CHALMERS
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VOLVO

# Towards a Circular Economy

## Enabling the development of circular products by investigating additional parameters in a profitability model

Master's thesis in Product Development

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CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2024
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Master Thesis Report 2024

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The development of a profitability model to be used in the product development process for circular economy for Volvo Group Truck Operations. Investigating circular processes and usage regarding raw materials, customer usage, re-usage, refurbishing and other aspects regarding environmental load.

EMILIA FRISK JONSSON
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Cover: Volvo Logo

# Abstract

The transition towards a circular economy presents both challenges and opportunities for industries worldwide. The European Union is changing the playing field by implementing legislation to ensure access to raw materials, decrease pollution, and secure strategic interests. Additionally, materials necessary for the transition to sustainability are increasing in demand and cost. Navigating this transition requires a comprehensive understanding of circular economy and circular product designs. In the context of the automotive sector, Volvo Group faces the imperative to develop circular products while maintaining profitability.

This project aims to investigate in which ways Volvo Group can evaluate and incorporate circularity criteria in their product development process. Identifying and incorporating key parameters that influence profitability calculations for circular projects becomes increasingly important in this transition.

The project has been conducted using a combination of a literature study and semi-structured interviews, involving product developers and sustainability experts within the automotive industry. Through this combined approach, the study provides Volvo Group with insights necessary for more informed decision-making processes by creating an understanding of the challenges and opportunities associated with transitioning toward a circular economy.

The results of this study yield two key parameters, End-of-Life value and Material Supply Chain risk, both of which were deemed crucial for profitability calculations in the context of circular product development within Volvo Group. Additionally, based on the findings, short-term recommendations include further investigation of the proposed parameters. The parameters can assist in navigating the complexities of transitioning towards sustainable and profitable circular product development within the automotive sector.



Keywords: Circular Economy, Circular Product Design, Profitability model, Circular Business Models, End-of-Life Value, Material Supply Chain Risk

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This master's thesis was conducted during the spring of 2024 at the Department of Industrial and Material Science at Chalmers University of Technology. The study was conducted in collaboration with Volvo Group Trucks Operations.

We would like to start by expressing how we are truly grateful to each and every individual who has provided support and guidance during the course of our master's thesis project.

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Emilia Frisk Jonsson and Jacob Kylin, June 2024

# List of Acronyms

Below is the list of acronyms that have been used throughout this thesis listed in alphabetical order:

| | |
|---|---|
| B2B | Business to Business |
| BM | Business Model |
| CBAM | Carbon Border Adjustment Mechanism |
| CBM | Circular Business Model |
| CE | Circular Economy |
| CRMA | Critical Raw Material Act |
| DO | Development Objective |
| ELV | End-of-life Vehicle Directive |
| EU | European Union |
| EO | Evaluation Objective |
| EOL | End-of-Life |
| EPR | Extended Producer Responsibility |
| IRR | Internal Rate of Return |
| KPI | Key Performance Indicators |
| MSC | Material Supply Chain |
| NPV | Net Present Value |
| PaaS | Product-as-a-Service |
| PRO | Producer Responsibility Organization |
| PSS | Product Service System |
| R&D | Research and Development |
| RO | Research Objective |
| RQ | Research Question |
| UN | United Nations |
| Volvo GTO | Volvo Group Trucks Operations |
| Volvo GTT | Volvo Group Trucks Technology |

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# 1 Introduction

This introductory chapter includes a description of the background, aim, limitations of this project and ends with a report outline. This master thesis report was conducted at Volvo Group Trucks Operations (Volvo GTO) during the spring of 2024. The project team consisted of two students, Emilia Frisk Jonsson and Jacob Kylin, both from Chalmers University of Technology. This study investigates factors important when evaluating the profitability of circular product design.

## 1.1 Background

As the global push for sustainability intensifies, manufacturing giants like the Volvo Group are actively responding to the call for action. With ambitious targets set to achieve net zero emissions across their entire value chain by 2040, Volvo Group stands at the forefront of the transition towards a more sustainable future (Volvo Group, 2024). However, amidst these aspirations lies a challenging landscape, particularly concerning impending laws and directives that regulate the pressing need for resource efficiency and increased material utilization (European Commission, 2020). The regulations pose a significant set of challenges for industrial companies like Volvo Group Trucks Technologies (Volvo GTT), prompting a critical examination of their operational strategies. Amidst this uncertainty, one pathway towards enhanced resource utilization emerges: the adoption of circular economy principles.

The concept of a Circular Economy (CE) was introduced by Pearce and Turner (1989), and is a way of working meant to conserve material and energy as much as possible and to utilize the resources put into the system over time (Tuladhar et al., 2022). There are many effects of CE, and it is described as being one possible way for businesses to sustain economic, ecological, and social sustainability over time (Schroeder et al., 2018).

The European Union (EU) is promoting circularity and sustainability, especially concerning critical raw materials (European Commission, 2024c). The EU has ratified laws that in the following years will force manufacturers using batteries, tires, and electrical components to; keep track of these during their lifecycle; ensure components are from responsible, ethical manufacturers, and lastly; to collect and use these responsibly at end-of-life.
The European Commission (2020) has also expressed similar requirements for other materials such as steel, aluminum, plastics, textiles, and leather to promote a more sustainable and circular critical raw materials economy (European Commission, 2024c). These are some of the expressed goals of the EU's Circular Economy Action Plan:

- Improving product durability, reusability, upgradability and reparability, addressing the presence of hazardous chemicals in products, and increasing their energy and resource efficiency.
- Increasing recycled content in products, while ensuring their performance and safety.
- Enabling remanufacturing and high-quality recycling.
- Reducing carbon and environmental footprints.
- Introducing a ban on the destruction of unsold durable goods.
- Incentivising product-as-a-service or other models where producers keep the ownership of the product or the responsibility for its performance throughout its lifecycle.
- Mobilising the potential of digitalization of product information, including solutions such as digital passports, tagging and watermarks.
- Rewarding products based on their different sustainability performance, including by linking high performance levels to incentives.

Attaining genuine sustainability within society will most likely demand the integration of a broad spectrum of approaches and fundamental changes in mindset. The collaborative efforts of governments, businesses, academia, and the general population could lead to a sustainable society by developing technology and changing consumer behavior and business models. Schroeder et al. (2018) contends that the CE stands as a viable path towards sustainability, offering innovative strategies for resource management and promoting long-term environmental and economic resilience. The author also states that the CE is a viable way to promote social sustainability by decreasing the labor required for material extraction. At the same time, social sustainability can be encouraged by increasing the demand for labor and maintenance-related work. In a more circular society, the business models prevalent in today's linear economy may face a competitive disadvantage. According to KPMG (2021), a linear business model could evolve into a liability in the future due to changes in market dynamics, regulatory frameworks, and cost-revenue structures.

Volvo GTT has demonstrated a keen interest in enhancing their resource management practices, aiming to optimize the utilization of resources consumed in their operations. This endeavor holds significant promise for the future, particularly as the company moves towards embracing a more circular business model, which is anticipated to increase material efficiency (AB Volvo, 2023). Furthermore, incorporating principles from the CE may be legally required, and embracing more of these principles could provide advantages in sustaining economic growth and competitiveness. According to Kühl et al. (2018), a Product Service System (PSS) can play a pivotal role in promoting circularity, making it an apt business model within the context of a circular economy. While Volvo GTT's current business model does incorporate financing offers such as Product-as-a-Service (PaaS), this segment remains relatively minor in comparison to traditional sales. In 2022, Volvo Group reported approximately 17 billion SEK in revenues from leasing, significantly lower than the 310 billion SEK in revenues generated from the sale of trucks according to the annual report of AB Volvo (2023).

### 1.1.1 Circular Economy

Historically the concept of the Circular Economy arose and gained momentum during the latter half of the 20th century, in important works such as *The Limits of Growth* by Meadows (1972), *Economics of natural resources and the environment* by Pearce and Turner (1989), and *Product life as a variable: the notion of utilization* by Stahel (1986). The main focus of the CE is the combination of sustained economic growth and environmental stability. The concepts of the Circular Economy and sustainability share overlap in that the CE and circular design are a subset of tools for sustainability. There is critique of the CE that it does not necessarily result in sustainability in all domains as it is an economic model for a society that efficiently utilizes material and energy (Kühl et al., 2018). From the environmental perspective the CE has evolved to use three different principles to control energy and material flows; slowing, closing, and narrowing 'loops'. The concepts of narrowing loops came along significantly later in the work of Andersen (2006).

In a CE, loops are the flows of material and energy that occur throughout a product's lifecycle. The ultimate goal of the CE is that these loops are entirely closed, meaning that no material and very little energy leave the system and that no material needs to be added to the system, which is only possible in the ideal case without entropy. However, the main focus of the CE is often the increased utilization of material. To extend the degree of utilization actions and guidelines are needed. In this context, an often-cited framework to rank the ways of increasing the efficiency of a system is the R-framework. The R-framework presents 10 strategies to make the CE more efficient, see Figure 1.1.

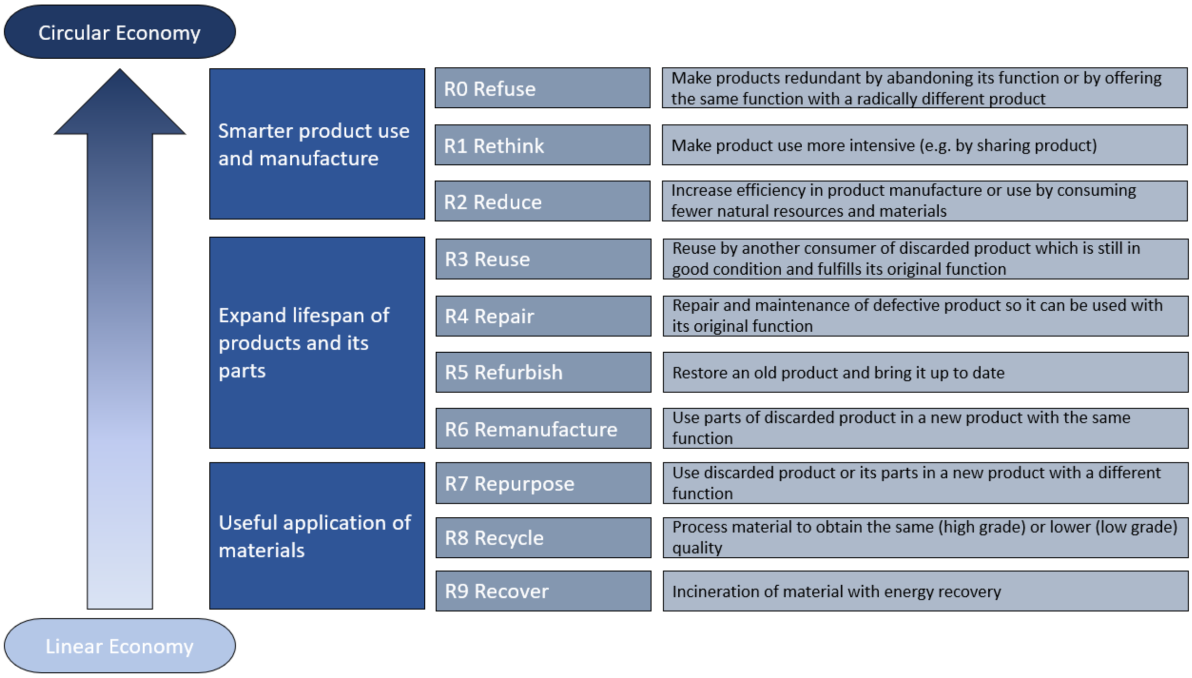



**Figure 1.1:** Value of operation to material and value maintained of products decreases as the R-number increases by, adopted from Potting et al. (2017).

Bocken et al. (2016) describes *Narrowing loops* as limiting the amount of material and energy that flows into the system or a certain process or part of the lifecycle. It could mean to use lightweight design, a different business model, or to rethink the need of a solution or sub-solution. The loop is narrowed by implementing *Refuse, Rethink,* and *Reduce.*

Moreover, the authors mention that the second group of operations is to focus on *Slowing loops*, which is to incorporate methods that increase the utilization and value maintained over time of a product within a system. This is often practically implemented by adding material or energy to sustain the value of the product, which in the 9R framework means to *Reuse, Repair, Refurbish, Remanufacture* or *Repurpose.* Most work done to upkeep the functional value of the product over time belongs to this category, from everyday maintenance to more extensive services and remanufacturing.

In the context of the CE, as highlighted by Bocken et al. (2016), the last resort is to attempt to *Close* the material loop, thereby minimizing environmental harm and potentially reintroducing materials into circulation, although often through energy-intensive recycling. If a product makes it to this stage, very little of the original value embedded from production is kept after this step, carried out through *Recycle* or *Recover.*

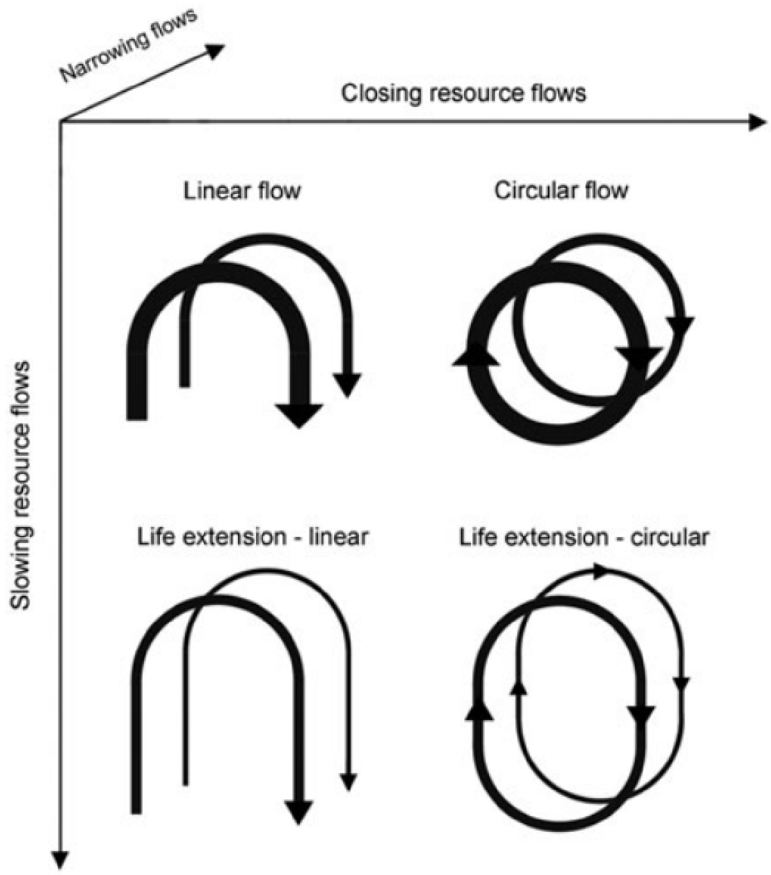



**Figure 1.2:** Resource cycles: slowing, closing, and narrowing loops (Bocken et al., 2016).

Figure 1.2 displays the resource cycles and how the loops are connected. An organization aiming to enhance resource efficiency and sustain economic productivity can achieve this goal by using the same or even fewer material and energy inputs. A CE works by trying to increase the utilization of the products in it by as much as possible (Bocken et al., 2016). That is the definition used in this report to describe circularity. Circular products or circularity means a product, service, or resource that is renewed or regenerated, rather than wasted with the ultimate goal of increasing the utilization of resources.

One important aspect of designing products for a circular economy is to design for a longer lifetime. In practice, this is realized in large part by Designing for Longevity (DfL). The design principles of DfL aim to provide guidelines to estimate the optimal lifetime, that slow the flow of resources to develop products sustainably, by making robust products that will be relevant for a long period of time for both the user and the business (Carlsson and Mallalieu, 2021). There are three important dimensions of DfL to consider, firstly the perspective of the user often shortens product lifetime. Products can often be regarded as useless by their user for several reasons of obsolesce, the most common being technological, psychological, and economical obsolesce. Psychological obsolesce is when the user deems the product to be irrelevant, unfashionable, old, or otherwise not suitable. Through new product development old products could become functionally irrelevant, or economically unjustifiable. Lastly, through wear and tear the product becomes less useful or optically pleasing and ceases to provide its intended function. The second perspective, the business perspective; to generate profit. This is currently done through linear business models where a longer lifetime is not always easy to motivate, unless from the perspective of the user (by charging a higher price). Thirdly, the use of a product should only continue if it is the best choice environmentally as well. While it is important to design for a long lifetime, for many products that emit most of their greenhouse gas emissions during their use, the development of newer more efficient technology will in turn make the older solution technically obsolete (Carlsson and Mallalieu, 2021). In these cases, it is important to also design for recycling, disassembly, or other similar factors. For products with low environmental impact during use, designing for longevity can be very impactful. Practically, these three perspectives result in complexity: in order to increase resource efficiency solutions must be designed such that they will functionally and structurally last, not become obsolete by their users, and if technologically obsolete, be designed such that the material can easily be recycled or upcycled to create other products.

### 1.1.2 Product Service System

A circular economy places actors at its core, highlighting economic and environmental benefits, while institutionalizing its principles through the emphasis on economic advantages for businesses (Bocken et al., 2017). Stahel (1982) also emphasized selling utilization instead of ownership of goods as the most relevant sustainable business model for a loop economy, allowing industries to profit without externalizing costs and risks associated with waste. Kühl et al. (2018) continues on the research of Stahel (1982) and concludes that the most recognized business model for economic success in a circular organization is a Product Service System (PSS). A PSS offers a view of product ownership and how different businesses can offer different solutions to their customers. Although this system does not inherently increase sustainability or resource efficiency, its potential to do so is often described across the literature. There are three distinct types of PSS, according to Tukker (2004), product-, use- and result-oriented, which are explained below.

- Product-oriented: A product is the main focus of the sales strategy and is owned by the customer. Relevant services are added, such as maintenance or advice on how to optimize the usage. Most linear business models fit into this category, including the majority of the Volvo Group's revenue.

- Use-oriented: Ownership of the product stays with the manufacturer but the usage is controlled by the consumer. Common examples are leasing, rental, and pooling of the product.

- Result-oriented: A result-oriented PSS is one in which the user pays per unit of result. The solution used to get the result is not specified, but only the result. Common examples from this category are cleaning, regulation of office climate, catering, and dry-cleaning.

The relationship between product as a product and product as a service is presented in Figure 1.3. Tukker (2004) means that there are in total eight types of PSS types. Whereas Product-related and Advice and consultancy are a part of product-oriented. Product lease, Product renting/sharing, and Product pooling is use-oriented and finally, Activity management, Pay per service unit, and Functional result are result-oriented. Some nuance exists between these distinct types of PSS, however, in this project the term PSS will be used to encompass the offerings described in Figure 1.3, ranging from *Product related* to *Functional unit*. Whilst PSS includes a wider range of offerings, PaaS is a subset of PSS. The term PaaS will be used to describe use-oriented and result-oriented products in Figure 1.3 below.

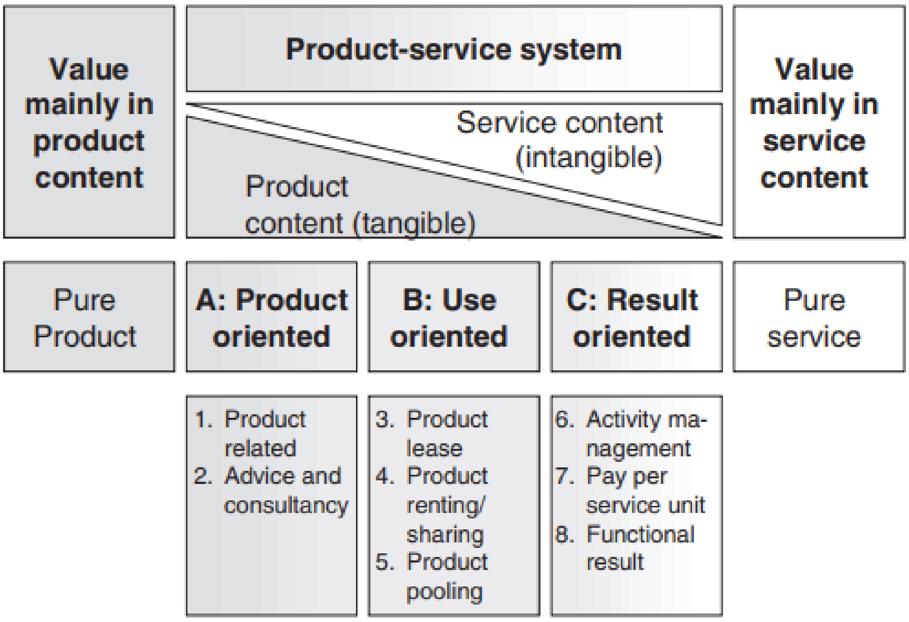



**Figure 1.3:** Product Service System showcasing product relationship from pure product to pure service (Tukker, 2004).

### 1.1.3 Criticism Towards Circular Economy

There are not only benefits with a Circular Economy. Bocken et al. (2017) provides a critical perspective on the CE, highlighting not only its potential benefits but also the crucial need to address its inherent costs. Maintaining balance among these elements within circular systems is imperative, especially concerning the technical constraints associated with establishing a closed-loop model (Bocken et al., 2017). The technical constraints associated with the CE include, but are not limited to; sustaining economic growth while reducing or eliminating the input of energy and material, which implies an ever-increasing efficiency; the energy required to recycle materials is in some cases larger than the energy to create new virgin material, resulting in more GHG emissions for recycling; compared to sustainability the CE does not take social sustainability as one of its main focuses, although some positive social development is expected, mostly as a consequence of the shift towards occupations in repair and maintenance (Stahel, 1986).

### 1.1.4 Challenges of a Linear Business Model

The linear business model of *take, make* and *dispose* has been prevalent since the third industrial revolution and has led to the climate crisis according to Lahti et al. (2018). A mechanism of the linear business model that is implicitly unsustainable is the dependency on the extraction of resources whilst generating significant volumes of waste, expediting environmental degradation. Many actors globally, Volvo Group among them, are aware of this issue and are actively trying to combat this problem.

However, there is a gap in knowledge of how to properly address value creation in such a different perspective (Jørgensen and Pedersen, 2018). Products in circular business models are required to generate profit continually throughout their use. The authors further explain that being successful in a circular economy will require different guiding design principles based on those from the R-Framework, Design for Longevity, Design for Modularity, etc. Finding mechanisms by which circular products could be more profitable, especially in a linear or transitional business model, could be an important step toward a circular economy.

### 1.1.5 Product Development Process at Volvo Group Trucks Technology

Volvo Group Trucks Technology (Volvo GTT) currently has a product development process that often starts with a Product Change Request (PCR). After a PCR has been approved the next phases include idea generation, feasibility study, concept development, and then further product development. Between the concept development and further product development is the profitability gate. This is where calculations are made regarding the profitability of the product change. The process is presented in Figure 1.4 below. The profitability model calculates the costs and revenues the product is expected to generate during its lifetime, from development costs to production costs, and revenues. This results in an estimation of the profit or loss generated by a project, which provides the main base for deciding whether or not to proceed. The initiative from engineers aiming to develop more circular and resource efficient solutions encounter barriers in this gate. Therefore, there is a need to investigate the potential of circular solutions, and the future risks of a linear business model.

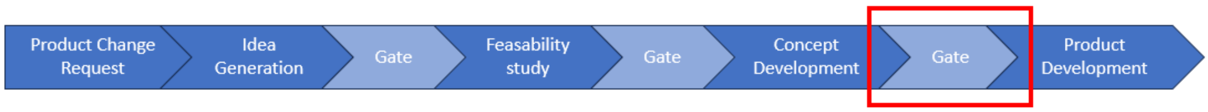



**Figure 1.4:** Product Development process, highlighting the profitability gate.

## 1.2 Purpose

Circularity and designing products that can be used in circular business models require a different set of economic measures when compared to linear product development. The profitability model that Volvo GTT currently uses for evaluating projects does not consider all aspects of a circular economy. Legislation, material prices and sustainability goals are all important aspects that influence the profitability of product and business model. Changes in these factors could make circular products and business models more profitable than their linear counterparts. The purpose of this master thesis was therefore to assist in the transition towards a circular economy by gathering parameters that Volvo GTT could use when making profitability calculations for projects.

