan (CEAP) that was adopted in 2020 is one of the main building blocks of the European Green Deal as well as one of the prerequisites to achieve the EUs 2050 climate neutrality target (European Commission, 2020.). Objectives of the Circular Economy Action Plan include making sustainable products, services and business models the norm in order to transform consumption patterns and reduce waste (European Commission, 2020). The EU commission views CE as an opportunity to reduce the pressures on the environment while also enhancing the security of raw materials, increasing competitiveness among firms, as well as driving innovation and job creation (European Commission, 2020). There are however some challenges to the transition to a circular economy, including high transition costs for companies and the lack of key economic enablers pricing systems that act as barriers to the transition (European Parliament, 2016).

In 2016, the Netherlands implemented the "*A Circular Economy in the Netherlands by 2050*", with the goal of having a complete circular economy by 2050, i.e., that the environmental impacts should fall within the planetary boundaries. The policy program focuses on primarily four areas to do this (Government of the Netherlands, n.d.). These are:

1. Reducing raw material usage
2. Substituting raw materials
3. Extending product life
4. High-grade processing

They aim to do this through a great variety of different policies such as pricing measures, for example taxes and levies, standard-setting measures, and stimulus measures. They are intended to both level the playing field for sustainable frontrunners as well as changing the mindset of already incumbent regimes operating within the Dutch market (Ministry of Infrastructure and Water Management, 2023.).

Sweden on the other hand has not come as far as implementing specific policies to reach a circular economy. They do, however, have a strategy and a vision in place to act as a support for actors in commerce and industry, the public sector, universities and the general public. The strategy is primarily in place to reach FNs goals in the 2030 Agenda including the 17 goals for sustainable development (Government Offices of Sweden, 2020). The strategy has four main focus areas, these are:

1. Circular economy through sustainable production and design
2. Circular economy through sustainable ways to consume and use materials, products and services
3. Circular economy through non-toxic and closed-loop systems
4. Circular economy as a driving force for industries and other actors through measures that promote innovation and circular business models

There is also an action plan in place with suggested measures to be taken to reach the goals. Some prioritised resource streams to be targeted to reach a transition to a more circular economy are plastics, textiles, the food sector, renewable and biobased raw materials, the construction and property sector, and innovation-critical metals and minerals (Regeringskansliet, n.d.).

2.2. Decoupling

An important aspect of circular economy is the concept of decoupling human wellbeing and economic growth from resource extraction. This means to use less material resources per economic output (resource decoupling) as well as reducing the environmental impacts of the resources used (impact decoupling) (UNEP, 2011). Decoupling is usually talked about as either relative or absolute. Relative decoupling is defined as when the economic growth rate is quicker than the growth rate of resource use, while absolute decoupling is on the other hand defined by that the use of a resource is declining regardless of the growth rate of the economic drivers (Hennicke et. al., 2014).

Decoupling economic growth from resource use becomes more and more important as environmental pressures increases, it is estimated that between 1900 - 2005 the global resources extraction grew by a factor of 8 (UNEP, 2011).

This number is expected to grow even more as the global south catches up to the consumption patterns of the western world (Hennicke et. al., 2014), and as the global population increases (UNEP, 2011).

2.3. Sustainable Business Models

A business model can be described as a business' plan to create profit, or in other words how a firm does business (Evans et. al. 2017). It is the strategy on how to turn resources into economic value, and it is typically defined by three core elements: value proposition, value creation and delivery, and value capture (Bocken et. al., 2014).

In the past decade, there has been a surge in business model innovation research as changes to business models have been recognised as an important approach for companies to become more sustainable (Evans et. al. 2017). Sustainable business models differ from traditional models by explicitly incorporating society and the environment as key stakeholders in the firm. They can be described as the firm's way of capturing, delivering, and creating value while operating within the planetary boundaries and supporting the wellbeing of both current and future generations of humanity (Bocken, 2023).

One such model is product-service systems (PSS) which is a business model where a company offers a combination of material products and services that combines to fulfil the customer needs (Annarelli et al., 2016). They are characterized by the firm not only providing a product, but the function that the product provides. Product-service systems can be categorized in three main categories (Tukker, 2004):

1. Product-oriented services that focus on the product while also providing extra services such as maintenance or financing.
2. User-oriented services where the firm retains ownership of the product while providing the function of the product to consumers through leasing, renting or sharing.
3. Result-oriented services, where the supplier and customer have an agreement about a certain result, without an agreement about which specific product is needed to achieve this result.

Product-service systems (PSS) can be useful for achieving a more circular economy, and some estimate that PSS have the potential to reduce environmental impacts with up to 90% (Bocken, 2023). However, their implementation does not inherently guarantee sustainability (Annarelli et al., 2016). It is not enough to simply combine products and services, the system needs to be designed to minimize environmental impacts from the beginning (Kjaer et al., 2016). For a PSS model to be genuinely sustainable, it should aim for absolute resource decoupling. However, PSS alone does not guarantee this outcome (Kjaer et al., 2018), even if it is often recognised as a promising approach to do so (Bocken et al. 2017). In some cases, it might even encourage products to be replaced more often (Kjaer et al., 2018) and create negative rebound effects (Kjaer et al., 2016). Sharing or rental services for example, might make products more available, increasing the overall consumption instead of decreasing it. Even though this might be positive from an economic perspective, such changes in user behaviour might diminish the model's potential for resource reduction and environmental impact reduction (Kjaer et al., 2018).

In order for PSS to lead to decoupling of resources and be a sustainable business model Kjaer et al. (2018) argues that three requirements within the business model must be fulfilled. These are:

1. Ensure net resource reduction.
2. Avoid burden shifting between life cycle stages.
3. Mitigate rebound effects.

Corporations that adopt circular business models that aim to slow resource loops, such as PSS, can encounter different obstacles related to customer desire as well as feasibility and viability of the business model. For customer desirability the customers desire for novelty and new things can be an obstacle (Bocken & Geradts, 2022). Users often prefer new products with no terms or conditions for use (Behavioural Insights Network Netherlands, 2023). Novelty can however be included in the value proposition of a circular business model in other ways than providing new products. One such example is by including the flexibility and variability of renting products without owning them (Bocken & Geradts, 2022). The feasibility of the business model can also be challenged by technological and operational factors related to the design of the products and reverse logistics required for maintenance and repair (Bocken & Geradts, 2022). To extend the life cycle of the product, and slow resource loops, it needs to be designed with these factors in mind. Bocken et. al. (2016) lists six strategies to design for slower resource loops:

1. Design for attachment and trust.
2. Design for reliability and durability.
3. Design for ease of maintenance and repair.
4. Design for upgradability and adaptability.
5. Design for standardization and compatibility.
6. Design for dis- and reassembly.

The viability of the business model can also be improved by introducing a premium price for long lasting products which can offset the negative effects on the replacement market of the product (Bocken & Geradts, 2022). It is also argued that models such as PSS can generate a continuous stream of income and greater customer lock-in compared to traditional linear business models (Bocken & Geradts, 2022).

Even if sustainable business models, such as PSS, have become an area of great interest in academia the assessment of potential environmental impacts of these models is yet underexplored. Most approaches to assess the environmental impacts are based on life cycle assessments, which although they give a broad overview of environmental impacts of the product as such, often lack real applicable company data about the business operations in practice. There is also a need to take potential changes to user behaviour into consideration in determining the sustainability of a business model. As mentioned, potential rebound effects, such as increases in efficiency leading to more usage by consumers, might negate the potential benefits (Bocken, 2023).

2.4. Life Cycle Assessment

Life cycle assessment (LCA) is a method to analyse the environmental performance of a product, process or service throughout the full life cycle (Baumann & Tillman, 2004). The method takes into account all activities from the life cycle of the product, from extraction of material, production, use, and end-of-life. LCA can be used both as a tool in the design process and as an evaluation tool for existing systems (Kjaer et al., 2016).

An LCA study is done in four interconnected steps. The first step is the goal and scope definition, where the purpose of the study is defined and the specific product and environmental impacts that will be studied are determined. The first step also includes defining the system boundaries and determining the functional unit, which is the basis for comparison. During the second step, the inventory analysis, data is collected regarding all relevant material and energy flows that are associated with the product or service throughout the life cycle. In the third step, the impact assessment, the collected data is categorised and characterized to quantify the contributions to various environmental impact categories. The fourth step is interpretation. The interpretation step of LCA involves analysing results, identifying significant impacts and evaluating the completeness and consistency of the study. The interpretation also includes drawing conclusions to inform decision makers as well as give recommendations for improvement (Baumann & Tillman, 2004).

2.5. BM-LCA

Business model life cycle assessment (BM-LCA) is a method to analyse the environmental performance of business models. It is built on the methodology of LCA but instead of having a product lifecycle as the focus of a study the focus is instead on the business itself, utilising the business model as the object of analysis. This allows room to incorporate costs and revenues in the assessment allowing for a socio-material understanding, connecting the stream of money within a business with the material and energy flow of the products/services produced. It follows the LCA methodology of goal and scope definition, life cycle inventory (1), life cycle impact assessment (LCIA), and interpretation. The difference being primarily in the goal and scope step where it is divided into a descriptive and coupling phase (Böckin et al., 2022).

In the descriptive phase the boundaries of the system are set, the business models being investigated are described, and the products associated are defined by their characteristics. A connection between production and transactions are also established and the actors involved in the product chain are mapped out. In the coupling phase on the other hand, the functional unit is defined as a certain amount of profit, and the material and monetary flows are coupled through equations. To do this, all costs and revenues need to be identified. The equations created can then be solved in order to calculate the amount of transactions needed to reach the determined profit in the functional unit (Böckin et al., 2022).

2.6. Conclusion of theoretical background

During the last couple of years, the concept of circular economy has emerged as a potential solution for various environmental problems. The increasing pressure to adopt more circular business practices are evident from companies and policymakers alike. Policies such as The European Green Deal and The New Circular Economy Action Plan show that circularity is a growing priority within the EU.

Circular business models, such as product service systems, have gained increasing popularity in both society and academic research. However, there is a need to investigate how to make them both profitable and environmentally beneficial. Assessments of the effect business models have on companies' environmental impact is still an emerging field of research that is not as developed as the assessment of the environmental impact of products and services. Currently, most methods for evaluating environmental impacts rely on life cycle assessments. While these assessments can provide a broad overview of environmental effects, they often lack practical, company-specific data and do not include financial measures. An exception is the relatively new method BM-LCA that is a method specifically developed for assessing the environmental performance of business models.

The environmental and economic success of a circular business model is also dependent on the design of the product and user acceptance. Previous research suggests that users often prefer new products with no terms of use and that the novelty aspect of new products can impact the customers' choices. However, it is not clear whether all products are equally affected by such preferences. Further investigation into how user behaviour can affect the potential for business to adopt more sustainable business practices, and what actions are suitable for what kind of products are therefore needed.

To conclude there is therefore a need to further develop the application of BM-LCA with more real cases to further the credibility of the method as a tool to assess the sustainability of businesses. By evaluating the case company's business models through BM-LCA there is therefore a great potential to better understand how their choice of business model might affect their environmental impact. BM-LCA has a great potential to fill the gap in the assessment of the sustainability of business practices, but the method is still relatively untested with only a few assessments currently having been made.

3. Method

This chapter aims to explain the methodology that took place for the project. The project employed a mixed-methods approach, integrating a Business Model Life Cycle Assessment (BM-LCA) framework with a continuous literature study and qualitative data collection through unstructured observations. The BM-LCA framework as developed by Böckin et al. (2022), served as the central analytical tool and enabled a systematic comparison of the environmental impacts associated with the two business models under study. In addition, the literature study was used to fill knowledge gaps and provide context while the qualitative data collection offered additional insights into how the BM-LCA method can be useful for companies when implementing sustainable business models.

3.1. The Case

This project assessed two business models used by a Dutch distributor of mobility aid products operating in the Netherlands. A lending business model and a sales business model was assessed and compared. The sale model was assessed and compared for two products a rollator and a shower chair. The lending model was only assessed for the shower chair, and compared against the sale of the same product, as seen in table 1. The rollator is procured and made by a Norwegian manufacturer and the shower chair is procured from a Swedish manufacturer.

Table 1: Cases being investigated

	Business Model	
	Sale Business Model	**Lending Business Model**
Product	Rollator	
	Shower Chair	Shower Chair

The sale model is linear where products are procured by the case company to then be sold on to the users, who gain ownership of the product at moment of purchase. The lending business model on the other hand, operates by allowing users access to the product through their health insurance. The cost is covered by the insurance provider and users do not pay for the product directly. Instead, they are allowed to borrow the product for free for up to 26 weeks. The insurance company pay for the loan at a set amount regardless of how long the user loans the product.

3.2. Literature study

To start of the project a study of the existing studies done on the research area was performed in order to establish a solid theoretical background for the project. Online databases such as Chalmers Library and Google Scholar were used to find academic journals, using relevant keywords for the areas being investigated.

Areas that were investigated included, among others:

- Business model innovation for sustainability.
- Sustainable business models

- What tools currently are available to determine the sustainability of a business model.
- Circular economy
- Decoupling

3.3. BM-LCA

In order to answer the first three research questions and develop an understanding of the of the environmental performance of the business models under study, two comparisons were done using business model life cycle assessment. The BM-LCA method was first used to compare the rollator and the shower chair within the sales business model. The same method was then used to compare the sale business model and the lending business model for the shower chair. The method developed by Böckin et al. (2022) was applied in five steps:

1. Goal and scope: descriptive phase
2. Goal and scope: coupling phase
3. Life cycle inventory
4. Life cycle impact assessment
5. Interpretation, including a sensitivity analysis.

3.3.1. Goal and Scope: Descriptive Phase

In the descriptive phase of the goal and scope, a general description of the setup of the two business models under study were created. Relevant actors in the product life cycle were identified using actor analysis, along with the production-transaction relationships that take place between them. Additionally, the system- and geographic boundaries were defined, and relevant environmental impact categories were selected.

3.3.2. Goal and Scope: Coupling Phase

During the coupling phase, the functional unit were defined as a specific amount of profit to be achieved by each business model. Equations were established and solved, to couple the flows within the business models based on the profit, revenue, and direct, indirect, and contingent costs across the products lifecycle.

