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Incorporation of Product Carbon Footprint in the Sourcing Process of Electronic Components

A Case Study of a Global Automotive Company and a First-tier Supplier

Master's thesis in Supply Chain Management

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SUMMARY

Today, society is well aware of the global warming of our planet and the need to protect the environment. This puts pressure on companies worldwide, and the automotive industry is an example of an industry in need of change to meet the environmental pressure. Since vehicles are currently going through a digital transformation, they are built with a large number of electronic components. Those components have a significant impact on the global warming potential and thus actions need to be taken to reduce the negative impact. Since the procurement function handles the material flow into a company, research has shown that the department significantly contributes to the organisation's environmental performance. Therefore, there is a need for incorporating more green sourcing practices. One type of green sourcing practice is to let suppliers conduct product carbon footprint (PCF) on the components they sell. This method generates a CO2 impact number in kilograms for the component, hence it enables the buying company to choose the component with the lowest CO2 number. Thus, this thesis aims at conducting a PCF on a specific electronic control unit (ECU). It will further investigate how PCF can be incorporated in the sourcing processes of electronics.

To fulfil the aim of the study, a single-case study with a global automotive company and a first-tier supplier was performed. In the study, a PCF was conducted on the ECU by using material data from the supplier and general environmental data in a software program. Furthermore, nine interviews were held with 13 representatives from the focal automotive company and the first-tier supplier. A theoretical frame of reference was also established to discuss the empirical findings from the interviews and the gained experience from conducting the PCF.

In the findings, eight drivers for incorporating PCF in sourcings' were identified, i.e., it can improve organisations' environmental performance, reduce organisational costs, help companies avoid violations of environmental regulatory laws, create a competitive advantage, improve organisational performance, meet customer requirements, protect firms images and increase collaboration with suppliers. Additionally, seven barriers were identified, i.e., internal costs, alignment of goals, complexity of supply chain, low maturity of using green sourcing practices, lack of transparency from suppliers and supplier-related costs. Furthermore, five capabilities were identified which are important in a successful incorporation. These are: the liaison between procurement and other business units, detailed procurement procedures, partnership approach with suppliers, digital systems and technical skills of procurement and advanced understanding of environmental issues in supply. Lastly, the conducted PCF on the ECU showed that the component emits 14,8 kilograms of CO2 equivalents from raw material extraction until its finalised and exits the first-tier supplier's gate.

Keywords: Green Sourcing, Product Carbon Footprint, Sustainability and Electronics.

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Moreover, we would like to sincerely thank our supervisor at the case company for always supporting us and believing in us. It has been a pleasure to work with you to get insights into how the procurement processes work at the company. Additionally, we would like to thank the team manager for the team we have worked with during these months. The insightful comments and guidance provided by the team manager throughout the thesis work have been very valuable for us.

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Elisa Karlsson & Sally Sheik
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1. Introduction

In the first chapter, a background to the thesis topic will be presented and followed by a description of the focal case scenario. Thereafter, the aim and delimitations of the study will be defined.

1.1 Background

Today's enlightened society is well aware of the global warming currently happening and the need to protect the environment (Walker et al., 2008). With this said, stakeholders are putting pressure on corporations to address environmental concerns and improve their environmental performance. This has resulted in a green trend and increased awareness amongst companies, thus including various types of corporate social responsibility in their activities (Blome et al., 2014). According to Schneider and Wallenburg (2012) the implementation of corporate social responsibility relies upon the involvement of several departments. The procurement function is the centre of a successful corporate social responsibility and has a significant contribution to the organisation's environmental performance. The primary reason for this is because they handle the flow of materials into the company. As stated by Schneider and Wallenburg (2012) “Each organisation is only as sustainable as its upstream supply chain” (p. 245). Furthermore, more companies have started to implement a core competence strategy, where the firm focuses on those areas in which they have competence. This has resulted in an increased importance of the procurement function since companies are relying more on outsourcing. It is therefore essential for a company aiming for a high level of corporate social responsibility to involve their suppliers when addressing environmental concerns and improve their environmental performance.

One strategy that has been used by organisations to fulfil the external criteria and to extend green initiatives to upstream suppliers is to incorporate green procurement (Pelton and Smith, 2015). Green procurement is defined as the integration of environmental consideration during sourcing decisions, thereby it will henceforth be referred to as green sourcing. The aim is to minimise the environmental impact of the upstream supply chain. Procurement has the ability to influence supply markets by demanding more sustainable products from their suppliers. The procurement department can set up sustainability criteria for recycled material, level of toxicity and the efficiency in suppliers manufacturing operations. According to Zsidisin and Siferd (2001), in green sourcing it is important to put a criterion for waste loss, rethink the selection of material and evaluate the suppliers environmental performance. Moreover, companies have started to understand the positive aspects involving green sourcing, as it can in some instances provide a competitive advantage (Rusinko, 2007). This is because it can lead to eco-efficiency, cost savings, and improved reputation (Walker et al., 2008). According to Walker et al. (2008) there exist several drivers for incorporating green sourcing practices. These can be divided into internal ones, e.g.,

reduction of organisational costs and improved quality, and external ones, e.g. meeting customer requirements and protecting firms' images and reputations.

However, the implementation of green sourcing faces various internal and external barriers as well (Walker et al., 2008). One internal challenge recognised by Adham and Siwar (2012), is the lack of knowledge among stakeholders and workers in the organisation. According to Buniamin et al. (2016), the low level of understanding and knowledge will make it difficult for the personnel to appreciate the benefits of green sourcing thus obstructing the implementation. It has also been found by Bowen et al. (2001), that costs related to limited resources, and misalignment of strategic goals between departments in the organisations are two other examples of internal barriers. Furthermore, Blome et al. (2014) highlighted the importance of top management engagement, since low commitment in terms of money and time will slow down the implementation. Another reason why organisations find it difficult to adopt green practices is because of external barriers. According to Walker et al. (2008) can a poor supplier commitment affect the incorporation of green sourcing practices in a negative way. Furthermore, Zhu and Sarkis (2006) also highlight that different sectors face industry specific barriers.