## 1.3 Project Aim

This project aims to investigate in which ways Volvo GTT could evaluate and incorporate circularity criteria in its business case methodologies and profitability model. This project therefore examines a profitability model to understand how it is used to evaluate products and components. Furthermore, the aim includes proposing a set of additional parameters to enhance the profitability tool, thereby enabling it to more accurately reflect the value of circular products.

### 1.3.1 Research questions

The project postulates that circular products are aligned with Volvo GTT's sustainability goals. Therefore, it is important to understand which parameters are necessary to include in a financial profitability evaluation to appropriately value circular products and components. This master thesis investigates what parameters should be applied to the profitability model to facilitate circular strategies and operations, which leads to the following research questions:

RQ1. What does Volvo GTT need to consider to generate profit from circular products?

RQ2. What key parameters should be integrated into the profitability model to enable circular products?

RQ3. What is currently hindering Volvo GTT from becoming more circular?

## 1.4 Scope and Limitations

This master's thesis was conducted during the spring semester of 2024, concluding at the end of May 2024. This timeline imposed significant constraints on the processes available and the scope of what could be achieved. The evaluation and implementation of key parameters for circular products in profitability calculations within the product development process comprise a large body of research. Due to time constraints, this study had to limit the depth and breadth of this evaluation.

The thesis was structured into three phases: research, development, and evaluation. Each phase included numerous activities, all constrained by the time limitations of the spring semester. Consequently, while a broad array of aspects was explored, the depth of analysis in each aspect was compromised, presenting a significant limitation of the study.

The research questions addressed in this project necessitated the use of numerous activities to gather and analyze information from the research phase. Given the wide range of methods employed, the extensiveness of each process was necessarily limited by the available time. This limitation led to a study with a broad scope but a relatively shallow depth in each area investigated.

The study was further constrained by its focus on a single company, which facilitated a thorough analysis of the specific case but limited the generalizability of the findings. While some results may be applicable to other contexts, the primary findings and recommendations are tailored to the Volvo GTT and have not been explicitly tested for broader applicability. Moreover, the recommendations provided for the Volvo GTT have not been implemented, meaning their practical effectiveness remains unverified. Overall, these limitations should be considered when interpreting the findings and conclusions of this thesis.

## 1.5 Report Outline

This master thesis report is split into seven chapters in the following order: Methodology and Project Process, Research Phase Results, Development Phase Results, Evaluation Phase Results, Discussion, and lastly Conclusions and Recommendations.

The second chapter, *Methodology and Project Process*, describes the project phases and which methods were used in each phase. The project consists of three main phases, research, development, and evaluation. Each of the phases is described along with the objectives set up for each phase. Following these chapters, the subsequent three chapters present the corresponding results of each phase.

Consequently, chapter 3 presents the *Research Phase Results*, chapter 4 presents the *Development Phase Results*, and lastly chapter 5 presents the *Evaluation Phase Results*. All these chapters will end with a summary of results from each phase, which can be used as an overview of the result from each specific chapter.

After the results chapters, the *Discussion* is presented. Lastly, in the *Conclusions and Recommendations* chapter recommendations for future work and conclusions are presented.

# 2

# Research Approach Methodology

The project was comprised of three primary phases, each designed to answer the research questions outlined in Section 1.3.1. Every phase was carefully structured with objectives, defining essential activities for achieving the project goals. The methods employed in each phase draw from established practices from product development processes merged to suit the project's needs. Figure 2.1 illustrates a color-coded process to delineate the subsequent sections. The green area signifies Section 2.1 Research Phase, where data and information were gathered. Following this, the blue area represents Section 2.2 Development Phase. Finally, the orange area symbolizes Section 2.3 Evaluation Phase, focusing on assessing the outcomes of the development process. Within each phase, additional clarity is provided through color-coded elements: green boxes denote inputs, representing the resources or information utilized; blue boxes represent processes used to move the project forward; and orange boxes signify outputs, tangible or measurable results of the project.

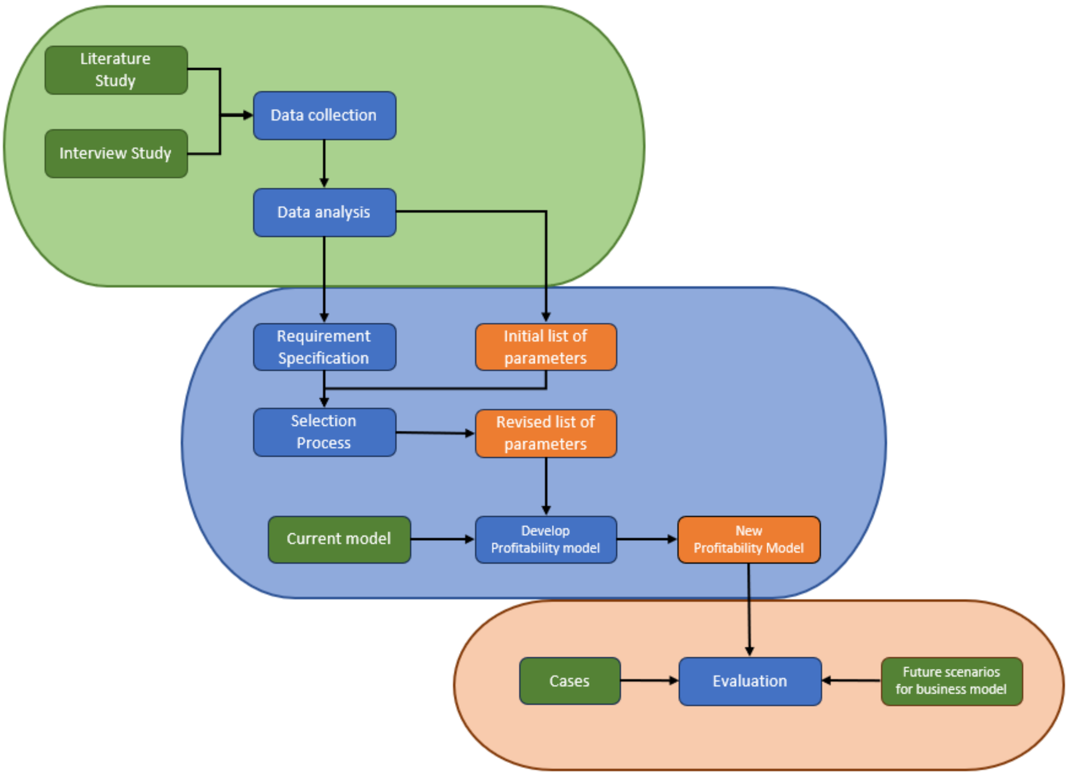



**Figure 2.1:** Project Phases, illustrated by three phases and their included activities. The research phase is presented in green, the development phase is presented in blue and lastly, the evaluation phase is marked in orange.

## 2.1 Research Phase

The first phase of the project was the research phase. The first phase was divided into two main processes: Data collection and Data analysis, as shown in Figure 2.2. The data collection process consisted of a literature study and an interview study.

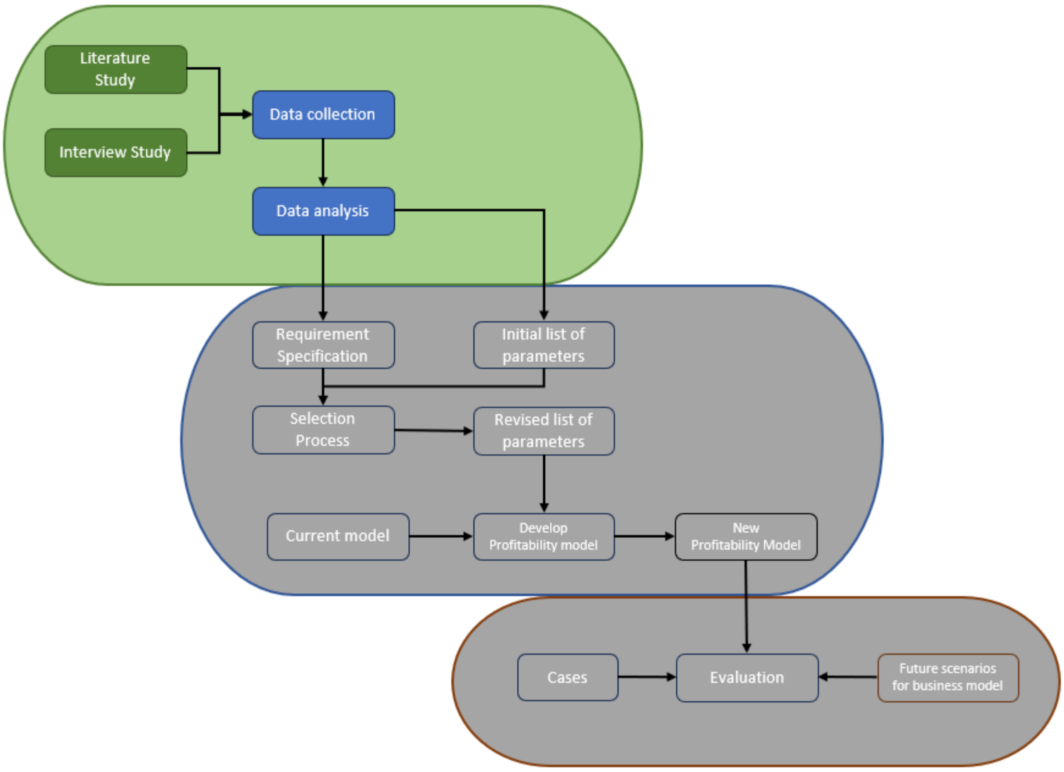



**Figure 2.2:** Highlighted in green, the Research Phase included a literature study, interview study, data collection, and data analysis.

The research phase had the purpose of amassing information for the project, and investigated the following 5 objectives:

RO1. Investigate design principles that increase the profitability of circular products.

RO2. Identify the important attributes of circular products in product design.

RO3. Determine key drivers motivating organizations to pursue circularity.

RO4. Evaluate the current perception of the circular economy within the manufacturing industry.

RO5. Establish parameters for calculating profitability to enable circularity.

The first objective had the purpose of investigating the overlap between circular products and the profits they are able to generate. This was an interesting objective since the financial potential of circular solutions was the main interest of the project.

The second objective was of interest since it was important what attributes a circular product consisted of. This would help in determining whether or not a certain type of parameter was contributing to more circularity.

Understanding the main drivers behind organizations striving towards circularity was seen as important. This would describe why companies consider changing an already very profitable way of working, and therefore probably have an impact on the profit of the developed solutions.

How circular economy is perceived in the current industry was deemed important because it would benefit the understanding of why there those for and against more circular development.

The last objective was important to investigate in the research phase since the goal of the project was to integrate parameters that would enable more circular product development.

### 2.1.1 Literature study

The research phase was the first phase of the project and was conducted to gather relevant information about circularity and circular development, which was achieved in the literature study. The literature study included finding relevant articles, books, and other sources, used to create an understanding of current research, practices, recommendations, strengths, and shortcomings in circular operations. To find relevant information, the following keywords in both singular and plural were used: Circular economy KPI, Circular Economy*, Circular Product Development, Circular Design*, Circular Business Model*, Product Service System, Sustainable Transitions*. These keywords were used on Google Scholar, Science Direct, Chalmers Library, and Web of Science.

Considering the vast amount of literature and publications available through various search engines, it became imperative to further narrow down the results to achieve a comprehensive yet manageable state within the allotted time frame. Initially articles were gathered by using the list of keywords described above, as well as variations of these keywords. To find additional papers the snowballing method, by Wohlin (2014), was used to identify key references within relevant literature. Wohlin (2014) describes another method to assess an article's relevance, in the forward rolling approach. This method starts by identifying articles to be evaluated by their titles, then the abstract of each article, the citations used, and lastly the full paper. The overall process is illustrated in Figure 2.3 and was iterated until a sufficient amount of literature to cover relevant subjects had been gathered. As the project progressed and more relevant subjects appeared more literature was amassed.

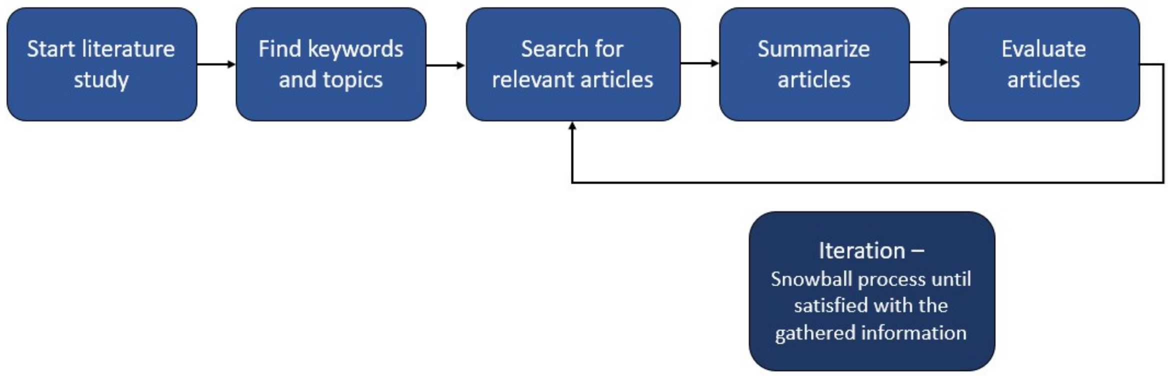



**Figure 2.3:** Snowball method adapted from Wohlin (2014).

To ensure the relevance and reliability of the literature, specific criteria were established. The criteria are presented in the list below:

- Published within the last 15 years - The literature included in the study should be relevant and recent.
- Peer-reviewed scientific publications - The literature included should be of high quality, which inclusion in a peer-reviewed publication is indicative of.
- Frequently cited or referred to - The literature included should be looked upon more favorably if it is central to the science, one measure of this is the number of citations.

- Relevance to the study's topic - Above all, the inclusion of literature is decided by the relevance of the literature to the study itself.

In order to work systematically with large amounts of literature a spreadsheet documenting literature was used during the project. In the spreadsheet information about the literature was stored, such as: publication title, authors, year, search keyword, notes from reading, a decision of inclusion or exclusion, and in what context. In total 32 articles were read, discussed, and summarized. A spreadsheet presenting each article's title, authors, year, publication/source, type and topic can be found in Appendix A.2.

### 2.1.2 Interview study

To understand the product development process within Volvo GTT a qualitative interview study was chosen to collect information from employees involved with the product development process at different stages. The interviewees were employees from departments of Volvo Group Trucks Technologies, such as product development, circular operations, financial management, aftermarket, purchasing, and sales as well as other companies within the Volvo Group. The initial selection of interviewees was provided by a stakeholder and expanded by using a snowball selection where recommendations from interviewees generated additional study participants (Wordpress, 2024). The list of interviewees can be found below in Table 2.1.

| **List of Interviewees** | |
|---|---|
| *Company* | *Role* |
| Volvo Group Trucks Technology | Chief Strategy Engineer |
| Volvo Group Trucks Technology | Vehicle Strategy Architect |
| Volvo Group Trucks Technology | Financial Project Manager |
| Volvo Group Trucks Technology | Sustainability Strategy |
| Volvo Group Trucks Technology | Technology Exploration |
| Volvo Group Trucks Technology | Technology Strategy |
| Volvo Group Trucks Operations | Circular Business Developer |
| Volvo Group Trucks Operations | Circular Business Developer |
| Volvo Group Design | Sustainability Designer |
| Volvo Trucks | Director Transport Industry |
| Volvo Trucks | Product Manager |
| Volvo Trucks | Product Manager |
| Volvo Trucks | Environmental and Innovation Manager |
| Volvo Construction Equipment | LCA Manager |

**Table 2.1:** List of Interviewees.

The interview study was chosen as a process to contribute to all research phase objectives by ascertaining the state of the Volvo Group and some of its employees' knowledge regarding circularity, circular products, business models, and parameters. However, the interview study contributed especially to the following research objectives:

RO3. Determine key drivers motivating organizations to pursue circularity.

RO4. Evaluate the current perception of the circular economy within the manufacturing industry.

RO5. Establish parameters for calculating profitability to enable circularity.

To understand why Volvo GTT and other manufacturing companies are trying to become more circular, the problem as described for their particular context was best answered through an interview study. The problem described by the interview participants would also show the drivers behind Volvo GTT wanting to become more circular.
Additionally, the interview study would clarify why Volvo GTT is facing hinders in circular development, in line with the research question from the introductory chapter:
*RQ:3 What is currently hindering Volvo GTT from becoming more circular?*
The interview study was in large part based on a set of prepared themes, which can be seen in Appendix A.1. The project wanted to investigate the themes as possible avenues of increasing circularity or to understand the problem. These themes were based on learnings from the literature study and from discussions with stakeholders, and were initial areas of relevance to discuss. Lastly, the interview participants were seen as an important source of knowledge since the majority of the participants had both interest and experience trying to implement circularity at Volvo GTT. This meant the participants were asked to provide suggestions for parameters that could enable circularity and some of the requirements that could be placed on a parameter for it to be suitable in a profitability model.

Before conducting the interviews, all interviewees were provided with an email outlining the purpose of the study, as well as a reminder of the study's questions and details regarding confidentiality, in accordance with protocols outlined by Davidsson and Patel (2019). Furthermore, at the commencement of each interview, participants were again briefed on the study's purpose, confidentiality measures, and the intended use of the information provided. The interviewees were also asked if they consented to being recorded. The study aimed to ensure a high reliability, which according to Davidsson and Patel (2019) meant that the study needed to be carried out in a trustworthy way. Reliability was ensured by recording audio during the interviews, which was then later used during the data analysis as a source. It is important to note that the interview study was conducted under conditions of confidentiality, meaning that the identities of the interviewees are undisclosed within this thesis. Davidsson and Patel (2019) outlines that participants are more likely to express themselves openly in an anonymous study, which aligns closely with the aim of this research.

The interviews were conducted using a semi-structured approach, and the questions were asked in an order adapted to the interviewee's role and the questions were asked in an appropriate order, adapted to each of the interviewee's roles. This meant that the questions were prepared beforehand, yet left room for additional questions that could emerge during the interview. The questions were asked in a funnel-like order and started with a set of standardized questions in order to gather relevant background information while simultaneously systematizing the process. Lastly, all interviews ended by giving the respondent the opportunity to ask questions and provide comments on the study if they regarded it to be prudent (Davidsson and Patel, 2019). The questions asked during the interview study can be found in Appendix A.1.

After conducting the interviews, they were subsequently synthesized using the method of in vivo coding. This particular approach to interview analysis is commonly employed in the preliminary examination of interviews to condense passages by utilizing direct quotations from the interviewees. These excerpts, denoted as codes, serve to delineate significant themes articulated by the participants (Miles et al., 2019). An inherent advantage of in vivo coding lies in its capacity to encapsulate the perspectives specific to a particular culture or group, as exemplified in this instance by the workforce of Volvo GTT. The coding methodology itself proved to be a less arduous process, aligning effectively with the requirements of the project and offering a favorable compromise for the qualitative data analysis.

The compilation of quotations ensued from a thorough review of all the interviews, resulting in a total of 201 quotes extracted from the 14 interviews. Throughout this process, duplicate quotes, sharing similar content with those already recorded, were intentionally omitted. Such an omission was deemed appropriate given the scope of the study, which was not geared toward statistical analysis but rather towards gaining insight into the work environment of the interviewees. Consequently, certain quotes that might have otherwise been recorded were excluded, as their content had already been adequately represented by other data. The quotes were selected to be included in the coding process if the quote or passage fulfilled either of the following aspects:

- The quote fits into the list of beforehand created themes.
- The quote was new in subject matter/meaning.
- The quote was deemed as important/interesting.

As a consequence of the selection process for the quotes, the codes closely resembled that of the beforehand created set of themes. This was seen as a necessary consequence of the interviews being semi-structured and aided in the goal of receiving feedback on already gathered parameters. The list of parameters grew during the interview study as information surfaced. While this iterative process led to the exclusion of a significant volume of data, it was deemed congruent with the project's objectives of utilizing interviews to fulfill the aforementioned objectives. The subsequent coding of these interviews was conducted individually by both project members using the same set of codes and quotes. The coding process was a manual sorting of quotes from participants to the jointly created codes. The list of quotes was then sorted one quote at a time to the codes.

In order to assess intercoder reliability, both project members independently coded the same set of raw data derived from the interviews. The resultant datasets exhibited a high degree of similarity with minor discrepancies, primarily attributable to the overlap between code and data. Many quotes exhibited elements of overlap across different thematic categories, and delineating between codes was often challenging due to their interconnectedness within the broader topic of circularity. For instance, a quote pertaining to legal risks associated with material supply chains could feasibly be categorized under codes pertaining to Risk, Laws and Regulations, or Material. Following a comparison and discussion of the individual coding outcomes, these results were amalgamated to form the qualitative data presented in this report. This reliability assessment served as an efficient means of evaluating the robustness of the data.

### 2.1.3 Output from Research Phase

The research phase gathered information pertinent to the project by using an interview study and a literature study. The literature study provided an understanding of circular economy, circular product design, circular business models, and the interplay between these subjects, which along with input from the interview study fulfilled RO1 and RO2. By interviewing experts within the manufacturing industry, the objectives RO3 and RO4 were met. The last objective, RO5, was fulfilled by both the interview and literature study to gather parameters relevant to enable circular product development. The results generated from the research phase will be presented in Chapter 3.

## 2.2 Development Phase

The project's second phase was the development phase with the purpose of answering the second research question ”What key parameters should be integrated into profitability calculations to enable circular products?”. To provide an answer to this research question, the development phase used several processes which can be seen in Figure 2.4 below. The methods used in each process are presented in the following sections. The phase consisted of the following objectives:

DO1. Generate a list of parameters using results from the research phase.

DO2. Create a requirement specification for the screening process.

DO3. Finalize the list of parameters.

DO4. Develop the profitability model.

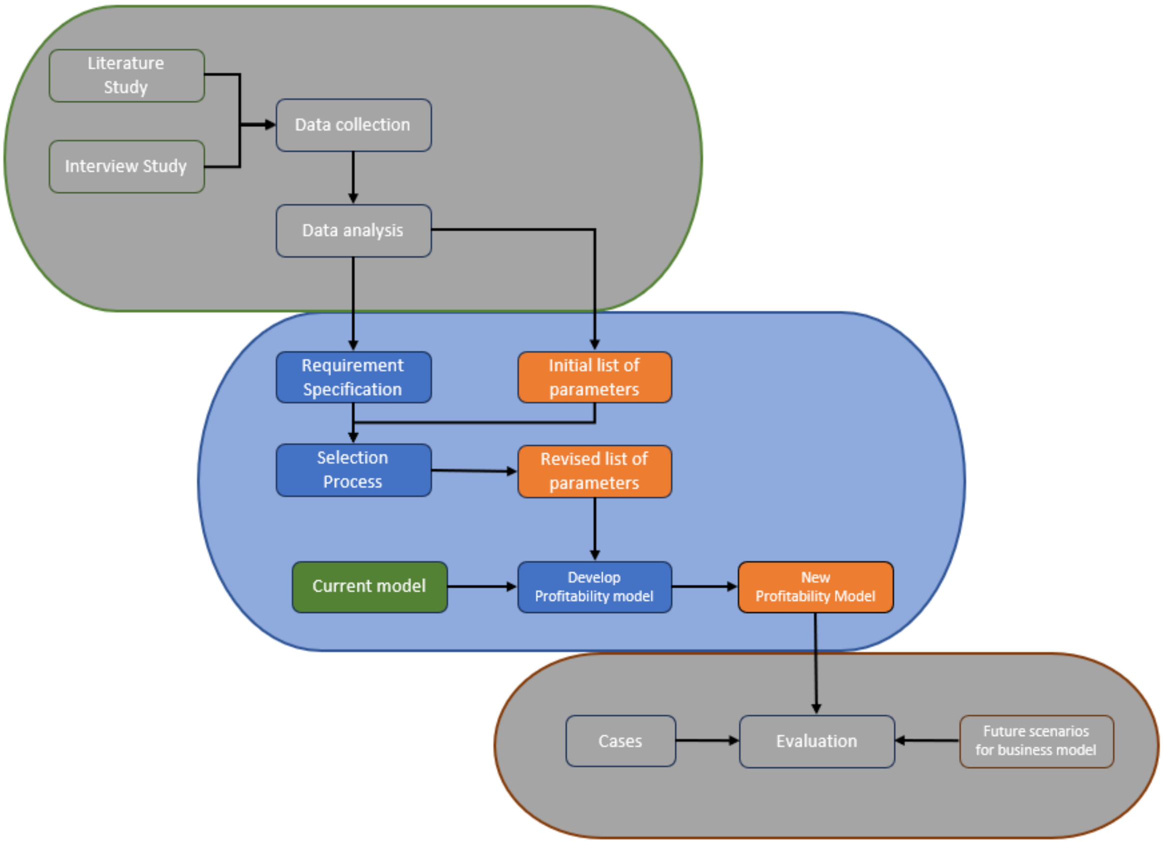



**Figure 2.4:** Highlighted in blue, the development phase included creating a requirement specification, screening list of parameters, and the creation of a new profitability model.

