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Environmental Life Cycle Management in the Upstream Supply Chain

An Automotive manufactures perspective

Master's Thesis in the Master's Programme
Supply Chain Management

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ABSTRACT

Considering the increased pressure on organizations to account for their products environmental footprint, this report investigates the topic of *Environmental Life Cycle Management* (LCM) from an automotive manufacturers perspective. The research is focused on how to integrate LCM in functions related to the supply chain of products in order for a company to gain knowledge and control over processes occurring in their supply chain. A case company, referred to as Company X, faces challenges on how to cope with the environmental impact in their supply chains. This is an issue considering that the main part of the environmental footprint occurs before the materials and components arrive to Company X.

The purpose of this study is thus to investigate how LCM could be integrated in an automotive manufacturers organization to increase the knowledge of the environmental burden of a vehicle and to be able to improve the environmental performance in the upstream supply chain. Interviews with three interest groups: employees within Company X, suppliers to Company X, and *Life Cycle Assessment* (LCA) experts at Chalmers where conducted. In combination, literature regarding LCM, LCA and supply chain management where reviewed as a basis for this research.

The identified challenges with integrating LCM from Company X's perspective where find to be lack of transparency in the supply chain, lack of data required for specific LCA calculations, the complexity of understanding LCM, terminology and consistency issues, and aspects connected to the time it takes to gather necessary data. In contrast, the opportunities to gain from integrating LCM further in functions at Company X where: improved stakeholder relations, brand differentiation, increased product system knowledge, and the fact that LCM can serve as an innovation driver for product development. In order to overcome the barriers and take advantage of the opportunities, the recommendation for Company X are to increase their environmental collaboration with key suppliers, improve their internal communication between functions connected to the supply chain as well as to the environmental department, and finally to create strategies to limit their scope when applying LCM in their supply chain.

Keywords: Life Cycle Management, LCA, supply chain, automotive manufacturer, LCM opportunities, LCM challenges, environmental footprint

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We would also like to emphasise our gratitude to the experts at Chalmers that contributed to the great insight we got in the field of life cycle management as well as the employees at the case company whom we interviewed. And last but not least, thank you to ourselves for the amount of support we given each other.

Gothenburg, May 2018

Erik Jodlovsky & Hanna Zachrisson.

Research outline:

This report is divided into seven different chapters. The following list describes what each chapter includes in order for the reader to get an overview of the report.

1. *Introduction*

The introduction provides a background to the investigated area, why LCM and LCA is of importance to reduce a company's environmental impact as well as the integration of LCM in supply chains of automotive manufacturers. Furthermore, it presents the purpose of the study and the research questions this study aims to answer.

2. *Literature Review*

The literature review aims to give the reader further understanding of the concepts LCM and LCA. LCM is presented in detail were challenges and possibilities are further discussed to later give support to the analysis of this study. Further, how LCM and LCA could be integrated in supply chain management as well as the characteristics of an automotive company and its supply chain.

3. *Method*

The method describes how this investigation was carried out in terms of research approach and research strategy. Furthermore, it describes how both primary and secondary data were used.

4. *An Industry Perspective of LCM*

This chapter includes the empirical data, which is based on interviews with people that were found to be relevant to satisfy the aim of this study. The chapter provides further understanding of how different stakeholders are viewing the integration of LCM and LCA in the supply chain of an automotive manufacturer. The data presents the different interviewees perspective of the challenges and possibilities with LCM and how the actors views collaboration within the supply chain network to improve the environmental performance.

5. *Analysis of LCM usage*

This chapter provides an analysis of how an automotive company could overcome barriers and gain potential opportunities connected to LCM in the upstream supply chain.

6. *Improvements and Recommendations*

Company X current LCM approach is discussed and evaluated. A further discussion about how Company X could approach LCM in the future is provided considering the shift towards electrification of vehicles. It also provides recommendations for how Company X could further integrate LCM within the organization and thereby reduce the environmental impact in their supply chain. It is additionally presented how the company could work in collaboration with suppliers to integrate LCM in the supply chain.

7. *Conclusions*

This chapter concludes the findings of this study, the delimitations and gives suggestion on future research in the field.

Abbreviations:

CDP - Carbon Disclosure Project
CO2-e - Carbon dioxide equivalents
GHG - Greenhouse Gases
ECOInvent - Life Cycle Assessment database
EMAS - Environmental Management and Audit Scheme
GABI - Life Cycle Assessment Software Tool
ISO - The International Organization of Standardization
ISO 14001 - Environmental Management Certification
ISO 14040-series - Different Life Cycle Certifications
ISO 14067 - Life Cycle Certification
kWh - Kilowatt Hours
LCA - Life Cycle Assessment
LCI - Life Cycle Inventory
LCIA - Life Cycle Inventory Analysis
LCM - Life Cycle Management
MSA - Manufacturing Site Assessment
OBH - Operational buyer of Hybrid batteries
OBP - Operational buyer of Plastic components
OEM - Original Equipment Manufacturer
PESA - Interviewee: PhD Environmental System Analysis
SAQ - Supplier Assessment Questionnaire
Simapro - Life Cycle Assessment Software Tool
SSAE - Interviewee: Senior Strategic Advisor for Environment
SQM - Supplier Quality Management

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1. Introduction

The Intergovernmental Panel on Climate Change (2007) stresses the importance of sustainable manufacturing and transportation systems in today's society, in 2007 manufacturing accounted for 19% and transportation for 13% of the world's total *Greenhouse Gas* (GHG) emissions. The increased knowledge of the environmental impact of the way people consume and produce goods has led to a higher demand for environmentally friendly products and processes (Von Corswant & Fredriksson, 2002). The trend of taking greater responsibility and produce environmentally friendly products creates a challenge for traditional producers in most industries. The automotive industry is highly affected by this since emissions associated with transportation are a large contributing factor to climate change. In combination with demand from consumers and new policies, the traditional actors within the automotive industry are now facing challenges of improving their environmental performance in all aspects of their activities associated to the production of a vehicle, in particular the activities they are not directly in control of such as the ones in the vehicle's supply chain.

The manufacturing companies are aware of these issues, and one way to increase the knowledge of a company's actual environmental footprint it is to apply *Life Cycle Assessment* (LCA) (Baumann and Tillman, 2004), which aims at calculating the environmental burden along a product's "life", and thus get an idea of the total impact. However, LCA does not really assess the way of handling the indications the study provides, it is more of a measurement tool to support decision making and comparisons of products. To utilize the knowledge provided by an LCA study it is common to integrate it to something referred to as *Life Cycle Management* (LCM), which is a way of managing the processes within a products life cycle and act upon the indications that the LCA study provides, to decrease the environmental impact. The concept of LCM is far from new and it is somewhat of a trend to apply. According to the researcher Hanna Nilsson-Lindén (2014) LCM appears very straightforward in research but fails to be integrated successfully in organizations since a lot of the focus is still on conducting LCA's rather than taking it to the next level and create a company culture where LCM is more than just a set of tools. Nilsson-Lindén (2014) states that a successful way of applying LCM is to integrate it in all functions that are a part of the product chain in a company and let it be a part of everyday business activities. There are many reasons to why information about a products life cycle is important to have access to and understand. One factor could be that in the future, there will be stricter laws and policies that will regulate the emissions from certain materials and processes. Another factor could be to further gain consumers trust by having an environmental profile, and maybe most importantly, to keep a sustainable business for the future.

1.1 Background

Company X is a global automotive manufacturer with European roots. In a relatively near future, the company aims at becoming carbon neutral, which means that the company will only use energy from renewable sources as well as to produce electric vehicles and thus be independent from fossil fuels. Company X has an extensive sustainability program with ambitious yet reachable targets. Due to this, the company are somewhat facing challenges with how to integrate new strategies in order to reach their goals. One action Company X has taken in order to get more knowledge about the environmental impact of their business activities is to use LCA studies on their products. The LCA provides indications of the environmental performance on a product level. This is an important part of Company X's sustainability plan since an LCA covers everything from raw material extraction to "end of life" of the vehicle and its components. Currently, Company X is to a limited extent using

LCM where LCA is the main tool. The environmental department together with R&D are the two functions where LCM is practiced within the organization, however the concept of LCM is not applied to other functions that is believed to have a key role when it comes to reducing the environmental footprint of a product. The purchasing department is such a function with a significant role in reducing a product's environmental impact since they decide from whom to source the material to the final product. Moreover, the purchasers are the ones with the most connection to the suppliers and can thereby influence suppliers to improve the environmental performance. According to Foerstl et al. (2010) little is known regarding how organizations should manage and get insight of the environmental impact connected to their suppliers since companies are traditionally focusing on having environmental assessments strategies only of their own processes.

In the current state, Company X are well aware of the environmental impact from their own processes and have extensive programs and well formulated strategies on how to further improve the environmental performance of those. However, the environmental impact that their supply chains are responsibly for is still quite unknown. This is for the activities that occur before the material and components reaches Company X I.e. the upstream supply chain or the early phases of the products life cycle. The upstream supply chain consists of the actors that are producing and processing the material and components all the way from raw material extraction to the point when it arrives to Company X's factories. This is a common situation in the industry and consequently, there is a need of developing strategies and tools for how a company can cope with the uncertainty of how large the environmental footprint of a product actually is and how big portion of the impact the suppliers are responsible for. By gaining insight of the environmental impact of specific parts in the product supply chain it is possible to achieve a decreased environmental burden of upstream processes. This is especially important considering the shift towards electrification, since this will lead to that the heaviest environmental impact which today is during the vehicles user phase, will shift to the early phases of the vehicles life cycle, which are connected to the upstream supply chain. Further there are several benefits coming from applying LCM on a supply chain basis, all which will be discussed in this report.

Current literature in the LCM-field most often consider LCA as a main tool for managing the life cycle of products and is based on generic data from supply chain processes. The LCA therefore gives an indication on the processes with the highest environmental burden, but the information obtained from the LCA study is not specific for a supply chain flow nor product, which can lead to that the estimated environmental impact is significantly underestimated (Crawford, 2008). This study investigates how LCM can be integrated further into Company X's organization and how it is possible to improve the company's way of managing the environmental impact connected to their suppliers. The report includes current literature in the field of LCM and other associated fields such as supply chain management and purchasing. The focus is limited to how to affect the early stages of a products life cycle, this includes the steps from raw material extraction to the point where the material is delivered to Company X. LCA experts, employees at Company X and suppliers directly linked to Company X were interviewed to get an understanding of the challenges of working with LCM-processes and how to enable Company X to further work with LCM and LCA in the future. The study provides a unique contribution of how LCM can be integrated within different functions of an automotive company with the aim to reduce the environmental burden of the company's upstream supply chain.

1.2 Purpose

The purpose of this report is to investigate how LCM could be integrated into different functions within an automotive manufacturer's organization, to make automotive manufacturers increasingly aware of the environmental burden of a vehicle, as well as to be able to improve the environmental performance in the upstream supply chain.

1.3 Research questions

The research questions for this report in consideration to the purpose are the following:

> RQ1: How is Company X currently using LCM to understand the environmental impact in their own organization and their upstream supply chain?
>
> RQ2: What are the opportunities and challenges of integrating LCM within functions connected to the upstream supply chain processes of an automotive manufacturer?
>
> RQ3: How could LCM be integrated within functions in Company X connected to the upstream supply chain activities of a vehicle, with the aim to reduce the environmental impact?

1.4 Scope

The scope of this report has been limited to a "cradle-to-gate" perspective, meaning the environmental assessment in the upstream supply chain, from the extraction of raw material to the point where material reaches the manufacturer. *Figure 1* describes the different life cycle stages that are considered in this report. Further, the report only considers the environmental focus within LCM. Specific consideration was given to how the purchasing department could apply LCM and the possibility of integrating LCM in the supply chain to reduce the environmental footprint on material flows.

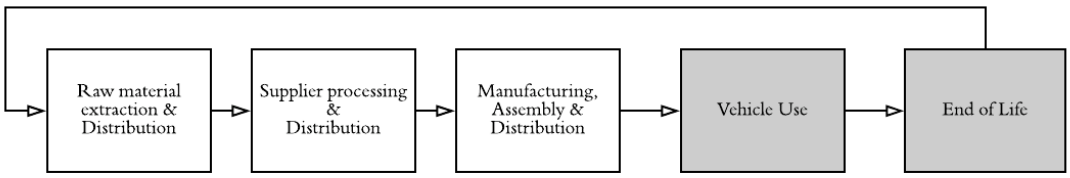


Figure 1. Overview of the life cycle of the products, including marks grey markings for the delimitations of this study (based on Adams and Schmidt, 1998)

2. Literature review

This chapter covers the relevant literature for the study. First, the purpose of using an LCA and how LCA is connected to supply chain management is presented. Secondly, this chapter describes the differences between LCA and LCM and how LCM can be connected to different organizational functions and processes. Finally, this chapter gives an insight in available environmental standards connected to LCA and LCM and the contribution of this research study.

2.1 Life Cycle Assessment

One tool that is commonly used to get an overview of a products environmental impact is an LCA study. Every physical product can be viewed to have a "life" starting with design/development of a product, continuing with the extraction of resources, production, usage and finally end of life activities including sorting, reuse, recycle and waste disposal (Rebitzer et al., 2004). All activities and processes in a product's life have an impact on the environment due to the consumption of resources and associated emissions. Egede (2016) and Guinée et al. (2016) describes an LCA as a way of analyzing the environmental impact of a product such as contribution to climate change, stratospheric ozone depletion, smog creation, acidification, toxicological stress on human health and ecosystems, land use, water use, noise and others during the product's entire life cycle. For instance, the lifecycle of a car consists of the extraction of raw materials, distribution, production processes, the vehicle usage and the processes related to the disposal of the product, see *figure 2*.

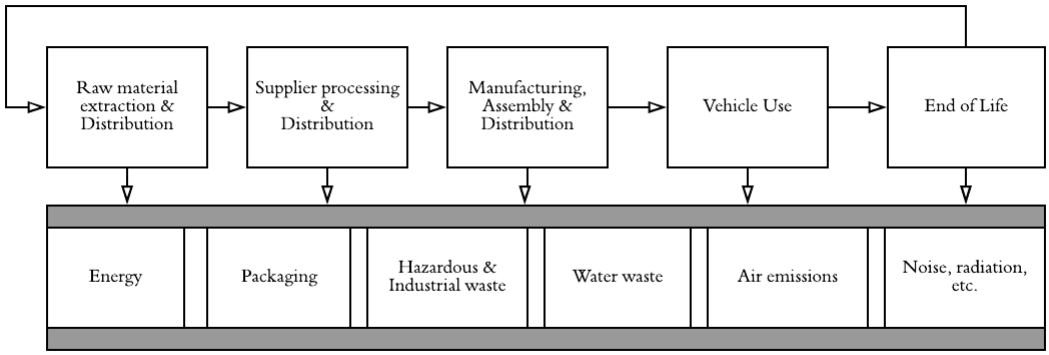


Figure 2. The life cycle of an automotive (based on Adams and Schmidt, 1998).

When conducting an LCA analysis of upstream supply chain processes it is important to first take use of specific supply chain data when accessible and generic data from different databases in cases when specific data is not accessible (Usva et al., 2008). Data about specific supply chain processes should therefore be gathered to the largest extent when conducting LCA's to have the highest possible data accuracy. According to Sonnemann (2015) and Bauman et al. (2004) the LCA data used is usually generic and based on approximations and calculations of similar supply chains. A drawback with using generic LCA data is the lack of available data and the impossibility of accounting for every pathway forcing it to draw artificial boundaries that exclude certain processes (Lenzen, 2000). According to recent research, this can cause the actual environmental impact to be significantly underestimated by as much as 87% (Crawford, 2008). Because of this, this report will further investigate how an automotive manufacturer can do more accurate LCM, taking use of what we call "the supply chain perspective" of LCM, which refers to the LCM processes that are including the entire supply chain and not only the indoor processes of Company X.

2.1.1 Conducting an LCA study

The *International Organization of Standardization* (ISO) has developed several different standards, which describes the principles (ISO 14040) as well as requirements and guidelines (ISO 14044) of how to conduct an LCA analysis (Egede, 2016). Overall the ISO standard describes the methodology of conducting an LCA analysis as an iterative process including four different steps, see *figure 3*.

(1) The first step in this iterative process is the goal and scope definition, which gives insight into the cornerstones of the LCA study. The goal and scope definition, define the system boundaries and the functional unit, which is the basis for the LCA analysis (Rebitzer et al., 2004). A functional unit is the input in the LCA analysis that can be compared when assessing different life cycles. Hence, the functional unit is not only the product in consideration but should also be stated in the amount of material and specific characteristics.

(2) The second step of the LCA is the inventory analysis also called *an Life Cycle Inventory* (LCI) and is related to the data gathering and the interpretation of the data. This process is about analyzing the consumption of resources and all other processes and activities that generate emissions and are related to the functional unit stated in the goal and scope definition of the LCA analysis. An LCA inventory analysis is about quantifying the waste and emissions emitted during the life cycle of the functional unit (Rebizer et al., 2004).