Life cycle management is the concept of integrating environmental work into the organisational processes by integrating environmental thinking in every step. Various procedural and analytical tools are used to manage the total life cycle of goods and services. One common tool used is the life cycle assessment (LCA), which has the aim of mapping out the environmental impact in every life cycle step of a product (Finnveden et al., 2009). Furthermore, Finnveden et al. (2009) claim that LCA can be a useful tool for the sourcing strategy to minimise the environmental impact of the purchased items. The result from the LCA study can provide important inputs that can be used in decision making during sourcing. For instance, Agarwal et al. (2012) claim that LCA can lead the way in engaging suppliers to understand their footprints and how they can act to reduce these. Furthermore, the method can help in sourcing new suppliers, since actors can be compared against each other based on their environmental performance (Agarwal et al., 2012).

According to Yung et al. (2018), there exists a type of practice within the LCA boundaries that have gained increased attention in recent years, and it is the PCF. The PCF builds on the LCA principles but focuses on climate change and global warming potential (GWP) only. The GWP index for a greenhouse gas (GHG) measures the amount of energy one ton of the gas absorbs over a specific time period (typically 100 years) relative to the emissions of one ton of CO2 (EPA, 2022). Thus, it does not consider the broad number of impacts similarly to what a LCA does. However, according to Yung et al. (2018), this single environmental impact is significant, and it is seen as one of the biggest threats to the livelihood of humankind and natural resources. The PCF may also act as the first part of a LCA, where other impacts can be addressed at a later stage.

In order for a firm to incorporate green sourcing practices such as for instance the PCF methodology, to improve the environmental sustainability of purchased components, it is necessary to develop relevant sourcing capabilities (Bowen et al., 2001). These capabilities define the status-quo of what is achievable when intending to incorporate new sourcing strategies. The managers of the firm need to be aware of the capabilities required and how to develop them. A framework has been formed by Bowen et al. (2001) which articulates the role of sourcing capabilities and supports managers in implementing these capabilities.

1.2 Electronics Environmental Impact

The rapid growth in GHGs has increased the concern among government organisations (Vasan et al., 2014). In order to mitigate the effects of global warming, governments, investors and customers are compelling companies to control their GHG emissions. According to Vasan et al. (2014), the electronic industry is estimated to have global GHG emissions of 2%, which is comparable to the airline industry's contribution.

An electronic component is characterised as a device in an electronic system dealing with the emission, behaviour and effects of electrons (Heath and Ratner, 2003). The electronic components can be categorised as active or passive. Examples of electronic components can be transistors, resistors, diodes, inductors and capacitors. They are generally mounted on a printed circuit board (PCB) to create an electronic circuit that can perform simple and complex operations (Scherz and Monk, 2016). PCBs have various attributes and are found in all electronic equipment. The electronic components' complexity is the main reason for having them custom designed with a long design cycle time. The manufacturing processes and equipment are designed based on the product's attributes.

An electronic component goes through different life cycle stages, from raw material extraction, manufacturing, distribution, usage phase and lastly end of life phase (Vasan et al., 2014). A variety of minerals needs to be extracted and processed before going into manufacturing. For instance, the PCB can contain copper traces and plastic resins. Furthermore, gold wire bonds can be found within the integrated circuit (IC). The IC is a set of semiconductors, wafers, copper and other materials that are interconnected. A wafer is a type of silicon plate and acts as the foundation for the ICs with its semi-conducting capabilities. According to Vasan et al. (2014), the mining of the material contributes to the emissions of GHG. Manufacturing of the circuit board and the assembly processes is the next phase in the life cycle. Here, machines are used to carry out different processes such as coating the PCB with a protective surface finish and placing the electronic components onto the PCB. These machines are powered by electricity which also has an effect on global warming.

Since electronic components are classified as high GHG emission-intensive materials, the electronic industry will be affected by directives associated with GHG emissions

(Vasan et al., 2014). For instance, Electrical and Electronic Equipment is an European Union directive used with the purpose of reducing disposal waste from electronic components. GHG emissions emitted from electrical product manufacturing facilities usually need to be reported. The main reason behind collecting GHG data is to forecast future policy decisions. Vasan et al. (2014) argue that members of the electronic industry should start to map out the supply chain of their products and identify hotspots of GHG emissions along the life cycle. The aim of this mapping is to verify what actions are necessary to reduce emissions. PCF is a common method used to identify CO2 drivers in a product or process.

According to Vasan et al. (2014), there are several challenges when performing a PCF of an electronic product. Electronic product manufacturers tend to underestimate the emission numbers due to the challenges they face and thereby fail to identify hotspots and improvement areas. Another challenge with PCF is that there is an inconsistency in the method and tools used by companies in the electronic industry. This results in that manufacturing companies who are conducting PCFs on electronic products or components receive results which are difficult to compare.

1.3 Case Situation

The initiative for the study originated from a procurement department for software and electronics at a global automotive company. The company is currently in a transformation phase with new technologies and sustainability, and in parallel to this, they try to convert a traditional business model into a customer centric model (Case Company, 2022a). External pressure from society has affected the company to improve their work with sustainability, and this has resulted in the development of several corporate sustainability targets. The company has a goal of achieving climate neutrality by 2040 and becoming a leader in ethical and responsible business (Case Company, 2022b). To achieve this carbon neutrality, they have set a goal to reduce 40% of the emissions per vehicle until 2025. This goal has further been split into the three sub-goals: reducing the tailpipe emissions by 50%, reducing the operational emissions by 25% and reducing 25% of the supply chain emissions until 2025 (Case Company, 2022b). Due to these goals, a need for investigating the CO2 emissions from purchased materials has evolved. This requires a collaborative and transparent dialogue with suppliers in order to receive information regarding the impacts of the components. Already in 1996 this was mentioned by Lamming and Hampson, where the authors stated that the firms who worked more collaboratively with their suppliers had a better understanding of the generated environmental impacts throughout the supply chain. Additionally, to reach the goals it is also essential that the focal company sets clear requirements for design specifications including environmental requirements for suppliers (Zsidisin and Hendrick, 1998).

Furthermore, the focal procurement department in this study has the main task to purchase electronic components and software. However, the focus of this study will be

on the procurement of electronics. Examples of electronic components being purchased are: sensors, wire harnesses and control units, used for the infotainment systems and body electronic systems in the vehicles. The purchasing department for software and electronics has already implemented several sustainability practices to achieve the focal company's sustainability targets. However, in order to reduce the electronics contribution to GWP, more actions must be taken.