### 2.2.1 Generating a list of parameters

The process of compiling parameters for the project started with a thorough examination of the interview study findings. From this review, an initial list of parameters was formulated, however, some of the suggested parameters required additional attention and clarification. Through a refining process, parameters exhibiting significant overlap or lacking clear definitions were systematically removed, resulting in the creation of the initial parameter list.

It is worth noting that the primary objective of the interview study was to gather parameters conducive to circularity within Volvo GTT. As such, it was not surprising that many of the parameters initially collected were already aligned with this overarching goal. This natural alignment underscored the relevance and applicability of the parameters identified during the interview study, setting a foundation for subsequent project phases.

### 2.2.2 Requirement specification

To ensure the relevance and appropriateness of parameters considered for integration into the profitability model, a requirement specification was developed. The beginning of this process involved the aggregation of potential requirements from the literature, interview study, and future legislature. These initial requirements formed the foundational framework, serving as the basis for subsequent deliberations.

After the initial insights, a brainstorming session followed within the project team. This session aimed to identify the potential needs and attributes essential for a parameter to qualify for inclusion in the model. Through collaborative discussion and ideation, a diverse array of perspectives and considerations were explored, enriching the initial set of requirements. Subsequently, the insights from the interview study were examined. The study yielded a list of requirements that could feasibly be imposed on parameters, offering valuable guidance in refining and augmenting the evolving requirement specification.

Finally, the requirement specification was evaluated by project stakeholders. Their input and feedback resulted in the refinement of the specification, ensuring a higher degree of alignment with project objectives and stakeholder expectations. Through iterative discussions and refinement cycles, additional clarity and precision were imparted to the requirement specification.

### 2.2.3 Screening process

After the establishment of the requirement specification, and the initial compilation of parameters, the screening process was initiated. This process utilized the requirement specification as a framework to screen and evaluate parameters, ensuring that only those deemed relevant to the project's objectives were developed further. The screening process commenced by categorizing parameters into two distinct groups: those aligned with existing laws and regulations, and those not directly related to legal frameworks. This initial grouping facilitated a more targeted evaluation process, allowing for more detailed assessments based on the specific context.

After this step, each parameter underwent evaluation following the criteria outlined in the requirement specification. Parameters were evaluated to ascertain their alignment with project objectives, feasibility of implementation, and potential impact on model outcomes. Figure 2.5 below offers a visual representation of the requirements and criteria that guided the parameter screening process, providing an overview of the evaluation framework that was employed.

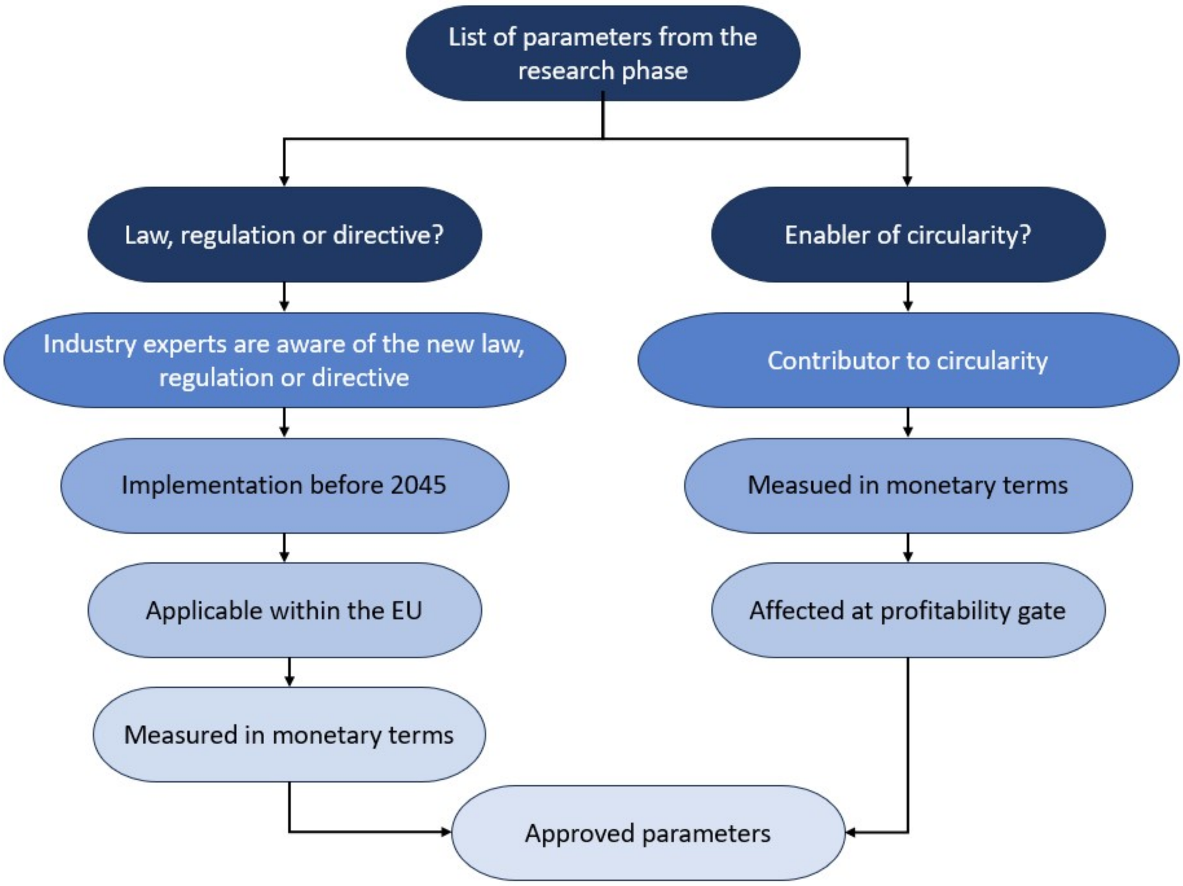



**Figure 2.5:** Screening Process illustrating the criteria parameters must meet to be considered for inclusion in the profitability model.

Following the screening process, a total of 11 parameters were identified as not meeting the requirements and were consequently eliminated from the initial list. The remaining 21 parameters, deemed suitable for integration into the model, proceeded to the next stage of evaluation.

In a subsequent step, the retained parameters were further ranked based on their perceived impact on the profitability model. This was an informal process with a stakeholder in which the discussion revolved around the potential impact on the outcomes of the profitability model in enabling the development of circular products. After the deliberations with a project stakeholder a decision was made to develop and implement 2 parameters further development in the profitability model. Only 2 parameters were retained as a consequence of time restraints within the project. It was seen as more beneficial to the project to develop parameters with some depth, so only 2 final parameters were chosen.

### 2.2.4 Development of Profitability Model

A profitability model was developed during this project, with the purpose of acting as a tool to investigate the suitability of the parameters originating from the screening process. To fulfill the second research question, the model was used to show the parameters' impact on circularity. The framework of the model was provided by a stakeholder at Volvo GTT and developed in concert with the same stakeholder to function as a tool suited to the project's needs, seen in Figure 5.3.

The development of the model was conducted during the development phase through a series of development sessions. The sessions were carried out alongside the profitability tool owner at Volvo GTT. These sessions occurred 1-2 times a week and lasted between 60-90 min. The development sessions consisted of the project group, the tool owner, and on occasion a circular business developer. Between these sessions, the model was developed by the project members. The sessions started developing the model from the template profitability model provided by the tool owner. The model was then modified to include the selected parameters.

The model was also developed to be able to represent two different business models, a linear direct sales model, and secondly a a circular product-as-a-service model. This approach enabled a more detailed investigation of the potential impact and feasibility of circular products.

### 2.2.5 Output from Development Phase

The development phase resulted in a list of parameters from the research phase, fulfilling development objective DO.1. The development phase also resulted in a requirement specification used to perform a screening process, resulting in a finalized list of parameters fulfilling objectives DO2 and DO3. After this, the profitability model was developed, considering aspects of circularity and the chosen parameters fulfilling objective DO4. The results generated from the development phase will be presented in Chapter 4.

## 2.3 Evaluation Phase

The evaluation phase was the last phase of the project. In order to understand the quality of the results, possibilities for improvement and future research needs an investigation into the validity of the selected parameters was performed. The objectives for this phase included:

EO1. Investigate the validity of the parameters' composition.

EO2. Investigate the validity of the parameters' influence on the profitability of linear and circular products.

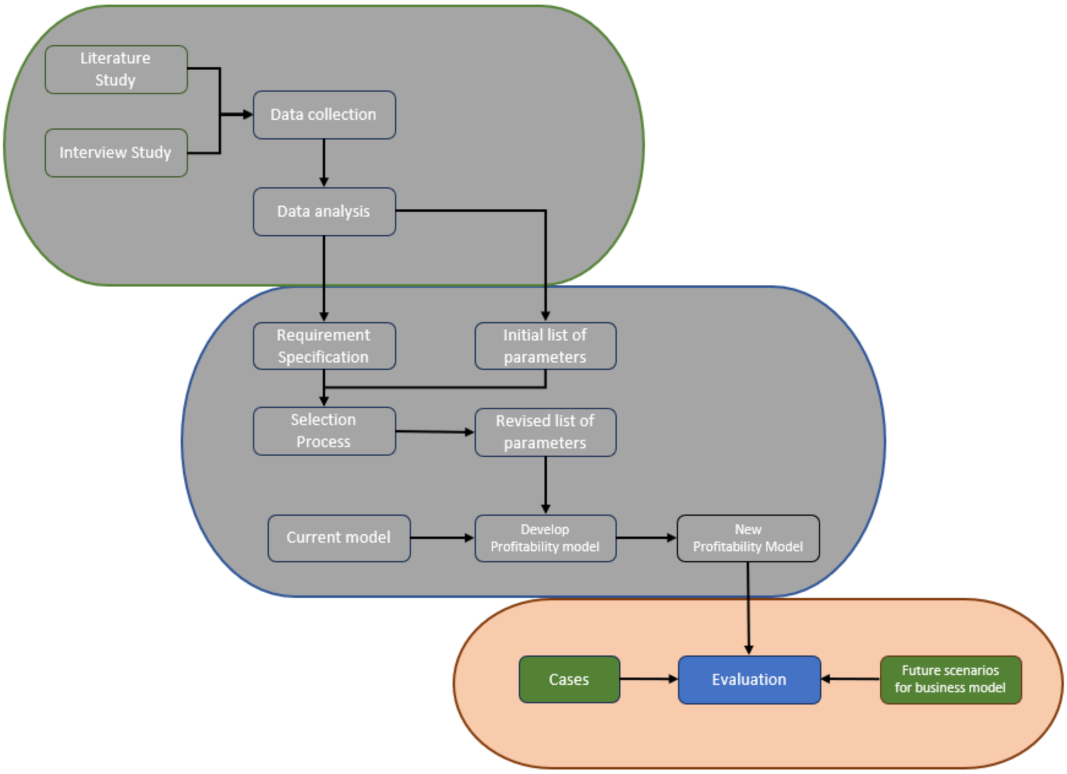



**Figure 2.6:** The Evaluation phase, shown in orange, included applying fictive cases to the developed model, assessing validity, and exploring future scenarios for business models.

### 2.3.1 Validation

Investigating the validity of the parameters was an important step in being able to discuss if, and how well, the results answer the research questions, see Section 1.3.1. Of these research questions, the most relevant to investigate the validity of was the second research question:

*RQ2: What key parameters should be integrated into the profitability model to enable circular products?*

The answer to RQ2 was in large part the two parameters developed in the model. In order to discuss the suitability of these parameters validity needed to be investigated. To be able to discuss validity two separate processes were used. Firstly, a workshop session with an extended project stakeholder team was convened to discuss the validity of the parameters. Secondly, the parameters' impact on profitability by varying business models and products from linear to circular, using 6 fictive cases.

**Validation study of parameter composition**
The validation of parameters was conducted through a dedicated workshop session, involving participants beyond the project team who held a vested interest in the project. The workshop session was started by the project members who presented the background of the problem, the found parameters, and their implementation in the profitability model. After the introduction to the problem, the discussion centered around the parameters, how they were measured, how they impacted the model, and what mechanisms could impact the value.

The questions central to the workshop were:

- Are the parameters understandable?
- Do the parameters have an impact that enables circular product design?
- Are the parameters being measured in the right ways?
- Are the parameters being implemented in the profitability model in the correct ways?
- How should the value of the parameters change as the product and business model become more circular?

During the workshop, the discussion mainly revolved around the two selected parameters. The workshop aimed to answer the questions stated above. The mechanisms that would change the value of the parameters were also a large topic of discussion. In this, the project asked the workshop what they thought would change across business models and across the different products. The workshop concluded with a questionnaire comprising 11 questions which was used to gather insight from the participants. Each question was framed to elicit responses on a Likert scale ranging from 1 to 5, with 1 denoting a low rating and 5 representing a high rating. There were 5 questions for each of the two parameters to assess different aspects of these. Additionally, the questionnaire featured an open-ended question, allowing participants to provide any additional feedback or comments they deemed pertinent.

**Validation study of parameter implementation**
The combination of various business models with products along a spectrum ranging from linear to circular aimed to show the impact of parameters, considering the circularity of both the product and the business model. The circularity of the product varied in its degree of design for circularity, while the business model varied in its degree of enabling circular operations. The objective of this assessment was to disentangle the financial performance of circular and linear products from that of their respective business models, thus revealing the extent to which profitability was influenced by the alignment between the product and its business model.

To introduce nuance in the evaluation process, three symbolic products were created along the linear-to-circular spectrum. The first point represented the current state of the product, while the second point reflected significant design adaptations towards circularity, and the third point depicted a product primarily engineered to embody circular principles. For the evaluation, an entire truck was chosen as the reference vehicle, as it was deemed to offer a clearer depiction of its general attributes and potential functionalities compared to individual components. Although selecting a vehicle facilitated the illustration of its value and income generation potential, it lacked the ability to showcase the design disparities necessitated by circularity. The attributes of the three vehicles were derived from insights in the research phase, which provided the project members with a general understanding of the requisites for a circular product.

The fictional cases were constructed by matching three products into two business models. The two business models and their economic structure of revenue and cost during a vehicle's lifetime were used as a basis. Two business models were considered an important part of the validation study, as the research phase demonstrated that the suitability between product and business model was important.

It was seen as very interesting to model how revenues and costs differ in the two business models since the effects on the profitability were expected to be significant. Consequently, it was considered important to create two separate scenarios with different business models, designed to illustrate the differences in costs and revenues between these. Through discussions with stakeholders, descriptive graphs of the revenue and cost streams during a vehicle's life in both a linear and circular business model were created. These graphs were used to communicate with stakeholders about the models and later used as a reference when building the business cases.

After the products had been described at an overarching level, the factors that influenced the cases were described, such as technical lifetime, disassembly efficiency, and initial product cost. The variations were based on learnings from the research phase.

### 2.3.2 Output from Evaluation Phase

The evaluation phase resulted in extensive discussions of the validity of the selected parameters. Through the workshop objective EO1 was fulfilled by discussing the parameters' composition. By creating the fictional cases and displaying the results to a stakeholder the validity of the parameters' influence on the profitability of circular products was investigated, fulfilling objective EO2. The results of the evaluation phase will be presented in Chapter 5.

# 3

# Results of Research Phase

In this chapter, the results from the research phase are presented. The results include findings from literature, and information collected during the interview study. The chapter ends with presenting a summary of the results of the research phase in relation to the objectives that were set up in Section 2.1.

## 3.1 Literature Study

In the following section, the articles and topics of the literature review are presented. The results from the collected information have been grouped into sub-topics related to circularity, circular economy, or circular development. Firstly the strategies for circular products are presented. Thereafter consumer behaviour and its interplay with the CE is described. The literature study concludes by reviewing influential laws and regulations.

### 3.1.1 Strategies for Circular Products

One main framework continuously referenced across the literature is the R-Framework, developed since 1990 according to Amarasinghe et al. (2024). Since 2017 Kirchherr et al. (2017) is one of the most cited articles, adopting the 10 R's from Potting et al. (2017). The framework presents 10 R's from R9 - Recover, in a linear economy to R0 - Refuse in a circular economy, which is presented in Figure 1.1. The different strategies can be adopted and modified to fit any type of business och product on different levels.

There are different ways that companies can work with the R-Framework to enable a circular economy. One business model that can enable the implementation of circular economy principles, promoting a new perspective on resource management is a product service system (PSS), as mentioned earlier (Kühl et al., 2018). The article explains that there are two core perspectives in a circular economy, firstly *systems perspective* and secondly *the waste hierarchy* - better known as the R-Framework. Whilst the system perspective is more focused on changes in different societal levels; micro, meso, and macro, the latter is related to the closure of resource loops.

Other authors such as Bocken et al. (2016) also imply the existence of various business models that can be leveraged to advance the circular economy. Mainly, Bocken et al. (2016) presents the business model strategy for slowing loops as "Access and performance model". Meaning that this type of business model can allow companies to capture the financial benefits of changing to a circular business, which companies might not be able to achieve in a linear model. By extending the life cycle of products and carrying additional costs, additional revenue can be captured through a product service system. According to Kühl et al. (2018), the business model most suited to fostering a circular economy is a PSS in which customers pay for the functionality of an asset. The authors further point out that product design is among the top three aspects of operationalizing a CE in a PSS. Moreover, the product must be designed with multiple usage phases in mind. Consequently, meaning that things like maintainability, enabling refurbishment, allowing for recycled materials, and considering multiple life cycles are of utmost scrutiny. Additionally, Kühl et al. (2018) explains that an offering within a PSS could enhance the potential to design circular products, especially a service-based business model where ownership of the solution is retained by the provider. However, one critique often aimed at servitization PSS is that they are not competitive and that today's consumers prefer ownership of products.

Muylaert et al. (2022) conducted a study on consumer preferences towards circularity in three different sectors: mobility, textiles, and tooling. They found that there were several barriers to implementing a service based PSS, based in part on the following important factors: preference for ownership, availability, aversion to subscriptions, and price. The study was in the context of private consumers, but the data could give an indication of where a service based business model could fail in a B2B context as well. Muylaert et al. (2022) states that their findings, see the list below, are similar to previous findings in similar research.

- The preference for ownership and aversion to subscription is strong. Ownership, especially in the 1st life of a product is seen as a more premium option when compared to buying used, leasing, or purchasing a service.

- Price was a barrier to services and leasing as consumers found it difficult to properly evaluate the true value and cost of a product.

- Availability of the service is an important aspect of the offering to convey the value of it. In shared pay-per-use offerings consumers felt insecure about the service since the availability could not be guaranteed.

- Sunk costs and transaction costs of sharing offerings. Sunk costs in purchased products motivate the owner to keep using their current solution. Servitization schemes also create transaction costs in time and emotion, spent searching for a solution, worrying if it is available, and spending more time getting to the solution. The consumers found it difficult to compare this transaction cost in time and emotion of the pay-per-use offerings compared to the corresponding costs of regular ownership such as service, insurance, cleaning, and careful use.

Akbar and Hoffmann (2018) found that consumers who are more environmentally conscious can be motivated to choose the sharing solution if it is competitive enough, by e.g. offering intangible benefits or by minimizing transactional costs. In their work, the authors also discovered that more educated, younger consumers were more likely to place a lower value upon ownership and in turn more likely to prefer sharing products. However, they also found that for many consumer groups, the environmental benefits of a servitization scheme do not contribute to the perceived value. This implies that a service-based offering should market its more environmentally friendly solution to capture a larger segment of the market needs to provide benefits that ownership could not. These benefits could include product variety or the need to socialize. The service needs to be a complete offering, meaning that it should be able to replace the alternative solutions. In the context of personal automobiles this could entail offering smaller vehicles for trips within cities along with minivans for moving, and SUV:s for more extensive vacations.

### 3.1.2 Consumer Behaviour in the CE

There are some mechanisms of the CE and how society and its consumers act that prove complex and challenging. Allwood (2014) critiques the reality of the utopian vision of the CE. The author states that circularity should not be the main goal, but should rather be to produce social welfare whilst simultaneously minimizing environmental impact. Circularity can contribute to sustainability, but the goal of increasing material efficiency should not be at the cost of environmental stability, economic growth, or social prosperity. Allwood (2014) also means that the increased efficiency in resources is a byproduct of technological development within a competitive market, by showing how consumer's expectations continually rise as technology allows it. An example is provided by plotting fuel efficiency in cars against weight and acceleration over time. The plots showed that as a consequence of material prices and legislative forces vehicles became more efficient and lighter, but that as material prices stabilized and decreased, acceleration and weight increased as consumers became less sensitive to fuel consumption.

Moreover, Allwood (2014) highlights the problematic consumer demand in the current society of owning products and favoring convenience, but comments that as population density in cities increases this may change. Many spokespeople for the CE also espouse the benefits of PaaS business models. This would in all probability be a good tool for decreasing environmental impacts and material waste. However, Allwood (2014) points out that there are very few examples of businesses that have been able to successfully implement a PaaS business model because the current society now favors owning objects as a status symbol by relative comparison within social strata. This consumer preference towards ownership would have to go away and status within society shift towards e.g. having a smaller environmental impact.

Due to complexities of market and consumer behaviour, circular businesses do not necessarily result in lower environmental effects, shown in the rebound effect. The rebound effect is the expected reduction in benefits from technological developments as the use of the technology will increase. This means that the reduction in environmental impact is lessened as the technology is utilized more. The definition provided by Thiesen et al. (2006) is: "the rebound effect deals with the fact that improvements in efficiency often lead to cost reductions that provide the possibility to buy more of the improved product or other products or services" The supposed increases in efficiency in cost, energy and environmental impact could then lead to an increase in use of that product or service.

### 3.1.3 Laws, Regulations & Polices

Worldwide, nations and regions such as the European Union (EU), have established comprehensive laws and regulations governing environmental, safety, and industrial standards. One significant driving force behind these efforts is the United Nations' Agenda 2030, comprising 17 sustainability goals UN (2015). Among these is goal number 12 - Responsible Consumption and Production, prompting the EU to enact multiple new regulations in response. Given the diverse legal landscapes across countries, the EU serves as a benchmark for global standards.

One prominent regulation established by the EU is the End of Life Vehicle (ELV) Directive. According to the European Commission (2024b), this regulation highlights prevalent challenges regarding circularity within the automotive sector in the EU, attributed to various factors. These factors encompass deficiencies in product design and production processes, insufficient waste management practices within the automotive industry, and reliance on virgin materials in supply chains. Additionally, the unaccounted disappearance of one-third of all vehicles in Europe through illegal disposal or exportation exacerbates the situation. Furthermore, persistent weaknesses in governance and collaborations among suppliers, producers, and recyclers contribute further to the situation. Additionally, the existing laws and regulations fail to encompass lorries, motorcycles, and buses, further underscoring gaps in the current regulatory frameworks.

The European Commission (2024b) continues to declare in the ELV directive that the automotive industry is the EU's top consumer of critical raw materials, such as aluminum, magnesium, platinum, and rare earth elements. Therefore, the EU has created another regulation called the Critical Raw Material Act, which presents the following facts about critical materials:

- 63% of the world's cobalt, used in batteries, is extracted in the Democratic Republic of Congo.
- 97% of EU's magnesium supply is sourced from China.
- 100% of the rare earths used for permanent magnets are refined in China.
- 98% of EU's supply of borate is provided by Turkey.