3.3.3. Life Cycle Inventory

The identified monetary flows from the coupling phase formed the foundation for the data needed in the life cycle inventory. A system model was created in Excel and necessary complementary data, such as environmental impacts of production, transportation, use phase activities, and end of life was gathered, scaled and analysed throughout this stage. For production related emissions an EPD and an LCA from secondary source were used to assess the environmental impact. Other life phases were modelled using Ecoinvent 3.11 in OpenLCA.

3.3.4. Life Cycle Impact Assessment (LCIA)

The result from the LCI was then aggregated into the impact categories chosen in the goal and scope. The results were modelled according to the life cycle inventory as explained in the previous chapter. All results were calculated based on the Environmental Footprint (EF) v.3.1. method using the Ecoinvent 3.11. dataset in openLCA. All results were also anonymized and normalised to protect the integrity of the case company.

3.3.5. Interpretation

The results from the LCIA were analysed to evaluate the environmental performance of the business models. To deepen the analysis, various sensitivity analyses were performed. Two main categories of parameters were studied, financial and transportation. These were considered to be the areas where the case company had the most influence and thus held the greatest significance.

3.4. Qualitative Data Collection

To gather additional data in order to answer the fourth question and get insights regarding the use of the BM-LCA method, unstructured observations were performed throughout the project. The unstructured observations aimed to document interactions between different project stakeholders with the purpose of uncovering potential unforeseen consequences and opportunities related to the BM-LCA method. The hope was to generate further understanding on how the BM-LCA method can be used to enable collaborative actions between different departments within the company, as well as between different companies within the production chain.

The unstructured observations were conducted throughout the project during data collection and verification meetings with representatives from both the distributing company and the parent company.

4. Results: BM-LCA Modelling for Lending and Sale Business Model

In the following chapter the results from the BM-LCA modelling will be presented, including the results from the descriptive phase, the coupling phase and the life cycle inventory.

4.1. Goal and Scope: Descriptive Phase

The following section provides the result of the modelling of the descriptive phase, describing the case, and how each business model operates. It also outlines the system boundaries and impact categories considered in the study.

4.1.1. Case Description

This project assessed two business models used by a Dutch distributor of medical aid products operating in the Netherlands. A lending business model and a sales business model was assessed and compared for two different products.

The first product is a rollator made by a Norwegian manufacturer. It is primarily made of aluminium, glass fibre reinforced polymer, polyurethane, steel, and polypropylene (edp-norway, 2023). It is currently only sold and is not part of the lending business model. The second product is a shower chair that is produced by a Swedish company and is currently part of both the lending and the sale business models. The shower chair known for its adjustability with hight adjustable legs and detachable arm- and backrests, making it possible to adopt the product for specific customer needs. Its primary materials are polypropylene and aluminium. The shower chair is currently used in both the sale and lending business model.

The lending business model operates by allowing users access to the product via their health insurance. The cost is covered by the insurance provider and users do not pay for the product directly. Instead, they are allowed to borrow the product for free for up to 26 weeks. Contrary to the lending business model, the sales business model allows the user to gain ownership of the product at the time of purchase. The product is paid for by the user and not the insurance company.

4.1.2. System boundaries

The study is limited to the market in the Netherlands where the distributing company operates. Environmental parameters include the full lifecycle from cradle-to-grave. The financial parameters are limited to the case company and does not include the parent company. The study is limited to one year.

4.1.3. Description of the Sales Business Model

The sales model is the same for both the rollator and the shower chair. Figure 1 shows a flowchart of the product system, illustrating the material flow and the associated costs and revenues.

The rollator and the shower chair are produced by two different companies in Scandinavia before they are shipped to a distribution centre located in the Netherlands. The procurement cost (C1s) refers to the price that the case company pays for the products and includes the cost of the transport.

From the distribution centre, the products are divided up and delivered to one of seven warehouses. This leg of the transport is carried out by lorry and is handled by an external logistics company, resulting in a transport cost (C2s).

At the warehouse, the products are stored before being purchased by the customer online or shipped to a physical store. The warehouse storage cost (C3s) includes both the operational cost of running the warehouse as well as additional labour costs. The transport between the warehouse and the stores are handled internally. The cost of transport between the warehouse and the stores (C4s) includes vehicles expenses and labour costs for the drivers. The storage cost of the physical stores (C5s) includes both facility costs and personnel expenses.

When purchasing the products in store, the customer picks up the product at the store and transports it to their home. The revenue (R1s) is generated through the sale of the products.

The rollator has a technical lifetime of approximately 10 years, while the shower chair lasts around 7 years. At the end of life, the products are disposed of, and parts are either recycled or incinerated for energy recovery.

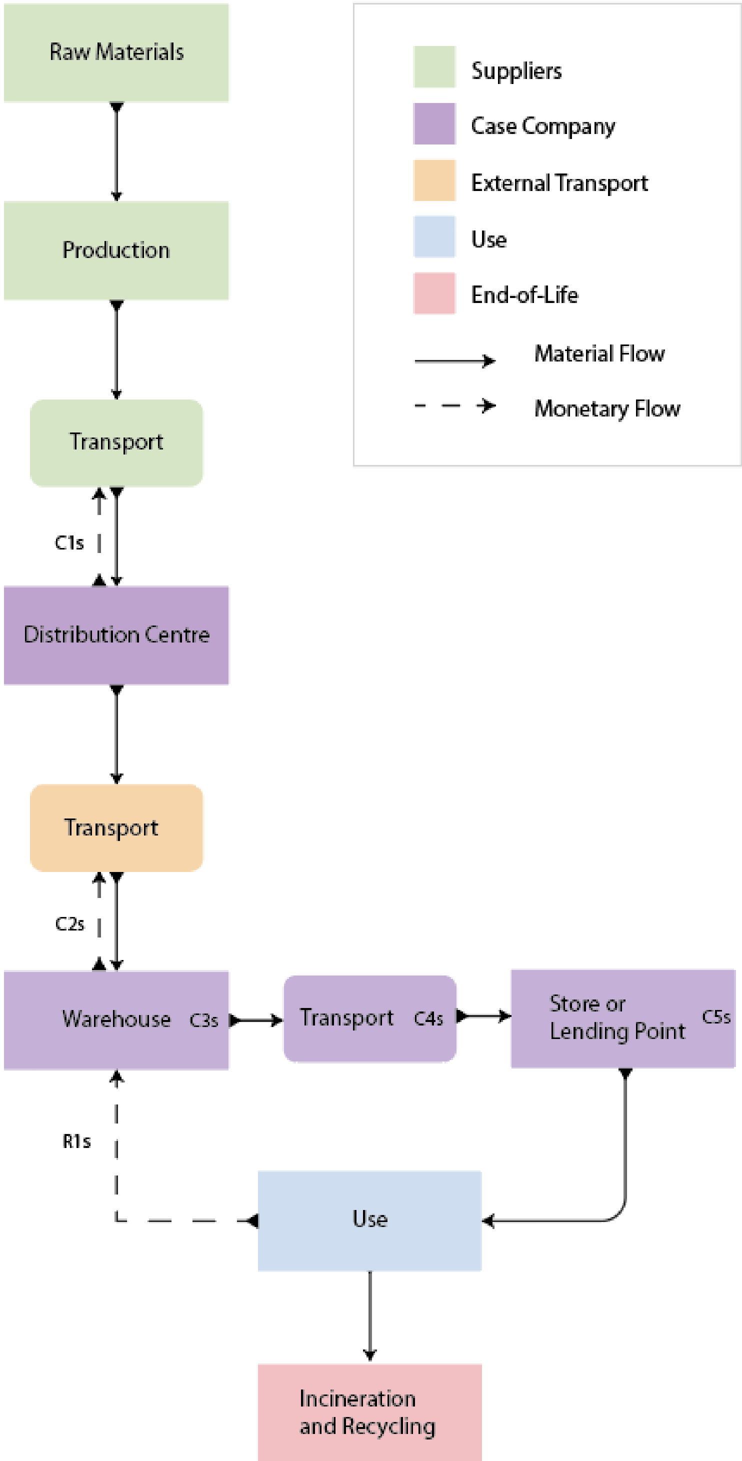

Figure 1: Flowchart of the sales business model.

4.1.4. Description of the Lending Business Model

The case company also offers access to their medical aids through a lending business model. This model is used for the shower chair and operates on the principle that customers can borrow medical aids for free for up to 26 weeks through their insurance. A flowchart of the model can be found in figure 2.

The product is acquired from a Swedish manufacturer and shipped to the case company's distribution centre in the Netherlands. The product procurement cost (C1l) and includes both the price of the product and the cost of transportation to the Netherlands.

Distribution from the distribution centre and the warehouses follows the same process as in the sales model, resulting in a transport cost paid to an external logistics company (C2l). Similarly, (C3l) is the cost of running the warehouse including both labour and utility expenses.

At the warehouse, the product is stored before being transported to the user. The user may also choose to pick up and return the product at a local store or lending point. The cost associated with the transportation to and from the user (C4l) and the cost of transporting products from the warehouse back and forth to the stores and lending points (C5l), both includes vehicles and labour costs. The cost of operating stores and lending points (C6l) includes both labour and utility costs.

Between each new user, the product is cleaned and, if needed, repaired to ensure it remains in good condition. The shower chair is cleaned using a cabinet dishwasher that can wash up to three chairs at a time. Each cleaning cycle lasts three minutes and uses detergent along with water heated to 63°C. The cleaning cost (C7l) includes the price of materials and the price of labour for the cleaners who are hired from an external company. Products that require maintenance are repaired using spare parts that are either bought from the supplier or reused from old products. The cost of repair (C8l) includes labour cost as well as the cost of new spare parts. Since both the cleaning and the maintenance take place at the warehouse and the same location that the product is stored, there are no additional transportation costs needed for cleaning and maintenance.

When a product is no longer considered to be in a functional condition and cannot be repaired it is discarded. The product is then disassembled, and the materials are divided into containers for hard plastic, metal, and soft plastic. Costs of disposal (C9l) include the cost to an external company that empties the containers and recycles the materials.

Since the service is free for the user through their health insurance the revenue (R1l) comes from reimbursement by the insurance company. At the end of the lending period the user can also chose to purchase the product at a reduced price resulting in additional revenue (R2l).

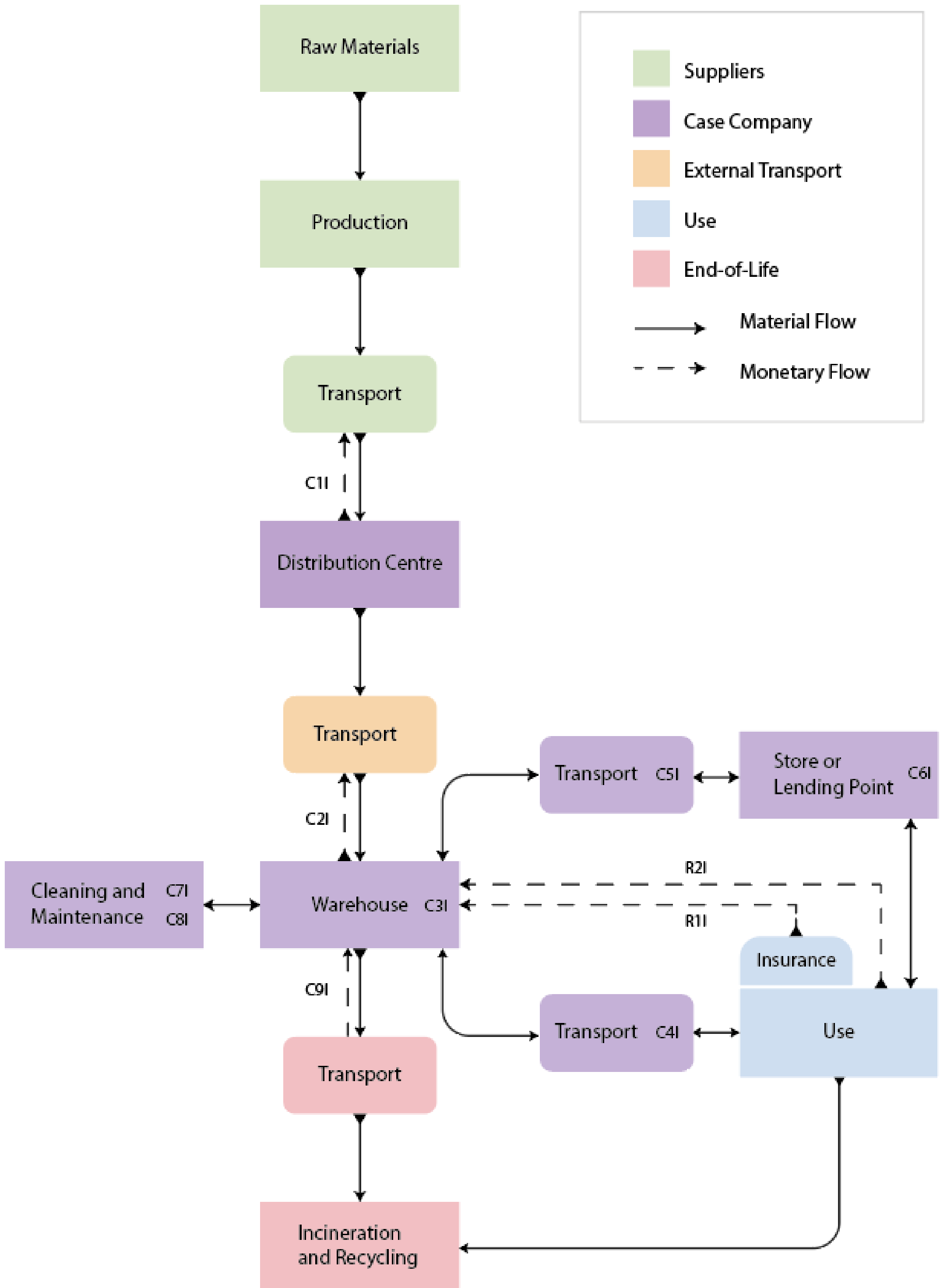

Figure 2: Flowchart of the lending business model

4.1.5. Impact Categories

The impact categories were chosen based on the emission data available for the production of the two products. Therefore, the result of the impact categories calculated for the other processes were calculated using the Environmental Footprint (EF) v.3.1 method to get results with the same categories and units.

Among the available impact categories, four impact categories were chosen to be examined closer due to their relevance for the company and the products. Due to the company being a supplier that coordinates transports of the products, impact categories that related to transport were chosen, as well as impact categories that reflect the resource use of the products. The impact categories chosen can be found in table 2 below.