The PCF on the focal automotive company's most purchased vehicle globally in 2021 indicates that electronics stands for 9% to 13% of the CO2 equivalent impacts of the vehicle, and is thereby the fourth largest CO2 equivalent contributor (Case Company, 2021a, 2021b). CO2 equivalents refer to the most significant GHG emissions including for instance the following gases: CO2, methane, nitrous oxide and freons (Case Company, 2021a). This has resulted in a demand for investigating the CO2 equivalent emissions for the purchased electronics on a component level and identifying the hotspots along the lifecycle. By conducting PCFs and mapping out the hotspots, actions can be implemented to reduce the environmental impact in the upstream supply chain and thereby support the focal company's journey towards becoming climate neutral. The company is currently not performing any PCFs on the purchased electronics. However, since the aim is to incorporate PCFs in the sourcings', it is of great interest to understand what drivers and barriers that exist, and which capabilities that are required to facilitate the incorporation.

For this thesis work will the CO2 equivalents of a specific sourced ECU for their next coming vehicle model be investigated further. An ECU is a small component in an automobile that is responsible for controlling a specific function (Case Supplier, 2020). It can for instance be the control of essentials like engine and power steering, but also comfort control in the form of power in windows and heat in seats. Additionally, they can be used in security and access control, for instance, to control door locks and keyless entry (Case Supplier, 2020).

The procurement department for software and electronics works cross-functionally with other internal stakeholders such as the research and development (R&D) department, and the sustainability centre during sourcing. This cross-functional collaboration was also performed during the sourcing phase of the ECU. The chosen supplier for this component was selected mainly because of the cost, quality and sustainability aspects. However, a PCF was not performed on the ECU during the sourcing phase, and therefore the CO2 equivalents for this specific item is unknown. The supplier for this component is a global manufacturing company that provides complete electrical systems and connection systems for vehicles.

1.4 Aim

The aim of this master thesis is to provide suggestions on how procurement of electronics in the automotive industry can be improved in terms of environmental sustainability. The study conducted will focus on the global automotive company and how the procurement department can use PCF as a tool during sourcing to compare between purchased components' specific CO2 equivalent emissions. The purpose is further to conduct a PCF on an ECU from raw material extraction until its finalised and exits the first-tier supplier's gate. Through this analysis, the most critical hotspots along the life cycle can be found. According to Baumann and Tillman (2004), the type of PCF that analyses the product from raw material extraction to the factory gate is called cradle to gate. However, in this report this concept will be used henceforth for referring to the raw material extraction until the product exits the first-tier supplier's gate. To understand the critical CO2 equivalent hotspots for the specific ECU, the following research question has been established:

RQ1: What are the CO2 equivalent hotspots along the cradle to gate for the global automotive company's ECU?

From the analysis, suggestions will be developed on how the procurement department of software and electronics can use the PCF mapping during sourcing to improve their work with environmental sustainability. Before the incorporation of PCF in the sourcing process, the focal company has to understand the drivers and barriers. By investigating the sourcing process in a global automotive company, drivers and barriers of using the PCF during sourcing can be identified, both from the company's perspective and the supplier's perspective. Therefore, the second research question will be:

RQ2: What are typical drivers and barriers for incorporating PCF in the sourcing process of electronics?

Additionally, an investigation of the sourcing capabilities needed by the focal company to achieve a successful incorporation of the PCF in the sourcing of electronics will be performed. The identification of the drivers and barriers together with the capabilities required by the company will create an understanding of how to successfully incorporate PCF in the sourcing processes of electronics. To guide this has the following research question been formulated:

RQ3: What sourcing capabilities are required by the focal company to incorporate PCF in the sourcing processes of electronics?

1.5 Delimitations

The thesis is limited to one automotive firm and a first-tier supplier, and the study will only focus on the procurement of electronic components. The thesis will be a case study by conducting a PCF on one component, i.e., the ECU. Furthermore, the PCF only takes GWP into account from cradle to gate and transports are excluded.

1.6 Thesis Structure

This thesis is structured into seven chapters, where the first chapter containing the introduction and background has previously been described. Followingly, chapter two will cover the theory that has been investigated to get a deeper understanding of green sourcing practices and PCFs in sourcing processes. After this, chapter three will aim at presenting the methodology used during this work. Thereafter, the next chapter will describe the central case in this study and more specifically the ECUs supply chain. In this chapter, the results of the conducted PCF on the ECU will also be presented. Furthermore, the data gathered from the semi-structured interviews with the focal company and the first-tier supplier will be presented in chapter five. In chapter 6, the findings from the semi-structured interviews together with the experience of conducting the PCF on the ECU will be compared with the theoretical frame of reference. Lastly, the main findings from the discussion of the study will be presented in chapter seven. The structure of the thesis is presented in the list below.

1. Introduction
2. Theoretical Frame of Reference
3. Methodology
4. Case Study
5. Empirical Findings from Semi-structured Interviews
6. Discussion
7. Conclusions

2. Theoretical Frame of Reference

In this section, the theoretical framework will be presented. It is introduced by a description of what procurement is and its involved processes. Thereafter, green sourcing practices are described together with how these can be incorporated in sourcing processes. Lastly, the concept of conducting PCF in sourcings is presented.

2.1 Procurement

Procurement relates to a range of activities involved in the acquisition of goods, services, capabilities and knowledge from an outside external source to be used in the firm's value chain (Van Weele, 2018). Figure 1 illustrates the procurement process model which is inspired by Van Weele (2018), it presents the main activities within the procurement function. Furthermore, the figure defines which processes are included in the procurement function and the sourcing for this study. The activities involved in the procurement function are gathering of business requirements, i.e., specifications of goods, services and solutions. The next step is to source by finding the most suitable supplier who can deliver the quality required at the best price point. Here, it is important to develop procedures and routines with the supplier to ensure compliance. Specifying terms and conditions is necessary to establish an agreement and write a legal contract. Furthermore, ordering, monitoring and controlling are performed to ensure proper delivery and payment. The last step involves following up and evaluating the supplier by measuring their performance.