It is clear that raw material usage can't continue as it is today. Producers across many industries must change and become less dependent on extracting raw materials. The European Commission (2024c) states that the challenges faced ahead in relation to material is the recycling of critical raw materials and securing supply chains. Across several industries including batteries, solar panels, and wind technologies, critical materials include gallium, tungsten boron, lithium, and cobalt. The European Critical Raw Materials Act aims to secure a sustainable supply of these critical materials and more. Currently, the majority of cobalt, magnesium, rare earth metals, and borate is supplied from outside the EU (European Commission, 2024c).

The ELV Directive was initiated in the year 2000, but was updated in March of 2023 and primarily aims to minimize the environmental impact of vehicles at end-of-life by promoting reuse, recycling, and recovery of materials (European Parliament and Council, 2000). Furthermore, the European Commission (2024b) outlines in the ELV-directive a new proposed regulation adding to the directive aiming to: design circularly, utilize recycled materials, enhance collection methods, implement improved treatment processes, hold producers accountable, and extend coverage to additional vehicles.

The addition to the directive is still under investigation, but a proposal of initiatives was released in an executive summary last year (European Union, 2023). The summary includes an impact assessment report on regulations of recycled materials in accordance with the processes outlined in the ELV directive. One objective that is proposed is to use more recycled materials, the target is set to use 25% recycled plastics by 2030, from which 25% should originate from closed-loop ELV treatment. The plastic content to be used is represented in Figure 3.1. The European Union (2023) continues to declare that more regulations are to be decided after a feasibility study is completed but mentions that it could include materials such as steel, aluminum, and other critical raw materials.

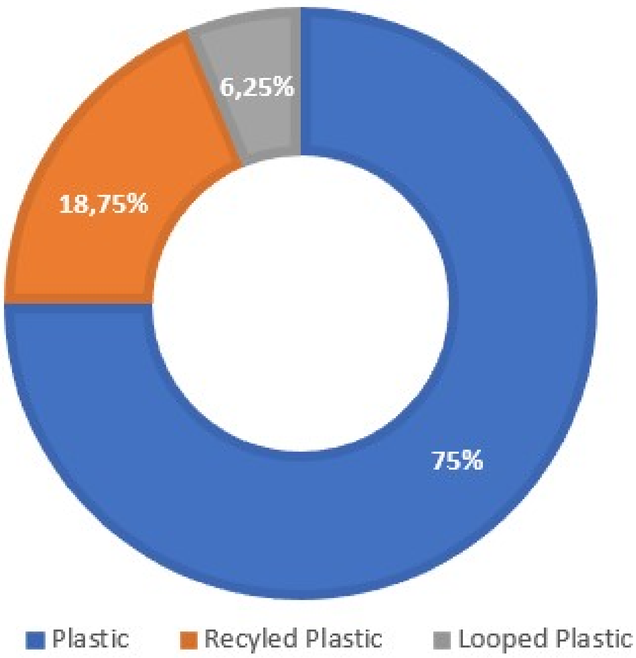



**Figure 3.1:** Plastic content in a vehicle under ELV directive according to the new proposed objective.

But these are not the only laws that will affect the automotive industry in the future. Regulations related to CO2, more commonly known as The EU's Carbon Border Adjustment Mechanism (CBAM) have been in active transition since October 2023 with the first CBAM reporting due date in January of 2024, (European Commission, 2024a). This transitional phase will be ongoing until 2026 when the full regulations will apply. CBAM is designed as a tool to establish equitable pricing for carbon emissions associated with the production of carbon-intensive goods imported into the EU. Additionally, it aims to incentivize cleaner industrial production practices in non-EU countries.

Moreover, policies such as the Extended Producer Responsibility (EPR) will have a broad impact across various industries, including the automotive sector. As defined by the OECD, EPR entails additional obligations for producers beyond conventional waste management practices (OECD, 2001). This environmental policy aims to shift the financial and/or physical burden of waste management upstream to the producer, thereby incentivizing the integration of environmental considerations into product design. In practical terms, EPR mandates that producers assume responsibility for their products at the end of their lifecycle. This may involve sorting products for proper treatment, ideally recycling or other elements of the 9-Framework, or providing the necessary financial resources to facilitate appropriate disposal by third parties.

The EPR policy can be adhered to through financial contributions or by taking charge of operational and organizational aspects. One way is through schemes like PROs (Producer Responsibility Organisations) (OECD, 2016). The EPR execution can vary across industries and companies, utilizing instruments such as product take-back requirements, economic incentives like deposit-refund systems, advance disposal fees, or even a combination thereof.

## 3.2 Interview Study

The interview study yielded a deeper understanding of both the Volvo Group's organizational structure and circularity practices. Its primary outcome was an increased awareness of the intricate challenges associated with transitioning from a linear to a circular business model within a large organization. Moreover, the interviews clarified the difficulties of the financial evaluation of circular products. They also provided perspectives on how circularity is perceived by both current customers and stakeholders within the Volvo Group. Additionally, information about and requirements necessary to develop and evaluate parameters surfaced. Lastly, the result of the study shows that the participants perceived the two largest drivers of circularity to be material supply chains and future legislation.

### 3.2.1 Developing Circular Products

A common remark when asked about the development of circular products was that the interest from product developers was high but that the changes required to make more circular products were denied as a result of them being costly. The tone of the majority of these comments was not one of frustration or resignation but rather a fact-of-the-matter type statement. Currently, engineers are only able to develop more circular or sustainable products when they simultaneously improve customer value or in concert with a general design update. The development of more circular products in many cases entails switching to recycled materials and in turn testing these, which often could not be approved within the project.

Volvo GTT excels in modular product design, a strength that enables significant product diversity. Many participants underscored the importance of modularity in achieving internal operational efficiency within circular product frameworks. However, the current emphasis leans heavily towards enhancing customer value rather than optimizing processes. Transitioning to a more circular business model would necessitate a shift towards prioritizing cost-effective repair processes, thereby accentuating design principles like design for disassembly, design for longevity, or design for repair.

Furthermore, participants highlighted a nuanced aspect of modularization in circular product development, particularly in modules characterized by rapid technological evolution, such as the battery module. Modules in this category should be designed for material return to the supply chain rather than prolonging product lifespan indefinitely. Sustaining a product beyond its technological relevance entails a delicate balance, as investing additional resources into maintaining its viability becomes increasingly impractical over time. Simply put, a battery pack manufactured in 2024 would likely lack competitiveness, resource efficiency, or economic viability for refurbishment in 2040.

### 3.2.2 Remanufacturing

Some individuals perceived that those actively engaged in remanufacturing initiatives tend to convey a message of organizational excellence in circularity. Indeed, those working within the aftermarket segment specifically dedicated to remanufacturing expressed confidence in their performance in this area. However, individuals closely involved in broader circularity efforts noted that only a small fraction of components undergo remanufacturing, sometimes even when repair would suffice. The aftermarket segment confirmed a preference for remanufacturing but clarified that components are often designed with remanufacturing in mind rather than repair. Several interviewees emphasized that repair is generally more favorably perceived by customers and holds a higher position in the R-Framework. Additionally, the interviewees from the aftermarket segment stated that remanufactured parts are typically sold with a deposit, resulting in the return of a vast majority of parts to Volvo GTT upon replacement. The only exceptions tended to be parts not returned due to import costs from certain countries.

On the other hand, some individuals voiced the opinion that Volvo Group's focus on remanufacturing may overshadow its commitment to sustainability. However, remanufacturing is acting both as a financial strategy to capture revenue and a core driver of sustainability. The tone of these statements suggested that the aftermarket segment is content with its current status, having undergone localized optimization efforts. They further conveyed the perception that the aftermarket segment is a significant source of profit for the organization, posing a substantial barrier to achieving greater circularity.

### 3.2.3 Organization

Throughout a vast majority of the interviews, it became evident that certain segments of the Volvo Group possess extensive knowledge in the realm of circularity. Participants exhibited a keen interest in the subject and expressed enthusiasm for the project's potential to drive forward circular development initiatives.

The exploration of various business models revealed a divergence from the predominant literature, which often emphasizes the role of Product-as-a-Service (PaaS) models in promoting circularity. Instead, interview participants highlighted the relevance of multiple business models, including take-back schemes, leasing arrangements, and PaaS models. These models are distinguished by the level of risk customers are willing to assume or pay for, their capital expenditure preferences, and their usage patterns. They clarified that larger haulage contractors have the capital to purchase products outright and that this suits their business better. As products increase in relative purchase cost and/or contractors decrease in purchasing strength the preference towards PaaS increases.

However, implementing circularity within Volvo GTT presents significant organizational challenges. Effecting such a transformation will necessitate substantial changes in business practices across all levels. Volvo GTT is already undergoing transitions in sustainability, digitalization, automation, and other areas, adding further complexity to the integration of circularity initiatives. Consequently, imposing additional restrictions and guidelines on product development, production processes, sourcing practices, and traceability during use could potentially diminish engagement, as these areas are already considerably complex. Thus, there's a risk of relegating circularity initiatives to a lower priority, one interviewee commented: "Circularity may have to wait"

### 3.2.4 Customers and Brand Perception

The sentiment among many participants is that the current internal dialogue surrounding circularity lacks sufficient emphasis on its potential customer value, focusing primarily on internal benefits instead. Volvo Trucks is an organization that sells to customers, and therefore it must have the customers' needs in focus. However, interviewees continued to elaborate that the internal brand dismisses circularity since the customers of today express little to no interest in circularity. These same interviewees continue their line of reasoning by stating that customers of tomorrow will be interested in circularity, sustainability, and services.

Concerns about external brand perception regarding circularity were also voiced. While Volvo GTT enjoys a strong reputation for quality, some participants expressed apprehension, that they believed circular products could impact this perception negatively. The stated reason was that by design a fraction of products will be older and potentially more worn and that a Volvo GTT product should be in pristine condition. Some participants stated that increased involvement in the secondary market would be risky. However, they also highlighted the opportunity to enhance customer perception by actively updating functionality and maintaining value, thereby reinforcing the brand's image as a provider of high-quality products that can be maintained. They emphasized that in the future, having circular products would demonstrate a commitment to sustainability and quality, aligning with Volvo GTT's current leadership position in these areas.

Modularization and product variety stand out as key strengths of Volvo GTT's offerings. Product variety is perceived as essential for a competitive edge and upholding a reputation for quality. However, some participants cautioned that modularization may be overextended, existing in areas where it fails to deliver customer value. They proposed that a circular business model could benefit from streamlining product variety internally. Moreover, they highlighted the potential synergies of combining service offerings with a simplified product range, suggesting that addressing customer needs for performance and variety could be achieved more efficiently through internal integration.

### 3.2.5 Legislation

The interview study confirmed that legislation is poised to play an important role in driving the transition towards a more circular way of operating and that Volvo GTT and Volvo GTO are very aware of future legislation. According to many interviewees, laws and regulations, alongside material prices, will serve as critical catalysts for change toward circularity.

The European Union (EU) stands at the forefront of setting standards for legislative action, having already ratified laws that are shaping the landscape. One such initiative is Extended Producer Responsibility (EPR), which, although not currently applicable to Volvo GTT trucks, is anticipated to become a significant factor in the future. The current EPR regulations cover packaging, batteries, and tiers. Interviewees underscored that the upcoming EPR directive could render a linear business model economically unfeasible or unprofitable.

Additionally, some participants speculated about future development of legislation addressing material extraction, water usage, biodiversity, and other planetary boundaries. While speculative, these discussions align with statements from the EU itself, suggesting a possible future trajectory.

Another significant mechanism under consideration by the EU is the Carbon Border Adjustment Mechanism (CBAM), as highlighted by numerous interviewees. CBAM would levy taxes on products entering the EU from outside to account for the environmental damage caused during production abroad. Many interviewees suggested that while laws ratified within the EU primarily impact operations within the region, CBAM could have broader implications beyond EU borders.

In essence, legislation, driven by the EU's proactive stance, is anticipated to exert considerable influence in reshaping business practices towards greater circularity, with initiatives like EPR, ELV, CRMA and CBAM at the forefront of this transformation.

### 3.2.6 Material

The importance of material supply chains emerged as a significant strategic consideration from many study participants. Amidst concerns over dwindling material supplies, less secure supply chains, and geopolitical tensions, the ability to secure an internal supply of materials was emphasized as crucial for maintaining profitability. Participants noted that Volvo GTT has previously encountered similar challenges, making strategic adjustments that, while initially unprofitable, ensured long-term viability e.g. by securing access to cleaner energy.

Even if utilizing recycled materials entails higher costs and renders circular products less immediately profitable, there was a consensus among interviewees that prioritizing the development of a more circular product offering and business model is necessary. Those actively engaged in circularity initiatives were particularly concerned with the risks posed by material supply chain vulnerabilities and anticipated future increases in material costs.

Irrespective of specific sourcing risks, all interview participants concurred that material prices are poised to rise, making materials increasingly scarce and valuable commodities. Many materials were identified as potential future scarce resources, including aluminum, steel (especially high-alloy stainless steel), rare-earth metals crucial for electrical components, lithium, cobalt, and copper (essential components of current lithium-ion batteries).

### 3.2.7 Financial Aspects

When asked about the major challenges of circularity and its profitability, many pointed to the issue of balancing the balance sheet. This problem is agreed upon, particularly when considering that implementing a circular business model might result in lower profitability. Circular products often find their best fit within a business model centered around services, a setup facilitated by Volvo GTT's ownership of the product. However, this ownership also invites one of the primary criticisms of servitization schemes: the considerable weight on the balance sheet, exposing Volvo GTT to significant risk through continued ownership of the product.

While selling a service typically promises greater long-term profitability, it also entails a longer payback period, tying up capital in the investment for an extended duration. In contrast, the current model of selling products yields a shorter payback period and lower risk by comparison, making it financially attractive.

Addressing concerns regarding tied-up capital, one interview participant proposed a more nuanced business model. This model involves initially selling the product with a buy-back agreement, effectively releasing the tied-up capital in the immediate future. Once the product reaches its first major overhaul, Volvo GTT buys it back, restores it to a like-new condition, and incorporates it into a servitization scheme. This approach allows Volvo GTT to maintain a high-quality brand perception among its initial customers while also accessing markets with differing purchasing power and decreasing the risk of a heavy balance sheet.

### 3.2.8 Requirements of Parameters

One of the key objects of the study concerned the requirements imposed on parameters. The interview participants produced several criteria the parameters should fulfill to be classified as a suitable parameter. These suggestions came both explicitly through verbal formulation and implicitly through participants' reformulation of parameters they found unsatisfactory, thereby revealing underlying requirements they deemed essential.

A recurrent theme among interview participants was the necessity for parameters to align with the long-term strategy of Volvo GTT to ensure successful integration into the profitability model. Moreover, parameters were expected to harmonize with, or at the very least, not contradict the short-term strategy.

A notable concern raised by several interviewees pertained to the perceived customer value in circularity. They argued that parameters must be justifiable from the customer's perspective, emphasizing that the transition towards circular practices is not just a strategic imperative but also a means to maintain relevance in an evolving business landscape. Considering Volvo GTT's reliance on customers for survival, the alignment of circularity parameters with customer interests could be important.

Furthermore, interview participants stressed the importance of parameters exerting tangible effects on business operations or product development. Some advocated for parameters to be prioritized based on their anticipated impact, with those yielding higher effects receiving priority.

Compliance with forthcoming laws and regulations emerged as another critical requirement for parameters. Additionally, parameters could be viewed more favorably if they contributed positively to other domains, such as social sustainability by minimizing material extraction or increasing the prevalence of service-based employment opportunities.

Lastly, interviewees underscored the necessity for parameters to be comprehensible and transparent in their intended measurement objectives. Clarity in parameter definition was deemed imperative to facilitate effective decision-making and interpretation of results.

### 3.2.9 Summary of interview study

The interview study aimed to investigate the main drivers behind organizations, the perception of circular economy practices in the manufacturing industry, important parameters, and their requirements.

**RO3. Determine key drivers motivating organizations to pursue circularity**

- **Legislation**: Driven by the EU, legislation will significantly influence the circular transition. Initiatives like Extended Producer Responsibility (EPR) and the Carbon Border Adjustment Mechanism (CBAM) are anticipated to shape business practices. The legislation aims to render linear business models economically unfeasible, prioritizing sustainability.

- **Material**: Material supply chain concerns are paramount due to dwindling supplies and geopolitical tensions. Securing internal material supplies is crucial for profitability. Despite higher costs, prioritizing circular product development is essential, given anticipated material scarcity.

**RO4. Evaluate the current perception of the circular economy within the manufacturing industry.**

- **Remanufacturing**: While some perceive remanufacturing positively, others view it as primarily profit-driven rather than sustainable. Concerns exist regarding the overshadowing of sustainability goals. Remanufactured parts are often returned to Volvo Group, indicating a strong aftermarket presence. However, there's a debate over the prioritization of repair versus remanufacturing.

- **Organization**: Participants expressed strong interest in circularity, acknowledging its importance in business models. They emphasized the need for varied business models, considering factors like customer risk tolerance. Implementing circularity poses organizational challenges, with a risk of relegating it to a lower priority amidst other transitions.

- **Customers and Brand Perception**: Internal dialogue on circularity often neglects customer value, focusing on company benefits. Despite concerns about brand perception, there's recognition of future customer interest in circularity. Modularization is a strength, but overextension may undermine customer value.

- **Financial aspects**: Achieving profitability in circular business models requires addressing the challenge of balancing the balance sheet. Selling services may promise greater long-term profitability but tie up capital for longer periods. A nuanced business model involving buy-back agreements could mitigate this risk while maintaining brand perception and accessing diverse markets.

**RO5. Establish parameters for calculating profitability to enable circularity.**

- The parameter must align with the long-term strategy of Volvo GTT.
- The parameter must contribute to customer value.
- The parameter should impact the product development or business operation.
- The parameter must align with laws and regulations.
- The parameter should be understandable.

## 3.3 Summary of results in Research Phase

The purpose of the research phase was to investigate five objectives presented in Section 2.1. The research objectives are presented and discussed below:

RO1. Investigate design principles that increase the profitability of circular products.

RO2. Identify the important attributes of circular products in product design.

RO3. Determine key drivers motivating organizations to pursue circularity.

RO4. Evaluate the current perception of the circular economy within the manufacturing industry.

RO5. Establish parameters for calculating profitability to enable circularity.

The research phase has gathered a substantial amount of information related to circular economy, circular products, and business models suitable to circular products, providing answers to objectives RO1 and RO2. Moreover, the research phase investigated objectives RO3 and RO4, the current perception of circularity within the industry, and the reasons for organizations' ambitions to become more circular. Lastly, the phase contributed to objective RO5, some parameters that could impact the profitability of circular products were produced along with requirements for inclusion in a profitability model which proved to be a starting point for the development phase.

# 4
# Results of Development Phase

This chapter presents the results from the Development Phase. The phase was divided into four activities, and firstly will the the generation of the list of parameters be presented. Subsequently, the results from creating requirement specification will be presented. Then, the finalized list of parameters and the selected parameters are presented. Lastly, the results from developing a profitability model will be presented. The chapter ends with a summary presenting the results from the development phase connected to the objectives that were set up in Section 2.2.

## 4.1 Initial list of parameters

In the following section, the assembled parameters are presented. The parameters were methodically collected throughout the research phase. Table 4.1 presents the key parameters that were collected through the project.

**Table 4.1:** List of initial parameters.

| Parameter category | Parameter name |
|---|---|
| Design aspects | Use less material, Better aerodynamics, Fewer variants, More upgrades, Additional services |
| Material usage | Weight reduction |
| Energy savings | Manufacturing processes, Testing |
| Material type | Virgin, recycled, looped |
| Laws | CBAM, CRMA, ELV, EPR, EOL-value |
| R-framework | Refuse, Rethink, Reduce, Reuse, Repair, Refurbish, Remanufacture, Repurpose, Recycle and Recover |
| Design for | Longevity, Modularisation, Assembly & Disassembly |
| Risks | Supply chain, access to material |

## 4.2 Requirement specification

The requirement specification was generated through an iterative process, beginning with insights from literature and legislature. From the literature study, a gap was identified in finding key parameters to enable circular products. Many authors point towards the revenue generating principles found in the R-framework by increasing resource utilization. Additionally, the literature study delved into upcoming legislation, reviewing directives such as Extended Producer Responsibility (EPR), Critical Raw Materials Act (CRMA), and End-of-life Vehicle Directive (ELV).

The findings from the literature study divided the requirements into two main groups. The first group were either a law, regulation, or other relevant legal document relevant to circularity. The second group of parameters were parameters that were not related directly to regulations but were deemed to contribute to circularity. After this division, the brainstorming session revealed numerous requirements within each group, leading to the emergence of more detailed specifications. At the same time, insights from the interview study specified the requirements further.

The last step of the creation of the requirement specification was input by project stakeholders. Their insights provided one key requirement - that all parameters must be able to be measured in monetary terms. This was very important for the profitability model since it was based on financial calculations measured in a monetary term. The requirements are discussed more deeply in the following section.

**Requirements for Laws, Regulations, and Directives**
In the first main group, four requirements were found that the parameters had to fulfill. The first requirement was that the parameter should be known to industry experts and deemed by them to be relevant. This filtered out many laws which were not of interest to the study. The requirement stated that laws should be familiar to knowledgeable industry experts. However, because these experts dedicated significant time each week to searching for laws, they were considered reliable sources for verifying the relevance of laws.

The second requirement specified that laws, regulations, or directives should be planned for implementation before 2045. Although this timeline may seem extensive, it aligns with the typically protracted process of implementing legislation. This meant that discussions currently going on could result in some inclusion to the study, but mostly as a relevant piece of information.

The third requirement was that the law should apply within the European Union. The European Union is seen as the benchmark within legislation in sustainable development, and also where a large share of Volvo GTT's business is located. This simplified the search for laws and regulations since North America, South America, Asia, Australia and Africa are all markets in which Volvo GTT conducts business, and these markets typically have less strict regulations for sustainable production and usage.

The fourth requirement was that the law should have a measurable financial impact on product design. This requirement originated from the tool owner, with the justification that the parameter would be included in a profitability model.

**Requirements for Other parameters**
The second group of parameters, those which were not laws, were subjected to the following parameters. The first requirement was that the parameters should enable the development of more circular products. This requirement originated from stakeholders within Volvo Group Circular Operations & Solutions and was seen as a core requirement since the project's purpose is to enable the development of more circular products.

The second requirement originated from a stakeholder and was that the parameter must be able to be measured or translated to monetary terms. Since the parameters were going to be implemented in a model that calculates revenues and costs, parameters that are only qualitative could be difficult to implement, and provide little value or effect on the use of the model. Parameters filtered out in this process could often be refined to be measurable.

The final requirement specified that a parameter must be able to influence the product at the profitability gate; otherwise, there was little justification for its inclusion. Parameters failing to meet this criterion were considered more suitable for inclusion as recommendations for potential future integration.

## 4.3 Finalized list of parameters

After the requirement specification had been created, all parameters from the initial list in Table 4.1 were examined against all requirements. This process excluded 11 parameters from the initial list and the finalized list of parameters can be found in Table 4.2.

**Table 4.2:** Finalized list of parameters able to be included in the profitability model.

| **Parameter category** | **Parameter name** |
|---|---|
| Material type | Virgin, recycled, looped |
| Laws | CBAM, CRMA, ELV, EPR, EOL-value |
| R-framework | Reuse, Repair, Refurbish, Remanufacture, Repurpose, Recycle and Recover |
| Design for | Longevity, Modularisation, Assembly & Disassembly |
| Risks | Supply chain, Access to material |

Following the selection process, this set of parameters was examined by a stakeholder at Volvo GTO. Considering the project's time constraints, the stakeholder opted to narrow down the list of parameters to be implemented into the profitability model, ultimately choosing two key parameters: End-of-Life (EOL) value and Material Supply Chain (MSC) risks. These parameters were deemed by the stakeholders as very relevant to the project, holding the potential for the most significant impact on the current profitability model.

Following that, discussions ensued regarding the Material Supply Chain risk parameter, which was then further delineated into several sub-parameters. These sub-parameters included factors such as access to material and transportation availability.