(3) The third step stated by ISO is impact assessment and is referred to as *Life Cycle Inventory Analysis* (LCIA), this step is important in the estimation of the external effects related to the consumption of resources in the inventory analysis (Rebitzer et al., 2004). The impact assessment stage is about the environmental impact of the processes and actions that are related to the functional unit, the environmental impact may be different in different environments depending on the energy consumption of specific types of machinery or the sources of energy, such as the effects coming from hydropower or nuclear power.

(4) The last step that communicates with all the other three steps is the interpretation. The interpretation step is about making trade-offs and conclusions based on the given information in each earlier stage in the LCA analysis (Rebitzer et al., 2004). By comparing data and analyze the collected data it is possible to make different types of interpretations. For instance, one step in the life cycle of the functional unit may result in more CO2 than the other, but on the other hand, the other may result in more NOX. The interpretation, in this case, could be that NOX is more hazardous to the environment than CO2, hence the interpretation may be that more effort should be put into decreasing the NOX particles.

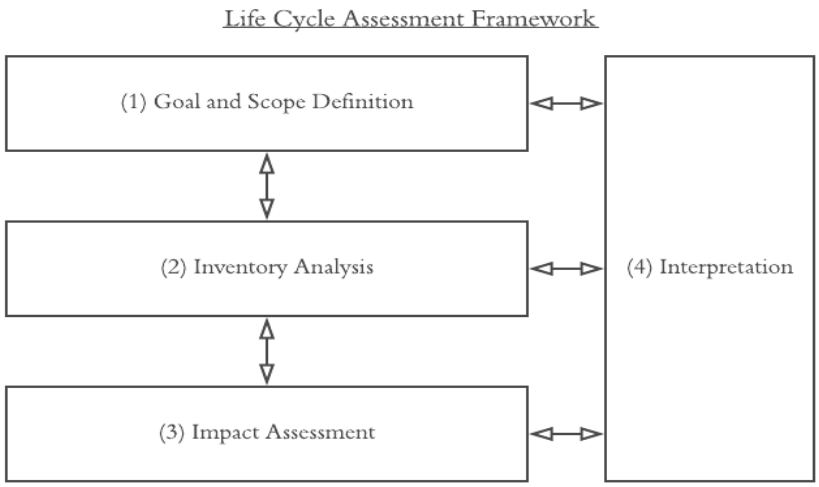


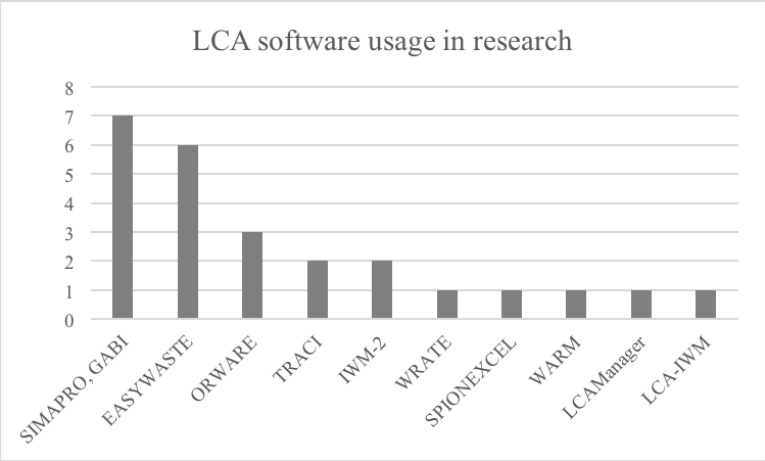
Figure 3. The Life Cycle Assessment framework (based on ISO, 1997).

2.1.2 Collecting LCA data

According to Reibtizer (2004), the data collection is the most time-consuming process when it comes to executing an LCA analysis, therefore he suggests that databases with high-quality information about often analyzed components should be used, instead of analyzing every specific flow in detail. Further, he describes that even though materials are extracted and processed in different parts of the world the processes are basically the same, thus LCA databases can be used to collect data and estimate emissions wherever the facilities are located. Important to consider is that some activities are more connected to the environmental policies and regulations in the specific area. For instance, agricultural production may differ to a great extent depending on regulations or typography in the specific regions. Therefore, it is important to use area-specific data for the cases that are affected by such regulations or other criteria. Both emissions data that are area specific and non-specific can be collected by the usage of LCA databases, such as *ECOInvent* (Rebitzer, 2004). ECOInvent is the database most commonly used in LCA softwares to calculate different types of emissions.

Norris (2001) describes an LCA Software as an assessment tool considering flows of pollutants, resources, inter-process flows and energy in all steps of the life cycle. There is a wide range of different LCA softwares on the market and different softwares may in some cases give different answers, therefore it is important to use the most trustful data available (Speck, Selke, Auras & Fitzsimmons, 2016). According to Kulczycka et al. (2015) the most frequently used LCA software used in research studies of waste management systems are *Simapro* and *GABI*, see *table 1*. Simapro is the world leading LCA software and is using the ECOInvent database (Striebig, 2017). The ECOInvent database was founded in Switzerland year 2000 as an attempt to build a wide database with high quality that can replace the multiple spread databases of that time with low quality and high grade of errors (Frischknecht & Rebitzer, 2005).

Table 1. Usage of different LCA softwares in waste management research studies conducted between 2005 and 2013 according to Kulczycka et al. (2015).



2.1.3 Hotspot LCA

According to Sarkar (2017), a complementary method of making an LCA analysis is to conduct a hotspot LCA analysis. A hotspot analysis is used to assess the environmental improvement possibilities with the processes within a products life cycle and can be divided into four different steps. The usage of these steps makes it possible to make better decisions about where in the supply chain changes should be done to improve the environmental performance.

Pelton and Smith (2015) describe the first step in the hotspot analysis as the identification of cycle hotspots. The meaning by this step is to identify the steps in the life cycle with significant environmental impact, this can be done by using environmental emissions related to the specific processes and compare the output from different processes with others. The second step is to identify system boundaries and to create a map of the system limited by the system boundaries. The mapping stage includes key processes, infrastructure and other activities that are relevant to the study. Pelton and Smith describe the third step as parameterizing baseline models, which is about finding ways to reduce parameters or making substitutes in the supply chain processes that generate less environmental impact. In this step, the hotspots identified in step one is investigated. If possible, ways are found to reduce the inventory input or making environmental friendly substitutions without decreasing the process effectiveness, these changes should be considered as possible improvements. The fourth step in the hotspot analysis is to assess and compare the change in environmental performance and to consider the actions that are conducted in step 3. It is important to make environmental assessments of each action so that the actions with the highest impact on emission reduction are taken. It is also important to consider other factors, such as external impacts of a reduction in inventory input or substitution that are affecting factors that are beyond the environmental scope, so that actions not are taken solely on an environmental basis. *Figure 4*, below shows the steps in the hotspot analysis and how they are connected.

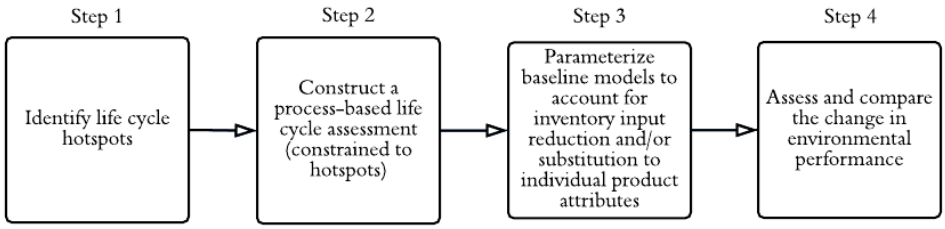


Figure 4. The four steps in an LCA Hotspot Scenario Analysis (based on Pelton and Smith, 2015).

2.2 Life Cycle Management

Sonnemann et al., (2015) describes LCM as the way of managing and deal with issues connected to a product's life cycle and the concept aims at integrating product sustainability into different management phases. It is a holistic view of dealing with issues connected to sustainability (ibid). The concept is widely used and many organizations have tried to adopt it. Yet the subjective nature of the concept has made it difficult to successfully apply in a company. LCM could also be described as the way a company acts to deal with issues related to the triple bottom line, i.e. the economic, social and environmental sustainability, of a product's lifecycle. In this report, the scope has been limited to the environmental sustainability. As stated, LCM is about integrating product sustainability into the different management phases within a company, such as the strategy and planning, product design and strategic purchasing (Remmen et al, 2007). Further, LCM connects and uses different tools within these phases to increase the sustainability of the life cycle for the particular product and one example of such tool is LCA(Sonnemann et al., 2015).

Nilsson-Lindén and Baumann (2013) states that the current LCM literature mostly presents tools and concepts about what LCM is, but not specifically about the gap between actually achieving successful LCM and how to integrate it into an organization. A successful LCM implementation is according to Nilsson-Lindén (2013) when the tools and concepts play a vital part in the everyday business activities and supports decision-making processes. Moreover, she states that it is rare to find research about how companies are working with LCM in practice. LCM implies a holistic approach of dealing with sustainability for company processes, but in practice companies lacks a comprehensive overview of initiatives related to LCM (Nilsson-Lindén et al., 2014). Further, Nilsson-Lindén (2017) describes that there are problems regarding the internal synchronization of LCM within organizations and LCM processes are not influencing the entire product life cycles. This is partly depending on the translation processes between different departments.

2.2.1 Integrating LCM into the organization

To integrate LCM into the organization it is important to consider the relevant functions and people that are related to the different processes in the supply chain of the product (Sonnemann et al., 2015). Finkbeiner & Spinger (2011) describes that one of the biggest challenges with life cycle engineering is to transfer environmental targets, such as the weight of a component to other organizational functions so that the final product will deliver the desired results. It is common that different functions of an organization to some extent have conflicting goals and different understanding of a specific concept and therefore have to align these in order to follow the organization's overall strategies and performance goals.

A good way to integrate LCM into the organization is to create a group of individuals that are working specifically with organizational LCM (Sonnemann et al., 2015). When composing this group, it is important to have a good mix of different competencies that are related to the purpose of the LCM application. A suggestion given by Sonnemann et al. (2015) is to compose cross-functional teams with members that have different backgrounds. When creating this group, it is suggested to have some full-time employees that are managing the group with a focus on continuous process improvements and other members are suggested to occasionally participate to give input into their areas. When choosing the specific team-members it is important that the teams not does not damage other functions within the organization. In some cases, it can be self-destructing to employ the best resources on specific processes, since the taking of these resources from other processes may harm other functions and processes within the company.

2.2.2. LCM between stakeholders

LCM focuses on management implications connected to the environmental performance of the product. Supply chain management consequently has the focus on making improvements regarding efficiency, customer satisfaction, and cost. The LCM perspective makes it possible to increase the environmental performance of all steps in the supply chain since it takes on a holistic perspective rather than looking at a process as an isolated activity, which results in a decreased risk of sub-optimization (Bauman et al., 2004). According to Bauman (2004), the use of LCA as a tool within LCM contributes to greening the supply chain by measuring its environmental performance and thereby be a support in decision-making processes.

According to Sonnemann et al. (2015), one of the biggest challenges with LCM is to meet the different needs and demands throughout the entire supply chain. To mitigate this challenge, it is important for the actors in the supply chain to strive towards common goals. One way of improving the communication between the parties is to standardize LCA applications in the supply chain (ibid.). To do this and also by sharing LCA data between the actors reduces the risk of multiple assessments of the same processes is performed within the supply chain. Moreover, this avoids unnecessary costs and audits for the parties in the chain. A standardization of LCA makes it possible to know the performance within the supply chain and creates a consistency of how the LCA studies are conducted and measured, which also allows the actors to improve the environmental processes in collaboration and avoid sub-optimizations (Together for Sustainability, 2015).

To manage environmental processes in the upstream supply chain sensitive environmental data has to be shared and in order to manage inter-organizational relationship there is a need of sharing sensitive information and knowledge across boarders in the buyer-supplier relationships (Harrison et al., 2005). Having better transparency and thereby better control of the upstream supply chain processes, makes it possible to monitor operational activities and control the actors and the risks connected to the upstream supply chain processes (Zhu et al., 2018).

2.2.3 Purchasing and LCM

An increasing grade of outsourced processes in the automotive industry has made the purchasing role increasingly important (Monczka et al., 2015). Already in 2007 around 60-70 percent of the total manufacturing costs of an automotive were spent on the purchasing of materials (Koplin et al., 2007). The suppliers to the automotive manufacturer are thereby contributing to a high grade of the emissions related to the production of the vehicle. The purchasing department becomes the supply

chain function that is creating the link between the supplier and the customer, and it is the purchaser's role to find new suppliers with the correct performance requirements to satisfy the needs of the internal customers within the buying organization (Monczka et al., 2015).

It is the purchaser's role to identify the key sourcing requirements and to reach supplier agreements to fulfill these needs, hence the purchasing has a vital role in the environmental performance of a product (Monczka et al., 2015). This is also the reason why Baumann and Tillman (2004) describes the purchasing division as having strategic relevance in the environmental performance of the final product. If a large portion of the suppliers is chosen without environmental performance criteria, the total emissions may be out of control for the manufacturing company. It is becoming more common that companies are collaborating with the suppliers to a higher degree than having arm-length relationships only including price negotiations (Moser, 2007), making it possible for the for the actors in collaboration develop processes to increase the performance for all included partners (Monczka et al., 2015). In order to succeed with the collaborative processes and to align business goals, the buyer and supplier need to share objectives, knowledge, information, build trust and be efficient in conflict management. Instead of looking at the currently available market offers of products and services, companies have started to evaluate suppliers and their capabilities (Odgen et al., 2005). This lets the buying company analyze how the sourcing of the supplier would suit the company's overall strategies (Weele, 2002). Different organizations are in need of different supplier capabilities, for some organizations the cost may be of highest priority and in another case, the buying firm may require an innovative supplier that is flexible against market changes (Araujo et al., 1999).

2.2.4 Transportation and LCM

Another part of the supply chain that is the main contributor to the environmental footprint, mainly GHG, is the transportation of goods (Bauman et al., 2004). The amount of emissions originating from transportation of goods depends on several factors, for instance, the fill rate and transport mode. According to Vanek & Morlok (2000), the globalization has made the transport sector the fastest growing sector when it comes to energy consumption. With an increased level of globalization and a higher grade of complexity in the supply chains, transport distances are becoming increasingly important to consider in the LCM work. To make an LCA analysis including CO2 emissions from the transportation steps a mapping of the supply chain actors is needed (Bauman et al., 2004). In order to create an exact mapping including the total transportation distance, it necessary to consider the whole route as well as the entire logistical system that have an impact on the total distance. It is difficult to make changes in how effective the transportation is regarding emission per kilometer, but on the other hand, changes can be made regarding transport mode or transport distances that have a huge impact on the overall transportation emissions.

2.2.5 Environmental supply chain

Jüttner et al. (2003) and Moser (2007) describes that there are large risks associated with a company's supply chain that must be considered. In recent years, OEM's have suffered economic losses and poor reputation due to environmental scandals that has taken place at a supplier level in the upstream supply chain (Caniëls et al., 2013). To avoid these problems, it is of great importance to engage with the suppliers and develop joint objectives that influences the supply chain actors (Smith, 2013). Especially environmental risks are critical to consider since the environmental performance are becoming increasingly important for the end customer. One scandal that was widely featured in media was the Volkswagen scandal, where Volkswagen made the choice of fouling statistics of how well their vehicles performed in environmental terms instead of actually improving the

environmental performance of their vehicles (Li et al., 2018). This lead to several negative effects for the company and the brand became widely connected to this scandal. It had a major impact on both the suppliers and customers' image of the brand (Tankerslev, 2015). Lack of transparency in complex supply chains makes it difficult for an OEM to know to what extent environmental damaging processes appear in upstream supply chains. To decrease this risk, many OEM's are working with supplier management to deal with environmental issues (Young et al., 2001). Common requirements and policies that the company is using to influence the upstream suppliers are environmental standards such as *ISO 14001* and *Environmental Management and Audit Scheme* (EMAS).

In contrasts to the risks with not using LCM on a supply chain basis, the potential opportunities with doing so are many. One of the opportunities that a company can gain from better environmental management is the possibility to differentiate the brand through environmental marketing (Linder, 2013; GHG Protocol, 2018). Customers are increasing their interests in documentations of emissions reductions, thus improvements of environmental processes within the supply chain as well as documented emission reductions on these can differentiate the brand and fulfill customer requirements (GHG Protocol, 2018). Furthermore, utilizing a comprehensive emission reduction approach provides incentives for innovation in product development and supply chain management (ibid). The environmental performance of processes often correlates with factors considering the efficiency of the operations within a factory, so by improving the environmental management applications, gained operational efficiency and sometimes reduced costs can be a positive outcome (ibid.). Moreover, Laari et al. (2016) describes that environmental improvement work across company boarders makes it possible to improve stakeholder relations and also improve economic efficiency. According to Srinivasan (2011), close collaborations with suppliers that are built upon trust and cooperation have positive effects on the supply chain performance. This makes it easier to understand both parties' objectives and to take use of each other's competences. Several studies within the manufacturing industry shows that environmental performance work with supply chain processes has not only improved environmental efficiency, but also economic efficiency and costs (De Giovanni et al., 2012; Rao et al., 2005; Zhu et al., 2013).