Table 2: Impact categories

Parameter		**Unit**
Global Warming Potential (GWP)		kg CO_2 eq.
Acidification Potential (AP)		mol H^+ eq.
Abiotic Depletion Potential (ADP)	Metals and minerals	kg Sb eq.
	Fossil resources	MJ, net calorific value

4.2. Goal and scope: Coupling phase

In the following chapter the result of the coupling phase is presented. Focusing on the equations coupling the monetary flows within each business model.

4.2.1. Functional Unit

The functional unit of a BM-LCA is as previously mentioned defined as a certain amount of profit, π, to be reached over a set time period, T (Böckin et al., 2022). To be able to compare the sale and lending business models the same amount of profit to be reached is set for both models.

$$\pi_s = \pi_l \quad (1)$$

The amount of profit given by a business model can also be calculated by the revenue and costs associated with the business model.

$$\pi = \sum Revenue - \sum Costs \quad (2)$$

This gives us the equation as seen below.

$$\pi = \sum Revenue_{sales} - \sum Costs_{sales} = \sum Revenue_{lending} - \sum Costs_{lending} \quad (3)$$

The set profit value can be based on either stated goals by the company or by average historical profit (Böckin et al., 2022). Historically for the products related to this project the profit level between the sales and the lending business model varies quite a bit for the products in question. Therefore, in this case the profit level was set as an historical average of the two to be able to make a comparison while not setting a value too high for one of the business models to achieve. The average was based on the revenue of the models during 2023 and 2024.

4.2.2. Sales Business Model

Based on the profit level the coupling equations were set up, and the amount of transactions and products needed to meet the set profit level were calculated. In table 3 below, the costs, revenues and their respective coupling equation for the sales model are presented. Explanations to the variables used in the equations are found in table 4.

Table 3: Coupling equations for the sale business model.

Category	**Equation**
C1s: Product Procurement Cost	$k1s * ts$
C2s: Transportation Cost, Distribution Centre to Warehouse	$k2s * ts$
C3s: Storage Cost, Warehouse	$k3s * ts$
C4s: Transportation Cost, Warehouse to Store	$k4s * ts$
C5s: Storage Cost, Store	$k5s * ts$
R1s: Total Revenue from Sales	$r1s * ts$
π_S: Profit Level	$\Sigma Revenues - \Sigma Costs$

Table 4: Explanation of variables used in the coupling equations for the sale business model.

Variable	**Name**	**Unit**
T	Time Period	Weeks
k1s	Procurement Cost	Euro/Item
k2s	Transport Cost, Distribution Centre to Warehouse	Euro/Item
k3s	Storage Cost, Warehouse	Euro/Item
k4s	Transport Cost, Warehouse to Store	Euro/Item
k5s	Storage Cost, Store	Euro/Item
ps	Number of Products Procured	Units
r1s	Price of the Product	Euro
R1s	Total Revenue over Time Period	Euro
ts	Total Amount of Transactions during Time Period	Units
π_S	Total Profit During Time Period	Euro

From the coupling equations in table 2, the profit can be set up as a function of the revenues and costs associated with the model. From the equation the number of transactions needed to reach the profit can be derived.

$$\pi_s = ts * (r1s - (k1s + k2s + k3s + k4s + k5s + k6s)) \quad (4)$$

Since this business model is linear the number of products needed to be procured is equal to the number of transactions made to reach the set profit level.

$$ps = ts \tag{5}$$

4.2.3. Lending Business Model

For the lending business model, the costs, revenues and their respective coupling equation are presented in table 5 below. Explanations to the variables used in the equations are found in table 6.

Table 5: Coupling equation for the lending business model.

Category	Equation
C1l: Product Procurement Cost	$k1l * tl * \frac{(Rr * Ul)}{(Ql * T)} + k1l * Sl * tl$
C2l: Transportation Cost, Distribution Centre to Warehouse	$k12l * tl * \frac{(Rr * Ul)}{(Ql * T)} + k12l * Sl * tl$
C3l: Storage Cost, Warehouse	$k2l * tl * (1 - Ql) * \frac{Ul}{(Ql * T)}$
C4l: Transportation Cost, Warehouse to Customer	$2 * (1 - Sl) * k7l * tl * (1 - Psr) + Sl * k7l * tl * (1 - Psr)$
C5l: Transportation Cost, Warehouse to Store	$2 * (1 - Sl) * k9l * tl * Psr + Sl * k9l * tl * Psr$
C6l: Storage Cost, Store	$k8l * tl * \frac{Ul}{(Ql * T)} * Psr * (1 - Ql)$
C7l: Cleaning Cost	$(k3l + k4l) * tl * (1 - Sl)$
C8l: Repair Cost	$(k5l + k6l) * tl * Drl * \frac{Ul}{(Ql * T)}$
C9l: Disposal Cost	$(k10l + k11l) * tl * \frac{(Rr * Ul)}{(Ql * T)}$
R1l: Total Revenue from Lending	$r1l * tl$
R2l: Revenue from Products Sold after a Lending Period	r2l ∗ Sl ∗ tl
π_l: Profit Level	$\Sigma Revenues - \Sigma Costs$

Table 6: Explanation of variables used in coupling equations for the lending business model.

Variable	Name	Unit
T	Time Period	Weeks
k1l	Procurement Cost	Euro/Item
k2l	Storage Costs, Warehouse	Euro/Item
k3l	Cleaning Cost, Material	Euro/Item
k4l	Cleaning Cost, Labour	Euro/Item
k5l	Repair Cost, Labour	Euro/Item

k6l	Repair Cost, Spare Parts	Euro/Item
k7l	Transport Cost, Warehouse to Customer	Euro/Item
k8l	Storage Cost, Store	Euro/Item
k9l	Transport Cost, Warehouse to Store	Euro/Item
k10l	Dismantling Cost	Euro/Item
k11l	Disposal Cost	Euro/Item
k12l	Transport Cost, Distribution Centre to Warehouse	Euro/Item
r1l	Average Revenue from Lending per Transaction	Euro
r2l	Price of Product Sold Off	Euro
R	Revenue	Euro
Rr	Average Rate of Replacement during Time Period	%
Ul	Average Lending Period	Weeks
Drl	Defect Rate	%
tl	Total amount of Transactions over Time Period	Units
Sl	Percentage of Transactions Where a Product is Sold off at the End of a Lending Period	%
Q	Number of Products in Circulation	Units
Ql	Lending Efficiency	%
Psr	Pick Up at Store Ratio	%
pl	Number of Products Procured During Time Period	Units
π_l	Profit Level	Euro

From the coupling equation in table 5 an equation for the profit level based on the identified costs and revenues can be derived. From the equation the number of transactions needed to reach the functional unit can be derived.

$$\pi_l = (\, r1l * tl + r2l * tl * Sl - (k1l * \frac{(Rr*tl*Ul)}{(Ql*T)} + k1l * tl * Sl + k12l * tl * \frac{(Rr*Ul)}{(Ql*T)} + k12l * Sl * tl + k2l * tl * (1 - Ql) * \frac{Ul}{(Ql*T)} + 2 * (1 - Sl) * k7l * (1 - Psr) * tl + Sl * k7l * (1 - Psr) * tl + 2 * (1 - Sl) * k9l * tl * Psr + Sl * * k9l * tl * Psr + k8l * \frac{tl*Ul}{(Qr*T)} * Psr * (1 - Ql) + (1 - Sl) * (k3l + k4l) * tl + (k5l + k6l) * Drl * \frac{tl*Ul}{(Ql*T)} + (k10l + k11l) * \frac{(Rr*tl*Ul)}{(Ql*T)}) \tag{6}$$

For the number of products needed to be procured the calculation differs from the sales model. Here the total number of products procured are equal to the number of products discarded plus the number of products sold off at the end of a lending period. This makes it possible to calculate the number of products needed to be procured over the time period, T, as the replacement rate multiplied with the needed size of the fleet of product plus the percentage sold off multiplied with the number of transactions made. Which gives the relationship as seen in equation 7.

$$pl = Rr * Q + Sl * tl = \frac{(Rr * tl * Ul)}{(Ql * T)} + Sl * tl \quad (7)$$

4.3. Life Cycle Inventory (LCI)

In this chapter the life cycle inventory (LCI) of the study is presented. It includes information on material composition, production processes, transportation, use phase, and end-of-life treatment.

4.3.1. Production

The inventory data used in this study is based on information provided both by the company and the manufacturers. For the shower chair, the environmental impacts of its production are based on a LCA conducted internally by the producing company. In the case of the rollator, an EPD carried out by a third party on behalf of the manufacturer serves as the basis for environmental impacts of its production.

The material composition of both products is presented below in table 7 and 8.

Table 7: Material composition of the rollator.

Material	Total Weight (kg)
Aluminium	2.34
Glass Fiber Reinforced Polymer (GFRP)	2.63
Steel	0.85
Polypropylene (PP)	0.63
Polyurethane (PUR)	1.51
Other materials	0.34
Cardboard	1.19
Polyethylene	0.01
Paper	0.16
Total Sum	9.32
Total Sum (without packaging)	8.26

Table 8: Material composition of the shower chair.

Material	Total Weight (kg)
Aluminium	0.644
Polypropylene	3.478
Thermoplastic Elastomer (TPE)	0.16
Stainless Steel	0.004
Polyamide (PA6)	0.016
Polypropylene /glasfiber PPH GF3030 PD2	0.512
Cardboard	0.555
Paper	0.035
Total Sum	5.404
Total Sum (without packaging)	4.814

4.3.2. Transports

Transport during the production stage was calculated by the companies producing the products for previous LCAs and EPDs, and its impact is therefore included in the production stage of this analysis. Additional transport data used for assessing the sales and lending business models are presented in the tables below.

Estimates for the average transport distances between warehouses and stores were calculated based on the assumption that stores were supplied by the geographically nearest warehouse. Similarly, the average distance between the store and the user was calculated based on the assumption that users in different cities visited the nearest store or lending point. To estimate transport from stores or lending points to users, the average distance between 208 cities in the Netherlands and the nearest store or lending point was calculated. These distances were then weighted according to the population of each city.

Table 9 shows the average transport distances used for the assessment of the sales business models for both the shower chair and the rollator, as well as the Ecoinvent dataset used for the assessment.

Table 9: The average transport distances related to the sale business model

Transport step	Ecoinvent 3.11 Process	Average distance [km]	Source
Production to distribution centre (Sweden to Lisse)	market for transport, freight, lorry, 16-32 metric ton, diesel, EURO 5	1082	Google maps
Production to distribution centre (Norway to Lisse)	market for transport, freight, lorry, 16-32 metric ton, diesel, EURO 5	1 556	Google maps
Distribution centre to Warehouse	market for transport, freight, lorry, 16-32 metric ton, diesel, EURO 5	92	Google maps
Warehouse to Store	market for transport, freight, light commercial vehicle, fleet average	28	Calculated
Store to User	passenger, car with internal combustion engine, fleet average	11	Calculated

Transport distances associated with the lending business model were calculated using the same method as for the sales business model. However, since lending can occur at both stores and dedicated lending points, the average transport distances differ slightly. Additionally, the lending model includes both customer pickup at stores and company delivery to users, resulting in an extra transport leg from the warehouse to the customer. Table 10 presents the average transport distances used in the assessment of the lending business models.

Table 10: The average transport distances related to the lending business model

Transport step	Ecoinvent 3.11 Process	Average distance [km]	Source
Production to Distribution Centre (Sweden to Lisse)	market for transport, freight, lorry, 16-32 metric ton, diesel, EURO 5	1082	Google maps
Distribution Centre to Warehouse	market for transport, freight, lorry, 16-32 metric ton, diesel, EURO 5	92	Google maps
Warehouse to Store	market for transport, freight, light commercial vehicle, fleet average	30	Calculated
Store or Lending Point to User	passenger, car with internal combustion engine, fleet average	10	Calculated
Warehouse to User	market for transport, freight, light commercial vehicle, fleet average	33	Calculated

4.3.3. Use

For the sales business model the products do not generate any direct emissions during the use phase. Emissions related to maintenance of the products, such as cleaning, is considered negligible and therefore not accounted for. For the lending business model there is considerably more maintenance as the products are cleaned in an industrial dishwasher in between each lending period. The emissions of a cleaning cycle were therefore modelled to calculate the emissions. It was approximated that about three chairs are cleaned at once due to the size of the machine. Therefore, a third of the emissions of a wash cycle were allocated to each transaction.

4.3.4. End of Life

The end of life was modelled based on the products material composition as seen in table 7 and 8. They were also based on the waste treatment method for each individual waste stream in the Netherlands. In table 11 below the composition of treatment options for each waste stream is found.

Table 11: Waste treatment method for each waste stream of the products (Eurostat. 2024).

Waste Stream	Recycling	Incineration With Energy Recovery	Landfill
Non-ferrous Metals	99.7%	0%	0.3%
Ferrous Metals	99.9%	0%	0.1%
Plastic Waste	74.3%	25.5%	0.1%
Cardboard and Paper, Packaging	99.8%	0.2%	0%

4.3.5. Scaling of Emissions

A business model perspective was chosen for all emission and the emissions was calculated per transaction for the use phase, per product procured in the case of production, and per product discarded per end-of-life related emissions.

In the case of the sales model, it was assumed that the number of products discarded are equal to the number of products procured, assuming a steady state scenario. For storage the emissions were calculated based on the area needed per product in storage. It was reasoned that even though the products both have a technical lifetime of about 7 and 10 years the same amount of products need to be purchased each year to maintain the profit level set for the business model.

For the lending model the total amount of emissions relating to the product being procured were assigned. Due to the existence of a stock in the model a seventh of the production emissions for those already in circulation were also assigned to the models' total emissions, based on the technical lifetime of the product. The same was true for end-of-life related emissions. The full environmental burden of products discarded was assigned as well as a seventh of the ones existing in the stock. The use phase emissions, including transports, storage, and maintenance, was calculated per transaction.

5. Results: The Environmental Impacts of the Business Models

This chapter presents the results of the BM-LCA conducted in the study, including LCIA and sensitivity analysis. It also presents the results of the qualitative data collection.

5.1. Sale Business Model

When it comes to the sale of the of the rollator, the distribution of the emissions of different activities for the impact categories can be found in figure 3 below. The results shows that the production has the greatest impact, contributing to over 75% of the emissions in all categories. The end-of-life phase, e.g. the disposal and waste treatment of the material also have some impact on the global warming potential (kg CO_2-eq), but it is significant less than that of the production. Transportation plays only a minor role on the overall emissions, with most of its contribution coming from the transport between the store and the user, and the primary transport from Norway to the Netherlands.