The subsequent development of the profitability model centered exclusively on these two key parameters. The remaining parameters listed in Table 4.2 are marked as recommendations for future implementation as they all fulfill the requirements.

## 4.4 Developed profitability model

The profitability model, constructed as a pivotal component of this study, was based on a framework provided by Volvo GTT. The model uses cost and revenue streams to compute the project's profitability in the form of Net Present Value (NPV) and internal rate of return (IRR). Rooted in fundamental economic principles commonly employed in financial models, this model was used as an analytical tool in this project.

The model included several common inputs found in other profitability models serving the same purpose. Inputs such as product cost, material price, and research and development expenses were calculated, while income was specifically computed through either direct sales or monthly premiums. Designed to estimate the profitability of a project as a whole, the model considered economic events from project initiation to discontinuation at an organizational level.

The model was developed with two key parameters: End-of-Life (EOL) value and Material Supply Chain (MSC) risk. EOL-value was derived from the value at the end of the technical lifespan of a component or product. The technical lifetime of a product is often much shorter than the lifetime of the product in use, meaning that at the end of its technical lifetime, the product can still be functional. This definition was necessary to estimate the possible value of a product after it had been substantially used. In the model, EOL-value was incorporated by multiplying the product cost, at the year of production, with a positive factor, usually smaller than 1 to represent the residual value at the technical end-of-life. Additionally, the effect of the EOL-value is that of purely profit, meaning that there are no parameters other than the EOL-value which describe or pertain to the end-of-life state.

In order to calculate the EOL-value, another aspect emerged that needed to be incorporated into the model - the number of vehicles returned at the end-of-life. This aspect was also estimated to differ between business models and dependent on the future implementation of laws. As explained in Section 3.1, the literature study found that the Extended Producer Responsibility (EPR) policy may require producing companies to take responsibility for products at end-of-life.

Incorporating the MSC risk was equally imperative as EOL-value. This parameter was integrated as a surcharge on the product cost, reflecting the anticipated higher procurement costs associated with material sourcing. The parameter was implemented in the model this way because the supply chain risk would lead to increased expenditure in material acquisition, hence warranting a percentage based increase in product cost. Moreover, the percentile rate at which the MSC risk increased the product price was identified as contingent upon various influencing factors, underlining the nuanced nature of this parameter's impact on the overall model outcomes. This aspect underscores the complexity inherent in assessing and mitigating supply chain risks within the profitability framework. The MSC risk parameter was to include three distinct aspects. Firstly, access to material as unforeseen activities can occur in the world such as production stops and geopolitics. If big manufacturers of materials today decide to stop supplying the world with these materials, there could be unimaginable consequences. Secondly, changing suppliers could become a strategic decision to decrease the risk of the supply chain. This could represent a large cost in the supply chain. A change in supplier could also be a necessary consequence of a failed supply chain. Lastly, transport costs could increase drastically as a consequence of having to reroute material if current solutions fail to function in the future. The parameter is closely linked with increases in material cost. However, the parameter takes other external factors into account and does not account for material price increases included in regular raw material cost evolution.

Integrating the parameter into the profitability model showed a current assumption of the model: material will always be available. The parameter showcases the consequences of events typically classified under Force Majuere. Possible scenarios include: geopolitical conflict, environmental disasters such as floods, failures in supply chains, such as those experienced during the Suez Canal or the semiconductor crisis, and political decisions e.g. in the form of an export restriction. The nature of these variables necessitated a different approach in the implementation to the model to show the risk of an array of possible events.

## 4.5 Summary of results in Development phase

The development phase aimed to fulfill the objectives that were presented in Section 2.2. The objectives are presented and discussed below:

DO1. Generate a list of parameters using results from the research phase.

DO2. Create a requirement specification for the selection process.

DO3. Finalize the list of parameters.

DO4. Develop the profitability model.

The development phase began with the generation of a comprehensive list of parameters derived from the findings of the research phase, fulfilling objective DO1. Subsequently, the second objective entailed the creation of a requirement specification, fulfilling objective DO2. Following this, the list of parameters underwent a finalization process, summarizing the selection of two key parameters for implementation, thereby fulfilling objective DO3. Finally, the profitability model was developed, with a particular focus on the seamless integration of the chosen parameters. This marked the successful completion of objective DO4, wherein the model's development was completed with the incorporation of the key parameters.

# 5

# Results of Evaluation Phase

This chapter describes the results of the evaluation phase. The phase consisted in large part of two activities both meant to contribute to a discussion of the validity of the parameters. The validation study was carried out through a workshop of project stakeholders, and a series of hypothetical cases to test the parameters. Concluding the evaluation phase is a discussion of the parameter's validity, both in how well the parameters are measured, and if the parameters have an impact enabling circular product design.

## 5.1 Assesing the validity of parameters

Assessing the validity of the parameters was conducted through discussion and a questionnaire during a workshop and a series of hypothetical cases. The workshop's discussion on the parameters was extensive. Participants examined the conceptual background of the parameters and the parameters' implementation into the model. The workshop served to investigate the validity of the parameters, which in combination with the case study allowed the project to discuss validity.

Overall, the workshop served as a platform for an in-depth exploration of the EOL-value and MSC-risk parameters, illuminating their complicated nature and the challenges involved in their practical application. Through discussion, the participants generated valuable insights into how the parameters could impact the profitability model and perhaps drive progress toward a more sustainable and circular economy.

### 5.1.1 End-of-Life value

Below the questions answered in the survey are presented in more depth and the comments made during the workshop elaborated on. In the Table 5.1 below the general survey results are shown. For the EOL-value parameter the workshop concluded that the parameter was good in intention and in effect, but the quality of the measurement process was complex and less reliable as can be seen in questions 2, 3, and 4.

**Table 5.1:** Results from the questionnaire for EOL-value.

| **Likert Scale Evaluation of EOL-value** | | | |
|---|---|---|---|
| **No:** | **Question:** | **Average result:** | **Median:** |
| 1 | How understandable is EOL value? | 3,625 | 4 |
| 2 | How easy was it to estimate EOL value? | 1,875 | 2 |
| 3 | How well is EOL value being measured? | 2,625 | 2 |
| 4 | How accurate do you think the EOL value is? | 2,25 | 2 |
| 5 | How well can EOL value enable more circular products if used in the model? | 3,875 | 4 |

**1. Is the EOL-value understandable?**

The discussion revolved around the concept behind the EOL-value parameter, raising fundamental questions such as its alignment with the ELV directive from the European Union and the potential salvageability of product components. There was a notable inquiry into whether materials could be harvested or recycled, reflecting a nuanced exploration of the concept's implications.

**2. How easy was it to estimate the EOL-value?**

The complexity of determining the EOL-value stemmed from various factors. Firstly, there was ambiguity surrounding what constitutes the EOL-value itself. Secondly, projecting the state of a product at its end-of-life proved challenging, given the multitude of potential conditions it could be in. This uncertainty not only hindered the assessment of their current state but also impeded efforts to assign a tangible value to them at that stage.

Moreover, the group acknowledged the difficulty in estimating the EOL-value due to a combination of factors. While there are reliable estimations of the value of vehicles after a decade on the current market, extrapolating these figures to predict their value two decades ahead proved intricate. The discussion highlighted the wide spectrum of conditions products might be in at their EOL, ranging from pristine condition to a condition suited best for scrapping, adding further complexity to the estimation process.

Interestingly, one potential reason behind the challenge in estimating the EOL-value could lay in its experienced simplicity. Members' understanding of the parameter paradoxically could illuminate its inherent complexities, making the estimation process more complex.

**3. Is the EOL-value being measured in the right way?**

The discourse regarding the measurement of a vehicle's End-of-Life value initially revolved around establishing a definitive understanding of what constitutes this value. Once consensus was reached on the definition, namely - the value of the vehicle after its technical lifetime — the conversation shifted to explore how accurate estimation could be made. One focal point was whether the EOL-value could be adequately approximated solely by considering the material weight of components like steel and aluminum, or, if these components possessed additional worth beyond their raw material content. Notably, discussions illuminated that in more circular designs, components often retain higher functional value as they're engineered for longevity.

The question of optimal dismantling emerged concerning locations for products, dismantling facilities, the responsible parties for this task, and associated costs. The group acknowledged the absence of legal decisions or actual implementations to refer to. One estimate raised by a participant pertained to the use of Product Responsibility Organizations (PROs), where dismantling costs were projected to equate roughly to the value of salvaged materials. This example finds application within Volvo GTT and other entities governed by the Extended Producer Responsibility or End-of-Life Vehicle (ELV) directive.

**4. Is the EOL-value being implemented in the profitability model in the correct way?**

The group engaged in a detailed conversation regarding the integration of the parameter into the profitability model. Consensus was reached that the current approach to when this parameter has impact was appropriate: a vehicle's financial "return" occurring after its technical lifespan is complete. The group also determined that this financial representation should be derived from a combination of the percentage of vehicles returned, their value, and the production volume from the relevant year.

However, discussions arose regarding which product cost should be considered. Should the End-of-Life value be conceptualized as a reduction in the product cost of the vehicle being manufactured at the time when the EOL value is applicable? Alternatively, should it be formulated as a percentage of its original product cost? The original formulation proposed was the latter and was agreed on as a good solution.

**5. Does the EOL-value have an impact that enables circular product design?**

The group posited that a more circular product would inherently possess a higher EOL-value, thus suggesting that the parameter facilitates the design of more circular products, also evidenced by the questionnaire results. Discussion leading to this conclusion showed how the EOL value of a product would be influenced by its degree of circularity, thereby influencing the model. The group reasoned that a circular product, designed with dismantling and end-of-life as considerations, would naturally command a higher EOL-value. This dual consideration was found to correlate with higher EOL-value for products exhibiting greater circularity, as highlighted in the workshop.

However, discussions also acknowledged nuances, particularly regarding the chosen business model's significant impact. In a linear model, retrieving vehicles at their technical EOL proves challenging, thereby complicating the access to the value. Conversely, in the Product-as-a-Service model, ownership is retained throughout the product's lifecycle, enabling strategic dismantling when it aligns with the organization's objectives to optimize value retention.

The workshop attendees reached a consensus that the End-of-Life value should increase for products exhibiting greater circularity and that are designed for disassembly. This implies that products engineered for circular processes, such as disassembly and module replacement, will inherently command higher material values upon reaching EOL and undergoing dismantling.

### 5.1.2 Material Supply Chain Risk

The validation study of the MSC risk parameter was also in large part based on discussions from the workshop and the results of the survey, as can be seen below in table 5.2. The results showed that the biggest difficulty in MSC risk was to produce an accurate estimate which was in line with expectations. The parameter received similar feedback as the EOL-value, namely that the effect of implementation would be towards a higher degree of circularity.

**Table 5.2:** Results from the questionnaire for MSC risk.

| **Likert Scale Evaluation of MSC-risk** | | | |
|---|---|---|---|
| **No:** | **Question:** | **Average result:** | **Median:** |
| 1 | How understandable is MSC risk? | 3,875 | 4 |
| 2 | How easy was it to estimate MSC risk? | 1,25 | 1 |
| 3 | How well is MSC risk being measured? | 3,125 | 3 |
| 4 | How accurate do you think the MSC risk is? | 2,5 | 2 |
| 5 | How well can MSC risk enable more circular products if used in the model? | 4,125 | 4 |

**1. Is the MSC risk understandable?**

The parameter was perceived as comprehensible. The group collectively acknowledged its complexity and the challenges associated with its measurement. Clarification was provided that the parameter aimed to encompass other significant events excluding conventional raw material costs, such as the semiconductor crisis or the obstruction of the Suez Canal, which solidified its clarity and purpose. Afterward, they expressed a clear understanding of the overarching effect intended by the parameter.

**2. How easy was it to estimate the MSC risk?**

Estimating the risk was deemed exceedingly challenging, given the intricate and unpredictable nature of the information determining the parameter's value. The group expressed that while the risk was present and would increase during subsequent decades, its estimation was complex.

**3. Is the MSC risk being measured in the right way?**

When asked about the appropriateness of the current methodology for measuring the parameter, the group held a generally neutral stance. The three primary inputs influencing the parameter's value were identified as heightened transport costs, expenses associated with changes in supplier and subsequent design alterations, and production downtime costs. The group reached a consensus that these categories of costs were indeed important factors affecting the value of the parameter.

Subsequently, these three inputs were delineated as susceptible to influence by various events, including geopolitical instability, force majeure occurrences, policy enactment, or other events. The group collectively acknowledged these events as plausible factors that would change the parameter's value.

**4. Is the MSC risk being implemented in the profitability model in the correct way?**

This discussion proved challenging. The group leaned towards the notion of a percentage-based increase in product cost as a viable representation. However, the concept of risk was articulated as elevating the product price incrementally each year, suggesting a series of minor events annually, which was deemed less plausible. The consensus emerged that a more realistic scenario involves fewer but more impactful events, resulting in accelerated cost escalation. Nevertheless, the group concluded that this approach was suitable, potentially offering greater accuracy over time. Additionally, the group noted the possibility of risk reduction in certain years due to positive global events.

The group adopted a similar line of reasoning as with the EOL-value when discussing the MSC risk. The MSC risk was perceived to diminish primarily as vehicles reached their end-of-life, particularly within a more circular business model. In a linear business model, the MSC risk was observed to decrease as vehicles attained greater circularity, largely due to the increased availability of high-quality parts and known material grades in the European market, where many Product Responsibility Organizations (PRO's) would be located. In circular business models, the MSC risk was anticipated to be significantly lower from the outset, as materials could be recalled and utilized in production if more lucrative activities became feasible.

**5. Does the MSC risk have an impact that enables circular product design?**

The group concluded that the parameter would enable more circular design, particularly in a circular business model wherein material ownership is retained. This sentiment was further underscored by the group's consensus, reflected in the highest score recorded from the questionnaire. Furthermore, the group concurred that a more thorough assessment of supply chain risks would incentivize the adoption of circular product design practices.

### 5.1.3 Other comments and feedback

The participants were also provided with an open text box at the conclusion of the questionnaire, allowing for the submission of comments or additional insights. This approach allowed participants to give written feedback to clarify feedback. The comments provided were in line with the discussion during the workshop and the results presented above, highlighting the multifaceted, complex nature of the problem at hand. Furthermore, concerns were raised regarding the difficulty in accurately assessing parameters' value, attributed in part to the absence of reference points. One participant underscored the importance of emphasizing these risks as their future impact could be substantial, even though the accuracy of the parameter was not necessarily high.

## 5.2 Results from Cases

The following section presents the results derived from the cases. Each case is accompanied by fictitious numerical representations of revenues and costs, chosen independent of Volvo GTT's financial data. These figures serve as indicative portrayals of potential product scenarios, facilitated by the developed model. These figures are not to be construed as actual business cases, but serve to discuss mechanisms.

A total of 3 fictional products were tested with the profitability model, with each product undergoing evaluation through both linear and circular business model frameworks. This methodological approach yielded 6 distinct business cases, as presented in Figure 5.1. The linear model adheres to a conventional direct sales paradigm, wherein products are directly sold to customers. Conversely, the circular model embodies a Product-as-a-Service (PaaS) sales strategy, maintaining product ownership within Volvo GTT while offering the product as a service to customers.

| | Linear Business Model (LBM) | Circular Business Model (CBM) |
|---|---|---|
| Linear Product (LP) | Business Case 1: LBM LP | Business Case 2: CBM LP |
| Circular Product 1 (CP1) | Business Case 3: LBM CP1 | Business Case 4: CBM CP1 |
| Circular Product 2 (CP2) | Business Case 5: LBM CP2 | Business Case 6: CBM CP2 |

**Figure 5.1:** Illustration of the three products used in cases. The figure presents the differences between the cases and products related to the business models.

While all cases revolved around the same product, a truck, they diverged in the extent of circular design integration. The initial first 2 cases portrayed the truck in its present state, devoid of any adaptations for life-cycle revenues or extended longevity. The technical lifetime for this truck was set to 10 years. The subsequent 2 cases feature a more circular truck, referred to as Circular Product 1 (CP1), with 15 years of lifetime and with some modifications for circular operations. The final cases showcase a very circular truck referred to as Circular Product 2 (CP2), boasting a doubled lifespan compared to the baseline model. These distinctions are further elucidated in Figure 5.2. The selection of a truck as the focal point stems from its significance as a flagship product within Volvo Trucks, facilitating comprehensible visualization for project members without unnecessary complexity.

| Linear product | Circular product 1 | Circular product 2 |
|---|---|---|
| • Traditional product, created for a linear business model.<br>• No adaptations for circular development | • Some adaptations for circular development and lifecycle revenues | • Full adaptations for circular development and lifecycle revenues |
| Lifetime of 10 years | Lifetime of 15 years | Lifetime of 20 years |
| Product cost 2024: 700'000 SEK. | Product cost 2024: 850'000 SEK. | Product cost 2024: 1'050'000 SEK. |
| EoL value:<br>Linear business model: 10%<br>Circular business model: 11% | EoL value:<br>Linear business model: 15%<br>Circular business model: 16% | EoL value:<br>Linear business model: 20%<br>Circular business model: 22% |
| Vehicles back:<br>Linear business model: 0%<br>Circular business model: 90% | Vehicles back:<br>Linear business model: 0%<br>Circular business model: 90% | Vehicles back:<br>Linear business model: 0%<br>Circular business model: 90% |
| Material Supply Chain risks:<br>Linear business model: 3%<br>Circular business model: 3-1.5% | Material Supply Chain risks:<br>Linear business model: 3-2.5%<br>Circular business model: 3-1% | Material Supply Chain risks:<br>Linear business model: 3-2 %<br>Circular business model: 3-0.5% |

**Figure 5.2:** Illustration of the three products used in cases. The figure presents the differences between the products and how parameters change depending on which business model the case is used in.

### 5.2.1 Linear Product

The initial fictitious case chosen for testing represents an 'as-is' truck, mirroring the current product line developed by Volvo GTT. As depicted in the first column of Figure 5.2, this truck undergoes no new adaptations for circular operations and boasts a technical lifespan of 10 years. Preliminary cost estimates for the product in 2024 indicate a fictional product cost of 700,000 SEK, excluding additional expenses and profit margins. The projected sales price for 2024 stands at approximately 845,000 SEK.

**Business Case 1: Linear Product in a Linear Business Model**
In this first case, of a linear product in a linear business model, the following inputs were made in the profitability model. In this case, the MSC risk is set to the same yearly rate of growth of 3%. Since both the product and the business model are linear, the MSC risk is anticipated to increase steadily over time. This is represented by the yearly increase of 3%. In this case, where there is a linear business model with and a linear product, no products are expected to be returned at their end-of-life. However, the EOL-value is estimated to be 10% of the product cost, as there is still value to products at their end-of-life today.

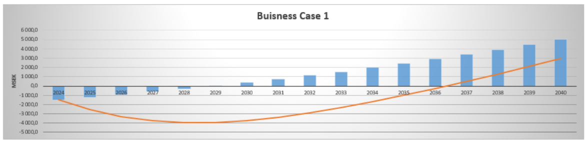
Material Supply Chain costs are anticipated to escalate over time due to risks within material supply chains. This escalation in costs is expected to affect the product cost, which in tandem with rising material costs, will increase the product cost by a factor of 2.6 by the year 2040. This in turn would result in a sales price of more than 2,2 MSEK, compared to the sales price of 2024, 0,85 MSEK. This sales price would in reality probably have a very negative effect on the sold volumes of trucks as the market is very competitive.

Additionally troubling, the EOL-value does not amount to a significant number, both as a consequence of the business model making it difficult to get access to vehicles, but also because the vehicles are not built to be dismantled to the same degree. The EOL-value was estimated to be quite low as the vehicle in this case is not designed for circular operations, and has low abilities for material separation and disassembly at EOL.

Despite these challenges, the linear model is exposed to very low capital commitment risk. However, it lacks secure future incomes as the model's projection of sold volume is unrealistic given the sales price and that purchases are made on a continuous basis. The case showed a long payback time of 12 years which probably meant that the product margin was not representative.

**Profitability tool for Circular Economy**
**Fictive case**
**Business Case over a trucks life-time**
**Lifetime of component/product [years]: 10 years**

| Product cost | |
|---|---|
| Cost of Sold Truck | 700 000 SEK |
| Circular Developement Cost | 0 SEK |
| **Total product cost 2024** | **700 000 SEK** |




| | | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 | 2032 | 2033 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Raw material cost evolution** | | 2% | 2% | 2% | 2% | 2% | 2% | 2% | 2% | 2% | 2% |
| **Material Supply Chain Risk:** | | 3% | 3% | 3% | 3% | 3% | 3% | 3% | 3% | 3% | 3% |
| **Proportion of vehicles that are returned** | | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| **End of life value of a vehicle after 10 years** | | 10% | 10% | 10% | 10% | 10% | 10% | 10% | 10% | 10% | 10% |
| **Year** | | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 | 2032 | 2033 |
| **Volume** | | 50 000 | 50 000 | 50 000 | 50 000 | 50 000 | 50 000 | 50 000 | 50 000 | 50 000 | 50 000 |
| **Cost of sales** | | MSEK | | | | | | | | | |
| Cost to implement (R&D Project Cost): | | 7 000 | 7 000 | 7 000 | 7 000 | 7 000 | 7 000 | 7 000 | 7 000 | 7 000 | 7 000 |
| Product Cost per truck / year | | 0,70 | 0,74 | 0,77 | 0,81 | 0,85 | 0,89 | 0,94 | 0,98 | 1,03 | 1,09 |
| Raw material cost evolution: | | 0,01 | 0,01 | 0,02 | 0,02 | 0,02 | 0,02 | 0,02 | 0,02 | 0,02 | 0,02 |
| Material Supply Chain Risk: | | 0,02 | 0,02 | 0,02 | 0,02 | 0,03 | 0,03 | 0,03 | 0,03 | 0,03 | 0,03 |
| Depreciation | | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |
| **Total cost of sale / year** | | 43 750 | 45 588 | 47 517 | 49 543 | 51 670 | 53 903 | 56 249 | 58 711 | 61 296 | 64 011 |
| **Incomes** | **Grossprofit** | 15% | 15% | 15% | 15% | 15% | 15% | 15% | 15% | 15% | 15% |
| | **ELV income** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | **Netsales** | 42 263 | 44 376 | 46 594 | 48 924 | 51 370 | 53 939 | 56 636 | 59 468 | 62 441 | 65 563 |
| | **Product Price to Customer** | 0,84525 | 0,88751 | 0,931888 | 0,978483 | 1,02741 | 1,078777 | 1,13271584 | 1,1893516 | 1,2488192 | 1,3112602 |
| **Total Cashflow (Outflow -, Inflow +)** | | -1 487,5 | -1 211,9 | -922,5 | -618,6 | -299,5 | 35,5 | 387,3 | 756,6 | 1 144,5 | 1 551,7 |
| **Discounted ISO** | 12% | -1 487,5 | -1 082,0 | -735,4 | -440,3 | -190,4 | 20,1 | 196,2 | 342,3 | 462,2 | 559,6 |
| **Acc DSCF** | | -1 487,5 | -2 569,5 | -3 304,9 | -3 745,2 | -3 935,6 | -3 915,4 | -3 719,2 | -3 377,0 | -2 914,7 | -2 355,2 |

| | | 2034 | 2035 | 2036 | 2037 | 2038 | 2039 | 2040 | 2041 | 2042 | 2043 | 2044 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Raw material cost evolution** | | 2% | 2% | 2% | 2% | 2% | 2% | 2% | 2% | 2% | 2% | 2% |
| **Material Supply Chain Risk:** | | 3% | 3% | 3% | 3% | 3% | 3% | 3% | 3% | 3% | 3% | 3% |
| **Proportion of vehicles that are returned** | | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| **End of life value of a vehicle after 10 years** | | 10% | 10% | 10% | 10% | 10% | 10% | 10% | 10% | 10% | 10% | 10% |
| **Year** | | 2034 | 2035 | 2036 | 2037 | 2038 | 2039 | 2040 | 2041 | 2042 | 2043 | 2044 |
| **Volume** | | 50 000 | 50 000 | 50 000 | 50 000 | 50 000 | 50 000 | 50 000 | 50 000 | 50 000 | 50 000 | 50 000 |
| **Cost of sales** | | | | | | | | | | | | |
| Cost to implement (R&D Project Cost): | | 7 000 | 7 000 | 7 000 | 7 000 | 7 000 | 7 000 | 7 000 | 7 000 | 7 000 | 7 000 | 7 000 |
| Product Cost per truck / year | | 1,14 | 1,20 | 1,26 | 1,32 | 1,39 | 1,46 | 1,53 | 1,60 | 1,68 | 1,77 | 1,86 |
| Raw material cost evolution: | | 0,02 | 0,02 | 0,03 | 0,03 | 0,03 | 0,03 | 0,03 | 0,03 | 0,03 | 0,04 | 0,04 |
| Material Supply Chain Risk: | | 0,03 | 0,04 | 0,04 | 0,04 | 0,04 | 0,04 | 0,05 | 0,05 | 0,05 | 0,05 | 0,06 |
| Depreciation | | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |
| **Total cost of sale / year** | | 66 862 | 69 855 | 72 998 | 76 298 | 79 762 | 83 401 | 87 221 | 91 232 | 95 443 | 99 865 | 104 509 |
| **Incomes** | **Grossprofit** | 15% | 15% | 15% | 15% | 15% | 15% | 15% | 15% | 15% | 15% | 15% |
| | **ELV income** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | **Netsales** | 68 841 | 72 283 | 75 897 | 79 692 | 83 677 | 87 861 | 92 254 | 96 866 | 101 710 | 106 795 | 112 135 |
| | **Product Price to Customer** | 1,3768232 | 1,4456643 | 1,51794756 | 1,59384494 | 1,67353718 | 1,75721404 | 1,84507475 | 1,9373285 | 2,0341949 | 2,1359 | 2,2427 |
| **Total Cashflow (Outflow -, Inflow +)** | | 1 979,3 | 2 428,2 | 2 899,7 | 3 394,6 | 3 914,4 | 4 460,1 | 5 033,1 | 5 634,8 | 6 266,5 | 6 929,8 | 7 626,3 |
| **Discounted ISO** | 12% | 637,3 | 698,1 | 744,3 | 778,0 | 801,0 | 814,8 | 821,0 | 820,7 | 814,9 | 804,6 | 790,6 |
| **Acc DSCF** | | -1 717,9 | -1 019,8 | -275,6 | 502,4 | 1 303,4 | 2 118,2 | 2 939,2 | 3 759,9 | 4 574,8 | 5 379,4 | 6 170,0 |

| | |
|---|---|
| IRR | 21% |
| NPV | 6 170,0 MSEK |

**Figure 5.3:** Business Case 1: Linear Product in a Linear Business Model.

Given a volume of 50'000 sold trucks each year, and a profit margin of 15%, the NPV of this business case is 6'170,0 MSEK and the IRR is 21%. To be noted is that the model calculated the profit on the product price. For this case, as mentioned earlier, this number does increase to about 2.2 MSEK, which is deemed unrealistic. This means that even if the business case appears well while viewing NPV and IRR numbers, the question remains if products can be sold at this price.