2.3 Environmental assessment standards

The United Nations (UN) and the European Union are constantly requiring new environmental standards. The automotive industry is especially affected because of the environmental impact of this sector. Below the current ISO standards for environmental certifications and the *Carbon Disclosure* Project (CDP) will be addressed.

2.3.1 ISO 14000-series

Companies all around the world are currently using environmental management systems and standards as environmental quality proofing (King et al., 2005). To generate value from the environmental processes Finkbeiner & Springer (2011) recommends ISO-certifications as a way to communicate the value of the environmental processes towards the customers.

ISO 14000-series is a widely used environmental standard both taking an organizational approach and a product approach. ISO 14001 has become the most well-known standard to confirm a company's environmental management and for a company to match the requirements of having an ISO 14001 standard, several guidelines have to be followed, which explains the efficiency of the

environmental management work (ISO, 2001). Together with ISO 9001, this is one of the most widely used certifications in the automotive industry.

Another environmental certification that has been developed during the last years is the *ISO 14044* standard, this is a certification saying that the company is analyzing the life cycle of their products from cradle to disposal (ISO, 2006). To get an ISO 14044 certification it is needed to perform the steps explained in chapter 2.1.1 in a detailed manner (ISO, 2006). Compared to ISO 14001, the difficulty to get this certification correlates to the complexity of the physical product. As described, a higher complexity means that more data needs to be collected and analyzed.

Another new certification that has been developed by the International Organization of Standardization is the new *ISO 14067* standard (ISO 14067, 2012). ISO 14067 makes it possible to see that the organization in mind has used trustable and standardized calculation methods to calculate the total carbon footprint load in the life cycle of a product or service. Except for the quantification of CO2 data this standard covers the communication of carbon footprints to customers. For an organization to be able to get ISO 14067 certified the organization shall have an external communication report and a carbon footprint performance report, serving as selection criteria for the customers. The ISO 14067 methodology is based on other ISO standards such as ISO 14040 and ISO 14044, the earlier described standards for life cycle assessment, but also standards in the ISO 14020 series, which are standards for environmental labels and declarations for communication. The standard ISO 14067 is aiming to increase the credibility of carbon footprint calculations and to increase the transparency in the supply chain, to in this way inform the buyer about environmental selection criteria.

2.3.2 CDP Supply Chain

The Carbon Disclosure Project is an impartial organization working with the gathering and analyzing of data to create better decision-making material for decision makers with the aim to make organizations aware of the advantages of using sustainable business strategies (CDP, 2018). CDP is in this way working as the link between decision makers and disclosures, see *figure 5*. The company decision makers are using the data gathered by CDP from different companies, states and municipalities to create a better understanding of how people's awareness of climate change will affect risks and create financial opportunities for firms.

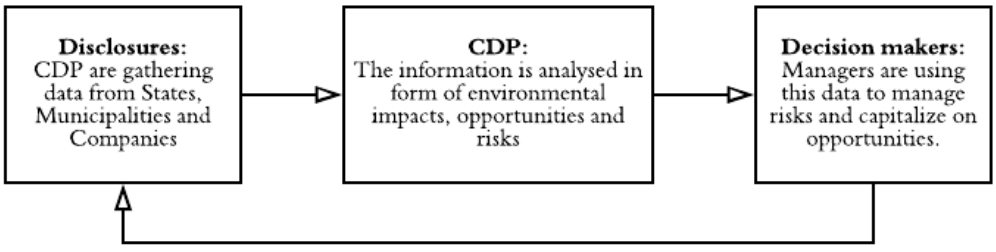


Figure 5. How CDP are linking the disclosures with the decision makers (CDP, 2018).

The Carbon Disclosure Project has during the last couple of years increased the international work to push for supply chain actions connected to decreasing carbon dioxide equivalents (CO2-e) and climate change (CDP Supply Chain Report, 2018). The GDP Supply Chain Report shows how the purchasing department can be engaged to push for actions that contribute to lower carbon footprints in the supply chain. In this report, several supplier organizations were interviewed with questions

regarding the engagement of environmental work in their supply chains. The results showed that only 23 percent of the included organizations are taking a supply chain perspective in their environmental work. This means that the companies are missing opportunities to decrease their environmental footprint, create competitive advantage and gain financial savings. According to the CDP (2018), the integration of sustainability criteria into the purchasing division is effective to ensure environmental improvements in the supply chain. Moreover, CDP describes that capacity and awareness building and peer-to-peer learning often are characteristics in well-functioning programs where companies are engaging their suppliers.

2.4 Contribution

The previous sections in this chapter provided an insight in what the literature states about LCM and how it could be applied within an organization. As described by Sonnemann (2015) and Baumann & Tillman (2004), current research is mainly focused on how LCM could be implemented within organizations on a general basis. It does not address the issue on how to manage and influence an organization's suppliers to thereby control the environmental impact of the upstream supply chain. There is also limited research on how LCM could be applied to different contexts such as the automotive industry. Further, the current literature states that there are issues regarding internal synchronization of LCM within organizations and how to address these issues to influence the entire product life cycles (Nilsson-Lindeén, 2017).

This research use literature about existing LCM practices and compares it to how an automotive manufacturer is currently working with LCM. In this way, this research gives a unique contribution of how a specific automotive manufacturer, working in a complex supply chain environment could develop LCM practices to improve the environmental performance in the upstream supply chain processes. A framework of how an automotive manufacturer could manage their suppliers in the upstream supply chain to map and reduce the environmental impact in the early stages of the product life cycle.

3. Methodology

This chapter describes the method and structure for this specific study. The chosen research approach is presented, followed by the research strategy. Secondly, how the data was collected and finally, the method behind the interpretation of results is discussed.

3.1 Research strategy

Bryman and Bell (2003) describe a qualitative research strategy as an in-depth investigation of a specific field where the data is based on sayings rather than numerical values collected from a sample, thus a qualitative research is non-numerical. The collection of qualitative data is commonly done through observations and used when there is a motive for understanding a certain behavior or phenomenon (Bryman and Bell, 2015). Bryman and Bell further argue that by using a qualitative strategy, the study becomes more flexible since it enables the researcher to react to changes during the investigation. The data and material are collected until a conclusion can be made and no further data is required. The purpose of this master thesis is to investigate how life cycle management could be integrated into different functions within an automotive manufacturers organization, to make automotive manufacturers increasingly aware of the environmental burden of a vehicle. Thus, to be able to answer the research questions, a qualitative research strategy has been chosen.

Bryman and Bell (2015) mentions two different research strategies, a deductive and an inductive. Inductive strategies are often related to qualitative research. Having an inductive approach means that the researchers are using observations to search for patterns and generate theories through analysis and hypothesis (Bernard, 2011). Inductive reasoning uses detailed observations of the worlds, which later on are developed to be more abstract generalisations (Neuman, 2003). Lodico et al. (2010) describes that inductive reasoning takes use of a bottom-up approach to create abstract ideas or pictures of the studied phenomenon. This report has a bottom-up approach starting with *Observation* which are analysed through a *Pattern* and developed to *Theories,* see ***figure 6.*** By using a bottom-up approach and combining it with an industry perspective with real case company interviews, it is possible to identify the current issues, and to come up with recommendations that are well grounded with both theoretical and practical insight.

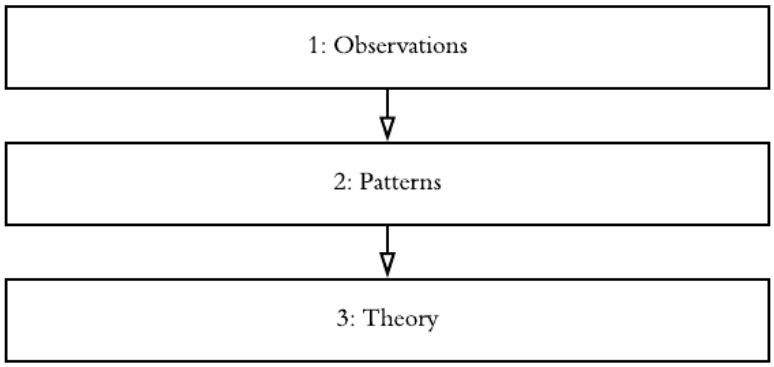


Figure 6. The bottom-up approach used for an inductive reasoning.

3.2 Research design

Research design can be described as the collection and analysis of data (Bryman & Bell, 2015). The initial phase included a literature review about the concept of LCM and LCA to serve as a base of how to formulate interview questions to Company X. After the first round of interviews had been conducted, the literature where reviewed once again based on the findings from the interviews. After that new interview questions could be formulated, and further interviews were held. This was an iterative process that continued until an analysis could be done and a conclusion stated. See *figure 7*.

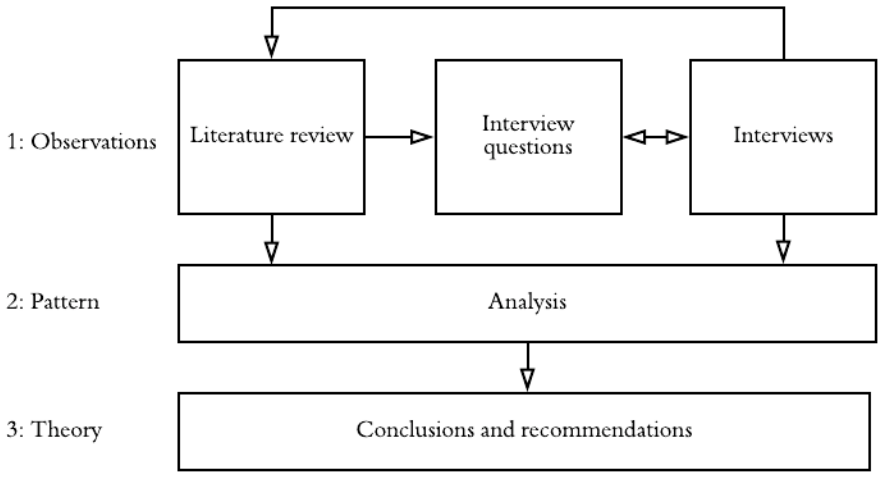


Figure 7. Illustration of the research design.

3.3 Data collection

According to Yin (2014) it is of importance to have a wide spread of sources to prove the validity of the research study. To have multiple sources makes it possible to make an impartial decision about the information that is given. In this study, three different approaches of data collection were used. Firstly, primary data was collected through interviews and testing of quantitative data collection. Secondly, secondary data was collected to get an insight in current environmental tools and certifications. Finally, literature was collected from research databases and libraries to give input to existing approaches and methodologies.

3.3.1 Primary data

The research strategy for this master's thesis was mainly of a qualitative nature where the majority of the data was collected through interviews. When conducting interviews for a qualitative study, semi-structured interviews is a commonly used technique where the interviewers conduct a framework with questions to ask the interviewee (Bryman and Bell, 2011). The order the questions are asked in are allowed to vary and during the interview, questions might be added or neglected depending on the discussions and answers (ibid.). This gives the interviewee and the interviewer a higher degree of freedom if other questions arise along the interview and thus leads to important findings that might otherwise have been left out due to only fixed questions (Bryman and Bell, 2003). In the beginning of this research, the interviews were more of an unstructured nature in order to get an oversight of the issues within the studied topic. Here the interviewees got to talk freely about their

specific role and connection to the investigated area. The answers given at these interviews served as a basis for coming interviews and directed the questions to be more specific for each interviewee.

For this report, 12 interviews were conducted, a list of the interviews can be seen in *Table 2-4.* Internal workers at Company X, external suppliers to Company X and researchers where chosen as suitable to interview in order to fulfill the aim of the study. The structure of the interviews can be found in *Appendix 1-3*. As described in the research design, *section 3.2,* the interview questions where formulated based on the studied literature, and in the later interviews answers from previous interviews where used.

During the initial phase of this study, interviews were conducted with people at different positions within Company X that were seen to have important knowledge and connection to Company X's supply chain, LCM and LCA. Starting with semi-structured interviews including themes to discuss rather than questions in order to summarize the current situation. This created an insight of the challenges with LCM in the automotive industry and eased the formulation of the questions in phase two and three.

Later on, a structured questionnaire was made to suppliers based on the information gathered in the initial phase of the study, this was based on a sheet and can be seen in *Appendix 1*. The interviewees were held with employees at three different suppliers to Company X. The idea with this was to make a testing of how challenges appears when the car manufacturer request data for an LCA study within specific material flows. The suppliers got asked to collect information about the emissions connected to production processes and distribution flows. Further, to get information about the upstream supply chain and contact information to the next tier of suppliers to enable a data collect from all suppliers upstream in the supply chain. The question sheet was sent to the different suppliers in advanced and followed up with a meeting to discuss the findings. The suppliers were given a time frame of five weeks to fill in the answers. The idea behind this was to make it easier for the interviewed suppliers to describe the challenges and opportunities that appears when gathering LCA data over company boarders.

At the same time, interviews were held in a more structured manner where questions were asked depending on the information obtained from the literature studies and previous interviews. Interviews were held with three different researchers working with the development and applications of LCM and LCA to get a wider picture of how it is used today, how to overcome barriers with LCM and the possibilities with LCM and LCA in the future. Furthermore, employees at Company X were interviewed to get a picture of Company X's current LCM and LCA usage to identify improvement possibilities. Here, employees working at the environmental department and the purchasing department were interviewed. The suppliers who were interviewed in phase two were asked about the barriers of collecting data that can be used for a more specific LCA study and the potential advantages with sharing this type of data with customers like Company X to enable further integration of LCM in the supply chain of the OEM. Before the interviews, the questions were sent to in advance in order to let the interviewee prepare for the answers.

Table 2-4. List of interviewees, the integer on the left side indicates the number of interviews with each interviewee.

No. of Interviews	Researchers:	Interview discussion areas:
1	Industrial PhD Candidate working with LCA within Company X	LCM /LCA professionals were interviewed to first get an overview of the different concepts and to access inofrmation about challenges and opportunities related to LCM in the automotive industry.
2	PhD within Environmental System Analysis (PESA)	
1	Doctoral student within sustainable building technologies	

No. of Interviews	Employees within Company X:	Interview discussion areas:
1	Senior Strategic Advisor for Environment (SSAE)	Employees within Company X were interviewed to get an overview of the current LCM/LCA processes. Employees within the environmental department, purchasing department and logistics department were chosen to get a wide perspective of the current LCM processes from functions that are closly related to environment and supply chain processes.
1	Environmental Manager	
1	Operational Purchaser Hybrid battery (OBH)	
1	Operational Purchaser Plastics (OBP)	
1	Sustainable Logistics Manager	

No. of Interviews	Company X's suppliers:	Interview discussion areas:
1	Supplier - Plastic Bumper Cover	Suppliers were interviewed to asses the difficulties and opportunities that appears when collecting environmental data that is supply chain specific. Three different suppliers were chosen to get an impartial perspective of the challenges and opportunities.
1	Supplier- Metallic Door Panel	
1	Supplier- Metallic Outer Panel	

3.3.2 Secondary data

The secondary data for this study was collected was mainly regarding how to conduct an LCA study, what frameworks and models to use and how they were applicable in different environments and scenarios. The literature was gathered using libraries, Google Scholar and other trustworthy search functions. The literature was gathered in an iterative manner meaning that as the project proceeds and actual data was obtained, the literature was constantly revised. When information was searched for, words like Supply Chain Management, Life Cycle Assessment, Life Cycle Management, Automotive Industry and LCM in Practice were used in combination.

First, general data was collected from sources describing the general concept of Life Cycle Management. The collection of the LCM concept data was based on the amount of citations of different researchers. The LCM data was chosen based on a trade-off between citutions and

publication data, but no major emphasis was put into investigating newer sources related to the subject since most of the research in this area was made during a specific time frame and is still used. When LCA software data was collected bigger emphasis was put into the age of the reports since softwares are rapidly developed. When general data had been collected about the LCM concept, more specific data about how the LCA can be connected to the automotive industry and supply chain management was collected. This to find relevant literature supporting the analysis of challenges, opportunities and how a framework within the industry could be developed.

3.3.3 Data analysis

A prepared framework was used to ease the analysis from the gathered information in the data collection phase. It is important to organise the data after the data collection is conducted in order to gain clearness to enable sufficient data to be analysed and interpreted (Backman, 2008). When analysing data, there are several stages to go through, interviews are commonly recorded and later transcribed so that the researcher can code the transcripts (Bryman and Bell, 2015). Consequently, the interviews in this study were recorded and afterwards transcribed. To understand the data one common approach is to perform a thematic analysis (Bryman and Bell, 2015) which implies that the collected data should be linked and analysed in line with the research questions and the chosen literature. The process of analysing the data enables the researcher to sort out the most sufficient information and interpret the findings into conclusions.