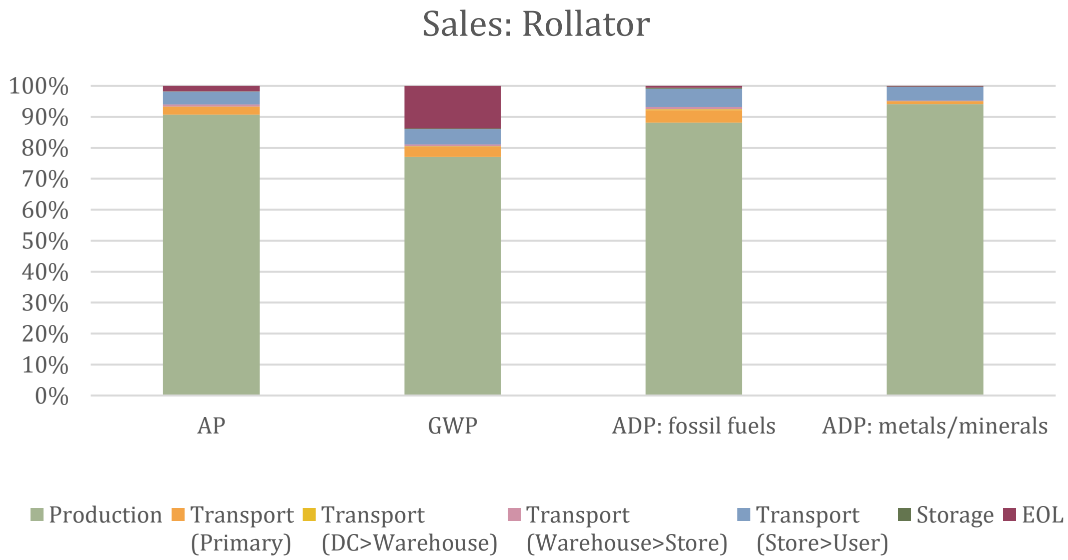

Figure 3: Distribution of emissions between different activities for the rollator sales business model for the chosen impact categories.

For the shower chair, as shown in figure 4 below, the emissions are more evenly distributed between different phases. Transportation plays a much larger role on the total emissions compared to the rollator where production was the main contributor. As with the rollator, most of the transport related impacts come from the transport from the store to the user. Production also still contributes significantly, particularly in categories such as global warming potential (GWP) and abiotic depletion potential (ADP) of fossil fuels.

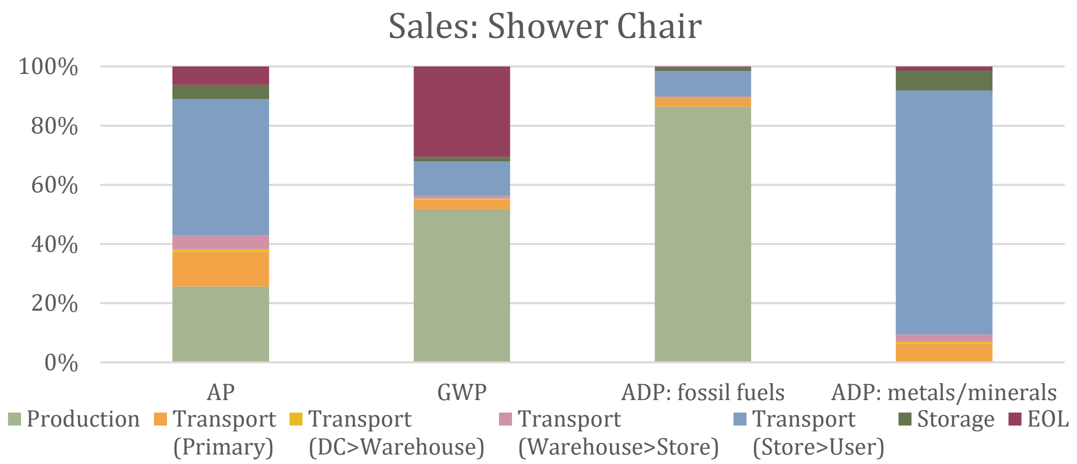

Figure 4: Distribution of emissions between different activities for the shower chair sales business model for the chosen impact categories.

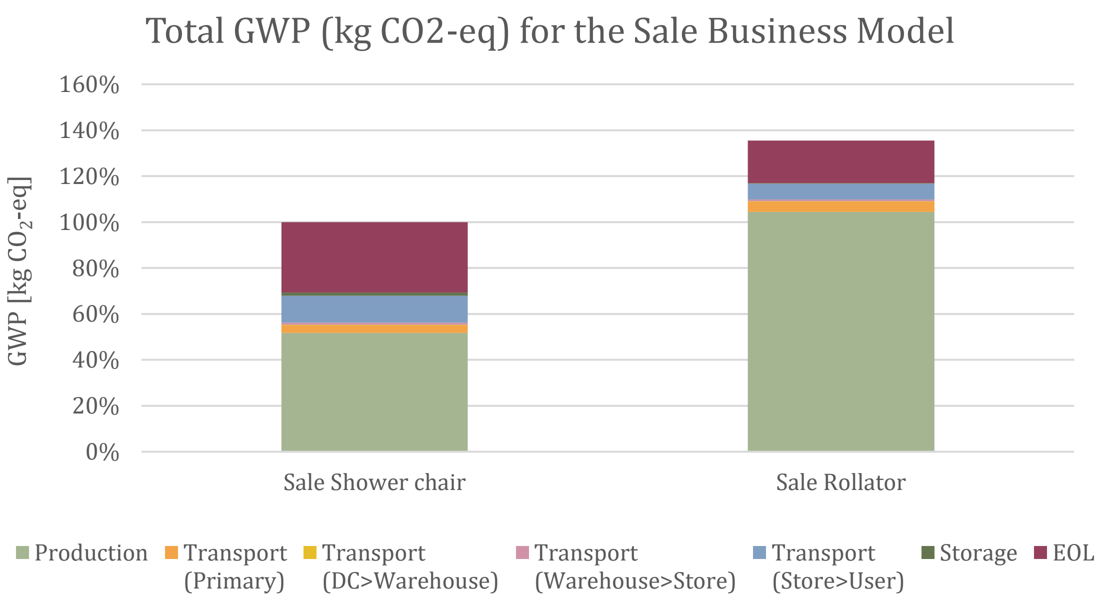

Figure 5: The total amount of kg CO2-equivalent emissions contributed to each product normalised to the shower chair.

Table 12: Emissions and number of products sold to reach the profit level π_s, normalised to the results of the shower chair.

Product	Profit level	Number of products sold	GWP (kg CO_2-eq)
Shower Chair	π_s	100%	100%
Rollator	π_s	59%	135%

A closer look at the global warming potential (GWP) of the two products shows that the rollator has a larger impact per euro of profit. As shown in figure 5, the emissions for the two sales models have been compared, with the values normalised to the sale model for the shower chair. The sale of the rollator results in 35% more emission per euro of profit. Although a larger number of shower chairs are sold to reach the same profit level, as seen in table 12, the environmental impact of the rollator is high enough to give it a greater impact overall. When comparing the other impact categories, it can be noted that the rollator performs significantly worse in all impact categories than ADP: fossil fuels, as seen in figure 6. For ADP: metals and minerals, the sale of the rollator results in 900% more kg Sb-eq emissions per euro. For acidification potential (AP) the rollator contributes to about 500% more mol H^{+}-eq per euro profit.

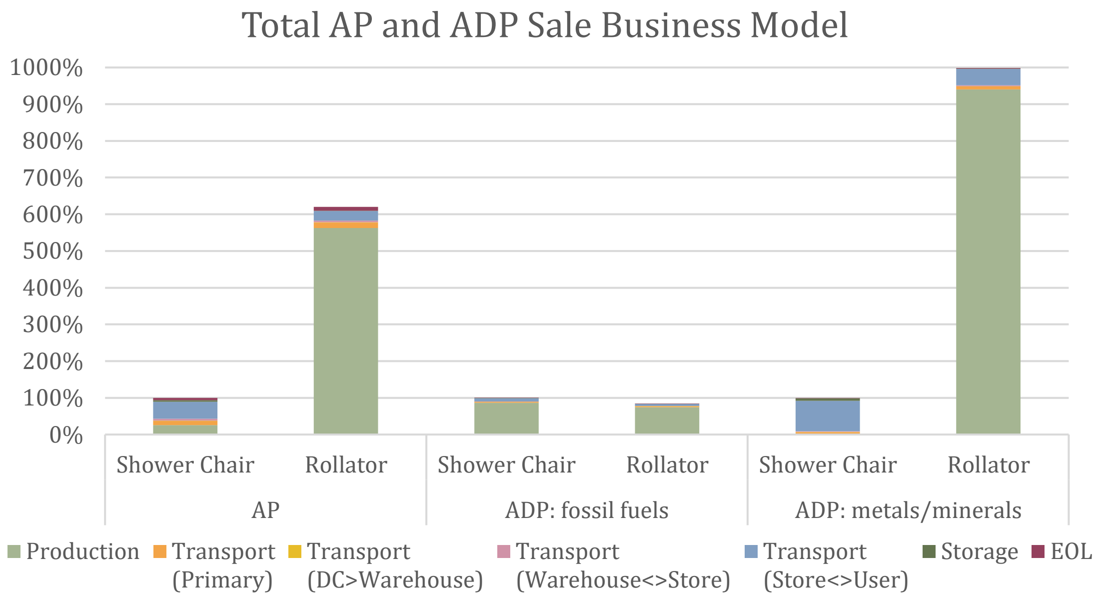

Figure 6: Total emissions for the other impact categories. Normalised to the shower chair.

5.2. Lending Business Model

For the lending business model, the distribution of the emissions between different activities can be found in figure 7. The largest impacts stems from the different legs of transportation, particularly the user's trip to pick up and return the product from a store or lending point. Transportation as a whole accounts for 42% of the total GWP emissions, with 65% of that coming specifically from transport between the store and user. Production is also a major factor, responsible for approximately 37% of total GWP emissions.

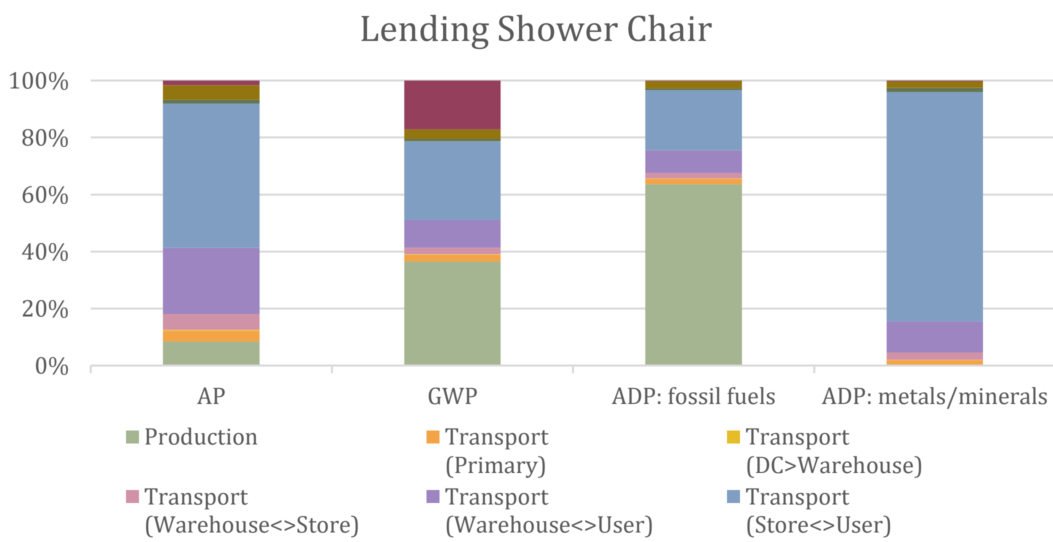

Figure 7: Distribution of emissions for the lending business model for the chosen impact categories.

Figure 8 below compares the global warming potential of the sale and the lending business model of the shower chair, with values normalised to the sale model. The results show that the lending model generates 44% less emissions per euro profit. The substantial difference is mainly due to the impact of the production and end-of-life, since fewer products need to be manufactured and ultimately disposed of to sustain the business model and achieve the same profit level, as seen in table 13.

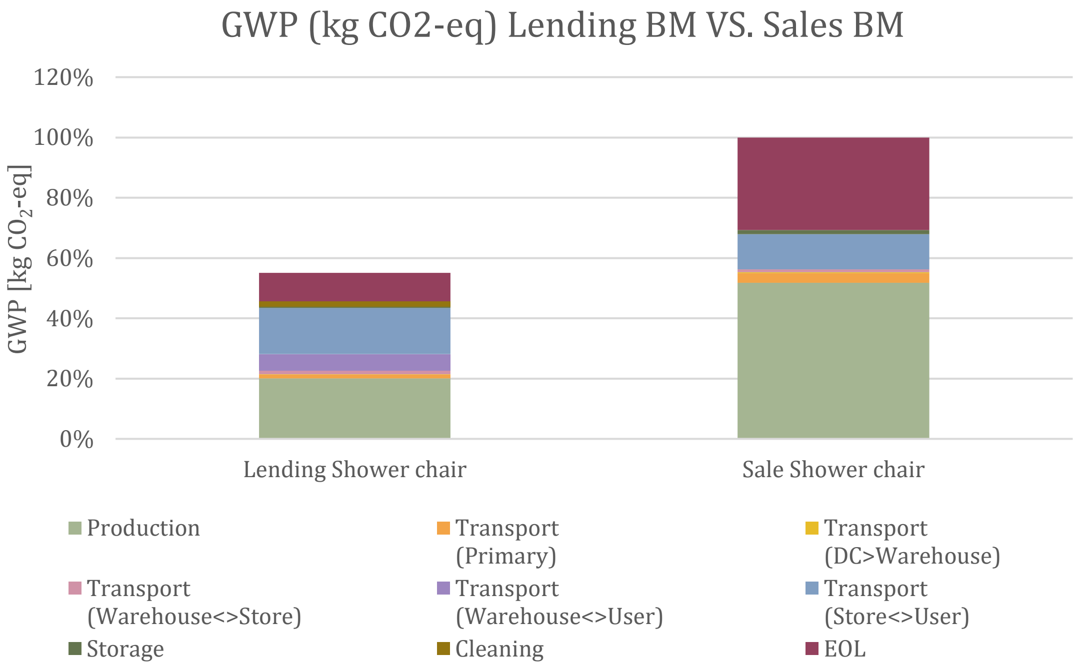

Figure 8: The total amount of kg CO2-equivalent emissions contributed to the sale and lending of the shower chair. The values are normalised to the sale model.