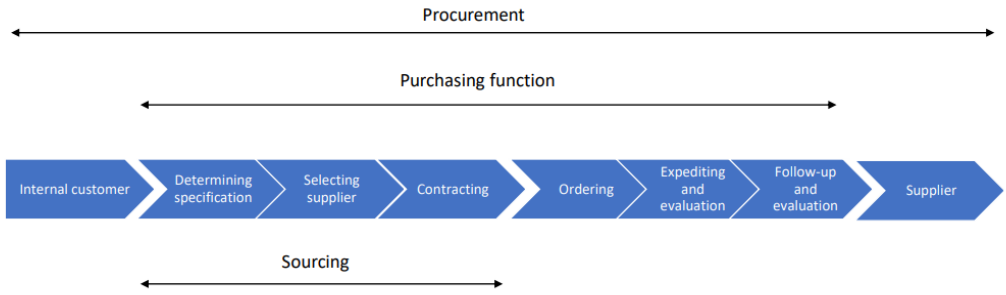

Figure 1: The linear procurement process model inspired by Van Weele (2018).

As can be seen in Figure 1, procurement includes all the activities involved to get the purchased item or service from the supplier to the focal company (Van Weele, 2018). Because of the growing awareness of environmental issues in recent years, many firms have also started to include green procurement practices. The procurement team works to receive the most value at the best possible cost. The teams are typically provided with a budget that specifies the value they can spend to aquisite the goods or services needed.

Procurement is a business function with the purpose of improving the organization’s profitability (Van Weele, 2018). This is done by making processes more efficient,

reducing purchasing prices and costs, and improving the sources of supply. Furthermore, the function is seen as a business necessity since it would be impossible for business operations to function without it. Projects and processes require a supply of items and services to proceed efficiently and successfully. According to Emiliani (2010), procurement has a big potential impact since 50-90% of the firm's cost of goods sold is taken up by purchased materials and services. Van Weele (2018) presented an analysis of the cost structure of manufacturing companies, and the result showed that the total procurement value may amount to 60-80% for manufacturers in the automotive sector. Procurement is based on total cost of ownership (TCO) thinking, which is the concept of looking at the holistic picture and calculating the purchase price of an asset and the costs of operations together (Van Weele, 2018). During the procurement decision, a buyer should not only consider the purchase price but the long-term costs and expenses during the product life cycle.

2.2 Sourcing Process Approach

The first phase of the sourcing process is to determine the requirements (Van Weele, 2018). These requirements are in general categorized into the functional specification and technical specification. The functional specification describes the products' intended functions and specifies the requirements to be implemented by the developers. A technical specification includes the attributes of the product and the technical properties. Furthermore, it also describes the activities that the suppliers are required to perform. According to Van Weele (2018), this way of working can lead to higher costs, since the product and suppliers are over-specified. During the technical specifications, basic technologies are selected with a few suppliers already in mind. Technical changes might occur during the sourcing phase, and it's the buyer's responsibility to inform the changes to suppliers and ensure that they are working according to the last specification sent.

After the sourcing requirement have been defined, the next phase is for buyers to start the supplier selection (Van Weele, 2018). This phase is one of the most important steps in the sourcing process. All potential suppliers with excellent vendor rating scores are put on the initial bidders' list. Thereafter, a request for information will be sent to each supplier on this list. The aim of the request for information is to receive information such as prior projects and previous experience to help evaluate the suppliers' capabilities and qualifications for the job. Supplier visits or audits are usually performed at this stage.

The next step is to create a supplier shortlist with the most promising suppliers based on the information gathered from the request for information (Van Weele, 2018). These suppliers will be contacted through a request for quotation to submit a bid. The particular reason for this is to compare between the suppliers in aspects such as technical, logistical, quality, financial, environmental and legal. Moreover, it is also important to receive detailed cost information from the suppliers to look at the TCO.

Once the supplier has been selected, the next step is to manage the contract agreement. This includes preparing contracts, using contracting expertise and negotiating expertise.

2.3 Green Sourcing

One strategy that has been used by organisations to fulfil the external criterion regarding sustainability is to work with green procurement (Pelton and Smith, 2015). The aim of green procurement is to consider environmental factors and try to minimise the environmental impacts during sourcing decisions, thereby it will continue to be referred to as green sourcing. Green sourcing includes practices such as reduction of waste and encouraging recycling and reclamation of the purchased materials without affecting the quality and performance (Min and Galle, 2001). Hence, green sourcing strategies that are usually incorporated by the firms will be described in the following section. Thereafter, drivers and barriers for incorporating green sourcing strategies will be presented. Lastly, a framework used to incorporate green sourcing in a firm will be presented.

2.3.1 Green Sourcing Strategies

The conceptualisation of green sourcing has developed a variety of environmentally based procurement strategies to be incorporated in the firm during sourcing. Lloyd (1994) presented a generalised typology which included two approaches for green sourcing: supplier environmental questionnaire, audits, and independent environmental certification for suppliers to undertake. In later years, Lamming and Hampson (1996) investigated how companies engage in green sourcing and found three types of strategies that can be used: vendor questionnaires, use of environmental management systems, and PCFs.

Furthermore, Seuring and Müller (2008) conducted a literature review where several authors stated that the use of environmental management systems was considered a sourcing strategy. The environmental management systems incorporate practices and processes in the firm to reduce the environmental impact. For instance, the requirement of official accreditations like ISO 14001 ensures that suppliers meet established standards. Companies could also develop codes of conducts which describe the company's principles, standards, morals and ethical expectations. These rules should be followed by all employees and organisations that interact with the focal company. An additional strategy mentioned by Seuring and Müller (2008) is supplier evaluation schemes whose purpose is to monitor the performance of suppliers by conducting quantitative and qualitative assessments during sourcing. Thereafter, a list of suppliers with the best environmental performance can be compiled and compared during supplier selection.

There is a need for environmental management throughout the whole supply chain, and therefore buyers should work with strategies that promote sustainable practices among suppliers (Hamner, 2006). The strategy used should cause suppliers to adopt environmental management as a behaviour paradigm. Ideally, the purpose should be for suppliers to pass on similar environmental requirements to their own suppliers and thereby achieve improved environmental performance throughout the whole supply chain.

According to Hamner (2006), collaborative relationships with suppliers is the most optimal green sourcing strategy since it will have the most effect on suppliers sustainability behaviour. This conclusion was justified by Charter et al. (2001), where their study revealed that efforts made by procurement companies to develop collaborative relationships had a significant impact on supplier behaviour towards sustainability. However, the sourcing strategy that promotes the most sustainable practices among suppliers also requires more cost and effort needed by buyers (Hamner, 2006). A summary of the different green sourcing strategies can be found in Table 1.

Table 1: List of green sourcing strategies.