The data was analysed based on how the organization in mind is working with life cycle management, how the focus will shift in regard to future changes in the industry and how the literature suggests how LCM should be integrated into organizations. Since no earlier emphasis has been on describing how automotive companies should work organizationally with LCM, existing literature about general LCM-methodologies were analysed in combination to how Company X currently are working with LCM. By comparing how general LCM-methodologies describes the concept and how it should be utilized it was possible to give an automotive specific description of how Company X could improve their LCM. The questions asked to the different interviewees enabled a comparison between the industry's perspective and the literature regarding challenges, but also opportunities and possibilities with LCM. This analysis provided support when making the recommendations. By taking both challenges and opportunities into account it is possible to give recommendations that are specific for Company X and are taking company and industry specific details into consideration.

3.3.4 Data quality

When conducting research, it is important to consider the reliability and validity of the data (Bryman and Bell, 2015). In order to get reliable results, the credibility, transferability, the dependability and the confirmability of the research must be considered. Credibility is about the number of sources used per citation. To increase the credibility in this research study, several interview objects were chosen within each area of investigation. Three researchers, five employees within Company X and three suppliers were interviewed to be able to analyse the data from different perspectives and thereby avoid a partial view of the specific context. Concerning transferability, the researchers made the choice to focus the research to a specific industry, this means that other actors with similar industry context can transfer the data and apply it to their specific context. In order to increase the transferability, further investigation about LCM within different company contexts are needed to be

able to get a generic model of how companies could use the data. According to Bryman and Bell (2015) dependability means that the output of the data would be the same, independent of the data collection situation. To decrease the risk of dependability, the scenario of "leading questions" was avoided during the interviews by formulating the questions in a way that did not guide the interviewee in any direction that could influence the answers. Lastly, Bryman and Bell (2015) describe confirmability as the objectivity of the research. To avoid that the researchers would miss out on important data as well as misinterpreting the answers, the researches asked the interviewees if audio recording was possible during the interviews, which it was in all cases. This enabled the researchers to listen to the interviews afterwards and confirm what was stated.

4. An Industry Perspective of LCM

In order to answer RQ1, this chapter targets the current use of LCM and LCA within Company X, based on the research Reibizer (2004) states about the use of generic data as well as what Sonnemann (2015) describes as a well-functioning LCM strategy. The chapter further targets the challenges and opportunities with integrating LCM in the uppstream supply chain at Company X as well as in the automotive industry in order to later analyse and answer RQ2. This chapter also provides a base to the reasoning in the later chapters describing the answer to RQ3.

4.1 Current LCM Strategy

During an interview with a *Senior Strategic Advisor Environment* (hereafter referred to as SSAE), it was stated that Company X applied LCA already during the mid 90's. Later on, top management decided to make strategic changes and the LCM-program was let down. These processes were not re-initiated until the late 00's, hence there are no deep organizational roots of LCM. The current LCM-operations are performed by the Environmental Department. During an interview with the environmental department and three of Company X's Environmental Managers questions were asked about Company X's current LCA and LCM strategies. The environmental department is working with LCA in an early stage of the product development process in order to be able to compare different designs and materials environmental impact. According to the Environmental Managers, Company X is mainly using LCA analysis to make comparisons between different materials, for instance, the environmental impact different steel materials. When an LCA analysis is made, Company X collects input data of each component of a car. By looking at the substances of each material in a component it is possible for the environmental department to summarize the total amount of different substances within a vehicle and thus make an inventory analysis. When the total amount of different substances is obtained, Company X uses the EcoInvent database to calculate the emissions by the different materials included in the vehicle. The EcoInvent database takes generic supply chain data into account, and the environmental department states that supply chain processes are included in the analysis, however, since this data is calculated with generic indexes the actual environmental impact can differ to a significant extent.

4.1.2 LCM and Supplier Management

According to an Operational Buyer within plastic flows, Company X's *Supplier Quality department* (SQM) is sending out *Supplier Assessment Questionnaires* (SAQ) to get an indication of how suppliers are performing in certain areas that are of special of interest for Company X. In the questionnaire, issues associated with sustainability and environmental aspects are included. When Company X are selecting suppliers, they are doing *Manufacturing Site Assessments* (MSA) were the SQM group are visiting the suppliers' production sites to get insight into how the operations are performing according to Company X's requirements. The assessment also includes a checking of how a supplier, in turn, chose suppliers, however, specific supply chain information is normally not shared between the actors. The Product Development function at Company X has commonly the last saying regarding the supplier selection. This function decides if the supplier criteria are qualitative enough to support the final product. Company X is not using LCA requirements as selection criteria, instead, ISO 14001 is used as environmental assessment requirement.

During an interview with one of Company X's *Operational Buyers of hybrid batteries* (hereafter referred to as OBH), the sourcing of the batteries and its environmental footprint was discussed. The

battery includes an enormous number of different components and materials and are assembled by a supplier in Korea and then shipped to Company X's factories. However, the production of the different components within the battery, before it arrives at the assembly, are produced in several different geographical areas. The lack of transparency in the supply chain is making this specific item extremely complex to trace. OBH highlights the importance of including the suppliers in LCM, due to the extensive energy consumption and environmentally damaging processes occurring when producing this item. When the finished battery reaches Company X the energy consumption related to the assembly is low compared to other parts of the chain. According to the OBH, the extraction of raw materials included in the cells are contributing to a large total portion of the environmental footprints emitted by an electric car, during its life cycle. This because the battery cells include several highly alloyed materials that are necessary to generate power to run an electric vehicle.

Furthermore, the OBH describes that the high complexity of the supply chain for a battery creates difficulties when trying to trace the origin of all included components due to the low supply chain transparency. Instead, Company X has set requirements on the suppliers to share upstream supplier information of specific materials, such as cobalt, to avoid the risk that Company X could be associated with for instance child labor since this has been a hot topic in media. The OBH further describes that Company X in the future will need to have dual sourcing of batteries, to minimize risks connected to one supplier as well as to be able to supply the Chinese market since China has set tollgates to obstruct vehicles made in other countries to enter into their automotive market. This issue may duplicate the complexity of hybrid battery sourcing and makes the supply chain of a hybrid battery even more complex to investigate and control in LCM terms.

During another interview with an *Operational Buyer for Plastic flows* (hereafter referred to as OBP) the connection between LCM and purchasing was further discussed. The OBP agrees with the OBH, that Company X has limited insight and knowledge of the different supply chain processes, however, Company X has as stated earlier, environmental requirements on their suppliers that is ought to permeate the whole supply chain, *see figure 8*. According to the OBP, the lack of control of upstream supply chain flows is a risk that has to be considered when making the choice of outsourcing processes or having the processes in-house in the first state.

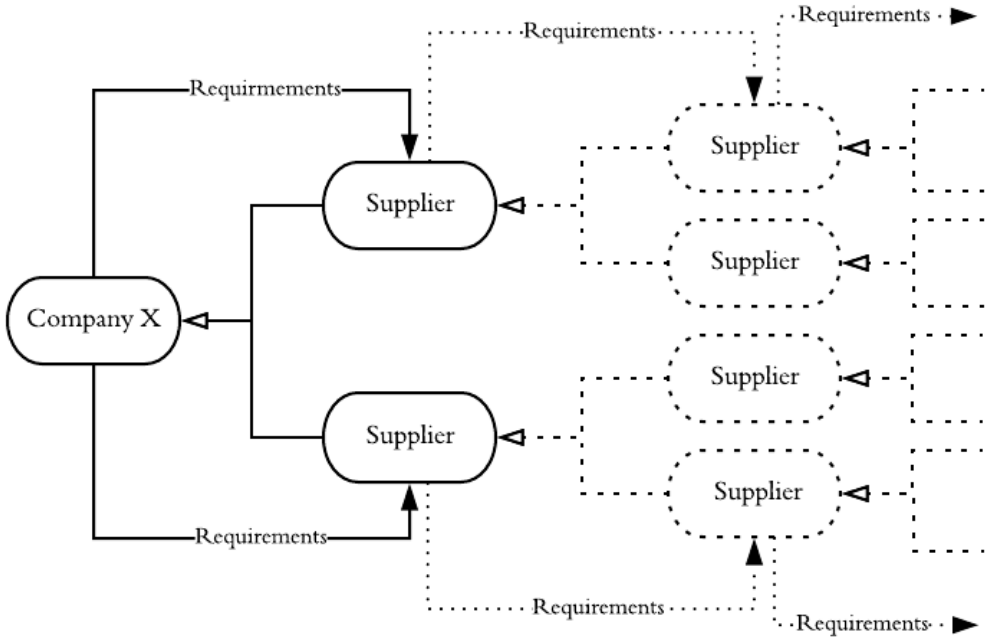


Figure 8. Simplified supply chain tree describing how Company X sets requirements on their first-tier supplier to influence the entire supply chain.

During another interview with a Senior Strategic Advisor Environment (hereafter referred to as SSAE), it was described that Company X has a paragraph in their supplier contract giving Company X the right to request environmental data about their processes. This data is not process and component specific, rather it covers the overall company emissions. This creates an uncertainty in how much emissions that relates to the process flows producing components and materials for Company X. The SSAE describes that process specific data probably won't be accessible in the nearby future, due to confidentiality reasons or the difficulty of finding the person possessing this information at the supplying company. However, it was explained that people are now starting to ask for supply chain specific information in some flows, especially for flows with strategic importance such as the hybrid battery, since people are questioning the difference in environmental impact for a normal combustion engine compared to an electrified engine.

Moreover, the SSAE describes that many of their suppliers are big actors in the automotive market where many of them have clearly defined environmental policies themselves. Last year during a conference, 80 of Company X's bigger suppliers were invited to discuss the suppliers' current environmental program. It was shown that many of the suppliers had come even further in improving their environmental performance by developing new strategies compared to Company X. According to the SSAE, this implies that Company X can learn from some of their suppliers in the chain that possess a greater knowledge regarding specific processes and thereby improve Company X's own environmental strategies. The SSAE additionally states that if Company X in the future wants to further differentiate on the market in terms of being environmentally responsible to their consumers, it is important to have a great knowledge about not only Company X's own processes but for the supply chain processes as well due to the risk that this would be investigated and asked for by the society. If Company X would market themselves by having a strong environmental profile yet not

have full knowledge about their environmental impact in all stages of a vehicles life, it is a risk that the company could lose credibility amongst its customers.

4.2 Future LCM Strategy

During an interview with a person whom has a Ph.D. within *Environmental System Analysis* and works at Chalmers University of Technology (hereafter referred to as PESA), the future development of the automotive industry was discussed. According to PESA, the environmental work within the automotive industry is today mostly about decreasing the fuel consumption of the car during the user phase due to the fact that when driving a car, a large number of greenhouse gases (GHG) are emitted see *figure 9*. However, if considering the electrification of vehicles, the focus of decreasing the environmental impact during the user phase of the car will shift. An electrified vehicle only emits a low amount of GHG during its user phase, since it is not powered by fossil fuels. According to PESA, the shift towards electrification changes the environmental focus drastically from the user phase to other phases of a car's lifecycle. PESA states that it might even be that the battery production would represent 50% of the emissions over the vehicle's entire life. In comparison to a vehicle with a standard combustion engine, it requires a new focus on which phase of the life cycle the majority of the emissions will occur. This is something that may affect how we are looking at the environmental footprint of a car. SSAE and an Industrial Ph.D. Candidate employed by Company X agrees with this statement that electrification will pass the emissions from user phase to other phases in the life cycle and stresses the importance of increasing the focus on environmental impact in the upstream supply chain.

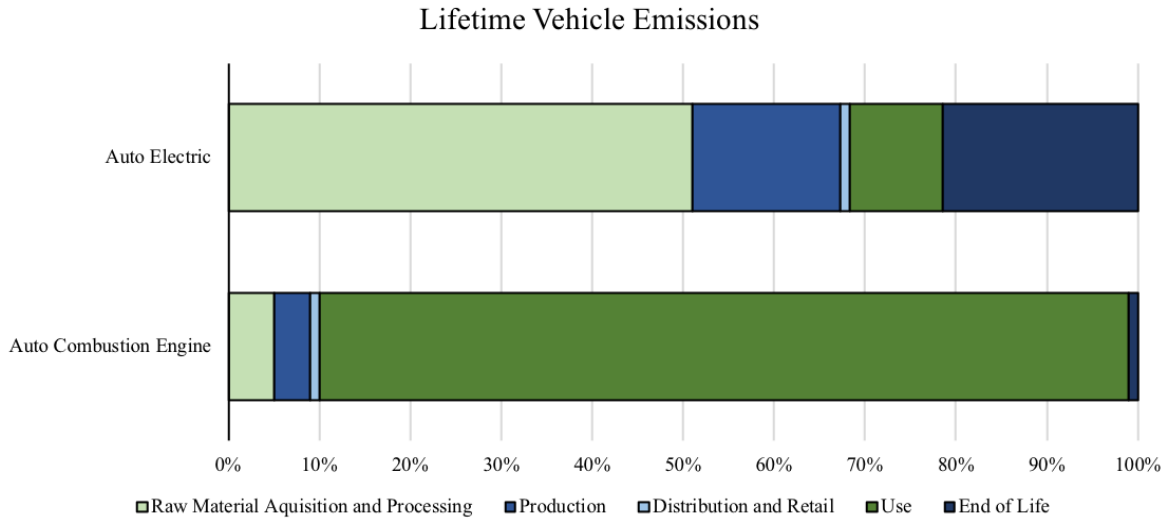


Figure 9. Possible emission change in the LCA of a car when going from a normal combustion engine to a electric engine. Based on Bosch et al. (2011) and the PESA interview information.

The OBP describes that supply chain transparency regulations may come for specific flows with high grades of emissions in the production processes, such as for the hybrid battery flows, due to the products characteristics mentioned by the OBH. The OBP also states that that it will probably be less prioritized to set stricter requirements within plastic and metal flows, compared to requirements on hybrid batteries, since the production of the hybrid battery will be one of the major contributor to the environmental footprint of a vehicle.

SSAE describes that Company X are currently not reusing their product parts when a vehicle is in the end-of-life phase. Instead Company X are purchasing all components from their suppliers, since the vehicles are sold to the buyer it is difficult to get in contact with parts that can be recycled or reused from old vehicles, see *figure 10*. Moreover, SSAE further describes that in the future, a shift from the consumers side of owning vehicles towards leasing vehicles will be more common, which means that Company X will remain as the owner of the vehicles. In this situation, it will possible and open up for opportunities to recycle parts within the vehicle and use them either as spare parts or for parts that supports the production of the vehicle. This requires a change in how Company X in the future will source their material, since less sourcing will be necessary. Instead Company X have the opportunity to use parts that are still of good quality and thereby extend the life of some components.

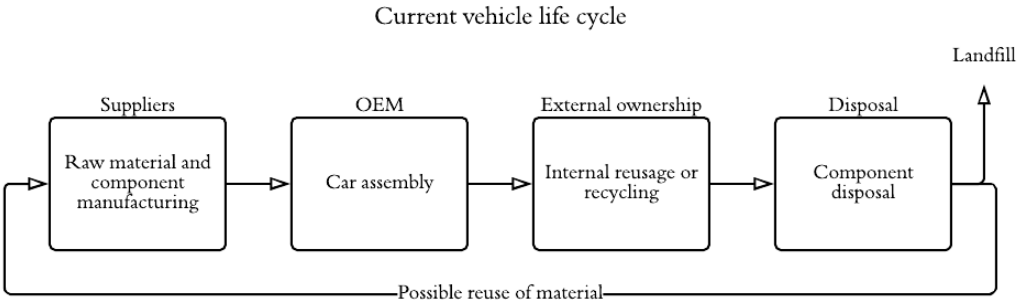


Figure 10. Life cycle of a Vehicle today.

SSAE describes that, Company X's department who work with Product Creation are working with the identification of improvement areas of a product's life cycle, both for the current state and for areas in the future that might be stricter regulated. The main focus right now is areas connected to the electrification transformation. The purchasing department has now joined the product creation phase and Company X has chosen to in the future have a life cycle perspective that concerns the production phase on a supplier level. Furthermore, SSAE describes that it is unlikely that a supply chain analysis including all supply chain processes will be conducted in the near future, however it is likely that continuous hotspot analysis will be performed to decide which supply chain processes that are of main concern to analyse further in terms of environmental aspects.

4.2.1 Challenges with LCM

This section gives an insight of researchers, Company X's and suppliers views of challenges that are connected to upstream LCM in the automotive industry.

A researcher perspective

During interviews with researchers, it was shown that the main challenge with integrating LCM was related to LCA. One of the most important parts when conducting an LCA study is the goal and scope definition. A doctoral student doing research within LCA stated the importance to make clear and defined limitations when conducting LCA studies in the automotive industry. Even though some parts are fairly simple products with a few ingoing components, it is an extensive task to make a total mapping of the material flow from raw material to finished part and calculate the total environmental footprint. In general, it is often underestimated how complex an LCA study actually is. Not only the

study itself but also how to make system boundaries since if these are not made properly the analysis can continue forever.