Table 13: Emissions and number of products procured to reach the profit level $\pi_s = \pi_l$, normalised to the results of the sales model.

Model	Profit Level	Number of Products Procured Yearly	GWP (kg CO_2-eq)
Sale	π_s	100%	100%
Lending	π_l	30%	56%

For the other impact categories, as seen in figure 9, a greater variance between the models can be noted. The lending model in the ADP: fossil fuels category but worse for the other two. The lending model contributes with 13% more acidification potential (AP) and 25% abiotic depletion potential (ADP): metals and minerals per euro profit. For ADP: fossil fuels however the lending model contributes to 56% less MJ per euro profit than the sale model.

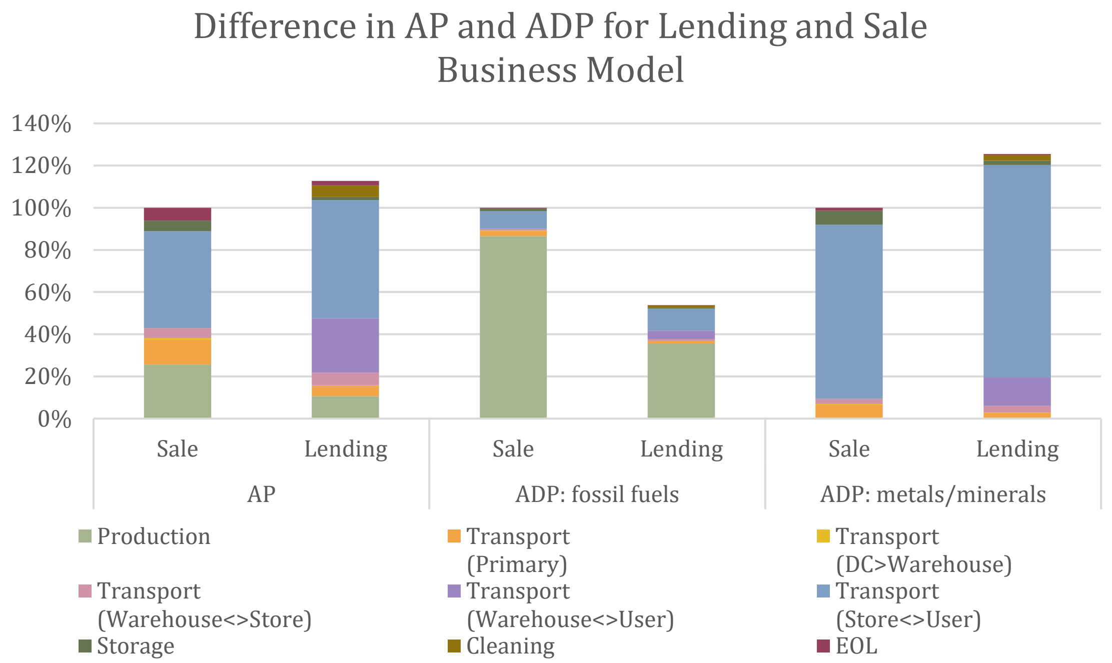

Figure 9: Total emissions for the other impact categories. Normalised to the sale business model.

5.3. Sensitivity analysis

Various sensitivity analyses were conducted to evaluate the impact of different variables on the system and to examine how uncertainties and assumptions affect the assessment results. The functional unit remains the same as previous results. The sensitivity analyses can be divided into two main groups, testing the impact of financial and transport parameters respectively.

5.3.1. Financial

The financial sensitivity analyses were used to test the influence of parameters such as the lending price, the sale price, and the ratio of products being sold through the lending business model. The parameters were only checked against one of the impact categories, global warming potential (GWP).

Lending Price

As previously stated, when lending a product from the company it is free of charge for the user, and the user can keep the product for up to 26 weeks. The price of the loan is instead paid by the users' insurance company at a set amount independently on how many weeks the user needs the product. However, since each insurance company has its own contract, the price paid to the case company can vary greatly. The revenue generated per transaction therefor depends on what insurance company the user has. For the result an average of the different prices was used to calculate the revenue. Since the variance was so great however, it was deemed interesting to see how the parameter could potentially affect the results. Therefore, an interval of prices from the lowest price paid by an insurance company to the highest was checked, as can be seen in figure 10. The figure depicts the difference in total GWP when changes to the pricing is made. The result was normalised to the baseline average used in the rest of the result. The result shows that a higher lending price greatly affect the amount of emissions per euro profit. It was found that if all insurance companies had paid the highest price, GWP emissions would be reduced with about 60% per euro profit. However, if all insurance companies had paid the lowest price the GWP emissions would increase with roughly 30% per euro profit. However, the total emissions would still be considerably lower than that of the sale model of the shower chair, as seen in figure 10.

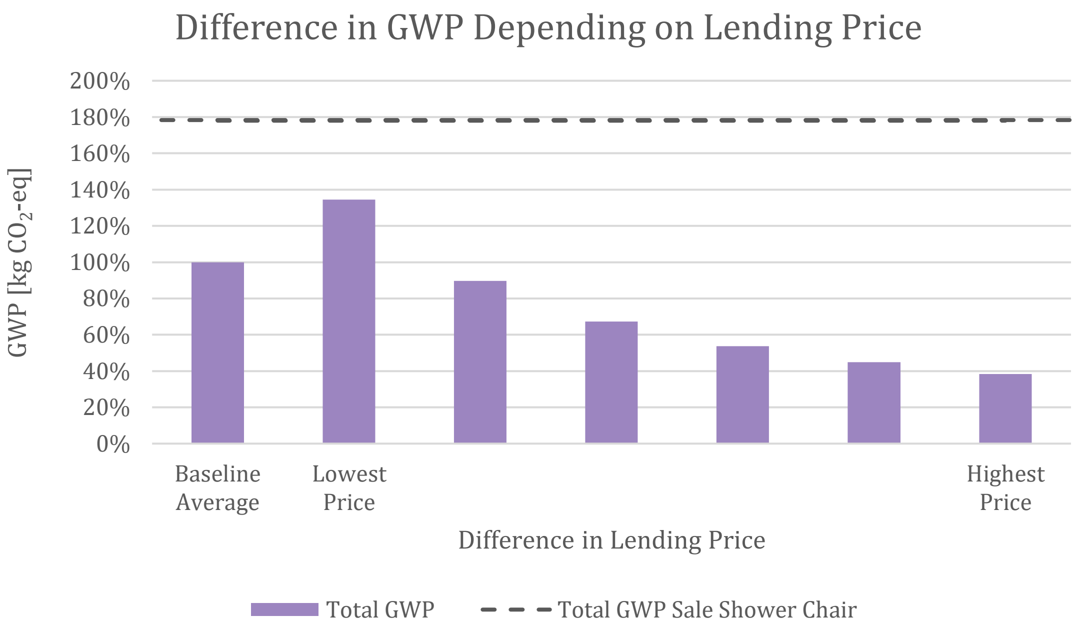

Figure 10: Difference in GWP depending on lending price, normalised to the average cost.

Sale Price Sale Business Modell

To see how the sale price affected the results the price parameter was tested between a reduction of 50% to an increase of 50% of the price currently set for the products, as seen in figure 11 and 12. For the rollator, decreasing the sales prices with of 50% meant that the product did not generate a profit and this scenario is therefore not included in the result. Only the total GWP values are displayed in the figures, as the relationship between the emissions from different life cycle phases is not affected by changing the price. The dashed line shows the changes in emission compared to the sale model of the shower chair for the rollator and the lending model for the shower chair. It can be noted that a reduction in price has a great impact on the environmental impact of the business model. As can be seen in figure 12 a reduction of price by 50% leads to an increase of about 400% of emissions per euro profit for the shower chair.

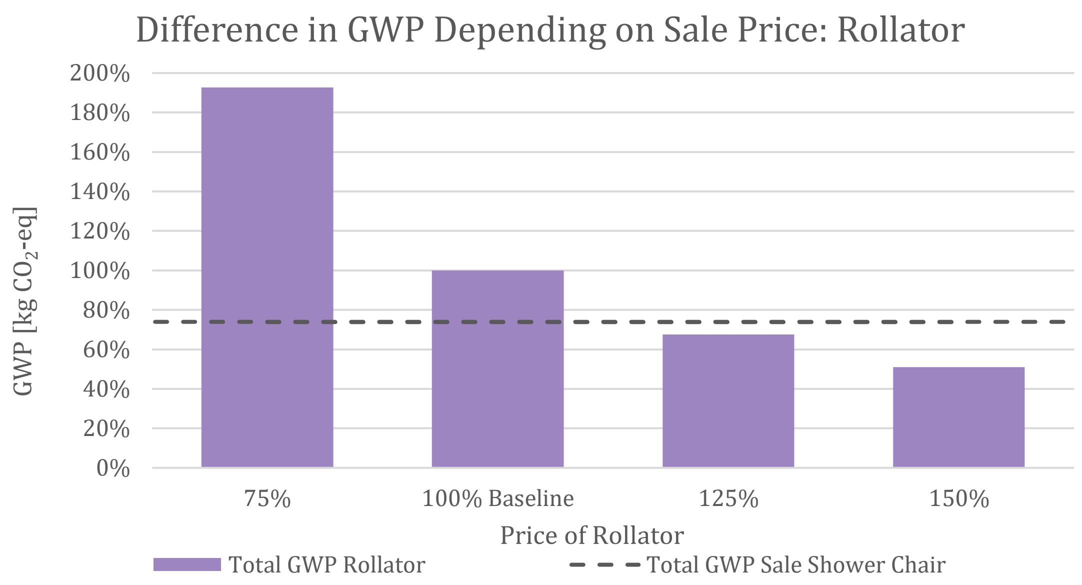

Figure 11: Difference in GWP depending on the sale price of the rollator normalised to the current price.

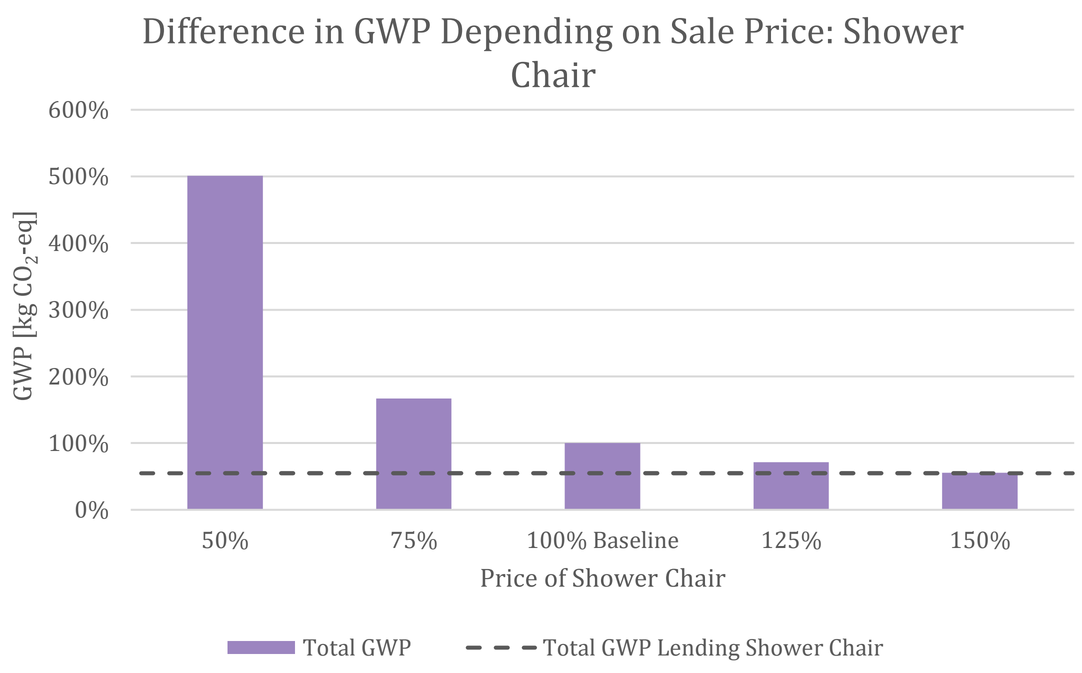

Figure 12: Difference in GWP depending on the sale price of the shower chair normalised to current price.

Percentage Sold off through the Lending Model

To ascertain the effect the percentage of transactions leading to a product being sold off (Sl) in the lending model, an interval between 0% to 100% was checked, as seen in figure 13. 0% indicating a scenario where all products stay in circulation within the model and 100% being that a chair is sold off after each lending period. The results showed that the emissions increased when the parameter increased, resulting from more and more products needing to be replaced. When 100% was sold of the total amount emissions became comparable to that of the sale lending model although slightly lower. That the model still performed better environmentally can be attributed to difference in transportation between the two models. In the lending model most of the products are shipped directly to the customer leading to lower transportation emissions compared to the sale model where the products are picked up by the user in a store. It should also be noted that should the option to purchase the product at the end of a lending period disappear the environmental impact in the GWP category would be reduced by 14%.