Strategies	Source
Supplier Environmental Questionnaires	Lloyd (1994), Lamming & Hampson (1996)
Supplier Environmental Audits and Assessment	Lloyd (1994), Seuring & Müller (2008)
Environmental Management system	Lamming & Hampson (1996), Seuring & Müller (2008)
Life Cycle Assessment	Lamming & Hampson (1996)
Collaboration and Relationship	Lamming & Hampson (1996)
Independent Environmental Certification	Seuring & Müller (2008)
Supplier Evaluation Schemes	Seuring & Müller (2008)
Code of Conduct	Seuring & Müller (2008)

2.3.2 Drivers of Green Sourcing

According to Walker et al. (2008) variables that promote the implementation of green sourcing can be divided into two types: internal and external. Walker et al. (2008) suggested that internal drivers include organisational factors and external drivers include regulation, customers, competition and society.

Carter and Dresner (2001) state that one organisational factor which facilitates green sourcing is the desire to reduce costs. This statement is justified by Walker et al. (2008) by mentioning that companies have started to understand the positive aspects involving green sourcing, as it can in some instances reduce costs and improve organisational performance. It has also been found that improved environmental performance can

result in superior quality. Furthermore, it can also improve a firm's reputation and work as a competitive advantage (Rusinko, 2007). Gimenez and Tachizawa (2012), argue that collaboration with suppliers can promote green sourcing. This includes creating trust between the buyer and the supplier. Additionally, top management involvement has also been found to be a driver for green sourcing.

Min and Galle's (2001) research revealed the environmental variables that affect supplier selections in a buying firm. The findings were that environmental liability and penalty topped are the main drivers for incorporating green sourcing. This includes avoiding cost for disposal of hazardous materials and following state and federal environmental regulations. This finding implies that firms usually incorporate green sourcing in a "reactive" manner rather than proactively embedding long-term sourcing practices that support the firm in achieving their environmental goals. Another finding is that firms tend to perceive their environmental programs as increased costs rather than a strategy to increase profit. A solution to reverse this tendency is to transform environmental impacts into tangible monetary terms, thus helping top management see the real benefits gained from green sourcing.

Carter and Carter (1998) point out the role of the customer and how they have a direct impact on firms' involvement with environmental procurement activities. Customers appear to be putting pressure on corporations to become greener (Walker et al., 2008). Furthermore, the overall society has increased its awareness regarding environmental issues. Companies have therefore started to implement green sourcing to protect the firm's reputation and image (Cousins et al., 2004). Table 2 summarises the drivers of green sourcing.

Table 2: Internal and external drivers of green sourcing.

Internal	
Organisational factors	Reduce organisational costs
	Improve quality
External	
Regulation	Avoid cost for disposal of hazardous materials
	Follow state and federal environmental regulations
Competition	Gain competitive advantage
	Improve organisational performance
Customer	Meet customer requirements
Society	Protect firms image and reputation
Supplier	Increase collaboration with supplier

2.3.3 Barriers of Green Sourcing

The implementation of sourcing practices faces various challenges. Walker et al. (2008) divided these into internal and external barriers. The internal barriers include costs and lack of legitimacy, while the external barriers include regulation, poor supplier commitment and industry-specific barriers. The barriers can be seen in Table 3 below. Research has found that the biggest barrier to effective green sourcing is the high cost of environmental programs (Min and Galle, 2001). The rationale is that many firms believe that the increased investments in green practices will increase the total procurement costs and thereby result in an economic disadvantage for them, thus affecting their competitiveness. This barrier might be common for startup companies with limited financial resources, and therefore they are not ready to implement green sourcing strategies. It has been found by the authors that larger buying firms with large purchasing volumes tend to be more involved in green sourcing practices compared to firms with small purchasing volumes. The main reason behind this is that larger buying firms usually gain more support from company-wide environmental programs thus easing the implementation of green sourcing practices. Moreover, larger firms can exploit their greater bargaining power towards their suppliers and set sustainability criteria. However, Zhu and Sarkis (2007) argue that implementation of green sourcing in manufacturing companies can be less costly compared to other green practices.

Table 3: Internal and external barriers for green sourcing.

Internal	
Costs	Increase purchasing cost
	Limited resources
Lack of legitimacy	Lack of top management commitment
Other	Lack of knowledge
	Misalignment of strategic goals
External	
Regulation	Environmental regulations can inhibit innovation
Industry specific barriers	Low maturity of green sourcing practices in the sector
Poor supplier commitment	Lack of transparency with supplier

Walker et al. (2008) defined lack of legitimacy as the lack of internal consensus for the green sourcing investment. One main challenge recognised by Adham and Siwar (2012), is the lack of knowledge among stakeholders and workers in the organisation. According to Buniamin et al. (2016), the low level of understanding and knowledge will make it difficult for the staff to appreciate the benefits of green sourcing, thus obstructing the implementation. Salam (2008) highlighted the importance of top management engagement since low commitment in terms of money and time will slow down the implementation. Another challenge the author mentioned is that many

companies encounter misalignment of strategic goals regarding the adoption of green sourcing.

Walker et al. (2008) identified regulation as one of the barriers for green sourcing. The argument presented was that environmental legislation and regulation can inhibit innovation. Another barrier mentioned by Walker et al. (2008), is the poor supplier commitment. Suppliers often fear to increase transparency and share information that can expose weaknesses. This is because sharing weaknesses might give other companies a competitive advantage. Zhu and Sarkis (2006) furthermore highlighted that different sectors face different challenges. For instance, according to their research they mean that the automobile industry has one of the lowest levels of practising green sourcing strategies.

2.3.4 Incorporation of green sourcing practises

According to Bowen et al. (2001), green supply includes the supply chain management capabilities that are the attempts to improve the environmental sustainability of purchased components or the suppliers providing the components. Thereby, these capabilities will henceforth be referred to as sourcing capabilities for green sourcing. Green sourcing can be divided into two main types of activities that will improve the environmental performance of purchased inputs (Bowen et al., 2001). The first main type, greening the supply process, represents the firm's supplier management activities which have the aim of changing suppliers behaviour and making them incorporate green practices. The second, product-based green supply, is the concept of developing and designing products to reduce its environmental impact such as selecting material that has lower CO2 emitted during material extraction.