Further, PESA stated the importance of having valid and accurate data in the LCA analysis and the difficulties of finding this type of data. It is also important to analyze and criticise the data that is included in LCA calculations to make valid estimations. In many cases, it is possible to get information about the specific plant's emissions in environmental reports, but in order to use this data, it is important to find out what portion of the data that is connected to the specific product. The optimal case would be to obtain data about energy consumption related to the specific machinery that contributes to the processing of the final product, this information is often difficult to get since it could be sensitive to share or the data is not generally measured by the supplier, thus researchers tend to use estimation methods. PESA describes that one way of allocating emissions to a specific product is to look at the economic flows and cost structure since the amount of energy consumed in a process often correlates to the value of the product. The more intense energy consumption the higher the value of the product. However, this information is often difficult if not impossible for companies to get from their suppliers since it exposes the companies cost and pricing strategies.

Company X's perspective

Currently, Company X is using generic methods based on open databases. This means that the data is non-specific for their suppliers resulting in that the results the LCA analysis provides can differ to a great extent from how it actually is in the specific processes. By other means, SSAE confirms the problem with generic data as discussed with PESA. SSAE also describes the difficulties to get specific emission data that is beyond the first tier of suppliers.

According to OBP, another obstacle of requiring environmental data is the power position Company X has against some of its suppliers, in this sense the difficulties to increase the requirements on suppliers who have a better power position than Company X becomes a challenge. OBP states that to increase the environmental requirements on suppliers depends on the power balance in the relationship. Thus, if Company X does not have the purchasing power, meaning that if the automotive company is a smaller customer for the supplier than other companies, it will be difficult to have a specification requiring the supplier to provide a specific type of environmental data as well as to increase their environmental performance in specific processes. Moreover, another risk stated by OBP is if Company X would set higher environmental requirements on their suppliers, there will be fewer suppliers that are qualified when the SQM department conduct their supplier assessments, this was additionally confirmed by SSAE. SSAE stated that the supply of some products is limiting the possibilities for Company X to prioritize suppliers in consideration to environmental aspects if there are few available suppliers on the market.

A supplier perspective

Three different suppliers were asked to collect data required to map the supply chain of a specific flow and to conduct an LCA study. The data that the suppliers were asked to collect found in Appendix 2. After that, they were asked to express the challenges of gathering and sharing the data. For the plastic flow, a supplier delivering bumper covers to Company X was interviewed. The bumper covers are produced in one of their sites in Poland and thereafter shipped to the Company X's factory in Gothenburg. The first challenge mentioned by the supplier concerns the sensitivity of some information, for instance, the contact information of their suppliers. It was stated that this kind of information is more or less regarded as confidential. According to the supplier, what makes it especially difficult in this case is due to the topic of this study. Moreover, the interviewee said that

the only communication the company itself has with the supplier is for business reasons and nothing else, therefore it could turn out to a non-pleasant situation for the supplier if they would provide contact information considering the purpose of this study. The second obvious challenge was the time it took to gather the data. The interviewee was in contact with more than 10 different people at different locations and positions at sales, purchasing, logistics, and engineering. It was stated that it was extremely time-consuming to gather the data. The third challenge was to find process specific data, for instance, emissions released in specific processes. The interviewee could not find this information in the given time period, further, it was stated that it is a large possibility that the data asked for had not been measured.

The second supplier delivers steel to Company X. The supplier is located in the Netherlands and the material is sent to Company X in the shape of metal roles to become outer panels. At Company X the rolls are later processed to the finished item. According to the supplier, the steel production processes are similar in other steel producing factories, thus it is possible to make comparisons between different steel producers and make quite accurate estimations of LCA data. This specific steel producer is connected to World Auto Steel, which is the automotive part of World Steel Association. According to the supplier this association supplies the automotive steel producers with information regarding the automotive industry's needs, for instance through support in LCA calculations. According to the supplier, the supply chain of steel is changed depending on the current world prices of different raw materials included in the metallic mix. This means that one day the iron may be bought from a supplier in Sweden and the next day the iron may be extracted in China. The supplier states that this has a minor effect on the environmental impact, since the production of steel is more or less the same all over the world, however it may have an effect on the emissions connected to the distribution processes. When considering the emissions related to the distribution of steel in regard to the production, is just a fraction of the total emissions, thus this part is not prioritized to investigate further in. Regarding the challenges of collecting data, the supplier of steel to outer panels stated that to have a supply chain specific analysis and mapping would require an update every time the supply structure is changed, and in the end, it would have negligible impact in the analysis.

The third supplier delivers steel to the door of the vehicle and is also a member of World Auto Steel. At this company, a person working with R&D and LCA was interviewed. According to this supplier, LCA analysis is an important part of the development of new materials within the company. The aim of their LCA analysis is to improve the environmental performance for both themselves and for the companies they supply to. The production of steel is very energy consuming which makes LCA an important tool to use in order to find hotspots in the production and thereby find improvement areas. Another reason for why the steel producer has used LCA for a long time is to drive innovation. According to the R&D worker, car producers has during the last years asked for as light material as possible to reduce the weight of the vehicle. LCA helps to compare different materials and their environmental impact during the vehicles life cycle. The interviewee at the steel company states that they see no disadvantages with sharing LCA data with clients since this in many cases is necessary, however, it was stated that the data they can share with their customers are approximations of the environmental impact. To share too detailed information would be like sharing the recipe of Coca-Cola, i.e. reveal corporate secrets. According to the interviewee at the steel supplier, another factor that contributes to why suppliers, in general, might be reluctant to share more specific information regarding their environmental impact is since it could result in that the customers chose suppliers with better environmental performance.

4.2.2 Opportunities with LCM

This section describes the opportunities mentioned during the interviews with the different interest groups.

A Researcher's perspective

According to PESA, it is important to have a life cycle perspective so that a life cycle mentality permeates the whole organization. Over time, a company should build up an understanding towards their suppliers so that they, in turn, understand why it is important to have a life cycle thinking and a solid LCM approach. Here, purchasing has an important role to play, since this division most often has the best connection to the suppliers and often are setting the requirements. Most commonly, the environmental requirements become sort of an "add-on" after everything else has been decided. When looking for new suppliers or evaluating existing ones, it is usually cost and quality that is the main drivers of whether to keep a supplier or not, the environmental aspect still has a very low significance in the end. The environmental aspect should be a fundamental part of choosing suppliers; this is why it is important to make purchasers involved since they usually are the ones with the closest connection to the actors upstream in the chain. They could in collaboration with the suppliers work towards increasing the environmental performance. This is important to create a better understanding of how a company's supply chain affects the total emissions during the products life cycle.

PESA states that it is not necessary to collect LCA data for all suppliers if the company tend to change suppliers often for a specific component since the production of a certain material or part will be more or less the same regardless of supplier. It is only important to have an understanding of the product system, in general, to be able to make an estimate of the environmental impact. LCM is a long-term approach and the main goal is to always improve and have the ambition to integrate it into every aspect of a company. The aim should therefore be to set higher priority to LCM in the decision-making processes.

When asked what kind of incentives PESA believes to be necessary to integrate LCM within a car manufacturer organization, the interviewee states that it is a tricky question with no simple answer. However, a crucial part of it is to start a debate about it within the company, especially at departments connected to the value chain. PESA suggests implementing an internal LCM learning process. Thus, at the purchasing departments, it is important to make the purchasers understand how they can apply LCM and their strategic role towards stretching LCM to suppliers. The internal learning process of LCM can be developed and implemented if it is regarded as a business goal for a company. If a company market themselves as environmentally friendly or sustainable, they must have good knowledge of what impact their environmental strategies actually has. In general, it is important to make every actor on the market aware of environmental issues in a deeper sense.

It is currently a debate whether to standardize LCA measures, which would make it possible to easier spread the tool and to transfer data and results between different actors in the supply chain network. However, according to PESA, this must be done with caution. If for example EU would create a standard for LCA and create guidelines and requirements in regard to that standard, the risk is that you "lock in" a way of executing an LCA analysis which is problematic due to the complexity of it. A Product life cycle is very much unique depending on which industry or product you analyze. If standardizing too much there is a risk that you only allow a certain way of executing LCA analyses and from that extract a specific type of data and indicators. Nonetheless, in some cases, this could be

beneficial since it enables comparison between products and materials in a unified way. It is important to understand that when considering standardizing LCA it becomes more like an environmental certificate you will standardize, not the tool itself. Currently, the debate is often about how to standardize LCA, but that is problematic because it might harm the research. Some people might think this is just a question of terminology, but it is of main importance to understand what is actually meant with the standardization, otherwise, people in EU and the industry, as well as researchers, will talk about, and sometimes mean different things when they discuss LCA. An LCA analysis does not provide answers such as this product is better than that one or this product is worse in environmental terms than another. An LCA analysis has many dimensions and rather provides an understanding of different products characteristics and qualities. The problem is that if you only use LCA in a specific way, there is only one set of rules on how to apply it, which limits the research as well as the development. The interviewee suggests that within the automotive industry, it is better to set guidelines and policies for the industry on how to use LCA rather than to put requirements on an EU level for how to conduct and use an LCA analysis.

An industry perspective

When the suppliers were asked what opportunities, an organization could gain from sharing emission and material data with their customers it was stated that it potentially could result in innovation through collaboration together with the customer where the two parties could strive towards a common environmental goal. Another opportunity said by the supplier is to be transparent towards their customers and always improve their environmental performance, both on an operational and strategic level so that the customers can be assured that it is a sustainable company.

Supply chain transparency was also discussed with the operational buyer for plastic components and SSAE. According to SSAE, it is difficult to get access to more information about the environmental processes in all steps further up in the chain, since it may be sensitive for the suppliers to share this kind of data. It is therefore important to use contracts to set requirements and thereby limit the environmental impact upstream in the supply chain since it according to SSAE is possible to control the set of suppliers that their own suppliers are choosing by contracting certain supply chain requirements.

5. Analysis

This chapter lists the main challenges and opportunities that appears when analyzing theory, researchers comments and Company X answers to the implementation of environmental LCM in the upstream supply chain. Both challenges and opportunities with upstream LCM are chosen based on what the authors experienced were the most critical points, after qualitatively have analyzed existing theory and material from the different interviews. This chapter targets RQ2, about the challenges and opportunities with upstream LCM in the automotive industry.

5.1 How to Overcome Barriers with LCM

Different types of challenges to conduct an LCM with an integrated supply chain focus were obtained during the different observations made in this study. The coming paragraphs discusses the different challenges one by one and the possibility of to overcome these challenges, the different challenges are summarized in *figure 11*.

Figure 11. The main identified challenges when integrating LCM into an automotive manufacturer.

Transparency

Transparency was one of the most frequent mentioned challenges when interviewing employees within Company X and researchers. As described by Zhu et al. (2018), better supply chain transparency makes it possible to monitor the upstream supply chain processes. The optimal scenario would thereby be a market with available data about a product and company with full transparency between the different supply chain stakeholders, to make it possible for the OEM to monitor the entire supply chain. In this way, a company could easily access important information from upstream suppliers and be able to take action when it is critical. Moreover, this would enable companies to make full mappings of their supply chains and obtain data related to each specific part of the chain and it would thereafter be possible to conduct a hotspot analysis to identify the flows that should be of main focus. Today however, as stated by the OBP the most common scenario is that companies tend to only be aware of the processes in the first step of the supply chain. In current state within

Company X the tiers beyond the first suppliers are only "controlled" by the requirements that the company is giving to the first tier of suppliers.

The reason for why the current situation remains is because the infrastructure of the system where transparency historically has been less prioritized since companies tend to mostly focus on their own processes, especially in environmental aspects. Now when different stakeholders such as the society and customers start to demand increased transparency it becomes difficult for some actors since this information and data could be a possible disadvantage to share. Suppliers, in this case, are concerned to reveal what they are referring to as sensitive or confidential information. The information that the suppliers would be required to share with Company X to enable a supply chain specific LCA-analysis, would for example be information about the supplier's suppliers. This information is necessary to make it possible for the OEM to trace emissions about transports and production processes further up in the supply chain. One of the risks, from the supplier's side, with sharing this information could the fear of the scenario where Company X use the information of the upstream suppliers to potentially skip unnecessary middlemen as stated by the OBP and do direct sourcing and in-house production instead of outsourcing to the supplier in mind. As stated by the R&D department at one of the bigger steel suppliers, emission data is often not shared between the suppliers, since the supplier sees the risk of losing their buyer to other suppliers that are using more environmental friendly energy sources.

Furthermore, it was discussed during the interviews that some suppliers, in this case the steel suppliers, were changing their suppliers depending on the world market of raw material to produce steel. This means that instant updates moving downstream the supply chains are needed for the OEM to get full transparency of the flows. As said by the steel supplier, the processes will not differ that much between different raw material extraction sites and their processes' emissions, however the transportation distances will fluctuate, but since the emissions from transporting steel is very small in comparison to the production it is considered negligible.

To increase the transparency and thereby ease the integration of LCM in the chain is closer collaboration and agreements between the parties that enables actors in the supply chain network to share information. Further, a supply chain communication system would in this case be beneficial that provides information about the upstream suppliers and the supplier's suppliers. The current transactional relationships can in this scenario be an issue, not only concerning the updates of supply chain data, but also because of the amount of shared data between the parties.

Time

The time it takes to collect LCA data on a supplier level was also mentioned as an obstacle. This became evident after contacting the three suppliers. In the plastic bumper supplier case, there was an issue to access internal company data. To get in contact with the right people who possessed information and answers to the questions in *Appendix 1* took approximately 7 weeks. In the end, the contact person had contacted more than 10 different employees at the company, still with information gaps that could not be filled due to the time constraint. Depending on the size of the company and the internal information sharing a company has, it is possible that this process will differ from company to company.

To overcome the issues related to time is a difficult task, because of the limited resources for every investigation and the possibility to get access to information. Thus, as explained by Reibizer (2004) it is important to set clear and definite system boundaries. As stated by both PESA and the literature

(Reibizer, 2004; Baumann et al., 2004), to set clear and suitable boundaries is a challenge that goes hand in hand with the time it will take to do a supply chain mapping.

Non-existing data/Data quality

In many cases, the information needed to make a supply chain specific LCA is not available for either the OEM or the supplier. As stated by SSAE, Company X can require the supplier to share environmental data if asked for, but this data says little about the isolated components produced, rather it is yearly reports on total company emissions. Process-specific emissions or factory specific emissions are often difficult to get if these are measured at all. In a factory, it may be that the producer is using several different types of production processes for different types of components going to different customers. The different production processes may have different emission outputs, therefore the total factory emissions are just a number for all processes without connection to the specific products. Hence a challenge is to actually start executing more detailed measures.

Even though it is possible to get data from the supplier it is important to somehow validate the trustworthiness of the data or the quality of the data. In some cases, it may be that the data do not fulfill the aim of the study or as earlier described, an estimation that is far away from the actual number, possibly biased to the benefit of the supplier (Crawford, 2008). It could additionally be different calculation methods used in the data collection processes contributing to a large variation in the results. It was shown in the supplier data collection that for instance, the supplier may have used simplified numbers in their calculations resulting in low data accuracy. In some cases, it might additionally be that the supplier uses other units of measurement or similar, that may confuse the translation to the final calculation.

As described by the OBP, to access qualitative data about specific operations connected to the supplier it is important to set clear requirements on the supplier when it comes to environmental data. Also, in this scenario, it is more difficult to gather supply chain data when having an arms-length relationship with the supplier. A closer relationship could lead to the possibility of sharing certain kind of data, which in turn could lead to that the supplier feels comfortable with for instance collect and share process specific data to the OEM. Even though this would not lead to better control of the second or third tier of suppliers, this may indicate better control of the first tier and give the OEM a better insight in the specific environmental footprint of some of the supply chain processes. As stated by the plastic supplier, to share process specific data is from their point of view not a disadvantage since also the supplier aims at becoming more environmentally friendly. Accordingly, the supplier, in this case, sees an opportunity in getting input from Company X in how their in-house processes could be improved to decrease the environmental footprint of the processes.

Terminology and consistency

Due to the current willingness of measuring a company's total environmental footprint where supply chain activities are included, the life cycle perspective has evidently become increasingly popular. At first, having a lifecycle approach seems fairly straightforward according to the literature and the industry, however as described by the PESA there are several confusions with the concept contributing to an inconsistency of how to apply it in practical terms. It is thereby a need to somehow increase the consistency in the usage of LCM terms in organizations, and to spread a knowledge about LCM.

Another challenge is consistency in usage of the LCM concept. In many cases, people cannot differentiate between LCA and LCM. This creates a confusion and makes it difficult for people to

align with the same goal. In terms of consistency, it is especially important when integrating different organizational functions and stakeholders in the supply chain. As described by (Sonnemann et al., 2015), standardization and consistency are needed to be able to align towards common goals and to be able to utilize each other's resources as much as possible.

Finkbeiner & Springer (2011) additionally highlights the importance of consistency in LCM in order to transfer environmental work to measurements that are tangible for the target groups. To have measurements that are tangible for the target groups makes it possible to differentiate the brand from other actors that are not working with LCM and to make the target groups aware of the current LCM processes to utilize existing resources in a way that can give environmental acknowledgment.