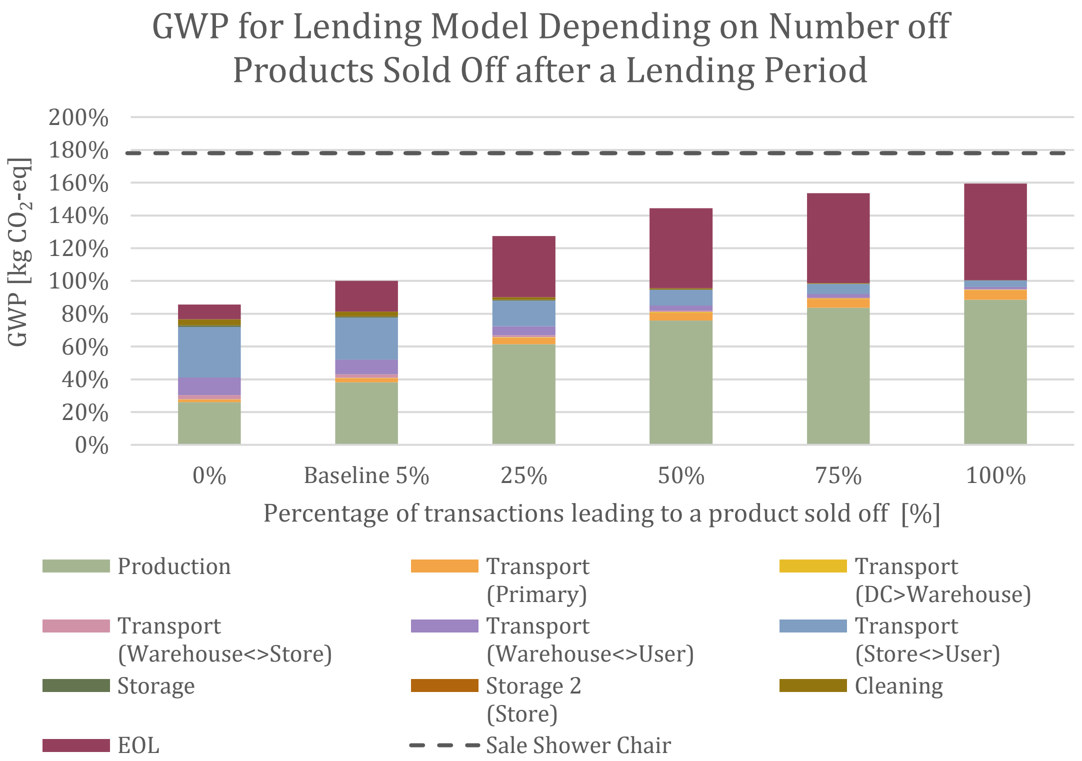

Figure 13: Change in GWP depending on the percentage of products sold off after a lending period. Normalised to the baseline scenario.

5.3.2. Transports

The transport sensitivity analyses test the impact of variables associated with transport. The transport between the user and the store was identified as a hot spot regarding the global warming potential. The impact of variables that effect this leg of the transport, such as the transport distance between the user and the stores and the ratio of products being delivered versus products being picked up in store was therefore tested. Additionally, the impact of the distance between the production and the distribution centre in the Netherlands was tested to assess the impact of the import distance on the business models.

Distance between User and Stores.

The transport between the user and the store proved to be the largest contributor to the environmental impact among the different transports. To evaluate the influence of this leg of the transport the distance parameters was changed between 0 and 200 percent of the baseline distance that was calculated to be 11km for the sales model and 10km for the lending model. By changing the parameters scenarios for longer distances as well as shorter distances or no travel distance at all, could be tested.

The result of the sensitivity analysis can be seen in figure 14 for the lending of the shower chair, figure 15 for the sale of the shower chair and figure 16 for the sale of the rollator when normalized to the baseline scenario.

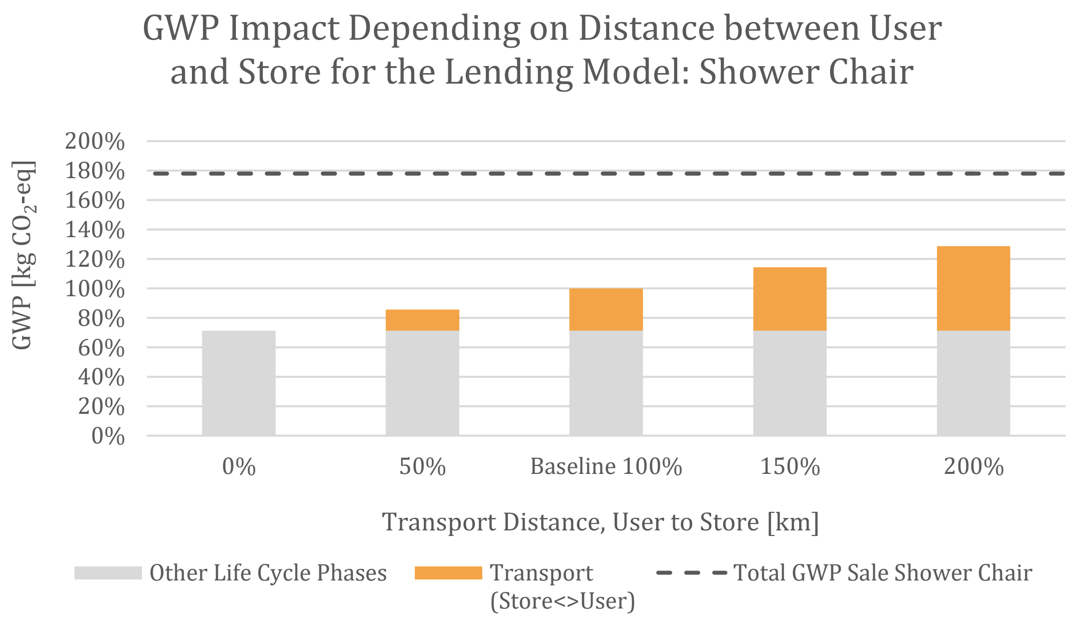

Figure 14: Difference in GWP depending on distance between user and store lending model.

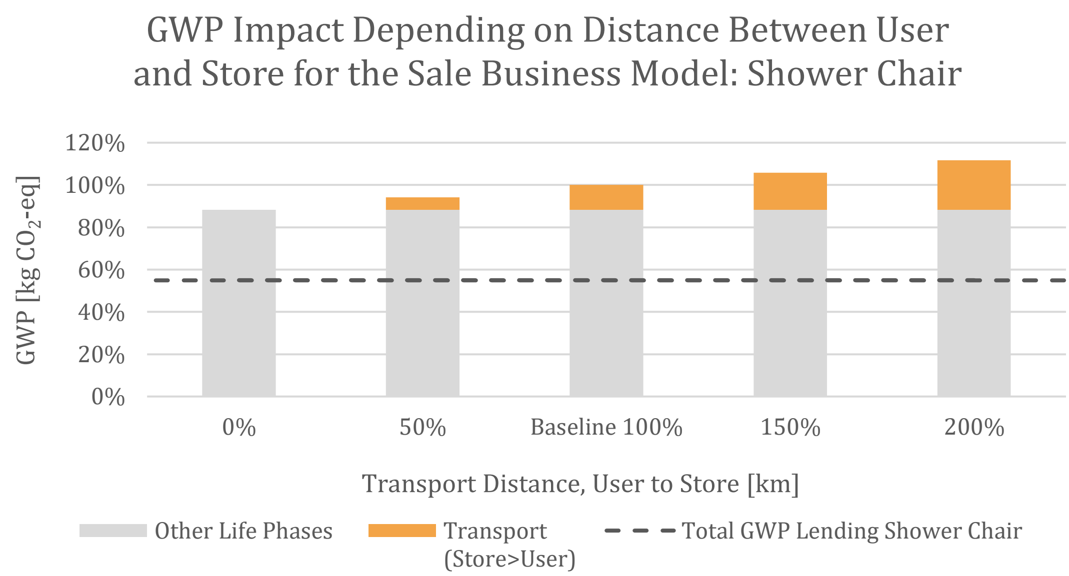

Figure 15: Difference in GWP depending on distance between user and store sale model, shower chair.

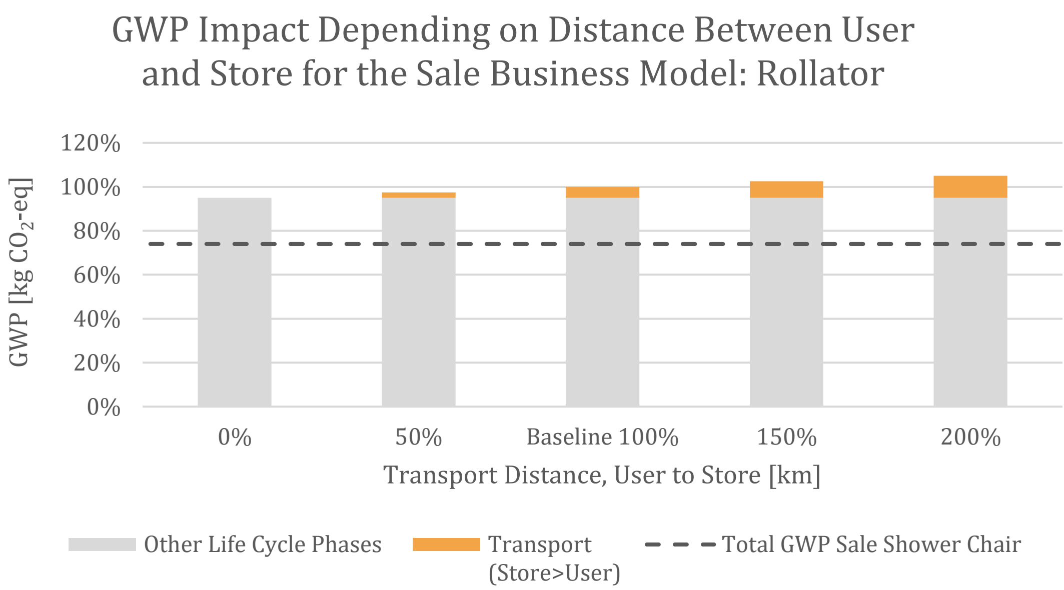

Figure 16: Difference in GWP depending on distance between user and store sale model, rollator.

The result indicates that the transport distance between the user and the store has an impact on the overall global warming potential of the business models and that the relative impact is larger for the lending model since the transports makes up a larger part of the total emissions. For the lending of the shower chair doubling the transport distance resulted in an overall increase of 29% compared to the sale of the shower chair, which resulted in an 12% increase in global warming potential. The sale of the rollator showed only a 5% overall increase when the transport distance was doubled, due to the high impacts from the production and end of life of the product.

Delivery Ratio

Another way to decrease the transport by car for the lending business model would be to increase the delivery ratio, meaning the number of products that was delivered by the company to the user. Different scenarios for the delivery ratio was therefore tested ranging from 0% where all products were picked up in store and transported by the user to their home, and 100% where all products were transported by the company to the user. The results were normalized to the baseline scenario of 80% which represents the current delivery ratio.

The results of the delivery ratio sensitivity analysis can be seen in figure 17.
By increasing the delivery ratio, the cost of transport between warehouse and user increased for the company. However, the cost of transport between the store and warehouse decreased, resulting in a relatively small overall increase in costs. The results indicate that the delivery ratio has a significant impact on the overall result for the lending model. For 0% delivery, the overall global warming potential increased by almost 100%. Resulting in the lending model contributing to more emissions than the sale model per functional unit.

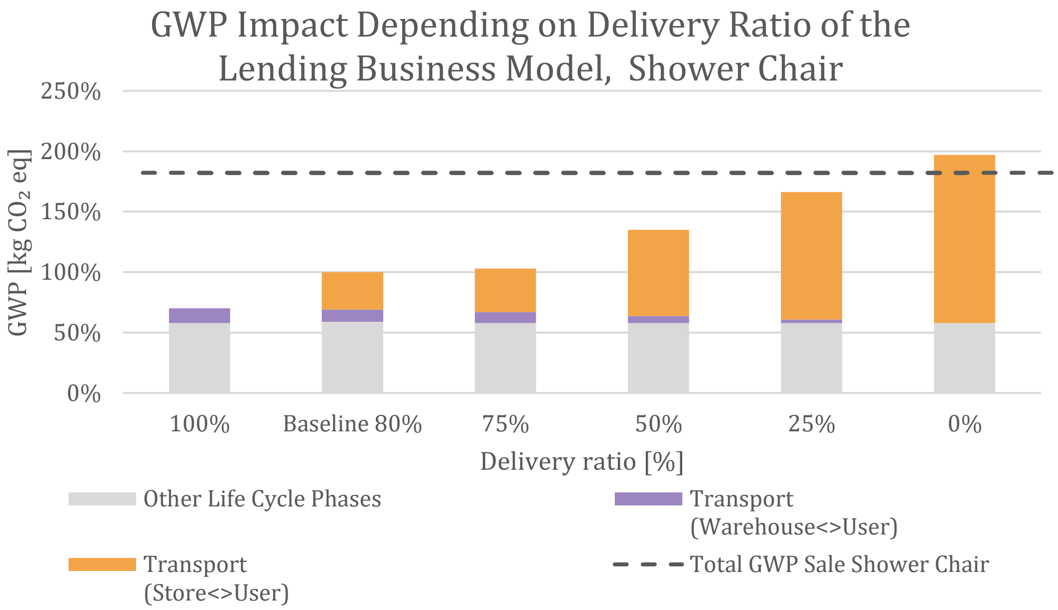

Figure 17: Changes in GWP impact depending on the delivery ratio. Values are normalised to the baseline scenario.

Primary Transport

The primary transport distance was tested to evaluate the impact of the distance between where the product was sold and where it was produced. Scenarios were tested for 0% to 200% of the current primary transport for the products in the different business models. The 0% scenario represents a scenario where the product is sold and produced in the same place, and the 200% scenario shows what would happen if the transport were to be doubled compared to the baseline scenario. The mode of transport was assumed to be the same as for the baseline scenario as can be seen in table 9. It is important to note that the cost of the primary transport was included in the procurement cost of the products. Since it is unknown how the procurement cost would be affected by the transport distance, the cost is assumed to be the same for all scenarios in the sensitivity analysis.

The analysis shows that the although the transport distance has an impact of the overall global warming potential, the relative difference compared to the baseline scenario is small. For the lending business model, the result showed a decrease of 2% GWP for the 0% transport scenario and an increase of 2% GWP for the 200% transport scenario. For both sales business models, the results showed a difference in +/- 3% in the overall GWP. The result can be seen in figure 18 for the lending of the shower chair, figure 19 for the sale of the shower chair and figure 20 for the sale of the rollator.