**Business Case 2: Linear Product in a Circular Business Model**

In the second case, of a linear product in a circular business model,the following inputs were made in the profitability model. In this case, the MSC risk is set to the same yearly rate of 3%, until the product reaches its end-of-life after 10 years. Then the risk is set to decrease to 1.5% as the circular model implies that vehicles are returned at their end-of-life. The number of vehicles returned after 10 years is estimated to be 90% of the number of produced vehicles. The EOL-value for this linear product in the circular model is estimated to be 11% of the product cost, similar to the first case. There is an extra percent of value included in the circular business model as the condition of the vehicle is expected to be higher than in a linear model. Even though the product is used for the same amount of time, in this example Volvo GTT remains in control of the product and is motivated to change parts during the course of the lifetime and are thereby able to maintain a higher product value.

Material Supply Chain (MSC) costs are also anticipated to escalate over time in this case due to the same risks within material supply chains. The escalation of product cost is deemed to be similar to Case 1, and modified after the trucks start to return at their EOL. The product price at 2040 is expected to increase by a factor of 2, since the MSC-risk drops from 3% to 1.5% after 2034. the cost of the produced truck does negatively impact the revenue of the model.

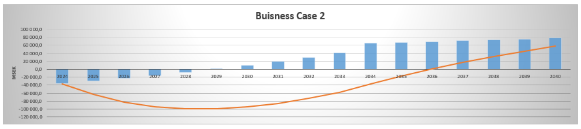
This model capitalizes on internal material circulation within the producing company, thereby decreasing MSC risks. The continuous material flow within the company reduces the influx of new materials into the loop and the exit of materials from the loop, thereby enhancing material and resource utilization. Although the products are not fully designed for dismantling, access to so much raw material is still deemed to decrease the risk.

The profit generated by each vehicle in the circular business model is set to increase along with the product cost. The truck is meant to have a payback time on its product cost of 4 years, meaning that the truck generates 25% of its product cost in profit. The assumed size of the profit per truck and the fact that the model assumes that all of the vehicles that are able to be out on the market are out on the market could be an unreasonable assumption. A more realistic strategy could show that Volvo Trucks saturates the market within the first 4 or 5 years of production, and then places emphasis on sustaining the market with any loss of vehicles or if the demand should increase.

The circular model accentuates the advantages of circularity and enables the EOL-value for the trucks. Additionally, numerous cost-saving opportunities arise in this model with the implementation of legislation such as CBAM, ELV directive, and CRMA. Fines or costs in redesigning supply chains, resource handling, or product design associated with these legislative directives are more likely to occur in the linear model. However, this model also has a protracted payback time, which impacts the balance sheet and the profitability in the short term. Many benefits of a PaaS business model are probably not fully realized, as the fit between product and business model in this case ensure that resource utilization, repair efficiency, and repair costs, are not optimized.

In reality, the revenue generated by a truck in a PaaS is more complicated to model. The cost a customer is willing to accept for a truck will depend heavily on the condition of the vehicle, its newness, relevance, functional value, status, and other important factors. This means that as the truck is new, the profit is the highest since the revenue is the highest, and costs incurred from repair are at their lowest. As the vehicle ages and worsens in condition, the revenue decreases while costs rise. At a certain point, the material value of the truck might be more valuable to the organization than the revenue it can generate through customers.

**Profitability tool for Circular Economy**
**Fictive case**
**Business Case over a trucks life-time**
**Lifetime of product [years]:** 10




| **Product cost** | |
|---|---|
| Cost of Sold Truck | 700 000 SEK |
| Circular Developement Cost | 0 SEK |
| **Total product cost 2024** | **700 000 SEK** |

| | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 | 2032 | 2033 | 2034 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Raw material cost evolution** | 2% | 2% | 2% | 2% | 2% | 2% | 2% | 2% | 2% | 2% | 2% |
| **Material Supply Chain Risk:** | 3% | 3% | 3% | 3% | 3% | 3% | 3% | 3% | 3% | 3% | 1,5% |
| **Proportion of vehicles that are returned** | 90% | 90% | 90% | 90% | 90% | 90% | 90% | 90% | 90% | 90% | 90% |
| **End of life value of a vehicle after 10 years** | 11% | 11% | 11% | 11% | 11% | 11% | 11% | 11% | 11% | 11% | 11% |
| **Year** | **2024** | **2025** | **2026** | **2027** | **2028** | **2029** | **2030** | **2031** | **2032** | **2033** | **2034** |
| **Volume** | 50000 | 50000 | 50000 | 50000 | 50000 | 50000 | 50000 | 50000 | 50000 | 50000 | 50000 |
| Cost of sales | **MSEK** | | | | | | | | | | |
| Cost to implement (R&D Project Cost): | 7 000 | 7 000 | 7 000 | 7 000 | 7 000 | 7 000 | 7 000 | 7 000 | 7 000 | 7 000 | 7 000 |
| Product Cost per truck / year | 0,70 | 0,74 | 0,77 | 0,81 | 0,85 | 0,89 | 0,94 | 0,98 | 1,03 | 1,09 | 1,14 |
| Raw material cost evolution: | 0,01 | 0,01 | 0,02 | 0,02 | 0,02 | 0,02 | 0,02 | 0,02 | 0,02 | 0,02 | 0,02 |
| Material Supply Chain Risk: | 0,02 | 0,02 | 0,02 | 0,02 | 0,03 | 0,03 | 0,03 | 0,03 | 0,03 | 0,03 | 0,02 |
| Depreciation | 3500,0 | 7350,0 | 11576,3 | 16206,8 | 21271,4 | 26801,9 | 32832,3 | 39398,8 | 46539,8 | 54296,5 | 57011,3 |
| **Total cost of sale / year** | **47 250** | **52 938** | **59 093** | **65 749** | **72 941** | **80 705** | **89 081** | **98 110** | **107 836** | **118 308** | **123 018** |
| **INCOME Gain** — **Income per truck out in service** | **0,22** | **0,23** | **0,24** | **0,25** | **0,26** | **0,27** | **0,28** | **0,29** | **0,31** | **0,32** | **0,33** |
| **ELV income** | 0 | 0 | 0 | 0 | 0 | 0 | 0,00 | 0,00 | 0,00 | 0,00 | **3465,00** |
| **Netsales** | 10 938 | 22 794 | 35 638 | 49 543 | 64 587 | 80 855 | 98 435 | 117 422 | 137 917 | 160 028 | 184 983 |
| **Total Cashflow (Outflow -, Inflow +)** | -36 312,5 | -30 143,8 | -23 455,5 | -16 206,8 | -8 353,9 | 149,8 | 9 354,0 | 19 312,1 | 30 080,8 | 41 720,5 | 65 430,4 |
| **Discounted ISO** 12% | -36 312,5 | -26 914,1 | -18 698,6 | -11 535,6 | -5 309,1 | 85,0 | 4 739,0 | 8 735,8 | 12 149,1 | 15 044,8 | 21 066,8 |
| **Acc DSCF** | -36 312,5 | -63 226,6 | -81 925,1 | -93 460,8 | -98 769,8 | -98 684,8 | -93 945,8 | -85 210,0 | -73 060,8 | -58 016,0 | -36 949,2 |

| | 2035 | 2036 | 2037 | 2038 | 2039 | 2040 | 2041 | 2042 | 2043 | 2044 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Raw material cost evolution** | 2% | 2% | 2% | 2% | 2% | 2% | 2% | 2% | 2% | 2% | |
| **Material Supply Chain Risk:** | 1,5% | 1,5% | 1,5% | 1,5% | 1,5% | 1,5% | 1,5% | 1,5% | 1,5% | 1,5% | |
| **Proportion of vehicles that are returned** | 90% | 90% | 90% | 90% | 90% | 90% | 90% | 90% | 90% | 90% | |
| **End of life value of a vehicle after 10 years** | 11% | 11% | 11% | 11% | 11% | 11% | 11% | 11% | 11% | 11% | |
| **Year** | **2035** | **2036** | **2037** | **2038** | **2039** | **2040** | **2041** | **2042** | **2043** | **2044** | |
| **Volume** | 50000 | 50000 | 50000 | 50000 | 50000 | 50000 | 50000 | 50000 | 50000 | 50000 | |
| Cost of sales | | | | | | | **MSEK** | | | | |
| Cost to implement (R&D Project Cost): | 7 000 | 7 000 | 7 000 | 7 000 | 7 000 | 7 000 | 7 000 | 7 000 | 7 000 | 7 000 | |
| Product Cost per truck / year | 1,18 | 1,22 | 1,26 | 1,31 | 1,35 | 1,40 | 1,45 | 1,50 | 1,55 | 1,61 | |
| Raw material cost evolution: | 0,02 | 0,02 | 0,03 | 0,03 | 0,03 | 0,03 | 0,03 | 0,03 | 0,03 | 0,03 | |
| Material Supply Chain Risk: | 0,02 | 0,02 | 0,02 | 0,02 | 0,02 | 0,02 | 0,02 | 0,02 | 0,02 | 0,02 | |
| Depreciation | 59006,7 | 61071,9 | 63209,5 | 65421,8 | 67711,6 | 70081,5 | 72534,3 | 75073,0 | 77700,6 | 80420,1 | |
| **Total cost of sale / year** | **127 079** | **131 281** | **135 631** | **140 133** | **144 793** | **149 616** | **154 607** | **159 774** | **165 121** | **170 655** | |
| **INCOME Gain** — **Income per truck out in service** | **0,34** | **0,35** | **0,36** | **0,37** | **0,39** | **0,40** | **0,41** | **0,42** | **0,44** | **0,45** | |
| **ELV income** | **3638,25** | **3820,16** | **4011,17** | **4211,73** | **4422,32** | **4643,43** | **4875,60** | **5119,38** | **5375,35** | **5644,12** | 37 512,1 |
| **Netsales** | 190 836 | 196 896 | 203 171 | 209 669 | 216 396 | 223 363 | 25 394 | 407 447 | 442 476 | 516 889 | |
| **Total Cashflow (Outflow -, Inflow +)** | 67 395,7 | 69 434,9 | 71 551,0 | 73 746,9 | 76 025,6 | 78 390,4 | ####### | 252 792,9 | 282 730,5 | 351 878,1 | |
| **Discounted ISO** 12% | 19 374,7 | 17 822,2 | 16 397,6 | 15 090,1 | 13 889,6 | 12 787,2 | -18 109,1 | 32 873,1 | 32 826,9 | 36 478,1 | |
| **Acc DSCF** | -17 574,5 | 247,7 | 16 645,3 | 31 735,4 | 45 625,0 | 58 412,2 | 40 303,1 | 73 176,2 | 106 003,1 | 142 481,2 | |

| | |
|---|---|
| IRR | 20% |
| NPV | 142 481,2 MSEK |

**Figure 5.4:** Business Case 2: Linear Product in a Circular Business Model.

With a volume of 50'000 trucks placed on the market every year, and a payback time on product cost of 4 years per truck, the NPV of the investment is 142'481,2 MSEK and the IRR is approximately 20%.

### 5.2.2 Circular Product 1

The second product introduced for examination represents a move towards circularity, although not achieving full circularity. In this fictitious product, termed Circular Product 1, the emphasis shifted from specific product specifications to the overall impact of these specifications. Circular Product 1 boasts a technical lifespan of 15 years, reflecting a 50% increase compared to the 'as-is' truck, as outlined in the second column of Figure 5.2. Characterized by a higher degree of circular design, this product facilitates an increased disassembly rate of 60%, enabling the retrieval of higher-quality materials at the end of life. This focus on disassembly suggests the potential for greater value extraction from end-of-life materials, a key consideration in circular business models.

The estimated product cost in 2024 is estimated around 850,000 SEK, with an increase of 150,000 SEK representing circular development cost and additional testing expenses. Similar to the preceding product, this cost excludes additional expenses and profit margin.

**Business Case 3: Circular Product 1 in a Linear Business Model**
The third case consisted of a more circular product in a linear business model, the following inputs were made in the profitability model. In this case, the MSC risk is also set to a yearly rate of 3%, until the product reaches its end-of-life after 15 years. Then the risk is set to decrease to 2.5%. The reduction in risk was made since after 15 years future regulations have come into effect, such as the ELV directive. The directive increases the responsibility at end-of-life, which in turn should lead to more recycled and looped material being available to the automotive industry. However, the risk is still considerable as other companies most likely also are interested in the same recycled and looped material.

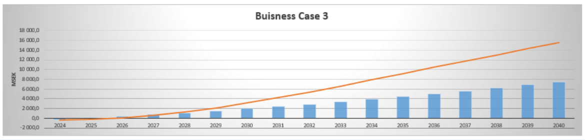
In this case, where there is a linear business model with a circular product, no products are expected to be returned at the end-of-life state. The upcoming EPR directive only implies that Volvo GTT must ensure that vehicles can be taken care of at end-of-life, which might be done through PROs. Therefore, the cost of dismantling can differ if this activity is outsourced to a PRO or if this activity is done by Volvo GTT. In this case, the EOL-value is estimated to be 15% of the product cost, as there is a higher value of the material than for the linear products as the product is designed more for disassembly. However, since the business model is linear, no products are returned to Volvo.

Similar to the first case, this case also faces challenges. As already stated, the linear model is exposed to very low capital commitment risk. But in this case, the financial investment in each product is higher, which might not be regained by Volvo GTT using a linear business model.

On the same note, the model lacks secure future incomes as the model's projection of sold volume might also be unrealistic given the sales price increase to 2.2 MSEK in 2040. The case has a payback time of 2 years, implying that the product margin was not representative. It is deemed unrealistic to have the same sales volume with high yearly increases in price, which should be taken into consideration.

**Profitability tool for Circular Economy**
Fictive case
Business Case over a trucks life-time
Lifetime of component/product [years]: 15 years

| Product cost | |
|---|---|
| Cost of Sold Truck | 700 000 SEK |
| Circular Developement Cost | 150 000 SEK |
| **Total product cost 2024** | **850 000 SEK** |




| | | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 | 2032 | 2033 | 2034 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Raw material cost evolution** | | 2% | 2% | 2% | 2% | 2% | 2% | 2% | 2% | 2% | 2% | 2% |
| **Material Supply Chain Risk:** | | 3% | 3% | 3% | 3% | 3% | 3% | 3% | 3% | 3% | 3% | 3,0% |
| **Proportion of vehicles that are returned** | | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| **End of life value of a vehicle after 15 years** | | 15% | 15% | 15% | 15% | 15% | 15% | 15% | 15% | 15% | 15% | 15% |
| **Year** | | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 | 2032 | 2033 | 2034 |
| **Volume** | | 50 000 | 50 000 | 50 000 | 50 000 | 50 000 | 50 000 | 50 000 | 50 000 | 50 000 | 50 000 | 50 000 |
| **Cost of sales** | | MSEK | | | | | | | | | | |
| Cost to implement (R&D Project Cost): | | 7 000 | 7 000 | 7 000 | 7 000 | 7 000 | 7 000 | 7 000 | 7 000 | 7 000 | 7 000 | 7 000 |
| Product Cost per truck / year | | 0,85 | 0,89 | 0,94 | 0,98 | 1,03 | 1,08 | 1,14 | 1,20 | 1,26 | 1,32 | 1,38 |
| Raw material cost evolution: | | 0,02 | 0,02 | 0,02 | 0,02 | 0,02 | 0,02 | 0,02 | 0,02 | 0,03 | 0,03 | 0,03 |
| Material Supply Chain Risk: | | 0,03 | 0,03 | 0,03 | 0,03 | 0,03 | 0,03 | 0,03 | 0,04 | 0,04 | 0,04 | 0,04 |
| Depreciation | | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |
| **Total cost of sale / year** | | **51 625** | **53 856** | **56 199** | **58 659** | **61 242** | **63 954** | **66 802** | **69 792** | **72 931** | **76 228** | **79 689** |
| **Incomes** | **Grossprofit** | 15% | 15% | 15% | 15% | 15% | 15% | 15% | 15% | 15% | 15% | 15% |
| | **ELV income** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | **Netsales** | 51 319 | 53 885 | 56 579 | 59 408 | 62 378 | 65 497 | 68 772 | 72 211 | 75 821 | 79 612 | 83 593 |
| | **Product Price to Customer** | 1,026375 | 1,0777 | 1,131578 | 1,188157 | 1,24757 | 1,3099435 | 1,37544066 | 1,4442127 | 1,5164233 | 1,5922445 | 1,6718567 |
| **Total Cashflow (Outflow -, Inflow +)** | | -306,3 | 28,4 | 379,9 | 748,9 | 1 136,3 | 1 543,1 | 1 970,3 | 2 418,8 | 2 889,7 | 3 384,2 | 3 903,4 |
| **Discounted ISO** | 12% | -306,3 | 25,4 | 302,8 | 533,0 | 722,1 | 875,6 | 998,2 | 1 094,1 | 1 167,1 | 1 220,4 | 1 256,8 |
| **Acc DSCF** | | -306,3 | -280,9 | 22,0 | 555,0 | 1 277,1 | 2 152,7 | 3 150,9 | 4 245,0 | 5 412,2 | 6 632,5 | 7 889,3 |

| | | 2035 | 2036 | 2037 | 2038 | 2039 | 2040 | 2041 | 2042 | 2043 | 2044 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Raw material cost evolution** | | 2% | 2% | 2% | 2% | 2% | 2% | 2% | 2% | 2% | 2% |
| **Material Supply Chain Risk:** | | 3,0% | 3,0% | 3,0% | 3,0% | 2,5% | 2,5% | 2,5% | 2,5% | 2,5% | 2,5% |
| **Proportion of vehicles that are returned** | | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| **End of life value of a vehicle after 15 years** | | 15% | 15% | 15% | 15% | 15% | 15% | 15% | 15% | 15% | 15% |
| **Year** | | 2035 | 2036 | 2037 | 2038 | 2039 | 2040 | 2041 | 2042 | 2043 | 2044 |
| **Volume** | | 50 000 | 50 000 | 50 000 | 50 000 | 50 000 | 50 000 | 50 000 | 50 000 | 50 000 | 50 000 |
| **Cost of sales** | | | | | | | | | | | |
| Cost to implement (R&D Project Cost): | | 7 000 | 7 000 | 7 000 | 7 000 | 7 000 | 7 000 | 7 000 | 7 000 | 7 000 | 7 000 |
| Product Cost per truck / year | | 1,45 | 1,53 | 1,60 | 1,68 | 1,77 | 1,85 | 1,93 | 2,02 | 2,11 | 2,20 |
| Raw material cost evolution: | | 0,03 | 0,03 | 0,03 | 0,03 | 0,04 | 0,04 | 0,04 | 0,04 | 0,04 | 0,04 |
| Material Supply Chain Risk: | | 0,04 | 0,05 | 0,05 | 0,05 | 0,04 | 0,05 | 0,05 | 0,05 | 0,05 | 0,06 |
| Depreciation | | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |
| **Total cost of sale / year** | | **83 324** | **87 140** | **91 147** | **95 354** | **99 330** | **103 485** | **107 827** | **112 364** | **117 106** | **122 060** |
| **Incomes** | **Grossprofit** | 15% | 15% | 15% | 15% | 15% | 15% | 15% | 15% | 15% | 15% |
| | **ELV income** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | **Netsales** | 87 772 | 92 161 | 96 769 | 101 608 | 106 180 | 110 958 | 115 951 | 121 169 | 126 622 | 132 320 |
| | **Product Price to Customer** | 1,7554496 | 1,84322204 | 1,93538314 | 2,0321523 | 2,12359915 | 2,21916111 | 2,319023 | 2,42338 | 2,532431 | 2,64639 |
| **Total Cashflow (Outflow -, Inflow +)** | | 4 448,6 | 5 021,0 | 5 622,1 | 6 253,2 | 6 849,6 | 7 472,8 | 8 124,1 | 8 804,6 | 9 515,9 | 10 259,1 |
| **Discounted ISO** | 12% | 1 278,9 | 1 288,8 | 1 288,4 | 1 279,5 | 1 251,4 | 1 219,0 | 1 183,2 | 1 145,0 | 1 104,9 | 1 063,5 |
| **Acc DSCF** | | 9 168,2 | 10 457,0 | 11 745,4 | 13 024,9 | 14 276,3 | 15 495,3 | 16 678,5 | 17 823,5 | 18 928,3 | 19 991,8 |

| | |
|---|---|
| IRR | 114% |
| NPV | 19 991,8 MSEK |

**Figure 5.5:** Business Case 3: Circular Product 1 in a Linear Business Model.

Given the same volume as the first product of 50'000 sold trucks each year and a profit margin of 15%, the NPV of the project is 19'991,8 MSEK and the IRR is 114%. This case is also calculated using the profit margin of 15% on product cost, which is unrepresentative of reality. This means that the business case appears very profitable when reviewing the NPV and IRR. However, it does seem unrealistic to assume that products can be sold at this increased price.

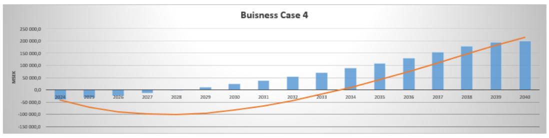
**Business Case 4: Circular Product 1 in a Circular Business Model**
In the fourth case, a circular product in a circular business model, the following inputs were made in the profitability model. In this case, the MSC risk is set to the same yearly rate of 3%, until the product reaches its end-of-life after 15 years. Then the risk is set to decrease to 1% as the circular model implies that vehicles are returned at their end-of-life. For the circular business model the same assumption was made as in case 2, that 90% of the vehicles are returned to Volvo GTT's possession. However, in this case, the EOL-value is estimated to be 16%, compared to 15% in BC3. Especially as the product becomes more circular the benefits of the circular business model should become apparent. As the truck becomes more circular the ease of implementing strategies from the R-framework increases, especially in the circular business model in which Volvo GTT can better control necessary maintenance. In this vehicle, it can also be expected that there are more sensors to accurately describe the condition of the vehicle's critical components.