To overcome the problems with terminology and consistency it is important to somehow standardize the LCA-measurements and communicate the LCM work within the organization, nonetheless, if the company wants to stretch LCM further up in the supply chain is additionally important to include external actors. However, to standardize LCA-measurements on a higher level, as described by PESA is not always beneficial. The differences in how LCA-analysis are made keeps generating new innovative solutions and supports product development to a large extent, and to standardize LCA could in this way limit the innovativeness since the LCA will follow a certain structure. Yet it was also shown that the broad usage of different LCA-tools and measurements makes it difficult for companies to choose how to work with LCM and to communicate it within the organization. The terminology used or how people describe LCM is something that seems rather subjective for employees at different functions within Company X as well as for the suppliers. Additionally, it becomes evident that there is a gap in how researchers view LCA and LCM compared to the people interviewed in the industry.

LCM Complexity

All researchers, as well as employees at Company X, stated the complexity of conducting an LCA analysis as well as to understand the dimensions of the study. To get a total understanding of the environmental footprint of a car including the supply chain flows is evidently an extent task. A thorough mapping of the supply chain flows is needed, and the data is in many cases not accessible. As stated by the doctoral student in building technology it is very important to limit the scope of this type of analysis since it could otherwise be a never-ending story.

One way to overcome supply chain complexity when doing LCA analysis is to reduce the size of the supply chain. Many actors are currently going towards closer relationships with their suppliers which also decreases the complexity since a smaller portfolio of suppliers will decrease the complexity of the specific components supply chain. According to the literature, on the other hand (Reibizer, 2004 Sarkar, 2017; Pelton and Smith, 2015), there are two specific ways of limiting the scope when doing an LCA analysis, by limiting the goal and scope definition, further it is also possible to make scope limitations by applying a hotspot analysis. By limiting the scope, it is possible to decrease the size and extensiveness of the LCA-analysis. The hotspot analysis, on the other hand, makes it possible to only consider the processes with highest environmental impact. It is necessary to do some kind of LCA-analysis before it is possible to hotspot these specific flows, but when this is done it is possible to only focus the LCM-processes on the processes that actually are in need of environmental improvement.

5.2 How to gain opportunities with LCM

In contrast to the challenges with LCM, opportunities regarding how to utilize environmental LCM with an integrated supply chain focus were consequently identified. These opportunities were recognized during different observations made in this study. The different opportunities are summarized in *figure 12*.

Figure 12. The main identified opportunities when integrating LCM into an automotive manufacturer.

Drive innovation

Both the literature (GHG Protocol, 2018) and the different suppliers expressed that one opportunity with the using LCM could drive innovation. According to GHG Protocol, to work comprehensive with emission reductions provides incentives for innovation, both when it comes to product development and supply chain management. The plastic bumper supplier highlights the collaboration stage in development of new materials and that increased environmental collaboration were the buyer and supplier strive towards the same goal could result in innovation. Also, the two steel suppliers that was interviewed both agrees to this statement. Since most of a car's weight comes from steel it is important to constantly try to make the material as lightweight as possible, since the higher the weight the more emissions during the user phase of the car. As stated in the interview with the steel producer, they in collaboration with its automotive customers develop the steel to make it lighter with support from LCA data. Thus, using LCA results in decision-making processes as a support to develop new materials or change design on existing products is proven to be of great advantage to decrease the environmental impact of a product.

In other words, it is possible to increase company innovation through working with supply chain specific LCM processes, companies can take use of each other to get further knowledge of how to more effectively work with environmental management through the sharing of company competences between company boarders. As shown in the empirical findings, Company X is already having conferences that intends to share environmental knowledge between company boarders. In this way it is not only possible for Company X to gain innovative knowledge regarding environmental processes, but also to share environmental innovation to supply chain actors and in this way influence the upstream supply chain.

Improve stakeholder relations

As stated by Sonnemann et al. (2015), if common goals can be set up to decrease the total environmental impact of a product this would hopefully lead to an improved environmental performance not only from the suppliers' side but from the OEM as well. Additionally, as mentioned in the literature (Harrison et al., 2005) and by the OBP, some product or process specific information is considered too sensitive to share or is even regarded as confidential. If trust and collaboration could be built with key suppliers with an aim to improve the environmental performance of the product's lifecycle the risk of sharing this information would be reduced and again the actors could work more proactively with environmental issues together. This was confirmed during the interviews with the different suppliers. Especially the plastic supplier stated that much information could not be shared since it was said to be confidential, but the plastic supplier was also eager to find information that would not damage the relation to the OEM, to be able to deepen the collaboration between the parties. It is therefore important for the OEM to be aware of the supplier's incentives to together improve the relation and take best possible use of the different competences inside the different firms.

System knowledge

As stated in the empirical findings, the current system knowledge for Company X is limited to the first tier of supplier in most cases. As stated by the PESA, to apply LCA based on specific data gathered from actors upstream in a supply chain, an increase in visibility and knowledge of the product system will be obtained since a mapping of the product system is required. As stated by Zhu et al. (2018), increased visibility will make it possible to monitor different types of upstream supply chain processes to thereby have better knowledge of the exact environmental footprint. This will lead to an increased understanding of what the possibilities with changing specific parts in the chain lead to. It opens up for opportunities to find steps in a products supply chain that in some cases are unnecessary and contributes to a larger environmental footprint. If an OEM only conducts LCA analysis on products with generic data from databases, it gives limited knowledge and insight into the actual supply chain of a product. By getting increased product system knowledge as described above, areas for where improvements in terms of efficiency will to some extent be more visible. This means that the OEM and the supplier can gain efficiency and optimize their processes and even reduce associated costs. For example, decrease the amount of waste and scrap and optimize the logistic system. This is a great benefit arising from implementing LCA based on specific prouct data and not generic data since using generic data will never tell the whole truth about a product system and its improvement areas.

It is also important to be aware of the difficulties in increasing the visibility in the supply chain. To deepen the system knowledge the suppliers need to share data from their own suppliers. As stated by the OBP, the suppliers often does not want to share this information, since it may harm their own situation by making it possible for the OEM to reorganize the supply chain, by skipping this step and doing their processes in-house instead.

Differentiation

As stated by the literature (GHG Protocol, 2018), one aspect with getting increased knowledge regarding a company's environmental performance through measuring and trace emissions in the company's upstream supply chain, is that it enables the company to take actions to flows with large environmental impact. This is a constant process that over time can reduce the environmental footprint of a product significantly. By implementing these processes, it is possible to differentiate the OEM on the market and from that gain competitive advantage. Further, as stated by Von Corswant & Fredriksson (2002) it is clear that external stakeholders such as end-customers have an

increased interest in documented emission reductions and if a company, for example, chose to get ISO 14040 certified they can show to the society that they have a solid life cycle approach that is in line with the current research and that they strive to constantly improve their environmental performance in all parts of the product's lifecycle. It is important to be aware of that it can be costly for the automotive manufacturer to do these supply chain mapping and to act to supply chain processes, and it is important for the OEM to consider the trade of in what the company gains from being associated with this environmental work in contrast to what they lose in monetary terms, since it would be very costly to make a thorough mapping of different supply chain processes in a very complex supply chain.

Avoid Supply Chain Risks

As described in the literature section there are several risks related to the performance of upstream suppliers (Jüttner et al.,2003; Caniëls et al., 2013; Smith, 2013). One opportunity that could be gained through introducing supply chain specific LCM, is thereby to avoid these supply chain risks. As stated by Smith (2013) it is possible to avoid these problems by having closer collaboration to the upstream supply chain actors.

As it seems Company X are putting a lot of effort into sustainability aspects and are trying to be associated with a well-functioning environmental improvement work. To not risk damaging this association it is very important to not be included in any upcoming scandals connected to the environmental performance. To avoid these scandals, it is important to both have internally and externally functioning environmental management. As stated by Caniëls et al. (2013) several OEM's have during the last couple of years been included in scandals regarding what has happened in their upstream supply chain processes. For Company X to avoid these risks it is therefore important to have control of the environmental quality within the upstream supply chain processes. It could be of interest to deepen the environmental collaboration to their suppliers to in this way increase their chances to avoid environmental damaging processes beyond their current supply chain visibility.

6.Discussion and Recommendations

Based on previous chapters and discussion around RQ1 and RQ2, this chapter targets RQ3 and discusses the improvement possibilities with the current usage of LCM applications within Company X. It further presents recommendations of how Company X could develop the LCM strategy, to better utilize opportunities connected to LCM and overcome LCM barriers.

6.1 LCM improvement areas

This section discusses the identified areas were improvements could be gained as well as the needs for realizing these improvements in accordance to the current usage of LCM in Company X's supply chain.

LCA data

Even though the use of generic LCA data does not give a total picture of the specific supply chain of Company X's processes, it gives a good overview of the material and components that could have more or less environmental impact. Reibizer (2004) describes that generic data can be used if it is used from high-quality databases and if area specific details are considered, such as area-specific regulations that may change pollution output from the specific factory. Company X is now planning to use Simapro as a software tool, this is the most frequently used one according to the literature. Simapro is also regarded as the most reliable LCA software together with Gabi, both using the EcoInvent database. The use of Simapro calculates the total environmental burden in all life cycle stages and provides a great oversight of the most critical processes, however the software does not consider the unique supply chain of Company X. The generic data cannot be used to make specific process improvements in the supply chain, but it could make guidance towards high energy consuming processes, i.e. hotspot where actions could take place. It can also be used as it is today, to support decision-making when the company aims at make better environmental choices in terms of choosing different materials and designs for the given purpose.

Company X current usage of LCA data is not used to assess how well their suppliers are performing in environmental terms and how large environmental footprint their production processes have. Even though the material of one product is more environmentally friendly in comparison to another; depending on what kind of energy sources the production site uses, what kind of production processes that are included in the creation of the material/component, or how far away the production site is from Company X, the emissions can differ to a great extent. Moreover some actors may produce these materials with significantly less environmental impact than others. The current generic data could nevertheless be used to estimate the highest pollutant processes and enable a decrease of the total environmental footprint of their supply chain, even though the most environmentally friendly material has been chosen.

Lack of internal communication

In order to successfully use LCM and LCA, as an environmental assessment tool it must to some extent be a part of the company's business goal, thus it needs to be assessed on a strategic level. Currently within Company X, the knowledge and usage of LCA at the environmental department is well structured, however, it seems to be a gap in how it is integrated and communicated to other departments. R&D is heavily involved in LCA since this department is the one developing the materials. However, at the purchasing department the knowledge is limited and according to the interviewees, LCM and LCA data is not anything that is used today when purchasers select suppliers.

If it is desired to get a clearer picture of Company X's total emissions in their supply chain then the purchasers have an important role to play, in the way the company chooses suppliers and materials. Hence, LCA can measure the potential environmental impact reduction of different sourcing strategies. To have a strong LCM approach will also make it possible to differentiate the brand. To use certifications such as ISO 14040-series or similar, will make it possible to prove the environmental performance of the products and thereby create a brand image that does not only show the environmental footprint of the product but also that the company is working to continuously improve their environmental footprint of the internal and external processes.

To be able to stretch LCM to more function in the organization it is important to create a team of employees that are working strategically with how Company X could develop LCM processes. As Sonnemann et al. (2015) describes, it is recommended to use cross-functionality i.e different types of competences working with different life cycle stages and functions that are related to LCM. The departments that have the highest impact on the different life cycle stages in this case are the environmental department, purchasing, logistics and product development as well as the after market department. Thus, it would be beneficial to have a team with members from these functions working with the strategic development of LCM. To not adversely affect the current processes within the different functions, it is important that this work does not take too much focus from the current operations. Therefore, the person/people leading this team are recommended to have existing LCM knowledge and not an irreplaceable role within the organization. Preferably, this should be a resource coming from the environmental department with a broad knowledge of LCM, LCA, ISO certifications and with a management background preferably within Company X. The other resources could be temporarily connected to the strategic LCM, to create an insight of how the other departments are currently working and how LCM could be developed within these functions, *see figure 13.*

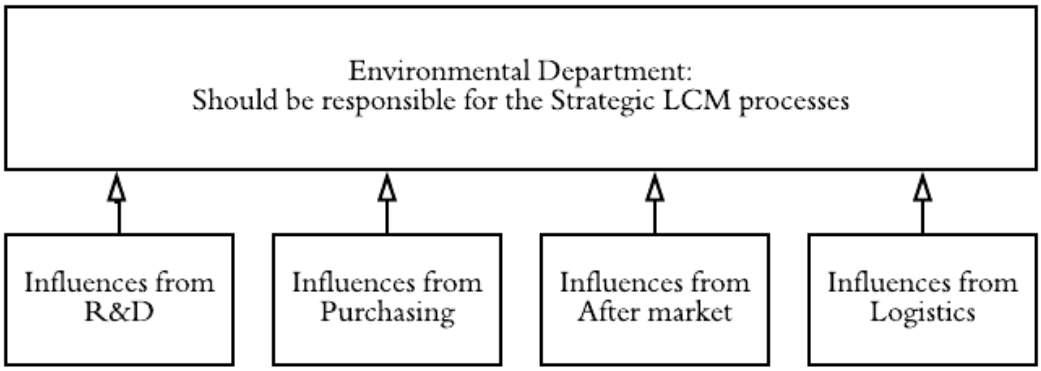


Figure 13. The Environmental departments should be influenced by different departments connected to different processes that have environmental impact in different life cycle stages of the product.

When this team is structured and implemented it is important to tackle the gap in how the other functions are looking at environmental LCM. To spread the need for increased environmentally friendly processes upstream the supply chain, a closer collaboration between the departments with current LCM knowledge and non-existing LCM knowledge is required. For instance, in the future set requirements on LCA reporting from the suppliers and to set the right environmental requirements in order to access more supplier data. A recommendation would thereby be to make use of the team that potentially could work with strategic LCM and apply the existing knowledge on the different functions through internal training programs. These programs could be focused on the LCM concept

and for instance how the requirements that should be set on the suppliers and how. Also, a closer collaboration between the environmental department and the purchasing department will be necessary. The purchasing function can influence the environmental impact by developing new sourcing strategies where they always consider the life cycle aspect of the material/component, this requires deeper knowledge of which flows to set specific environmental requirements on and what type of requirements that will have the greatest impact in environmental terms.

Supplier Relations

As described by OBP, Company X has requirements on its suppliers that they, in turn, must outsource to suppliers that take environmental responsibility with the aim that these requirements should permeate the full upstream supply chain. These requirements are there to exclude suppliers that are not following the environmental policies that Company X are requiring, however, Company X has in the end limited resources to investigate and control whether these requirements are followed or not. It was also shown that Company X in some cases is selecting suppliers that perhaps not satisfy the environmental conditions, stated by the OBP. The company is naturally valuing and prioritizing some factors over others such as quality and cost and selects suppliers that are closest to satisfy the policies that are set by Company X.

As further stated by OBP, to set stricter requirements on their suppliers may not be possible depending on the power balance in the buyer-supplier relationship. Another thing, yet not stated by Company X, would be that higher requirements could affect the relationship in a negative way. Independent on the power balance, stricter requirements may lead to negative effects in the buyer-supplier relationship and it is therefore important to consider the buyer-supplier context. According to one of the steel producers, environmental requirements today are mainly coming from regulations rather than requirements and if the buyer is small in relation to the supplier, the steel producer states that it is unlikely that the buyer could increase environmental requirements on the supplier. The same was stated by OBP, who described that these requirements could be increased if depending on the power balance between the actors. To set this type of requirement could damage the buyer-supplier relation, rather than giving improved environmental results in the supply chain.

From the interviews, it became clear that both the suppliers and OEM have the interest to increase the environmental performance of their operations. As stated by SSAE, Company X invited their suppliers to a conference where suppliers shared their thoughts about how to tackle environmental issues. In this way, both the suppliers and Company X could benefit from how the different parties were managing environmental needs. What was shown from the empirical data gathering process, was that it is much easier to gather data when both parties are aware of the positive outcome of sharing this type of data between company borders. If the outcome is known and the supplier knows what the data is used for, then the risk of sharing this data from the supplier’s perspective decreases.

Prepare for future changes

According to PESA, SSAE and the Environmental and the Industrial Ph.D. Candidate, the change towards electrification will require an increased focus on other phases in the life cycle of a vehicle than the user phase that has previously been the most critical. Different organizations such as ISO and CDP are working with methods and measurements in regards to LCM and LCA to cope with this type of transformations like the automotive industry are facing and other environmental changes that might arise in the future. To be aware of what kind of standards that are developed by ISO is not only beneficial in order to differentiate the brand, but also to see what environmental requirements that may come in the future and in which way to prepare for these changes and work proactively. As

shown, Company X is currently withholding the ISO 14001-certification, which shows that they have an environmental management strategy, both strategic and operational. However, they do not have any ISO certifications related to life cycle assessment. Since Company X already are familiar with life cycle assessment analysis, they are not far away from being able to get the ISO 14040-series certificates, which would enable them to show that they are doing progress with the environmental impact of their vehicles.

When an actor is working towards getting certified for LCA it might also be favorable to consider the ISO 14067 certification, since it is somewhat of an extension to the 14040-series and includes several supply chain benefits. As described, ISO 14067 aims to increase transparency and the credibility of the LCA calculations. It may, therefore be of interest to have the standard as an environmental certificate and also to utilize the standard to increase the environmental transparency in the supply chain.