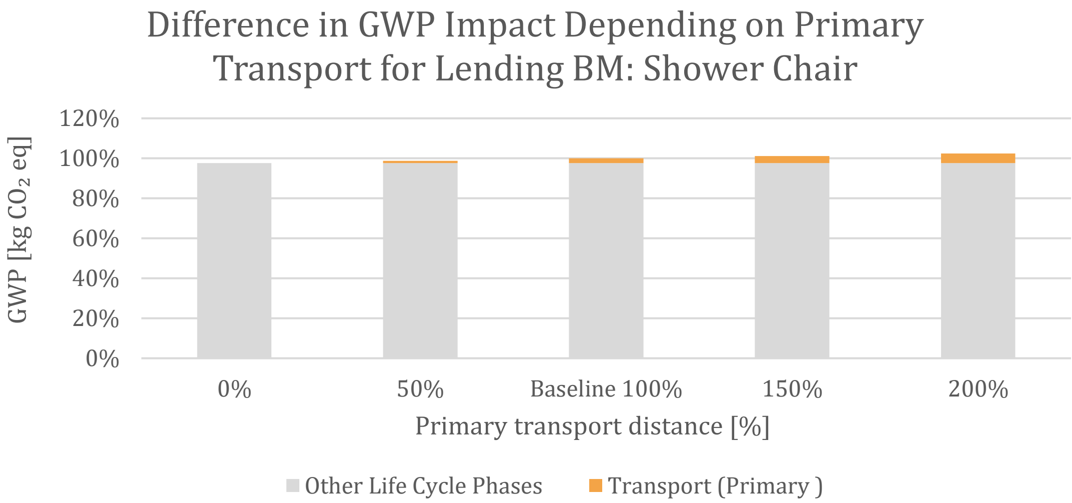

Figure 18: Difference in GWP depending on different distances of the primary transport for the lending BM. Normalised to the baseline scenario.

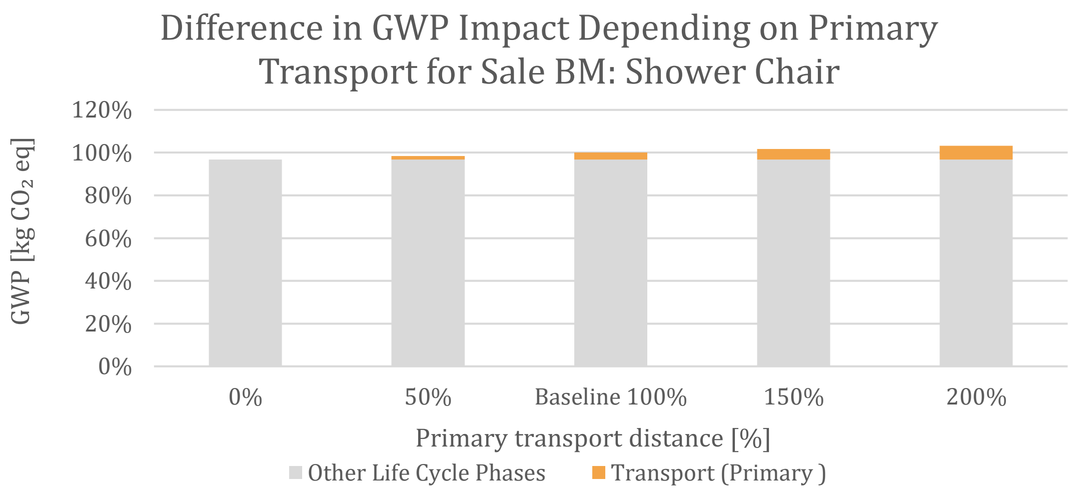

Figure 19: Difference in GWP depending on different distances of the primary transport for the sale of the shower chair. Normalised to the baseline scenario.

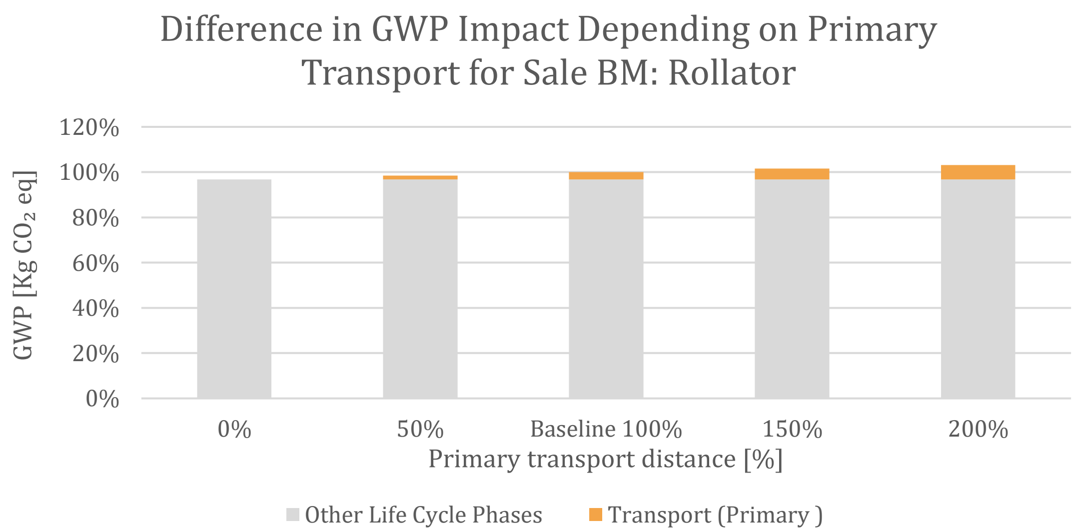

Figure 20: Difference in GWP depending on different distances of the primary transport for the sale of the rollator. Normalised to the baseline scenario.

5.4. Observation Results

During the project, observations were made regarding the use of the BM-LCA method and results within both the case company and the parent company.

Representatives from the case company indicated that the BM-LCA results could be used to validate business models believed to be more circular. They also noted that the hotspots identified through the BM-LCA could support strategic planning and guide the implementation or adaptation of similar business models in the future.

Similarly, the parent company expressed interest in using the BM-LCA to validate circular business models and to leverage identified hotspots to enhance its environmental management strategy. Representatives from the parent company also expressed interest in expanding the use of the circular business model to other subsidiary companies in different markets.

Conversations with the parent company's sustainability manager further emphasized that BM-LCA results could play a role in shaping the company's environmental strategy. Aspects such as fleet management and price setting were highlighted as areas that could be informed based on the result of the study.

The observations also suggested that the BM-LCA can function as a tool for knowledge sharing within the company. The data collection process involved representatives from various departments, including individuals previously unfamiliar with LCA or BM-LCA methodologies. Ongoing collaboration and repeated project introductions contributed to increased awareness and cross-departmental learning.

6. Analysis

This chapter analyse the result of the study and how the BM-LCA method can be used for business model evaluation. It also aims to answers the research questions for the study.

6.1. Business Model Evaluation

The text bellow discusses the use of BM-LCA for business model evaluation. This includes the assessment of environmental impact, identification of hotspots and the strategic implications of the results for the company

6.1.1. Environmental Impact

Regarding research question one, which aimed to answer which business model has the lowest environmental impact when coupled with a financial perspective, the comparison between the two business models for the shower chair showed that the lending model resulted in significantly lower environmental impact in the GWP category than the sale model. This outcome is primarily due to the difference in newly produced products required, as production is one of the primary sources of emissions for both models. However, it is important to recognize that several parameters significantly influence the outcome. For instance, increasing the product price by 50% in the sale model would reduce emissions to a level comparable with the lending model. Other factors, such as the user's transport distance to the store as well as the delivery ratio in the lending model, also have a considerable effect. These parameters have the potential to substantially shift the result, and it is therefore not possible to establish that a lending business model will always have a lower environmental impact than a sales business model. Having the individual factors in mind is therefore important when developing more sustainable business models. It is also important for future policy development, highlighting the need for a nuanced approach rather than over reliance on labels or general strategies.

The results also indicate a trade-off between different environmental impact categories in the lending model. While reductions in GWP and ADP (fossil fuels) were observed, these came at the expense of increases in AP and ADP (metals and minerals). Recognizing such trade-offs is crucial before implementing similar business models in the future. It is also important to acknowledge that business models considered circular, and that reduction in GWP, can still have environmental drawbacks. Therefore, setting clear and well-defined goals is essential before modifying or expanding business models.

For the sale model BM-LCA was used to compare how the type of product might affect the environmental performance of the business model to be able to answer the second research question. From the comparison it was found that the rollator contributed to approximately 35% more GWP emissions per functional unit even though far fewer units needed to be sold. Although a shower chair and a rollator are distinctively different products and therefore might not be functionally comparable, this finding emphasizes that the choice of product and associated business activities can significantly impact a business environmental performance. Which is reasonable as different products requires different materials and manufacturing processes to produce. However, the findings indicate the importance of understanding the costs and revenues associated with a transaction as the transactions are the main driver in a business models environmental impact. Reducing costs or increasing revenues is not only beneficial financially but might also serve as a tool to reduce a business environmental burden. The analysis for example suggests that pricing strategies could help mitigate environmental impacts. For instance, a 20% price increase for the rollator was sufficient to reduce its GWP impact to a level comparable with that of the shower chair.

6.1.2. Hotspots

Research question three which relates to environmental and economic hotspots identified within the business models, can be answered by analysing the results of the BM-LCA. Several hotspots were identified that can have important implications for the business models. Understanding these and working to mitigate them can positively influence the business model's environmental impact.

Financial hotspots also influence the environmental impact of the business models, since higher costs and lower revenue increases the number of transactions needed to fulfil the profit level. The most significant cost for all business models came from product procurement. This was true both for the lending and sale model. It was the main driver to the large amount of transactions that had to occur to reach the profit set as the functional unit, especially for the sales model. In addition, storage and transport associated costs were also identified as notable contributors to overall expenses. In particular, in store storage for the sales-based model stood out. However, this figure may be underestimated due to uncertainties regarding shelf time of the products. Meaning that the storage cost likely is higher than calculated. Transportation also played a large role especially in the lending model. Here the cost of delivering the product to the home of the customer stood for the second largest expense.

Environmentally, the manufacturing phase of the product life cycle was identified as the largest source of emissions. Although the production phase was identified as a hot spot, the case company's ability to mitigate these impacts are limited since they do not influence the production process directly. Among the sources of environmental impact that fall within the company's control, transportation stood for the largest number of emissions. Notably, customer travel to and from physical stores, either to purchase or pick up a product had the most significant impact. It was therefore identified that customer distance to store and the pick-up rate in the lending model were highly influential parameters when it came to environmental impact. User behaviour, such as how a customer travels, and geographic distribution can therefore heavily influence the environmental performance of these business models.

Regarding research question two, the comparison between the two products within the sale business model highlights that the choice of product has an impact on the hotspots identified. For the shower chair emissions are more evenly distributed across life cycle phases while for the rollator the production phase is more pronounced. This shows that different mitigating strategies might be suitable for different products within the same business model.

6.1.3. Strategic implications

Research question three also aimed to identify mitigating actions, and several strategies could be implemented to address the hotspots. Firstly, encouraging customers to choose home delivery could have a large impact in reducing the transportation related emissions. The delivery ratio for the lending model is currently at about 80% but increasing it even further could reduce emissions with up to 30%. Secondly, improving the fleet management by properly tracking the movement of products could also have a mitigating effect for both models. This could both optimize the number of purchased products as well as keep track of inventory already in circulation. Improving the accuracy of stock turnover estimates could help optimize storage space usage especially in the stores, which could help reduce costs. For the lending model an overly large fleet of products can significantly alter the results of the study. Thirdly, optimizing not only the fleet but also transportation is important. Since transportation is recognised as a significant hotspot especially for the lending model, optimizing the transportation of products could have a large impact. This include making sure to stock vehicles properly and optimizing delivery routes to keep environmental impact as low as possible.

The observations made during the project highlight how the companies intend to use the BM-LCA results. The input from company representatives increases the relevancy of the study and provides valuable insights into the practical usefulness of the BM-LCA results. Both the parent company and the case company aim to leverage these results to validate their circular business models and to support the inclusion of additional products within these models. However, the results of the comparison between the two products in the sales business model indicates that the same result is not applicable to all products. As previously stated, the production phase plays a big role in the overall environmental impact. Moreover, weight and size of a product can have an impact on transport related emissions and maintenance activities can vary for different products. The impact of these variables and the mitigating actions mentioned above should also be considered before introducing new products into the business model.

As previously mentioned, the parent company works with multiple subsidiary companies that include both suppliers and distributers and thus have a unique possibility for implementing circular business models throughout the supply chain. The large influence of the parent company also opens the possibility of expanding the circular business models to other markets. However, the results show that the GWP of the lending business model is dependent of factors such as transport distances, financial variables and energy systems. These variables can impact the result to such an extent that a lending business model will not by default have a lower GWP than a sales business model. The variables that impact the BM-LCA result, such as transport distances, financial variables and user preferences can be different depending on market. As mentioned in the background, careful planning is important when implementing circular business models to ensure a lower environmental impact. These variables should therefore be considered early in the planning process, before introducing the business model into new markets or at a new company.

The observations also showed that companies wish to use the results of the BM-LCA when setting their environmental management strategy. This includes using the hotspots identified to decide where to make improvements and prioritize efforts. It also includes getting advice on what type of data is required to optimize, for example, fleet management. As stated above, the result of the study can also be a way to include environmental considerations in the price setting of the products within both the lending and the sales business model. The results show that pricing can affect the environmental performance of the business model. However, since the case company offers multiple different rollators for sale, an increase in price could also lead to customers purchasing other rollators instead. Increasing the price could therefor lead to burden shifting to other products instead of reducing the emissions. Using pricing strategies to mitigate environmental impact can also have social implications. For example, raising prices may disproportionately affect lower-income individuals, and these social consequences must be carefully considered. In the case studied, higher prices could limit access to essential mobility aids. Therefore, such strategies may be more appropriate for products where overconsumption is common, rather than for products that meet basic needs.

The use of BM-LCA for environmental management strategies can in the future be improved by closer collaboration with the strategic decision makers in the early stages of the project. By for example formulating clear research questions together with the company to improve the usefulness of the result and increase the chance that actions are taken following the study

The results of the observations also indicate that the BM-LCA method can be used for knowledge-sharing within a company. The data collection phase provides a chance to engage individuals responsible for strategic decision-making and other individuals who may not typically be involved in the LCA process. Being part of the process in addition to viewing the results could in theory help stakeholders to better interpret the findings and ensure that important insights are not overlooked. The increased cross-department collaboration can also make the implementation of future actions to reduce environmental impact easier and more understandable for more people within the company.

7. Discussion

This chapter will discuss the validity of the results, the implications of the study, and future research as follow up research to the case study as well as for the BM-LCA method in general.