With the same line of reasoning as previous cases, the MSC-risk is expected to increase until the trucks are returned to the organization. This in turn means that the product cost increases much more than in Case 2, as it takes longer for the material in the trucks to return. The product cost is in this case projected to increase by a factor of 2.6, which is the same as in Case 1 since the vehicles are out on the market.

As the vehicle, in this case, is built to be more easily repaired, at a lower cost, and at less frequent intervals, the payback time of each truck was kept the same, but since the product cost is higher, so is the absolute profit.

**Profitability tool for Circular Economy**
**Fictive case**
**Business Case over a trucks life-time**
**Lifetime of product [years]:** 15

| | |
|---|---|
| **Product cost** | |
| Cost of Sold Truck | 700 000 SEK |
| Circular Developement Cost | 150 000 SEK |
| **Total product cost 2024** | **850 000 SEK** |




| | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 | 2032 | 2033 | 2034 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Raw material cost evolution** | 2% | 2% | 2% | 2% | 2% | 2% | 2% | 2% | 2% | 2% | 2% |
| **Material Supply Chain Risk:** | 3% | 3% | 3% | 3% | 3% | 3% | 3% | 3% | 3% | 3% | 3% |
| **Proportion of vehicles that are returned** | 90% | 90% | 90% | 90% | 90% | 90% | 90% | 90% | 90% | 90% | 90% |
| **End of life value of a vehicle after 15 years** | 16% | 16% | 16% | 16% | 16% | 16% | 16% | 16% | 16% | 16% | 16% |
| **Year** | **2024** | **2025** | **2026** | **2027** | **2028** | **2029** | **2030** | **2031** | **2032** | **2033** | **2034** |
| **Volume** | 50000 | 50000 | 50000 | 50000 | 50000 | 50000 | 50000 | 50000 | 50000 | 50000 | 50000 |
| Cost of sales | MSEK | | | | | | | | | | |
| Cost to implement (R&D Project Cost): | 7 000 | 7 000 | 7 000 | 7 000 | 7 000 | 7 000 | 7 000 | 7 000 | 7 000 | 7 000 | 7 000 |
| Product Cost per truck / year | 0,85 | 0,89 | 0,94 | 0,98 | 1,03 | 1,08 | 1,14 | 1,20 | 1,26 | 1,32 | 1,38 |
| Raw material cost evolution: | 0,02 | 0,02 | 0,02 | 0,02 | 0,02 | 0,02 | 0,02 | 0,02 | 0,03 | 0,03 | 0,03 |
| Material Supply Chain Risk: | 0,03 | 0,03 | 0,03 | 0,03 | 0,03 | 0,03 | 0,03 | 0,04 | 0,04 | 0,04 | 0,04 |
| Depreciation | 2833,3 | 5950,0 | 9371,3 | 13119,8 | 17219,7 | 21696,8 | 26578,6 | 31894,3 | 37675,1 | 43954,3 | 50767,2 |
| **Total cost of sale / year** | **54 458** | **59 806** | **65 570** | **71 779** | **78 462** | **85 651** | **93 380** | **101 686** | **110 607** | **120 182** | **130 457** |
| **INCOME Gain** — **Income per truck out in service per year** | **0,26** | **0,27** | **0,28** | **0,29** | **0,31** | **0,32** | **0,33** | **0,35** | **0,36** | **0,38** | **0,40** |
| **ELV income** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Netsales** | 12 906 | 26 928 | 42 149 | 58 659 | 76 552 | 95 931 | 116 903 | 139 584 | 164 096 | 190 570 | 219 146 |
| **Total Cashflow (Outflow -, Inflow +)** | -41 552,1 | -32 878,1 | -23 421,0 | -13 119,8 | -1 909,2 | 10 280,2 | 23 522,8 | 37 897,6 | 53 489,2 | 70 387,7 | 88 689,3 |
| **Discounted ISO** 12% | -41 552,1 | -29 355,5 | -18 671,1 | -9 338,4 | -1 213,3 | 5 833,3 | 11 917,4 | 17 142,9 | 21 603,4 | 25 382,5 | 28 555,6 |
| **Acc DSCF** | -41 552,1 | -70 907,6 | -89 578,6 | -98 917,0 | -100 130,3 | -94 297,1 | -82 379,7 | -65 236,7 | -43 633,4 | -18 250,8 | 10 304,7 |

| | 2035 | 2036 | 2037 | 2038 | 2039 | 2040 | 2041 | 2042 | 2043 | 2044 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Raw material cost evolution** | 2% | 2% | 2% | 2% | 2% | 2% | 2% | 2% | 2% | 2% | |
| **Material Supply Chain Risk:** | 3% | 3% | 3% | 3% | 1% | 1% | 1% | 1% | 1% | 1% | |
| **Proportion of vehicles that are returned** | 90% | 90% | 90% | 90% | 90% | 90% | 90% | 90% | 90% | 90% | |
| **End of life value of a vehicle after 15 years** | 16% | 16% | 16% | 16% | 16% | 16% | 16% | 16% | 16% | 16% | |
| **Year** | **2035** | **2036** | **2037** | **2038** | **2039** | **2040** | **2041** | **2042** | **2043** | **2044** | |
| **Volume** | 50000 | 50000 | 50000 | 50000 | 50000 | 50000 | 50000 | 50000 | 50000 | 50000 | |
| Cost of sales | | | | | | | MSEK | | | | |
| Cost to implement (R&D Project Cost): | 7 000 | 7 000 | 7 000 | 7 000 | 7 000 | 7 000 | 7 000 | 7 000 | 7 000 | 7 000 | |
| Product Cost per truck / year | 1,45 | 1,53 | 1,60 | 1,68 | 1,77 | 1,82 | 1,87 | 1,93 | 1,99 | 2,05 | |
| Raw material cost evolution: | 0,03 | 0,03 | 0,03 | 0,03 | 0,04 | 0,04 | 0,04 | 0,04 | 0,04 | 0,04 | |
| Material Supply Chain Risk: | 0,04 | 0,05 | 0,05 | 0,05 | 0,02 | 0,02 | 0,02 | 0,02 | 0,02 | 0,02 | |
| Depreciation | 58151,5 | 66147,4 | 74797,4 | 84147,1 | 88354,4 | 91005,1 | 93735,2 | 96547,3 | 99443,7 | 102427,0 | |
| **Total cost of sale / year** | **141 475** | **153 287** | **165 945** | **179 502** | **186 360** | **191 740** | **197 283** | **202 991** | **208 871** | **214 927** | |
| **INCOME Gain** — **Income per truck out in service per year** | **0,42** | **0,44** | **0,46** | **0,48** | **0,49** | **0,50** | **0,52** | **0,53** | **0,55** | **0,56** | |
| **ELV income** | 0 | 0 | 0 | 0 | **6120,00** | **6426,00** | **6747,30** | **7084,67** | **7438,90** | **7810,84** | **71 758,3** |
| **Netsales** | 249 972 | 283 205 | 319 015 | 357 579 | 373 639 | 384 183 | 395 050 | 406 249 | 417 790 | 501 444 | |
| **Total Cashflow (Outflow -, Inflow +)** | 108 496,2 | 129 917,8 | 153 070,3 | 178 077,6 | 193 399,5 | 198 868,8 | 204 514,4 | 210 342,2 | 216 358,4 | 294 327,5 | |
| **Discounted ISO** 12% | 31 190,1 | 33 346,7 | 35 079,8 | 36 438,2 | 35 333,4 | 32 439,8 | 29 786,4 | 27 352,8 | 25 120,7 | 30 512,0 | |
| **Acc DSCF** | 41 494,8 | 74 841,5 | 109 921,3 | 146 359,5 | 181 692,8 | 214 132,6 | 243 919,0 | 271 271,8 | 296 392,5 | 326 904,5 | |

| | |
|---|---|
| IRR | 27% |
| NPV | 326 904,5 MSEK |

**Figure 5.6:** Business Case 4: Circular Product 1 in a Circular Business Model.

With a volume of 50'000 trucks placed on the market every year, the NPV of the investment is 326'094,5 MSEK and the IRR is approximately 27%. The NPV is higher than that of BC3, even though the IRR is lower, due to the increased investment size of a CBM.

### 5.2.3 Circular Product 2

The final product in consideration embodies a fully circular design. While the specific design details are yet to be determined, for this fictitious case, a 100% circular product signifies its orientation towards circular operations and extensive disassembly capabilities. The product is designed for a disassembly rate of approximately 95%. With a lifespan of 20 years, double that of the initial linear product, this fully circular product reflects a commitment to longevity and durability, as depicted in the third column of Figure 5.2. This increased lifespan necessitates higher product costs and enhanced durability.

Given its circular nature, the product is anticipated to yield high-quality materials upon end-of-life disassembly. The estimated product cost for this truck in 2024 is 1,050,000 SEK, indicating a 350,000 SEK increase in circular development costs compared to the first product. Similar to its predecessors, this cost excludes additional expenses and profit margin.

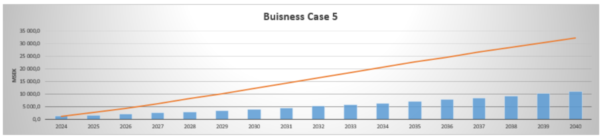
### Business Case 5: Circular Product 2 in a Linear Business Model

The fifth case consisted of a very circular product in a linear business model. The MSC risk is again set to a yearly rate of 3% until the product reaches its end-of-life after 20 years. Then the risk is set to decrease to 2%. The reduction follows the same reasoning as for the third case, given that future regulations will have come into effect. This product is still sold to customers, and in the linear model, no products are expected to return to Volvo GTT at end-of-life. But as stated previously, some material is expected to be returned to the market which may decrease the MSC-risk.

This product is made to be a 100% circular product, and have an efficient disassembly process. This implies that the quality of the material that can be harvested at the end-of-life is even higher than for Circular Product 1. Therefore, the EOL-value is estimated to be 20% of the product cost in the linear business model.

The linear business model again lacks secure future incomes as the model's projection of sold volume might still be unrealistic. The sales prices in this model indicate to be increased to 3.3 MSEK by the year 2040. But unlike the previous linear business models, this case has no payback time and is profitable in the first year. This could indicate an unrealistic model, which should be taken into consideration.

**Profitability tool for Circular Economy**
Fictive case
Business Case over a trucks life-time
Lifetime of component/product [years]: 20 years




| Product cost | |
|---|---|
| Cost of Sold Truck | 700 000 SEK |
| Circular Developement Cost | 350 000 SEK |
| Total product cost 2024 | 1 050 000 SEK |

| | | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 | 2032 | 2033 | 2034 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Raw material cost evolution | | 2% | 2% | 2% | 2% | 2% | 2% | 2% | 2% | 2% | 2% | 2% |
| Material Supply Chain Risk: | | 3% | 3% | 3% | 3% | 3% | 3% | 3% | 3% | 3% | 3% | 3% |
| Proportion of vehicles that are returned | | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| End of life value of a vehicle after 20 years | | 20% | 20% | 20% | 20% | 20% | 20% | 20% | 20% | 20% | 20% | 20% |
| Year | | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 | 2032 | 2033 | 2034 |
| Volume | | 50 000 | 50 000 | 50 000 | 50 000 | 50 000 | 50 000 | 50 000 | 50 000 | 50 000 | 50 000 | 50 000 |
| Cost of sales | | MSEK | | | | | | | | | | |
| Cost to implement (R&D Project Cost): | | 7 000 | 7 000 | 7 000 | 7 000 | 7 000 | 7 000 | 7 000 | 7 000 | 7 000 | 7 000 | 7 000 |
| Product Cost per truck / year | | 1,05 | 1,10 | 1,16 | 1,22 | 1,28 | 1,34 | 1,41 | 1,48 | 1,55 | 1,63 | 1,71 |
| Raw material cost evolution: | | 0,02 | 0,02 | 0,02 | 0,02 | 0,03 | 0,03 | 0,03 | 0,03 | 0,03 | 0,03 | 0,03 |
| Material Supply Chain Risk: | | 0,03 | 0,03 | 0,03 | 0,04 | 0,04 | 0,04 | 0,04 | 0,04 | 0,05 | 0,05 | 0,05 |
| Depreciation | | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |
| Total cost of sale / year | | 62 125 | 64 881 | 67 775 | 70 814 | 74 005 | 77 355 | 80 873 | 84 566 | 88 445 | 92 517 | 96 793 |
| Incomes | Grossprofit | 15% | 15% | 15% | 15% | 15% | 15% | 15% | 15% | 15% | 15% | 15% |
| | ELV income | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Netsales | 63 394 | 66 563 | 69 892 | 73 386 | 77 055 | 80 908 | 84 954 | 89 201 | 93 661 | 98 345 | 103 262 |
| | Product Price to Customer | 1,267875 | 1,331269 | 1,3978322 | 1,4677238 | 1,54111 | 1,618165486 | 1,69907376 | 1,784027448 | 1,873228821 | 1,966890262 | 2,065234775 |
| Total Cashflow (Outflow -, Inflow +) | | 1 268,8 | 1 682,2 | 2 116,3 | 2 572,1 | 3 050,7 | 3 553,3 | 4 080,9 | 4 635,0 | 5 216,7 | 5 827,5 | 6 468,9 |
| Discounted ISO | 12% | 1 268,8 | 1 502,0 | 1 687,1 | 1 830,8 | 1 938,8 | 2 016,2 | 2 067,5 | 2 096,6 | 2 106,9 | 2 101,5 | 2 082,8 |
| Acc DSCF | | 1 268,8 | 2 770,7 | 4 457,8 | 6 288,6 | 8 227,4 | 10 243,6 | 12 311,1 | 14 407,7 | 16 514,7 | 18 616,1 | 20 699,0 |

| | | 2035 | 2036 | 2037 | 2038 | 2039 | 2040 | 2041 | 2042 | 2043 | 2044 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Raw material cost evolution | | 2% | 2% | 2% | 2% | 2% | 2% | 2% | 2% | 2% | 2% |
| Material Supply Chain Risk: | | 3% | 3% | 3% | 3% | 3% | 3% | 3% | 3% | 3% | 2% |
| Proportion of vehicles that are returned | | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| End of life value of a vehicle after 20 years | | 20% | 20% | 20% | 20% | 20% | 20% | 20% | 20% | 20% | 20% |
| Year | | 2035 | 2036 | 2037 | 2038 | 2039 | 2040 | 2041 | 2042 | 2043 | 2044 |
| Volume | | 50 000 | 50 000 | 50 000 | 50 000 | 50 000 | 50 000 | 50 000 | 50 000 | 50 000 | 50 000 |
| Cost of sales | | | | | | | | | | | |
| Cost to implement (R&D Project Cost): | | 7 000 | 7 000 | 7 000 | 7 000 | 7 000 | 7 000 | 7 000 | 7 000 | 7 000 | 7 000 |
| Product Cost per truck / year | | 1,80 | 1,89 | 1,98 | 2,08 | 2,18 | 2,29 | 2,41 | 2,53 | 2,65 | 2,79 |
| Raw material cost evolution: | | 0,04 | 0,04 | 0,04 | 0,04 | 0,04 | 0,05 | 0,05 | 0,05 | 0,05 | 0,06 |
| Material Supply Chain Risk: | | 0,05 | 0,06 | 0,06 | 0,06 | 0,07 | 0,07 | 0,07 | 0,08 | 0,08 | 0,06 |
| Depreciation | | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |
| Total cost of sale / year | | 101 282 | 105 997 | 110 946 | 116 144 | 121 601 | 127 331 | 133 348 | 139 665 | 146 298 | 151 870 |
| Incomes | Grossprofit | 15% | 15% | 15% | 15% | 15% | 15% | 15% | 15% | 15% | 15% |
| | ELV income | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Netsales | 108 425 | 113 846 | 119 538 | 125 515 | 131 791 | 138 381 | 145 300 | 152 565 | 160 193 | 166 601 |
| | Product Price to Customer | 2,168496514 | 2,276921339 | 2,390767406 | 2,510305777 | 2,635821065 | 2,767612119 | 2,90599272 | 3,0512924 | 3,203857 | 3,332011 |
| Total Cashflow (Outflow -, Inflow +) | | 7 142,4 | 7 849,5 | 8 592,0 | 9 371,6 | 10 190,1 | 11 049,6 | 11 952,1 | 12 899,7 | 13 894,7 | 14 730,5 |
| Discounted ISO | 12% | 2 053,3 | 2 014,8 | 1 969,1 | 1 917,6 | 1 861,7 | 1 802,4 | 1 740,8 | 1 677,5 | 1 613,3 | 1 527,1 |
| Acc DSCF | | 22 752,2 | 24 767,0 | 26 736,0 | 28 653,6 | 30 515,3 | 32 317,8 | 34 058,5 | 35 736,0 | 37 349,3 | 38 876,3 |

| | |
|---|---|
| IRR | #NUM! |
| NPV | 38 876,3 MSEK |

**Figure 5.7:** Business Case 5: Circular Product 2 in a Linear Business Model.

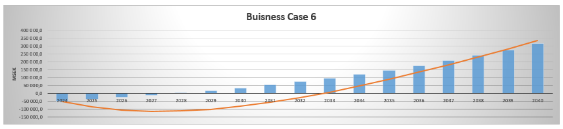
To compare to the other cases, the same volume of 50'000 sold trucks each year and a profit margin of 15%, gives this case the NPV of the project is 38'876,3 MSEK and the IRR is unable to be calculated since the product has no payback time. Just as in the other cases, the product price is calculated at a 15% profit margin with increases in the product price to extreme levels. Again, this points to the unrealistic use of the model.

**Business Case 6: Circular Product 2 in a Circular Business Model**
The last case shows the full fit between a much more circular product and a circular business model. In this case, the MSC risk is set to the same yearly rate of 3%, until the product reaches its end-of-life after 20 years. Then the risk is set to decrease to 0.5% as the circular model implies that vehicles are returned at their end-of-life. For the circular business model the same assumption was made as in BC2, that 90% of the vehicles are returned to Volvo GTT's possession. However, in this case, the EOL-value is estimated to be 22%, instead of 20% in the linear model. Especially as the product becomes more circular the benefits of the circular business model become apparent. As the truck becomes more circular the ease of implementing strategies from the R-framework increases, especially in the circular business model in which Volvo GTT can better control what maintenance is necessary to carry out. In this vehicle, it can also be expected that there are enough sensors to enable an optimization of maintenance operations.

With the same line of reasoning as previous cases, the MSC-risk is expected to increase until the trucks are returned to the organization. This in turn means that the product cost increases much more than in BC2 or BC4, as it takes longer for the material in the trucks to return. This MSC-risk could be an unrealistic assumption, as there is access to material even during the lifetime of the vehicles. Another aspect is that the increased cost of not being able to produce as many vehicles do not need to negatively impact the business case to the same degree as the revenue is not immediately dependent on the production of new trucks but rather is a consequence of the amount of vehicles already on the market.

**Profitability tool for Circular Economy**
**Fictive case**
**Business Case over a trucks life-time**
**Lifetime of product [years]:** 20

| Product cost | |
|---|---|
| Cost of Sold Truck | 700 000 SEK |
| Circular Developement Cost | 350 000 SEK |
| **Total product cost 2024** | **1 050 000 SEK** |




| | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 | 2032 | 2033 |
|---|---|---|---|---|---|---|---|---|---|---|
| **Raw material cost evolution** | 2% | 2% | 2% | 2% | 2% | 2% | 2% | 2% | 2% | 2% |
| **Material Supply Chain Risk:** | 3% | 3% | 3% | 3% | 3% | 3% | 3% | 3% | 3% | 3% |
| **Proportion of vehicles that are returned** | 90% | 90% | 90% | 90% | 90% | 90% | 90% | 90% | 90% | 90% |
| **End of life value of a vehicle after 20 years** | 22% | 22% | 22% | 22% | 22% | 22% | 22% | 22% | 22% | 22% |
| **Year** | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 | 2032 | 2033 |
| **Volume** | 50000 | 50000 | 50000 | 50000 | 50000 | 50000 | 50000 | 50000 | 50000 | 50000 |
| Cost of sales | MSEK | | | | | | | | | |
| Cost to implement (R&D Project Cost): | 7 000 | 7 000 | 7 000 | 7 000 | 7 000 | 7 000 | 7 000 | 7 000 | 7 000 | 7 000 |
| Product Cost per truck / year | 1,05 | 1,10 | 1,16 | 1,22 | 1,28 | 1,34 | 1,41 | 1,48 | 1,55 | 1,63 |
| Raw material cost evolution: | 0,02 | 0,02 | 0,02 | 0,02 | 0,03 | 0,03 | 0,03 | 0,03 | 0,03 | 0,03 |
| Material Supply Chain Risk: | 0,03 | 0,03 | 0,03 | 0,04 | 0,04 | 0,04 | 0,04 | 0,04 | 0,05 | 0,05 |
| Depreciation | 2625,0 | 5512,5 | 8682,2 | 12155,1 | 15953,5 | 20101,4 | 24624,3 | 29549,1 | 34904,9 | 40722,4 |
| **Total cost of sale / year** | **64 750** | **70 394** | **76 458** | **82 969** | **89 958** | **97 456** | **105 497** | **114 116** | **123 350** | **133 239** |
| **INCOME Gain** – **Income per truck out in service** | 0,31 | 0,32 | 0,34 | 0,35 | 0,37 | 0,39 | 0,40 | 0,42 | 0,44 | 0,46 |
| **ELV income** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Netsales** | 15 531 | 32 441 | 50 831 | 70 814 | 92 506 | 116 033 | 141 527 | 169 133 | 199 001 | 231 292 |
| **Total Cashflow (Outflow -, Inflow +)** | -49 218,8 | -37 953,1 | -25 626,0 | -12 155,1 | 2 547,7 | 18 576,1 | 36 030,3 | 55 017,3 | 75 651,0 | 98 053,1 |
| **Discounted ISO** 12% | -49 218,8 | -33 886,7 | -20 428,9 | -8 651,7 | 1 619,1 | 10 540,6 | 18 254,1 | 24 887,0 | 30 554,2 | 35 358,9 |
| **Acc DSCF** | -49 218,8 | -83 105,5 | -103 534,4 | -112 186,1 | -110 567,0 | -100 026,4 | -81 772,4 | -56 885,3 | -26 331,1 | 9 027,8 |

| | 2034 | 2035 | 2036 | 2037 | 2038 | 2039 | 2040 | 2041 | 2042 | 2043 | 2044 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Raw material cost evolution** | 2% | 2% | 2% | 2% | 2% | 2% | 2% | 2% | 2% | 2% | 2% | |
| **Material Supply Chain Risk:** | 3% | 3% | 3% | 3% | 3% | 3% | 3% | 3% | 3% | 3% | 0,5% | |
| **Proportion of vehicles that are returned** | 90% | 90% | 90% | 90% | 90% | 90% | 90% | 90% | 90% | 90% | 90% | |
| **End of life value of a vehicle after 20 years** | 22% | 22% | 22% | 22% | 22% | 22% | 22% | 22% | 22% | 22% | 22% | |
| **Year** | 2034 | 2035 | 2036 | 2037 | 2038 | 2039 | 2040 | 2041 | 2042 | 2043 | 2044 | |
| **Volume** | 50000 | 50000 | 50000 | 50000 | 50000 | 50000 | 50000 | 50000 | 50000 | 50000 | 50000 | |
| Cost of sales | | | | | | | | MSEK | | | | |
| Cost to implement (R&D Project Cost): | 7 000 | 7 000 | 7 000 | 7 000 | 7 000 | 7 000 | 7 000 | 7 000 | 7 000 | 7 000 | 7 000 | |
| Product Cost per truck / year | 1,71 | 1,80 | 1,89 | 1,98 | 2,08 | 2,18 | 2,29 | 2,41 | 2,53 | 2,65 | 2,79 | |
| Raw material cost evolution: | 0,03 | 0,04 | 0,04 | 0,04 | 0,04 | 0,04 | 0,05 | 0,05 | 0,05 | 0,05 | 0,06 | |
| Material Supply Chain Risk: | 0,05 | 0,05 | 0,06 | 0,06 | 0,06 | 0,07 | 0,07 | 0,07 | 0,08 | 0,08 | 0,01 | |
| Depreciation | 47034,3 | 53875,7 | 61283,6 | 69297,6 | 77959,8 | 87315,0 | 97410,8 | 108297,9 | 120030,1 | 132664,9 | 139298,1 | |
| **Total cost of sale / year** | **143 827** | **155 158** | **167 280** | **180 244** | **194 104** | **208 916** | **224 742** | **241 645** | **259 695** | **278 963** | **289 079** | |
| **INCOME Gain** – **Income per truck out in service** | 0,48 | 0,51 | 0,53 | 0,55 | 0,58 | 0,61 | 0,64 | 0,67 | 0,70 | 0,73 | 0,75 | |
| **ELV income** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 10395,00 | 113 036,5 |
| **Netsales** | 266 180 | 303 847 | 344 489 | 388 312 | 435 539 | 486 404 | 541 157 | 600 064 | 663 408 | 731 491 | 872 334 | |
| **Total Cashflow (Outflow -, Inflow +)** | 122 353,1 | 148 689,2 | 177 208,7 | 208 068,4 | 241 435,4 | 277 487,8 | 316 414,8 | 358 418,4 | 403 713,2 | 452 527,6 | 593 650,7 | |
| **Discounted ISO** 12% | 39 394,4 | 42 744,6 | 45 485,1 | 47 683,9 | 49 402,5 | 50 696,0 | 51 614,1 | 52 201,6 | 52 498,7 | 52 541,5 | 61 541,8 | |
| **Acc DSCF** | 48 422,2 | 91 166,8 | 136 651,9 | 184 335,8 | 233 738,2 | 284 434,2 | 336 048,3 | 388 250,0 | 440 748,7 | 493 290,2 | 554 832,0 | |

| | |
|---|---|
| IRR | 30% |
| NPV | 554 832,0 MSEK |

**Figure 5.8:** Business Case 6: Circular Product 2 in a Circular Business Model.

With a volume of 50'000 trucks placed on the market every year, and a payback time of 4 years for each truck's product cost, the NPV of the investment is 554'832 MSEK and the IRR is approximately 30%. This IRR is higher than that of Case 2 and Case 4, likely due to the much increased product cost as a consequence of the higher original product cost but also the prolonged impact of the MSC-risk which further increases the profit of each truck. The costs of production increase so much that this case has the lowest NPV of the circular business cases.