Future changes such as laws and regulations associated with environmental impact could be tackled through the use of external information. One way would be to start utilizing CDP-information to be aware of future risks related to this field and thus work proactively to manage changes that are in line with future regulations as well as to capture the opportunities that these changes possibly contribute to. Another way would be to continue with key supplier collaboration where common objectives to improve the overall environmental performance should be formulated.

When considering how to work with LCA analysis in the future it is of main importance to consider where the automotive industry is heading and the changes that will impact the life cycle of a vehicle in the future. One of the changes, as mentioned is the shift towards electrification, which will move the majority of the emissions in the user phase to earlier and later phases of the vehicle's lifecycle. Another transitions that will have a huge impact on the life cycle of a car is the new business model of "servitization of vehicles". As described by SSAE, the servitization of vehicles will make it possible to decrease the amount of purchased material directly from the suppliers by reusing parts and materials that still of good quality and controlled by the OEM. This means that parts of the incoming materials in a car will have less life cycle impact since these are reused or recycled by the OEM, see *figure 14*. This will lead to two different sources of assembly components, both those coming from suppliers and those from old vehicles. Reducing the number of components will lead to the reduced environmental impact of the production phase of the car. How much this is going to reduce the impact is difficult to speculate in, nonetheless, it is important to consider this change when developing the environmental assessment methodologies and tools in the car manufacturing industry since it could have a greater impact than expected.

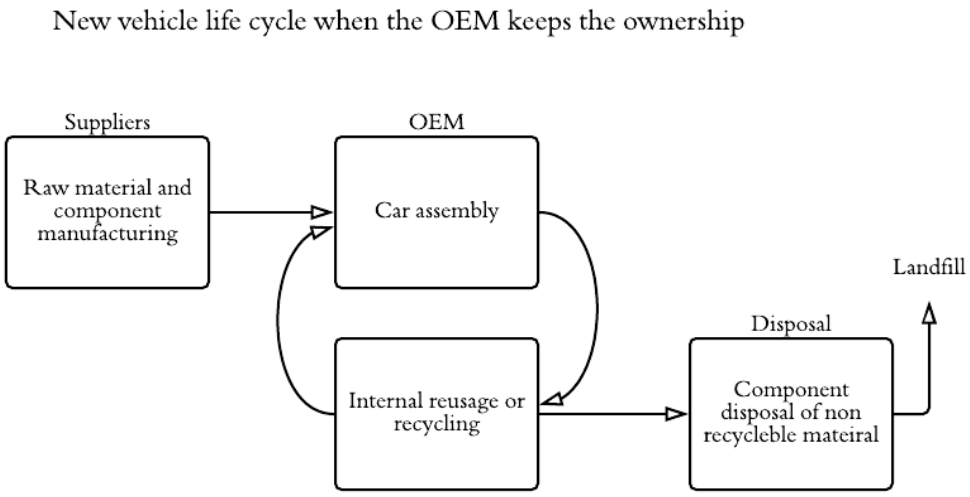


Figure 14. Potential future state were components within a car can be reused when starting with servitzation of vehicles.

6.2 Action Plan

To be able to increase the utilization of the LCM applications, a structured plan is needed as well as a solid LCM approach. If supply chain specific LCA-analysis should be feasible to implement, a structured approach where clear supply chain limitations are drawn is crucial. This section considers the challenges and opportunities with the integration of LCA in the supply chain and provides a recommendation of how the OEM could approach the integration in association to Company X's current LCA application. The model can be seen in *figure 15* and is further described in detail.

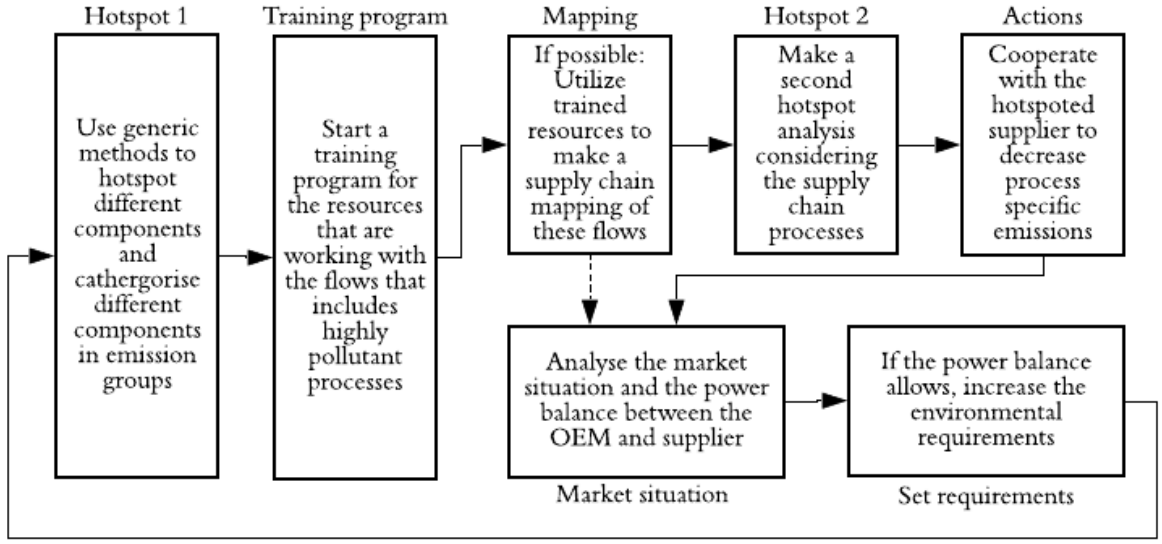


Figure 15. Model of how an automotive company could integrate LCA further in the supply chain.

Hotspot 1

As by Rebitzer et al., 2004 and PESA it is critical to have clear limitations when doing LCA analysis in the automotive industry otherwise the analysis will go on forever. Therefore, when conducting a supply chain specific LCA-analysis it is important to set up the goal and scope of the product. If the scope is not narrowed down enough, there will later be problems when mapping the supply chain of the specific materials/components. Thus the scope should be set to only consider the flows with the highest environmental impact. To analyze the supply chains that have the highest impact, a generic hotspot analysis should be made where the products later are categorized from low to high impact. As stated in the empirical chapter, Company X is currently using LCA to make comparisons between different materials, but in some cases, materials cannot be replaced by more environmentally friendly alternatives and in some cases, even the more environmentally friendly alternatives may also include highly pollutant processes. Thus, in these cases, it is important to decrease the emissions from the specific supply chain processes as much as possible. The generic LCA data that is used for the product development processes could in this case be used to categorize the flows with the largest environmental burden.

LCM learning program

When the environmental impact of the components identified from the previous step and the categorization is completed, a learning program should be employed to purchasers and other functions responsible for the categorized components. The aim with the learning program is to spread knowledge of how the purchasing department should apply LCM and use LCA studies when sourcing components and materials as well as to in a future state consider applying stricter environmental requirements on suppliers. By providing this internal learning program, and by having a closer collaboration between these two departments it is possible to utilize the existing resources and knowledge within the company and thereby increase the possibility to successfully integrate the LCM model. Furthermore, the learning program is beneficial to implement since it will create a unified view of what LCM and LCA is for the specific company since it is very often viewed differently depending on who you ask. To create consistency in how to use LCM and LCA is critical as well as to understand that LCA is not equivalent to LCM, LCA is rather a tool to use to support decision making and comparison between materials and suppliers whereas LCM is the management technique to apply.

Mapping

After the learning program has been done and the team has a greater understanding of environmental LCM, the team should control the available and existing environmental data from suppliers and thereafter start with a bottom-up approach to collect environmental data in the supply chain. As stated by the operational buyer for plastic flows, it is in many cases difficult to get detailed information of processes happening further up in the chain. Most likely it will not be possible to get a total insight into the supply chain of the product, as it looks today. It is realistic to state that it will probably only be possible to cooperate with the first-tier supplier. Therefore, it is important to get the first-tier supplier to influence the rest of the upstream supply chain, further discussed in section *Market situation*.

Thereafter it is important to create a mapping of the supply chain flows that are related to the specific component. In this phase it is important that the goal and scope definition mentioned in the first phase is decided and stated in a precise way, since a too wide scope would be very time consuming to map, further it is not only the quantity of the data that matters, rather measure the right things and the quality of the data.

When mapping the supply chain, it is important to collect and find as accurate information as possible. To get process specific information is optimal to calculate the environmental impact of each step in the supply chain. This must be done in collaboration with the suppliers since this data is commonly not measured or shared. However, as stated by one of the steel producers, in the current state, the reason for why this is not shared depends to a large extent on that the data is considered confidential. In this step, it is crucial to create trust between the actors to ease the information sharing. It is mentioned earlier that common goals and objectives with how to decrease the environmental footprint of a product in the different stages of the product's lifecycle can help to build this trust and collaboration.

Hotspot 2 and Actions

When the mapping of the supply chain processes is completed it is recommended to do a second hotspot analysis. This hotspot analysis also considers the environmental impact, but instead of looking at the impact between different components it considers the environmental impact in the supply chain processes of the particular component. In this case, it is important to use an

environmental impact scale as in the prior hotspot analysis. Moreover, to additionally measure the efficiency of the supply chain processes is important, since some processes may produce an unnecessary amount of waste or consume an unnecessary amount of energy. Thereafter, collaboration with the supplier is initiated to figure out a plan to together decrease the environmental footprint of the processes related to the OEM. This could either be to improve the efficiency of the process, or even remove/replace the process/supplier.

Market situation and requirements

When setting requirements for the suppliers it is important to consider the power balance. As described by OBP, the power balance differs depending on the market situation i.e. the supply and demand on the market, but also on the buying company's size as a customer in comparison to the supplying company. Depending on the power balance between the different actors, it is more or less difficult to set requirements on the supplier. If the power balance is in favor of the buyer (the OEM), then it will probably be easier to increase the environmental requirements on the supplier. It is also important to consider the environmental requirements that the supplier puts to the next tier of suppliers and the upstream suppliers all the way to the origin of the goods.

One example would be to set requirements that the suppliers are showing the process emissions related to the specific component and report it to the issuing company, see *figure 16*. If every supplier would be forced to show these calculations it would be possible to be more aware of the upstream supply chain emissions and thereby take other actions to decrease the environmental burden the supply chain is responsible for. In this case, it is suggested to use some kind of standardization to know how calculations and measurements are performed so that it is possible to make comparisons between different actions and outcomes. This would increase the environmental transparency in the supply chain that otherwise would be difficult to obtain. Hence, it is important to have a close collaboration to the first tiers of suppliers in the most critical flows, where this data is necessary.

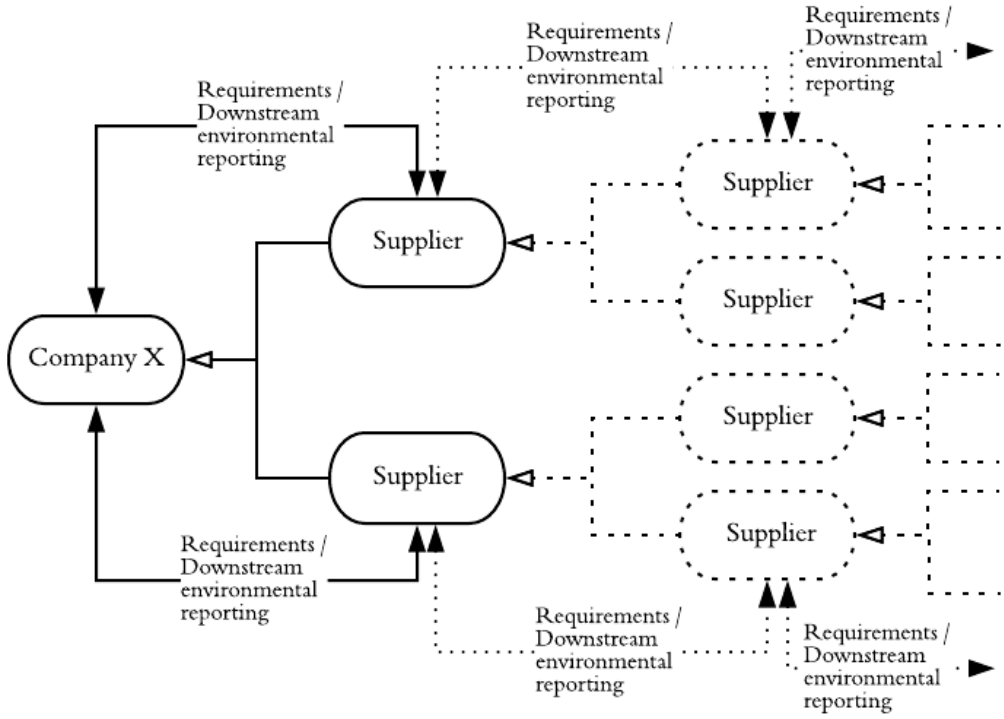


Figure 16. Simplified supply chain tree showing how upstream supply chain requirements theoretically could increase the specific environmental knowledge for the OEM.

In this phase of the action plan it is additionally important to consider the risk of setting too high environmental requirements on the suppliers, which possibly could damage the buyer-supplier relationship. It is therefore critical to not push the supplier by setting too high environmental requirements. A recommendation would be to work closely with the supplier, and also motivate the possibilities of increasing the environmental work and environmental certifications such as ISO 14040-series and to together make use of the existing environmental resources in an optimal way to increase the environmental performance.

In many cases it will not be possible to collect data from all suppliers, it is thus crucial to consider how much effort and resources the company should spend on gathering the data in the supply chain flow. To consider the trade-off in how much effort and resources that should be allocated to the supply chain processes contra the improvement possibilities of obtaining environmental data of upstream supply chain processes is thus necessary.

Continuous improvement

When the steps are finished, step one "Hotspot 1" should be done once again including the data from the specific LCA analysis that have been made, see *figure 16*. In this way other processes can be improved in environmental terms. The ranking of Hotspot 1 creates an understanding of which process that is the next one to allocate resources for. It is suggested that this should be an iterative process so that the company always develops and improve its environmental performance.

Important to consider is to keep the environmental knowledge within the organization and to spread this knowledge to new employees, especially if one person with great experience and knowledge leave the company. For instance, a new purchaser replacing an existing purchaser should attend the

LCM learning program. It is also important to consider the environmental footprint of new processes when replacing a supplier against another one. Hence, it is important to work continuously with updating supply chain processes and do a new mapping when changes occur.

6.2 Implementation Period

Considering the recommendations stated above, if they should be successfully implemented in the organization, it is important to have a plan on when and how to implement the different actions. A division of three groups was made: short-term, mid-term, and long-term objectives. These are listed according to feasibility and complexity.

Short term, year 1

- ❑ Start a generic hotspot analysis on components and materials that are known to have a large environmental impact and create an environmental impact categorization.
- ❑ In collaboration with the environmental department, start an internal LCM learning program for the purchasers associated to the components and materials decided in previous step and priorities according to the categorization.
- ❑ Make further integration between the environmental department and strategic purchasing to get the right LCM objectives into purchasing strategies.
- ❑ Compose a team working with Strategic LCM, find people that are relevant to include from the functions that have a strong connection and could influence the environmental impact during the different phases of the vehicles life.

Mid-term, year 1-3

- ❑ Look at the opportunity to work with LCA standards such as ISO 14040-series, ISO 14067 and aim at getting LCA ISO certified.
- ❑ Widen the scope from the short-term recommendations and create the same operations for other identified flows with large environmental impact and continue the LCM learning program for purchasers associated to these flows.
- ❑ Let the purchaser with LCM knowledge start with the rest of the steps stated in *7.1*, beginning with *Collaboration*.

Long-term, year 3+

- ❑ Encourage existing suppliers to get ISO 14040 and 14067 certified and consider making these future supplier requirements.
- ❑ Continue the LCM learning programs on the rest of the flows to stretch LCM within the purchasing department and create yearly learning programs for new purchasers.

7. Conclusions

The purpose of this study has been fulfilled and the research questions answered. To summarize the critical findings to the RQ's: Company X is currently using generic LCA-analysis to compare different designs and materials in the product development phase and serves as a support in the decision-making process in the early stages of product creation. The collaboration between the environmental department and the R&D department is thus large. However, the company is not using supply chain specific data when doing LCA analysis, which increases the risk of that the actual environmental impact is underestimated. The communication between the environmental department and other functions within Company X is limited in regards to LCA and LCM. This contributes to that the knowledge the environmental department posses, is not transferred to other critical functions that in the end can have a large impact on the final environmental footprint in the different life cycle phases. One critical aspect in this is how LCM could be further integrated and used in especially the purchasing department since the purchasing department plays a key role in the activities connected to the supply chain. LCM learning programs stretching the knowledge regarding how the different functions can affect the environmental impact of the upstream supply chain is suggested in Company X's case.