In order to implement green sourcing practices, it is necessary for the firm to develop relevant sourcing capabilities (Bowen et al., 2001). According to Gold et al. (2010), the capabilities "crucially define the status-quo of what is feasible for individual firms or whole supply chains when intending to conceive and implement sustainable sourcing strategies" (p.238). The capabilities should be developed in a strategic and proactive approach to ensure long term achievement (Bowen et al., 2001). Once developed, they will act as support for the implementation of green sourcing practices. Their unique formation which is shaped by the firm's asset position will make it difficult for competitors to imitate and thereby provide a competitive advantage to the firm (Teece et al., 1997). Bowen et al. (2001) argue that managers are aware of the capabilities needed, however the observations made indicate that many firms do not have a framework of how to develop them.

Therefore, a framework was developed by Bowen et al. (2001), which articulates the role of sourcing capabilities in green sourcing. Main sourcing capabilities are: (1) liaison between procurement and other business units (e.g. cross functional collaboration between business units regarding sustainability topics); (2) detailed

procurement policies and procedures (e.g. well established procurement practises); (3) partnership approach with suppliers, (4) technical competencies of procurement professionals (e.g. increase the knowledge of data gathering to PCFs among the personnel); (5) advanced understanding of sustainability issues and how they affect supply among employees.

Firstly, Bowen et al. (2001) explain that the liaison between procurement and other business units can support green sourcing since it allows specific environmental impact to be considered in the design of the product (e.g., reducing materials with high CO2 contribution). Furthermore, it gathers different specialists to discuss environmental problems. Secondly, Bowen et al. (2001) believe detailed procurement policies and procedures are key to a successful implementation of green sourcing practices. As cited by Bowen et al. (2001) "The policies may allow environmental issues to be built into existing structures rather than bolted on, and facilitate the integration of environmental issues into the strategic supply process" (p.177-178). Thirdly, the partnership approach with suppliers promotes the understanding between the focal company and its suppliers' on the environmental impacts of their activities (Bowen et al., 2001). Moreover, it facilitates the communication and transfer of data and information between the actors. The interorganisational relationships can also build more confidence which can support the incorporation of green sourcing practices. Bowen et al. (2001) also mention the need for developing technical skills and competencies of procurement personnel. Since the incorporation of green sourcing and PCFs requires an increased amount of data that needs to be gathered, this capability can support in carrying out the process effectively. The last capability, developing an advanced understanding of sustainability concerns and how they affect supply among employees, is central in incorporating green sourcing. Bowen et al. (2001) state that there historically has existed an environmental illiteracy among purchasing personnel. Therefore, it is important to train employees involved in sourcing processes in the basic understanding of environmental issues and the range of activities that can be used to improve green sourcing

Sharma and Vredenburg (1998) argue that corporate environmental proactivity can encourage the development of capabilities. The firm needs to prioritise environmental issues and go beyond compliance. Furthermore, if the firm has a proactive stance regarding environmental topics, it will gain a better understanding of the issues and thereby find solutions on how to acquire the relevant capabilities (Bowen et al., 2001). Another approach to developing skills and resources in the firm is by having highly strategic procurement and supply activities. This includes a well-defined procurement function and procurement plan. A more collaborative approach with suppliers is also a strategy that can be used to gain more knowledge, thus more capabilities. Figure 2 illustrates the framework for incorporating green sourcing practices in a firm.

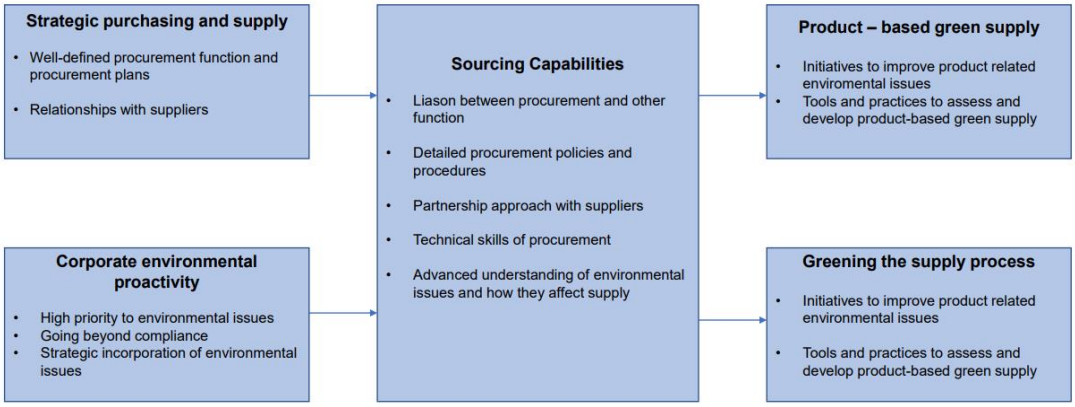

Figure 2: The framework for incorporating green sourcing practices in a firm.

2.4 Product Carbon Footprint in Sourcing

In this section, the concept of LCA is firstly introduced. Afterwards, the PCF approach only considering the CO2 equivalent emissions will be described. Thereafter, the methodology of looking at the hotspots of the PCF will be described. At last, the challenges with conducting PCFs in the electronics industry will be presented.

2.4.1 Life Cycle Assessment

According to Bjørn et al. (2018) the LCA methodology has four main characteristics. First, it takes a life cycle perspective when analysing the environmental impacts of a system or product. Hence, for a physical product, the analysis starts from the extraction of raw materials and ends when the object is treated as waste. Occasionally, can a product also be recycled or reused and thus closing the lifecycle loop. Secondly, the LCA considers multiple environmental issues when analysing a system or product. Bjørn et al. (2018) explain that rather than focusing on only one environmental impact, the LCA covers a broad range of environmental impacts to avoid burden shifting, which is also why a life cycle perspective is taken. Thirdly, a LCA has the characteristic of being quantitative. This means that the environmental impacts are analysed in numbers, thus making it possible to compare products and systems. For instance, can CO2 emissions be recalculated to kilograms and water consumption to litres. Hence, this enables valuable insights into which products or processes that are better from an environmental perspective, or which ones that are contributing in a negative way and therefore require more attention. The last main characteristic of the LCA is that it is based on natural science. Bjørn et al. (2018) state that the flows of materials often are based on measurements, and that relationships between emissions and impacts have a basis in confirmed casualties, such as for instance chemical formulas.