## 5.3 Summary of results in Evaluation Phase

The evaluation phase aimed to fulfill the objectives that were presented in Section 2.3. The objectives are presented and discussed below:

E1. Investigate the validity of the parameters' composition.

E2. Investigate the validity of the parameters' influence on the profitability of linear and circular products.

The evaluation phase investigated both assessing the validity of the parameters as well as the validity of their influence on the profitability model. Using the workshop as a discussion forum combined with the questionnaire was the validity of the composition of parameters investigated, fulfilling objective E1. Additionally, the workshop investigated the influence of the parameters both on the profitability of linear and circular products, fulfilling objective E2.

# 6 Discussion

In this chapter, a summary of findings from an exploration comprising literature study, interview study, and development of a profitability model based on identified parameters will be discussed and analyzed. This chapter offers an examination of the project's research questions, possible ways forwards, and areas of improvement. The limitations and their effects on the study are also described.

## 6.1 What does Volvo GTT need to consider to generate profitability from circular products

This project has posited that in to stay profitable one probable solution is to become more circular. Therefore, this project has investigated how circular products can generate profit. The study has intentionally avoided assuming that the business model must change since the project's stance was neutral in this aspect. However, as both literature and experts point to the importance of designing products in the context of the business model, it was prudent to investigate the effect of business models as well.

There is likely a spectrum of potential solutions to stay profitable. They are more or less proactive, each with their strengths and weaknesses. The anticipated effect of the laws ratified by the EU is an enforced increase in circularity. The question is not if Volvo GTT will design circular products, but rather to what extent Volvo GTT will benefit from the value chain during the products' lifetimes.

As mentioned, the question of generating profit from circular products is difficult to separate from the context of the business model. In a linear business model, circularity is difficult to motivate by the revenue it generates alone since a significant part of the profit in the linear model is from the aftermarket. Circularity in a linear business model could be driven by cost avoidance in the form of: legal fees, material costs, or disassembly. However, direct sales could become more difficult as the responsibility for products shifts to the producer. Retaining ownership of certain parts could become beneficial to avoid fees of outsourcing responsibility and additional costs of production. Ownership retention of strategic components could become the only way of dealing with the ELV directive in a linear business model.

As material costs rise and competitors offer competitive circular solutions ensuring the same degree of profitability could become troublesome. When products become more circular, the circular business model could become a more affordable and easy business model for both users and producers. A possible way of combating the downsides of a linear business model is through strategic partnerships with other producers to lower development costs. However, with partnerships there is a need to ensure that Volvo GTT's brand perception is maintained, and in extension sustain the profit margin. Other partnerships in Volvo GTT's value chain will be equally important, ensuring that Volvo GTT is a part of the solution during the entire lifetime of the products. This could ensure that Volvo GTT can profit from maintenance during the product's lifetime and access to the material at the end-of-life. This model's biggest advantage is the lack of bound capital, and possible shorter payback times. However, if supply chains become disrupted or material prices increase dramatically, the business model will have difficulty staying viable.

The other more demanding, risky, way, but possibly much more profitable way is to change the business model and product more extensively. This would be to adopt a circular business model and retain ownership of the products. This would result in a different motivation in product design as all forms of maintenance and production are increased costs. To increase material utilization while minimizing energy expenditure is almost analogous to increasing profits. There is also a big strength in the business model which is that the momentum of income will probably ensure viability in an economic downturn. Should material costs rise, the organization's income is not directly tied in time to the production of new vehicles. Therefore Volvo GTT could buy less material during periods of high prices, or have time to adjust to different suppliers or designs without causing complete financial chaos. For other producers in a linear business model, the onset of rapidly increasing material costs will mean that Volvo GTT will become more attractive, gain market share, or increase profits. However, there are two main risks of utilizing a circular business model. The first is the most commonly raised concern, that of the bound capital. Binding capital is a big risk, as it decreases flexibility and increases payback time. This risk could be mitigated in the future as banks are increasingly interested in circular business models and see these as good investments. In extension, this would functionally mean that Volvo GTT and the services it would provide would be owned to a large extent by the banks.

Another large disadvantage of the business model is that since Volvo GTT invests in their products for their entire lifetime, thereby keeping the risk, they also stake the survival of the business on that the market will stay relatively similar throughout the product's life. Two important ways in which the market could change are through technological and legislative development. Technology evolves rapidly, and radical developments could mean that upgrading products is not feasible technologically or financially, thereby making the fleet of products less useful. Legislature develops more slowly compared to technology and is in the coming decade partially predictable. However, should producers be responsible for products longer than the horizon of the committees developing the legislature it will be difficult for organizations to develop products that will follow the legislature for their entire life. This could result in organizations being hesitant to invest, as it is difficult to judge the safety of the investment. This becomes even more complex as the lead time from R&D to production could be close to 10 years.

## 6.2 What key parameters should be integrated into the profitability model to enable circular products

Many parameters would facilitate the development of more circular products. The claim from the project at the onset was that the evaluation of profit was based on a linear business model, which assumes that material will be available, production will be cheap, and the current methods used are legal. The project in extension postulates that this view could be incorrect and that an attempt at more realistic evaluations of future cost could lead to circular products becoming the more profitable choice. This assumption led to the investigation of possible alterations to the profitability model through the inclusion of new parameters.

The research phase produced a large set of parameters, many of which could be interesting to further investigate. As a consequence of the project's limitations, Material Supply Chain-risk and End-Of-Life-value were chosen as important for future development.

The Material Supply Chain-risk is at the very core of the question of circularity. Increased costs of production, and decreased availability of material. This parameter, if accurately valued, will probably be a large part of the answer to the question of choice in the business model and degree of circularity.

The End-of-Life value of a vehicle was seen to be highly dependent on the design and usage. A more circular design that inherently prioritizes the ability to maintain a high value throughout the product's lifetime. Thus, naturally results in a higher End-of-Life value, partly also because more of the vehicle is designed for the R-Framework in which design for disassembly is necessary.

## 6.3 What is currently hindering Volvo GTT from becoming more circular

There are many challenges to becoming circular and there are benefits of staying linear in the short term. Generally, the risks of becoming circular are related to a lack of knowledge, understanding, and examples about the problem, transition, solution, and customer preferences. To become circular means to change most of everything in the way the organization operates. When the profitability of the current solution is high, the problems are far in the future, and the customers express little interest in circular solutions, it is frankly quite clear why many are careful in changing the winning concept.

One way to begin to combat this is to start small. Implement local trial runs of more circular operations, primarily by using the as-is product of today, and accepting a lower margin if necessary. Learning from these experiences could help in designing vehicles that can more efficiently be used in a circular business model. By the use of smaller-sized operations, the customer proposition can also be developed and understood.

Another difficulty in product development is that when trying to develop circular components, the project is correctly valued in the profitability model. A circular component in a linear product, especially one as complex as a truck, will in most cases be less efficient than a linear component. This faulty logic could make it difficult to develop a circular truck. If no one is allowed to start, then no one will. The solution for this could be twofold. Firstly, from experience in circular operations, a prioritized set of projects should be created, to create the next minimal viable circular product. Secondly, for these projects a lower profit margin should be expected, and possibly motivated as a form of R&D.

Implementing the motivation and drive within Volvo GTT is another challenge in and of itself. From the interview study, it became clear that employees experience fatigue with the amount of prioritized areas, and feel too overwhelmed to add circularity to the list. Employees are utilized fully, as they should be. Understandably, circularity is not at the top of the agenda today. Nonetheless, prioritization could be more clearly communicated. Whether or not Volvo GTT wants circularity to be part of that agenda should be decided as well.

## 6.4 Project complexity and ambiguity

This project has been very challenging, developing, and rewarding. The focus of the study, change at an organizational level in a very large organization, has at times resulted in an almost overwhelming degree of complexity. The ambiguity and size of the problem led to difficulties in creating a specific scope. Combined with the fact that our ambition and interest in this project has been high, the scope was originally overly ambitious. Many stakeholders have also expressed great interest, for which we are very grateful. As some of the activities performed during this thesis did not produce the expected results, the complexity of the topic became more and more apparent. Simultaneously the problem's resolution increased, which resulted in a more refined problem, and a clearer path forward, with methods chosen in accordance with the project's needs, and not the original plan.

# 7

# Conclusion and Recommendations

This final chapter will present the project's overall conclusions in relation to the project aim and research questions. Lastly the future recommendations will be presented.

## 7.1 Project aim

The project aim was to investigate possible ways Volvo GTT could more accurately evaluate circular products in the product development process. This was facilitated by exploring additional parameters to add to the profitability model. The study resulted in the development and integration of two key parameters, Material Supply Chain risk and End-Of-Life value. The results from the validation study demonstrate the complexity of estimating business cases, while simultaneously showing that the parameters have some effect. This aim is concluded to be partially fulfilled as parameters have been included in the profitability model, however, the validity of these parameters requires further research.

## 7.2 Project research questions

In order to fulfill the aim of the project three research questions were formulated. The conclusions related to the research questions are presented below:

**RQ1: What does Volvo GTT need to consider to generate profitability from circular products?**
In conclusion, Volvo GTT is likely to find itself compelled to develop and manufacture circular products. To harness profitability from this transition, Volvo GTT must carefully evaluate several crucial factors. Firstly, it must determine when the risks of maintaining a linear approach surpass the benefits, prompting the shift towards circularity. Secondly, Volvo GTT needs to identify strategic partnerships necessary for the successful implementation of circular practices.

Moreover, Volvo GTT must recognize how future legislation may shape user and organizational preferences regarding the risk of ownership and payment models. Lastly, Volvo GTT must identify the possible significant costs associated with an insecure supply chain, emphasizing the importance of resilience and reliability in its operations. By addressing these aspects, Volvo GTT can navigate the complexities of transitioning towards circularity while ensuring profitability and sustainability in the automotive industry.

**RQ2: What key parameters should be integrated into the profitability model to enable circular products?**
The investigation of key parameters for profitability calculations in enabling circular products reveals important considerations for strategic decision-making. As profitability models currently in use are often designed for linear products, there is a need for a more realistic evaluation concerning circular products. This thesis found that Material Supply Chain risk and End-of-Life value parameters are considered to have a significant impact in the future. Material Supply Chain risk attempts to depict risks related to material availability, supply chain security, and force majeure events. End-of-Life value shows the importance of maintaining the product value over its lifecycle in accordance with circular design principles. These parameters could serve as a first effort to enable circular products in profitability calculations. This project opens up for further exploration and investigation, possibly enabling progress in the development of circular products.

**RQ3: What is currently hindering Volvo GTT from becoming more circular?** The journey towards circularity within Volvo GTT faces several challenges. Short-term profitability and current customer preferences favor linear models. Transitioning to circularity necessitates substantial operational shifts and changes to the current profitability gate. There is a need to overcome these organizational barriers to enable the development of circular products. The interview study showed that Volvo GTT has high ambitions for sustainable development, which can overwhelm innovators and cause circular initiatives to fall through the cracks. Moreover, the high profitability in their current linear business model, coupled with distant future risks and limited customer demand for circular solutions, underscores the cautious approach adopted by many. This inertia towards change is understandable, given the success of the existing paradigm.

Despite these challenges, it's imperative for Volvo GTT to confront the complexities of transitioning towards a circular economy. By addressing knowledge gaps, fostering understanding, and proactively engaging with stakeholders, Volvo GTT can mitigate the risks associated with circularity and capitalize on its long-term benefits. Embracing circularity not only aligns with their SDG's but also positions Volvo GTT as a leader in innovation and environmental stewardship within the automotive industry.

## 7.3 Recommendations

In order to advance the understanding and implementation of circular economy principles within the context of this study, several aspects for future research have emerged. Firstly, there is a need for deeper exploration and evaluation of the selected parameters Material Supply Chain risk and End-of-Life value, as this could provide valuable insights into strategic decision-making regarding product design and resource management. Additionally, future studies should aim to broaden the scope of analysis by incorporating a more comprehensive set of parameters, where the list of approved parameters can act as a guideline that can effectively capture the value proposition of circular products, thus offering a more holistic perspective on their environmental, economic, and social benefits. Furthermore, it is recommended that Volvo GTT conduct real case studies that involve actual products and business scenarios, allowing for a more nuanced understanding of the challenges and opportunities associated with circularity. Finally, to facilitate the successful implementation of circular strategies within organizations, future research should focus on fostering cross-functional collaboration and knowledge exchange, leveraging the diverse expertise and competencies of employees, particularly within specialized units such as Circular Operations at Volvo GTO, to drive innovation and process improvement initiatives.

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# A

# Appedix

## A.1 Interview Guide

Below is the questions that the interviews will be based on. Some questions contain a parenthesis which states the targeted stakeholder of the question, these questions will not be asked of other interviewees. If the questions does not contain a parenthesis

The parenthesis states the targeted group/stakeholders to the questions and it says nothing, the question should be asked to everyone.

**Introduction:**

- Introduce ourselves and the purpose of the interview.
- Briefly explain our study and how it relates to the topic of circularity and our expected outcomes.
- Explain how the information they provide will be used in Volvo tools.
- Inform about confidentiality in study.

**Background information about Volvo and the topic:**

- What is your name?
- What is your role?
- What do you work with?
- Can you explain if/how you work with circularity in your role?

**Parameters for financial calculations:**

- How can the following parameters be used in circular business cases? And what additional parameters need to be taken into consideration whilst evaluating circular projects?
  - Cost savings: Reduced sourcing cost by using recycled materials
  - Cost savings: Reduced use of virgin materials
  - Cost savings: Modular Vehicle Design
  - Cost savings: Reduced manufacturing waste
  - Cost savings: Remanufacturing and Refurbish
  - Cost savings: Reducing risk connected to material scarcity
  - Cost savings: Reducing taxes by minimizing environmental impact
  - Increased revenue: Second life sales, PaaS, subscriptions and leasing
  - Increased revenue: Right life-time
  - Increased revenue: Life cycle earnings (upgrades, refurbishment, repair, reman etc)
  - Increased revenue: Repurpose components, e.g. batteries
  - Increased revenue: Subsidization for circular business ventures
  - Increased revenue: EOL value

  Some of these parameters assume a linear business model with a longer life, some assume a circular business model.
- What requirements do you think should be placed on parameters included in the financial model?
- What organizational boundaries exist that would make it difficult for your organization to implement these parameters?

**Future outlook and goals:**

- What long-term goals have you, your team or organization set for circularity?
- Are there goals that contradict or support circularity?

**Challenges and obstacles:**

- What are the factors that can impede projects and initiatives?
- What challenges have you encountered when trying to implement circular processes

and sustainability measures at Volvo? (Circularity)

- What obstacles do you foresee Volvo facing in the future considering existing and upcoming regulatory requirements? (Requirements and Legal)
- Do you see any other important solutions besides circularity? (Strategy and Scenarios)
- What do you think is a major challenge in implementing circularity in your work? (PD)
- How do you think customers perceive circular development? (Aftermarket and Sales)
- When do you think customers will demand circularity? (Aftermarket and Sales)

**Specific projects and initiatives:**

- Can you provide examples of concrete projects or initiatives that Volvo has implemented to promote circularity?
- Can you provide examples of circular projects or initiatives that Volvo has been unable to implement?
  - What stopped these projects?
  - What was needed to implement the project?

**Technological innovations and research:**

- Can you share what important/future technological innovations are needed to implement circularity?
- What do you think is needed for Volvo to be able to create and manage circular products?

**Closing reflection:**

- Do you have any closing reflections or ideas regarding circularity at Volvo?

## A.2 Literature data spreadsheet

| Author 1 | Author 2 | Author 3 | Publication title | Year | Type | Publisher/Source |
|---|---|---|---|---|---|---|
| **Product Service System** | | | | | | |
| Carl Kühl | Benny Tjahjono | Michael Bourlakis | Implementation of Circular Economy principles in PSS operations | 2018 | Journal | Procedia CIRP |
| Wenting Zou | Saara A. Brax | Risto Rajala | Complexity in Product-Service Systems: Review and Framework | 2018 | Journal | Procedia CIRP |
| Payam Akbar | Stefan Hoffman | | Under which circumstances do consumers choose a Product Service System (PSS)? Consumer benefits and costs of sharing in PSS | 2018 | Journal | Journal of Cleaner Production |
| Arnold Tukker | | | Eight types of product–service system: eight ways to sustainability? | 2004 | Journal | Business Strategy and the Environment |
| Coralie Muylaert | Géraldine Thiry | Philippe Roman | Consumer perception of product-service systems: Depicting sector-specific barriers in the mobility, clothing and tooling sectors | 2022 | Journal | Journal of Cleaner Production |
| **Circular Design** | | | | | | |
| Tomas Santa-Maria | Walter J.V. Vermeulen | Rupert J. Baumgartner | The Circular Sprint: Circular business model innovation through design thinking | 2022 | Journal | Journal of Cleaner Production |
| Simon Carlsson | Adam Mallalieu | | DESIGN FOR LONGEVITY - A FRAMEWORK TO SUPPORT THE DESIGNING OF A PRODUCT'S OPTIMAL LIFETIME | 2021 | Journal | ICED21 |
| Marina Fernandes Aguiar | Daniel Jugend | | Circular product design maturity matrix: A guideline to evaluate new product development in light of the circular economy transition | 2022 | Journal | Journal of Cleaner Production |
| Thomas Germano Battesini Teixeira | Janine Fleith de Medeiros | Camila Kolling | Redesign in the textile industry: Proposal of a methodology for the insertion of circular thinking in product development processes | 2023 | Journal | Journal of Cleaner Production |
| Anna Diaz | Josef-Peter Schöggl | Tatiana Reye | Sustainable product development in a circular economy: Implications for products, actors, decision-making support and lifecycle information management | 2022 | Journal | Sustainable Production and Consumption |
| Nancy M.P. Bocken | C.A Bakker | Ingrid de Pauw | Product design and business model strategies for a circular economy | 2016 | Journal | Journal of Industrial and Production Engineering |
| **Circular Economy** | | | | | | |
| José Potting | M.P Hekktert | Ernst Worrell | Circular Economy: Measuring innovation in the product chain | 2017 | Journal | PBL Netherlands Assessment Agency |
| Sveinung Jørgensen | Lars Jacob Tynes Pedersen | | The Circular Rather than the Linear Economy | 2018 | Book | RESTART Sustainable Business Model Innovation |
| Tom Lahti | Joakim Wincent | Vinit Parida | A Definition and Theoretical Review of the Circular Economy, Value Creation, and Sustainable Business Models: Where Are We Now and Where Should Research Move in the Future? | 2018 | Journal | Sustainability |
| Julian M. Allwood | | | Chapter 30 - Squaring the Circular Economy: The Role of Recycling within a Hierarchy of Material Management Strategies | 2014 | Journal | Handbook of Recycling |
| Anna Diaz | Rupert J. Baumgartner | | A managerial approach to product planning for a circular economy: Strategy implementation and evaluation support | 2024 | Journal | Journal of Cleaner Production |
| Nancy M.P. Bocken | Martin Geissdoerfer | Paulo Savaget | The Circular Economy – A new sustainability paradigm? | 2016 | Journal | Journal of Cleaner Production |
| Julian Kirchherr | Denise Reike | Marko Hekkert | Conceptualizing the circular economy: An analysis of 114 definitions | 2017 | Journal | Resources, Conservation and Recycling |
| Trevor Zink | Roland Geyer | | Circular Economy Rebound | 2017 | Journal | Journal of Industrial Ecology |
| Patrick Schröder | Kartika Anggraeni | Uwe Weber | The Relevance of Circular Economy Practices to the Sustainable Development Goals | 2018 | Journal | Journal of Industrial Ecology |
| D.H Meadows | | | The limits to growth | 1972 | Book | Universe Books |
| Walter R Stahel | | | The product life factor | 1982 | Journal | Houston Area Research Center |
| David Pearce | R. Kerry Turner | | Economics of natural resources and the environment | 1991 | Journal | American Journal of Agricultural Economic |
| Walter R Stahel | | | Product life as a variable: the notion of utilization | 1986 | Journal | Science and Public Policy |
| Alisha Tuladhar | Konstantinos Iatridis | Dimo Dimov | Chapter 6 - History and evolution of the circular economy and circular economy business models | 2022 | Book | Circular Economy and Sustainability |
| **Business Models** | | | | | | |
| Marina P.P. Pieroni | Tim C. McAloone | Daniela C.A. Pigosso | Business model innovation for circular economy and sustainability: A review of approaches | 2019 | Journal | Journal of Cleaner Production |
| Milan Mansuino | Jagruti Thakur | Akshaya Lakshmi b | Turning the wheel: Measuring circularity in Swedish automotive products | 2023 | Journal | Sustainable Production and Consumption |
| Nancy M.P. Bocken | S.W. Short | P. Rana | A literature and practice review to develop sustainable business model archetypes | 2013 | Journal | Journal of Cleaner Production |
| Andrea Urbinati | Davide Chiaroni | Vittorio Chiesa | Towards a new taxonomy of circular economy business models | 2017 | Journal | Journal of Cleaner Production |
| Nancy M.P. Bocken | A van Bogaert | | Sustainable business model innovation for positive societal and environmental impact | 2016 | Book | Sustainable Development Research at ICIS : Taking stock and looking ahead |
| Iliana Papamichael | Irene Voukkali | Pantelitsa Loizia | Measuring Circularity: Tools for monitoring a smooth transition to Circular Economy | 2023 | Journal | Sustainable Chemistry and Pharmacy |
| Isuri Amarasinghe | Ying Hong | Rodney A. Stewart | Development of a material circularity evaluation framework for building construction projects | 2024 | Journal | Journal of Cleaner Production |

**Figure A.1:** List of literature read during thesis.

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