Considering the challenges and opportunities with applying LCM on a supply chain basis that RQ2 addressed, It was shown that the main challenges are: Lack of transparency in the supply chain, poor data quality, terminology and consistency issues, time aspects and finally the complexity with understanding and conducting LCA studies. In contrast, the opportunities that could potentially be gained from applying LCM further is that it opens up for improved stakeholder relations since the actors in the supply chain would need to communicate to a greater extent than they currently do. LCM could further drive innovation due to closer collaboration between functions within a company as well as across company boarders and thus promote product development. Further, increased product system knowledge would be gained due to the product mapping phases and thus create a better understanding of how the material/components are produced and how large the environmental impact approximately is. This information and knowledge is very important to obtain since it is in today's state, somewhat an impossible task to trace a components origin and get insight to the product flow before the material/component reaches Company X. The last yet not least beneficial opportunity is the differentiation aspect. If Company X aims at getting LCA certified and integrate LCM throughout the critical functions in the organization, the company could differentiate from competitors, this is a very important aspect since the society as a whole increasingly put higher environmental demands on companies.

Targeting RQ3, a closer relationship to suppliers as well as decreasing the supplier portfolio makes it easier to collect supply chain specific data because of the high supply chain complexity permeating the automotive industry. Furthermore, a closer collaboration with suppliers producing materials and components with a large environmental footprint enables the OEM to target these specific flows and thus formulate strategies and take actions to reduce the impact in associated supply chain. It was shown that a total supply chain mapping for environmental development would be extremely resource demanding, especially in terms of the time it would take to complete the investigation. It can be concluded that the resources spent on a full supply chain mapping in relation to how much value it is likely to bring are not correlating. Therefore, it is critical to limit the scope when conducting the mapping to the processes that have the highest environmental burden.

Delimitations

The most obvious obstacle that prohibited this study to have a more extent data collection and deeper analysis was the actual time it took to gather data from suppliers, which had been underestimated resulting in that some information could not be obtained that might have been of value for the report. Furthermore, the difficulties of getting in contact with employees possessing the right knowledge within Company X contributed to that people with further experience regarding LCM and purchasing could not be interviewed which might lead to a bias of this study. The geographical spread of the suppliers led to difficulties in making visits and conduct more interviews and thus obtain a deeper knowledge of the specific operations and the structure the supplying companies had.

Future research

This report has applied environmental LCM to the upstream supply chain of a specific company in the automotive industry and only considers environmental. To make the results less biased and to be able to develop a framework of how to take action with LCM, further investigation concerning other automotive manufacturers and how these companies could work with LCM is needed.

In the current state, supply chain transparency is an obstacle that is making it difficult to apply LCM in the upstream supply chain of an automotive manufacturer. Further investigation is therefore needed to explore how relationships between actors could be developed with the aim to reduce the environmental impact of a product and to make the supply chain more transparent. It is also suggested to make further investigation in how the LCM approach of an automotive company should take the servitization of vehicles into consideration, since the reuse of components will affect the end-of-life phase for many components which will change the current structure of the upstream supply chain for the automotive company.

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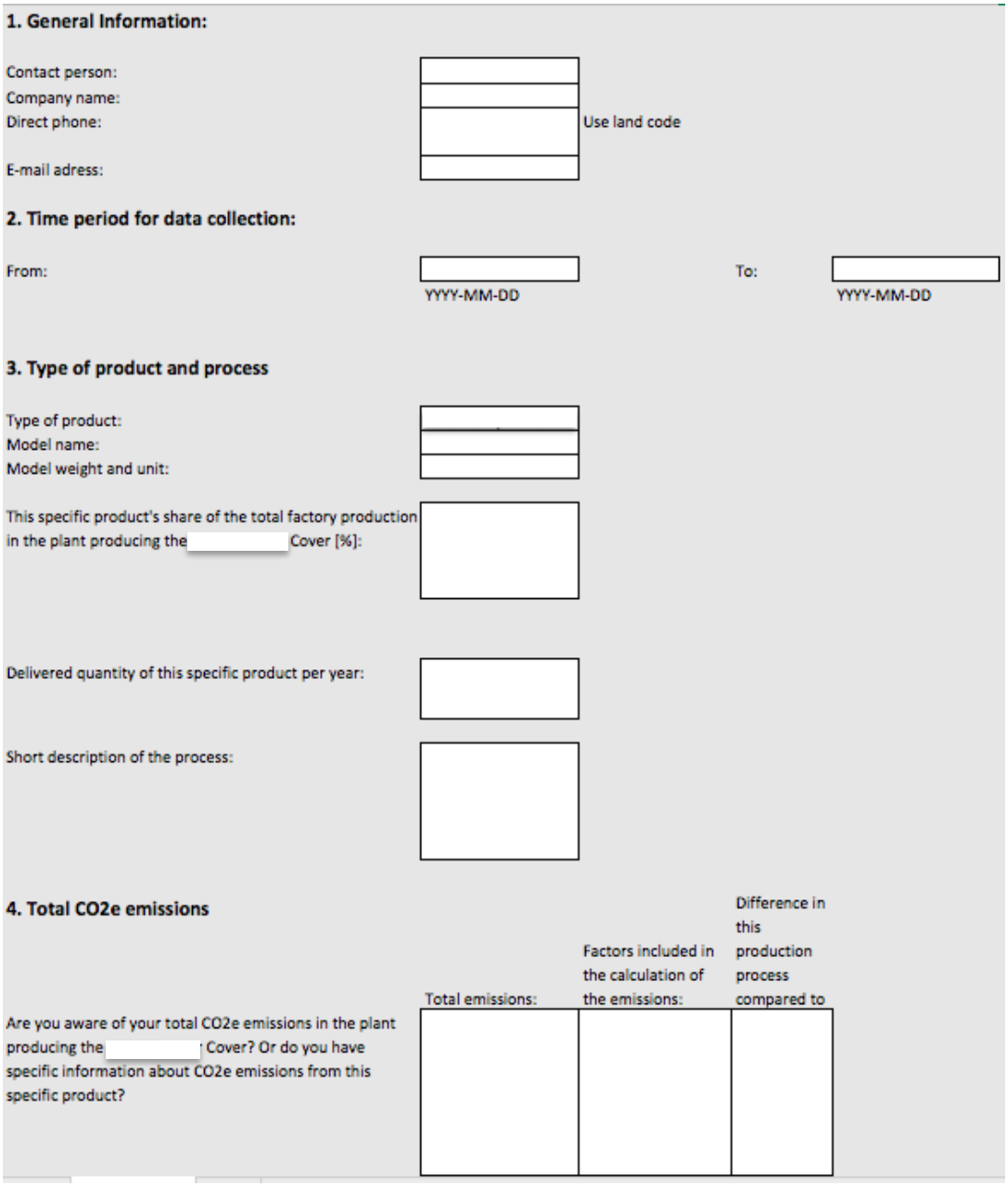
Appendices:

Appendix 1: Supplier interviews

Appendix 1 includes the interview questions that were given to investigate the challenges and opportunities of collecting supply chain specific LCA-data from a supplier's point of view. First, questions regarding collecting specific environmental LCA-data were sent out to the suppliers, these can be seen in *figure 1-3*, each supplier had five weeks to collect this data. After this, interviews following a semi-structured approach were held regarding the difficulties and opportunities of gathering this data. Some additional questions and subjects were discussed, and the questions were not fixed to follow the order in the following interview structure.



1. General Information:

Contact person:
Company name:
Direct phone:
E-mail adress:
Use land code

2. Time period for data collection:

From: YYYY-MM-DD
To: YYYY-MM-DD

3. Type of product and process

Type of product:
Model name:
Model weight and unit:
This specific product's share of the total factory production in the plant producing the Cover [%]:
Delivered quantity of this specific product per year:
Short description of the process:

4. Total CO2e emissions

	Total emissions:	Factors included in the calculation of the emissions:	Difference in this production process compared to
Are you aware of your total CO2e emissions in the plant producing the Cover? Or do you have specific information about CO2e emissions from this specific product?			

Figure 1. The first four questions in the data collection form given to the suppliers.

5. Input:

Raw materials and components used for the specific [redacted] cover:

Description:	Quantity:	Unit:	Weight:	Supplier:	Supplier location:	Supplier contact information:	Comment:

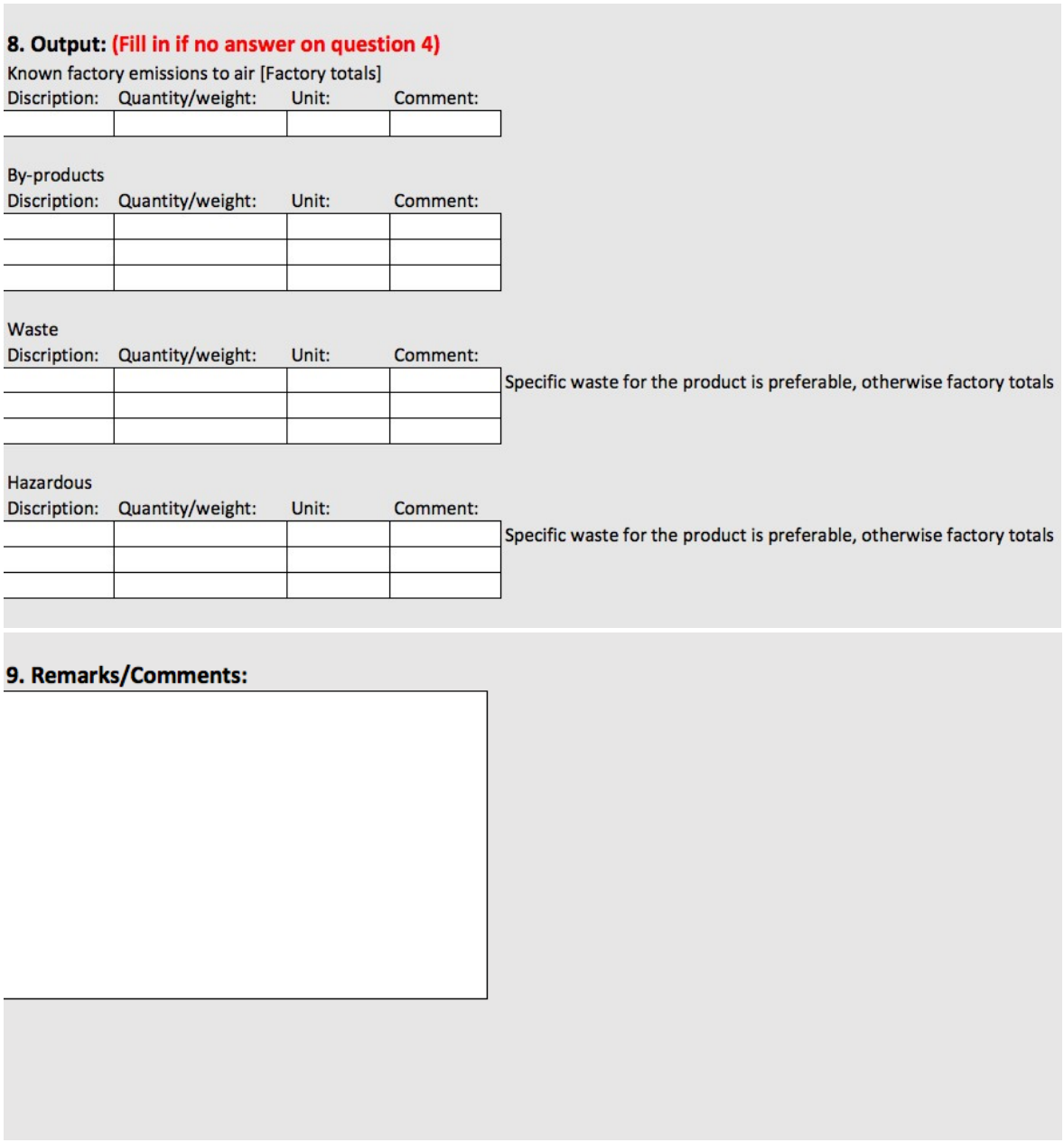
6. Transports from your suppliers:

Goods description:	Distance [km]:	Weight:	Unit:	Quantity:	Mode of transport:	Average fill-rate:	Average transport frequency:	Transport packaging (Material and type):

7. Energy usage in factory site (Fill in if no answer on question 4)

Type:	Consumption:	Unit:	Comment:
Electricity			
District Heating			
Steam			
Natural gas			
Fuel oil			
Liquid Petrolium gas			
Coal			
Diesel			
Gasoline			
Other			

Figure 2. Question 5 until 7 in the data collection form given to the suppliers.



8. Output: **(Fill in if no answer on question 4)**

Known factory emissions to air [Factory totals]

Discription:	Quantity/weight:	Unit:	Comment:

By-products

Discription:	Quantity/weight:	Unit:	Comment:

Waste

Discription:	Quantity/weight:	Unit:	Comment:

Specific waste for the product is preferable, otherwise factory totals

Hazardous

Discription:	Quantity/weight:	Unit:	Comment:

Specific waste for the product is preferable, otherwise factory totals

9. Remarks/Comments:

Figure 3. Question 8 and 9 in the data collection form given to the suppliers.

Follow up questions for suppliers to Company X:

- Can you briefly describe your position within your company, and how your role is connected to Company X?
- How do you on a daily basis work with environmental issues?
- How are your company working with LCA, are you currently sharing LCA-data to your customers?
- Which challenges appeared when you searched to find the information to fill in this form?

- Do you think any opportunities can come from sharing this type of data, both for your company and Company X?
    - What do you think about having a relationship with Company X where LCM is practiced in collaboration to reduce the environmental impact?

- How is your organization preparing for stricter environmental requirements from your customers that might be implemented in the future?

Appendix 2: Questions to employees at Company X

Appendix 2 includes the interview questions that were given to investigate the LCM applications within Company X.

General questions to employees at Company X:

- Can you briefly describe your position within Company X?
- How do you work with environmental issues on a daily basis?
- What are the main challenges of integrating LCM in the Supply Chain?
- According to you, what are the main opportunities with the integration of LCM operations in the Supply Chain?

Questions to people involved in purchasing at Company X:

- Can you describe the purchasing process and the environmental criterias that are included when choosing suppliers?
- What environmental requirements do you have on your suppliers today?
    - Is it difficult to find suppliers that are fulfilling your current environmental requirements?
- Are you working closely to the supplier to develop the environmental performance?
    - How do you ensure the suppliers are following your requirements?
    - What are the challenges with getting suppliers to increase their environmental performance?
- Considering existing suppliers, does the purchasing department take a supply chain perspective? Can you describe what transparency means for your company and how increased transparency could lead to improved environmental performance?
- What kind of information about the upstream supply chain do you require from the supplier?
- When choosing new suppliers, do you take a supply chain perspective and in that case in what way do you do so?
- Do you currently cooperate with environmental departments to increase the environmental performance in the purchasing work?
    - Do you have any thoughts on how the environmental work could be developed and integrated at the purchasing department to improve the environmental performance of the suppliers and associated supply chains?

- Are you currently requesting any information that is related to LCA from the suppliers?

- Are you aware of ISO 14040-series and what do you think about getting LCA certified?
    - Do you think it is possible to increase your environmental requirements by including LCA data from the suppliers as a requirement?
    - What do you think the consequences would be?

Questions to employees at the environmental department for Company X:

- Can you describe how you currently work with LCM and your view of LCM?

- Can you describe the different departments who are involved in LCM and how Company X currently are working with LCM and life cycle thinking?
    - How is the Environmental department working with LCM?
    - Does the Environmental department communicate LCM to other departments?
    - What do you think of purchasing's role in LCM?

- What kind of incentives are needed to deepen the current use of LCM?
    - Do you see any opportunities with conducting specific LCA-analysis to obtain further information about a products environmental footprint on a supply chain basis (considering mapping a products supply chain to obtain specific information for that product)?

- What do you think could be improved with the current LCM use and what do you think is lacking in the LCM use within Company X?

- How do you think future development of the automotive industry will affect the LCM applications?

- What are the challenges and of integrating LCM and purchasing?

- What are the opportunities of integrating LCM and purchasing?

- How is the decision-making process working, concerning LCM issues?

Appendix 3: Interview questions to researchers

This appendix includes the questions asked during interviews with researchers connected to the LCM and LCM field.

Questions to researchers:

- How do you think LCM should be used within an automotive manufacturers organization?
    - What benefits would come with integrating LCM at the purchasing department in?
    - What benefits would come with integrating LCM at the logistic department?

- What are the possibilities of using specific LCA data in an LCA study that includes actual supplier data, and what are the challenges with carrying out this type of study?

- Which are the challenges connected to the collection of supplier specific LCA-data?
    - Challenges in the data collection?
    - Challenges related to current knowledge, organizational interests, costs, organizational cooperation, etc.?

- Which incentives are needed to motivate a company to do more detailed LCA-analysis, i.e. more extent analysis than those that are performed today with supplier specific data?

- What is reasonable to expect from automotive manufacturers in the future when it comes to LCA and LCM?
    - What should be included in the analysis that not is included today?

- How will the shift towards electrification in the automotive industry affect how LCM are used within automotive companies?
    - Legislations?
    - Supplier requirements?

- Are you aware of any upcoming requirements or legislations when it comes to conducting life cycle assessments?