2.4.2 Product Carbon Footprint

As previously mentioned, the LCA covers the entire environmental impacts of a product or system throughout its lifecycle, whereas a PCF focuses on climate change and GWP only (Yung et al., 2018). According to the ISO standards (2018), the carbon footprint of a product is calculated through a summarisation of GHG emissions and removals in a product system. It is further based on a LCA and contains four phases, but focuses only on climate change. According to ISO (2006; 2018), this is an iterative process that consists of the four phases: the definition phase for the scope and goal, the inventory analysis phase, the impact assessment phase, and the interpretation phase. A picture of the four phases can be seen in Figure 3.

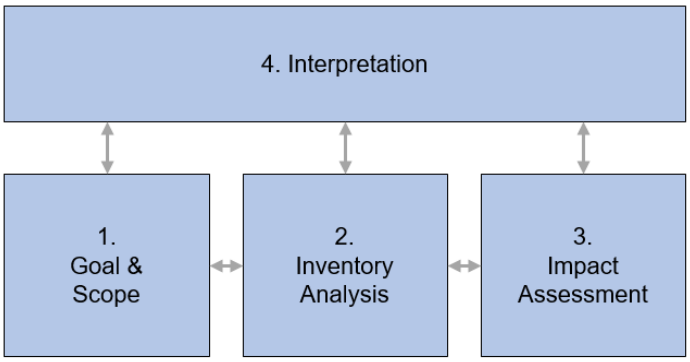

Figure 3: The four phases of a PCF. Inspired by ISO (2006; 2018).

The scope and goal phase focuses on clarifying the context of the study and describing its intended application. This phase also includes defining the boundaries of the system that should be studied and establishing the main assumptions and limitations (Hauschild, 2018). Furthermore, in the inventory analysis phase an inventory of the inputs and outputs from the system is being studied (Hauschild, 2018). To meet the goals of the defined study, this phase aims at collecting the relevant data that is needed to meet those. In the life cycle impact assessment phase additional data is searched for in order to support the assessment of the inventory data, and thus evaluating the real environmental consequences this data has (Hauschild, 2018). It can for instance be the recalculation of all emission flows of CO2 into GWP. Life cycle interpretation is the last phase described by ISO (2006), and the purpose of this phase is to combine, summarise and discuss the results from the life cycle impact assessment phase and the inventory analysis phase. Thus, recommendations and conclusions can be formulated and act as a foundation for decision-making. Furthermore, ISO (2018) states that the GHG emissions and removals shall be expressed as CO2 equivalents, which is a unit where the mass of a GHG is multiplied by its GWP.

2.4.3 Hotspot Analysis

According to Pelton and Smith (2015), generating full PCFs on multiple products across multiple criteria is time-consuming and costly. Since PCFs are specific to a particular product, a new PCF must be conducted each time the product has added new features or changed design. Stakeholders usually put pressure on buyers to work on a project for a certain time period, and therefore they are not able to wait for a full PCF report. Lamming et al. (2001) stated that PCF is only useful in the procurement context if data, time and cost requirements are reduced. This has led to several attempts made to simplify the PCF analysis.

Hotspot analysis is a method used to efficiently identify potential areas in the supply chain to reduce the carbon footprint (Huang et al., 2009). Conducting PCF on the identified hotspots will reduce the requirements for data, time and cost, while still capturing the largest portion of the supply chain impact.

2.4.4 Challenges with PCF Approach for Electronic Products

According to Vasan et al. (2014), there are several challenges when performing a PCF on an electronic product. Electronic product manufacturers tend to underestimate the emission numbers due to the challenges that they face and thereby fail to identify hotspots and improvement areas. In order for manufacturing companies to calculate accurate PCF results, they have to identify the main challenges and take action to overcome those. The reason for wanting accurate PCF results is to make effective decisions on how to minimise the emission drivers in the product life cycle.

A challenge with PCF is that there is an inconsistency in the method and tools used by companies in the electronic industry (Vasan et al., 2014). This results in that manufacturing companies who conduct PCFs on electronic products or components receive results that are difficult to compare. The reason for the inconsistency can be because of differences in the boundary system and life cycle inventory used in the PCF. Some customers ask manufacturers to deliver a PCF report during the selection phase of a supplier since they want to consider environmental aspects as well. However, not having a standard for how a PCF should be conducted will make the results incompatible. The result could also be inaccurate since the inventory analysis phase database used could have old and outdated data, and therefore it loses its validity.

3. Methodology

This chapter aims at presenting the methodology of the study by describing the chosen methods that have been used to answer the research questions. The core of the methodology consists of a case study of the purchasing department for software and electronics at a global automotive manufacturing company, and their dialogue with one first-tier supplier. According to Yin (2018) there exist six phases in a case study: plan, design, prepare, collect, analyse and share. Yin (2018) further explains that the process is a linear but iterative process, where several steps need to be reviewed. The core phases described by Yin (2018) have been used in this thesis as a foundation. However, the phases have been modified and split into several sub-phases to support the specific case. A picture of the methodology for the thesis project is shown in Figure 4, and the different phases are explained in the following sections.