7.2. Validity of the Result

For the production phase of the two products, the emissions were based on studies made by other parties. An LCA performed internally by the manufacturer of the shower chair and an EPD performed by EPD Norway for the rollator was used to evaluate the impact of manufacturing the products. Only emissions attributed to steps before the products leave for transport to the customer was included in the analysis. The rest was calculated in the study. However, this makes this study inherit potential errors and assumptions made in the previous studies making the emission values for the production somewhat unreliable. The validity of this study could have been increased if a closer look into the manufacturing steps could have been made to validate the result. It was, however, not feasible to do this in the study due to time constraints as well as the production companies not being part of the original study.

Another aspect that could affect the validity of the results is the uncertainty around some parameters. Parameters such as the size of the current fleet of shower chairs as well as the average amount of product in storage for the lending model was based on estimations by the case company. These values were used to calculate some parameters used in the coupling equations such as the lending efficiency (Ql), rate of replacement (Rr) and percentage of fleet sold off after a lending period (Sl). These parameters are therefore subject to some uncertainty.

The transport distance between stores and users was estimated based on the distance between cities and the stores with the assumption that users visited the nearest store or lending point. This leg of the transport was not allocated instead assuming that the full journey is done for the sole purpose of transporting the mobility aid. It is also assumed that the transport is done by car and does not consider use of public transport or that users who live close to stores can pick up or drop of products without needing to use a car. This means that the contribution from this leg of the transport is likely overestimated.

Secondary data from Ecoinvent v3.11was used to establish the emissions for transports and End-of-life processes. Due to the lack of suitable Ecoinvent processes the transport done with a light commercial vehicle does not consider the use of electric vehicles to and from warehouses. This will also affect the results and could lead to an overestimation of the emission.

Despite the uncertainties the validity of the study can be considered high, and it is unlikely that the existing uncertainties and estimations would have any major impact the results. Furthermore, the most uncertain variables, such as the rate of replacement (Rr) and the user to store transport distance, have been tested through sensitivity analysis to show their impact on the overall results.

7.3. Implications of the study

The study demonstrates that the BM-LCA method can effectively address the research gap identified in the theoretical background regarding the assessment of circular business models. Furthermore, while the results show that the circular model has a lower global warming potential in this case, the findings are not universally applicable. This highlights that the environmental impacts of business models are context dependent, challenging the common assumption that such circular models always lead to environmental improvements.

This study also includes the first comparison between two different products evaluated within the same business model. The two products have significantly different functions and wouldn't be directly comparable using traditional LCA methodology. However, by connecting them through a financial perspective, they became comparable in regard to the environmental burden per profit made by a company. The study therefore shows how the BM-LCA method can be used to compare products that would not be possible using a traditional LCA.

The results also highlights that the type of product sold plays a significant role for the environmental performance of the model and that different products require different mitigating strategies. This study shows how the BM-LCA can be used to identify these strategies by evaluating different parameters within a model and establishing relationships between environmental impact and business activities. Applying the BM-LCA method to business models that are not considered conventionally circular or sustainable, such as the sale business model, therefore expands the usefulness of the method and shows its potential to be used for strategic planning and business model innovation.

7.4. Future Research and Limitations

For future research it would be relevant to perform BM-LCAs on other business models and on other products within the lending business model. The study was limited to two products produced in Scandinavia. Including other markets for production and distribution would help build further understanding of the impact of market specific factors on the environmental impact of business models. It would also increase the understanding of the impact on transportation.

Further exploration is also needed to understand the impact of conducting a BM-LCA for a company, including an assessment of actions taken as a result of the findings. For the specific case company, the suggested mitigating actions such as improved fleet management and optimized transport routes warrants further investigation. Conversations with the company representatives also indicate that they wish to use the BM-LCA result to implement similar models in other markets. For this purpose, further scenario analyses are needed to evaluate the environmental impact in different markets. This study was limited to the Dutch market, however testing the business models with relevant electricity mixes, transport distances and production processes can be useful when utilizing BM-LCA for business model expansion.

It would also be relevant to further investigate the use of BM-LCA for price setting. The result of the BM-LCA can be used to show the impact of price on the environmental impact of the business model, introducing this factor in the environmental strategy of a company. Studying the use of BM-LCA for the purpose of price setting would therefore be relevant when continuously developing the method.

As previously stated in the background, user preferences are believed to impact the success of circular business models. For example, the results of this study also show that the delivery ratio of products has a large impact for this specific company. It would therefore be interesting to follow up on user preferences regarding delivery and in store purchase, both for the Netherlands market in general and for the specific mobility aids in question. Further investigation into the user preferences for different demographics and markets would also be beneficial for both price setting purposes and for using BM-LCA results when motivating the implementation of circular business models in new markets.

Furthermore, future research should include the use of BM-LCA as a knowledge sharing tool within a company. The effects of including more people from the company can be evaluated in more detail to understand how the time and resources used to do a BM-LCA can be as beneficial for a company as possible.

8. Conclusion

This study aimed to assess and compare the environmental performance of a product-service system model with that of a traditional linear sales business model, while also identifying potential areas for improvement. The study also aimed to compare two different products within the linear sales business model. In doing so, the study extends the application of the BM-LCA method to evaluate functionally different products against a common profit level. It offers valuable insights into the factors influencing environmental performance and highlights the market- and product-specific variables that should be considered when planning and implementing future circular business models.

Another objective was to evaluate how the findings could be utilized by both the case company and its parent company. By doing so, the study also demonstrates how the BM-LCA method can support companies in strategic decision-making and suggests ways the method could be refined for this purpose.

The result of the study shows that in the case of the shower chair, the lending business model has a lower environmental impact for GWP and ADP fossil fuels when compared to the sales business model. However, the sensitivity analyses show that the relative benefit regarding GWP of the lending business model compared to the sales business model is dependent on factors such as transport distances, delivery ratio and lending price. This shows that a lending business model is not by default better than a sales business model. Careful planning is therefore needed before implementing a similar business model in new markets or when introducing new products in a business model.

The comparison of different products within the same model also showed the impact the choice of product might have on the overall environmental performance of a business model. The rollator resulted in 35% more GWP than that of the shower chair even though fewer transactions were needed to reach the set profit level. This indicate that the results of a BM-LCA aren't directly transferable between different products. Careful considerations should therefore take place in regard to how and what product are introduced in business models, as different products come with different environmental burdens. It was also concluded that different mitigating actions might benefit different products and that such actions should be context specific in order to be effective.

The production stage was identified as a significant hotspot in both the lending and sales business models for both products. However, as the case company functions solely as a distributor, its ability to influence this stage is limited. The parent company may have greater potential to drive improvements, particularly when the manufacturer is part of its subsidiary group. This suggests that the parent company can leverage its position and use the result of the BM-LCA to influence environmental performance across the broader supply chains. The sensitivity analysis also show that price has a large impact on the overall impact of the sale business model. Indicating that it can be an important part of environmental management strategies. Careful consideration needs to be taken when adjusting prices, however, to avoid burden shifting to other products.

The study also shows that the BM-LCA result can be useful for companies that aim to validate and assess the sustainability of their business model, and when planning and improving environmental management strategies. This includes prioritizing improvement efforts using the identified hotspots and integrating environmental considerations in price setting of products. Suggested actions to improve the lending business model include:

- Encouraging home delivery rather than in-store pickup to reduce transport related emissions.
- Improving fleet management to maintain a clear overview of products in circulation, prevent over-purchasing products, and reducing unnecessary stock buildup.
- Optimize transportation operations to reduce transportation related emissions, particularly in the lending model where it's a major environmental hotspot.

In conclusion, this study not only demonstrates the environmental potential of circular business models like lending, but also highlights the complexities involved in implementing them in a sustainable manner. The findings show the importance of a tailored approach that accounts for product, market, and operational factors for companies aiming to integrate environmental sustainability into their core business strategy.

9. References

Annarelli, A., Battistella, C., & Nonino, F. (2016). *Product service system: A conceptual framework from a systematic review*. Journal of Cleaner Production, 139, 1011-1032. https://doi.org/10.1016/j.jclepro.2016.08.061

Baumann, H., Tillman A,-M, (2004) The Hitch Hiker's Guide to LCA, An orientation in life cycle assessment methodology and application. Studentlitteratur

Behavioural Insights Network Netherlands (BIN NL). (2023). *A wealth of behavioural insights: 2023 edition*. Behavioural Insights Network Netherlands. https://www.binnl.nl/home+-+en/knowledge/publications/bin+nl+publications/HandlerDownloadFiles.ashx?idnv=2719979

Bocken, N. M., 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.

Bocken, N. M. P., & Geradts, T. H. J. (2022). *Designing your circular business model*. Stanford Social Innovation Review. Retrieved from https://ssir.org/articles/entry/designing_your_circular_business_model

Bocken, N. (2023). *Business Models for Sustainability.* Oxford Research Encyclopedia of Environmental Science, Forthcoming, http://dx.doi.org/10.2139/ssrn.4731205

Bocken, N. M., 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*. Journal of Industrial Ecology, 21(3), 476-482.

Bocken, N. M., Short, S. W., Rana, P., & Evans, S. (2014). *A literature and practice review to develop sustainable business model archetypes.* Journal of cleaner production, 65, 42-56.

Böckin, D., Goffetti, G., Baumann, H., Tillman, A.-M., & Zobel, T. (2022). *Business model life cycle assessment: A method for analysing the environmental performance of business.* Sustainable Production and Consumption, 32, 112-124. https://doi.org/10.1016/j.spc.2022.04.014

edp-norway. (2023). Environmental Product Declaration: Olympos ATR. The Norwegian EPD Foundation. Retrieved February 1, 2025, from: https://www.epd-norge.no/getfile.php/1349721-1702641950/EPDer/Ganghjelpemidler/NEPD-5536-4840_Olympos-ATR.pdf

Ellen MacArthur Foundation. (2015). Growth within: A circular economy vision for a competitive Europe.

European Commission. (2020). *A new circular economy action plan: For a cleaner and more competitive Europe* (COM(2020) 98 final). EUR-Lex. https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1583933814386&uri=COM:2020:98:FIN

European Parliament. (2016). Assistive technologies to support people with disabilities. European Parliamentary Research Service. https://www.europarl.europa.eu/RegData/etudes/BRIE/2016/573899/EPRS_BRI(2016)573899_EN.pdf

European Parliament. (2024). *Greenhouse gas emissions by country and sector (infographic)*. Retrieved February 1, 2025, from https://www.europarl.europa.eu/topics/en/article/20180301STO98928/greenhouse-gas-emissions-by-country-and-sector-infographic

Eurostat. (2024). *Treatment of waste by waste category, hazardousness and waste management operations.* https://doi.org/10.2908/ENV_WASTRT

Evans, S., Vladimirova, D., Holgado, M., Van Fossen, K., Yang, M., Silva, E. A., & Barlow, C. Y. (2017). *Business model innovation for sustainability: Towards a unified perspective for creation of sustainable business models*. Business strategy and the environment, 26(5), 597-608.

Government of the Netherlands. (n.d.). *Circular Dutch economy by 2050*. Retrieved January 31, 2025, from https://www.government.nl/topics/circular-economy/circular-dutch-economy-by-2050

Government Offices of Sweden. (2020). *Cirkulär ekonomi – strategi för omställningen i Sverige*. Retrieved February 1, 2025, from https://www.regeringen.se/globalassets/regeringen/bilder/klimat--och-naringslivsdepartementet/klimat-och-miljo/cirkular-ekonomi---strategi-for-omstallningen-i-sverige/

Hennicke, P., Khosla, A., Thakur, M. S., & Wilts, H. (2014). *Decoupling economic growth from resource consumption.* Berlin: Internationale Zusammenarbeit (GIZ) GmbH. www.giz.de/de/downloads/giz2014-en-IGEG_2_decoupling-econimic-growth.pdf

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://www.sciencedirect.com/science/article/pii/S0959652616000834

Kjaer, L. L., Pigosso, D. C., McAloone, T. C., & Birkved, M. (2018). Guidelines for evaluating the environmental performance of Product/Service-Systems through life cycle assessment. Journal of Cleaner Production, 190, 666-678. https://www.sciencedirect.com/science/article/pii/S0959652618311351

Meadows, D. H., Meadows, D. L., Randers, J., & Behrens III, W. W. (1972). The limits to growth-club of rome.https://policycommons.net/artifacts/1529440/the-limits-to-growth/2219251/

Ministry of Infrastructure and Water Management. (2023). *National Circulare Economy Programme 2023-2030*. In cooperation with the Ministries of Economic Affairs and Climate Policy, the Interior and Kingdom Relations, Agriculture, Nature and Food Quality, and Foreign Affairs. Government of the Netherlands. Retrieved January 31, 2025, from https://www.rijksoverheid.nl/binaries/rijksoverheid/documenten/beleidsnotas/2023/02/03/nationaal-programma-circulaire-economie-2023-2030/NPCE+Circulaire+Economie+rapport+Engels.pdf

Regeringskansliet. (n.d.) *Cirkulär ekonomi – Handlingsplan för omställning av Sverige*. Retrieved January 31, 2025, from https://www.regeringen.se/contentassets/4875dd887fd34edabd8c1d928a04f7ba/cirkular-ekonomi-handlingsplan-for-omstallning-av-sverige.pdf

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

UNEP. (2011). Decoupling natural resource use and environmental impacts from economic growth: A report of the working group on decoupling to the International Resource Panel. Fischer-Kowalski, M., Swilling, M., von Weizsäcker, E. U., Ren, Y., Moriguchi, Y., Crane, W., Krausmann, F., Eisenmenger, N., Giljum, S., Hennicke, P., Romero Lankao, P., Siriban Manalang, A., & Sewerin, S. UNEP.

United Nations. (n.d.). *What is climate change?* Retrieved February 1, 2025, from https://www.un.org/en/climatechange/what-is-climate-change

United Nations Framework Convention on Climate Change (UNFCCC). (n.d.). *The Paris Agreement.* Retrieved February 1, 2025, from https://unfccc.int/process-and-meetings/the-paris-agreement

World Health Organization. (2023). Operational framework for building climate resilient and low carbon health systems. World Health Organization.

DEPARTMENT OF TECHNOLOGY MANAGEMENT AND ECONOMICS
DIVISION OF ENVIRONMENTAL SYSTEMS ANALYSIS
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden
www.chalmers.se

CHALMERS
UNIVERSITY OF TECHNOLOGY