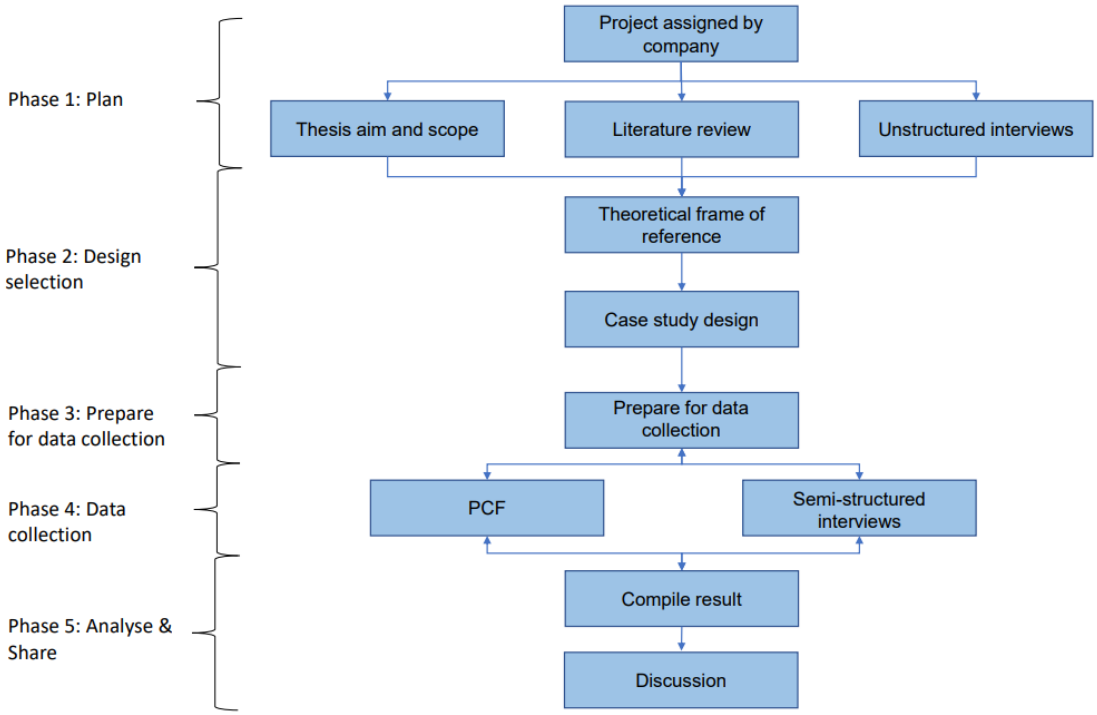

Figure 4: The methodology for the thesis project. The timeline to the left indicates in which order the different phases were conducted.

3.1 Phase 1: Plan

In the first phase of a case study, Yin (2018) states that it is important to understand why a case study would be a suitable method to use for the research. The case study method allows researchers to obtain the holistic and significant characteristics of a real-life event, like for instance small group behaviour, maturity of companies and managerial processes (Yin, 2008). Thus, this method has been chosen to understand the characteristics of procurement of electronics in a real procurement department at a global automotive company. Yin (2018) further explains that it is crucial to narrow

down and specify the area of study. This was performed in the first phase of the methodology, where the assigned project from the company was discussed to define a scope and aim of the thesis. This process was conducted in parallel with a literature review and unstructured interviews to investigate and specify the topic. The following sections will aim at explaining those sub-phases.

3.1.1 Literature Review

In the beginning of the study a literature review was conducted. This included searching together with reading relevant articles and theories regarding sustainability, and more specifically green sourcing practices. The aim of the literature review was to gain an understanding of the context and more expertise within the area. This work was primarily performed in the first month of the project, but it was to some extent ongoing throughout the whole study. Research articles and books were retrieved through the Chalmers Library database and Google Scholar. The literature search focuses on the following keywords: *green sourcing, green procurement, sustainability and electronics, life-cycle assessment and product carbon footprint*. Together with this were internal documents from the focal company studied to understand their procurement processes and their work with sustainability.

3.1.2 Unstructured Interviews

In parallel with the literature review, unstructured interviews were conducted with employees at the focal company and representatives from suppliers. The discussions with the employees at the central firm were held in an open-structured design, where the researchers barely did any preparation since the focus was to have an open discussion to specify the topic and understand the company's interests and desires. Those meetings were primarily held with the supervisor from the company and the sustainability team at the procurement department.

Before the unstructured interview with the first supplier a few questions were developed, and during the discussion, a pitch was conducted to attract the supplier's interest in the work. The supplier was also asked to review a document developed by the automotive company consisting of guidelines for performing PCFs. The list of the unstructured interviews can be found in Table 4.

Table 4: List over unstructured interviews.

Interview	Date	Discussion Topic	Length (min)	Subject	Role	Department	Company
1	18/1/2022	Component Selection	60	Interviewee A	Category Buyer	Procurement: Software & Electronics	Focal Automotive Company
				Interviewee B	Senior Software Buyer	Procurement: Software & Electronics	Focal Automotive Company
				Interviewee C	Category Buyer	Procurement: Software & Electronics	Focal Automotive Company
2	24/1/2022	Align Scope & Component Selection	60	Interviewee D	Team Manager	Procurement: Software & Electronics	Focal Automotive Company
				Interviewee E	Senior Manager	Cost Engineering: Software & Electronics	Focal Automotive Company
3	24/1/2022	Introduction to Cost Engineering	30	Interviewee F	Cost Engineer	Cost Engineering: Software & Electronics	Focal Automotive Company
4	26/1/2022	Sustainability in Procurement	60	Interviewee A	Category Buyer	Procurement: Software & Electronics	Focal Automotive Company
				Interviewee B	Senior Software Buyer	Procurement: Software & Electronics	Focal Automotive Company
				Interviewee C	Category Buyer	Procurement: Software & Electronics	Focal Automotive Company
5	28/1/2022	Procurement Processes at the Focal Company	60	Interviewee C	Category Buyer	Procurement: Software & Electronics	Focal Automotive Company
6	31/1/2022	Introduction to the ECU	30	Interviewee F	Cost Engineer	Cost Engineering: Software & Electronics	Focal Automotive Company
7	16/2/2022	Plan for Supplier Meeting	30	Interviewee A	Category Buyer	Procurement: Software & Electronics	Focal Automotive Company
8	18/2/2022	Potential Candidates for the Semi-Structured interviews	60	Interviewee A	Category Buyer	Procurement: Software & Electronics	Focal Automotive Company
				Interviewee B	Senior Software Buyer	Procurement Software & Electronics	Focal Automotive Company
				Interviewee C	Category Buyer	Procurement: Software & Electronics	Focal Automotive Company
				Interviewee G	Procurement Director	Procurement: Software & Electronics	Focal Automotive Company
9	22/2/2022	Environmental Impact of the ECU	30	Interviewee A	Category Buyer	Procurement: Software & Electronics	Focal Automotive Company
				Interviewee H	Strategic Innovation Manager	R&D: Core System Platform Development	Focal Automotive Company
				Interviewee I	Sales Representative	Sales	ECU Supplier (Tier 1)
				Interviewee J	Project Manager	Sales	ECU Supplier (Tier 1)
				Interviewee K	Project Manager	Sales	ECU Supplier (Tier 1)

10	23/2/2022	PCF discussion of the ECU	60	Interviewee A	Category Buyer	Procurement: Software & Electronics	Focal Automotive Company
				Interviewee H	Strategic Innovation Manager	R&D: Core System Platform Development	Focal Automotive Company
				Interviewee I	Sales Representative	Sales	ECU Supplier (Tier 1)
				Interviewee K	Project Manager	Sales	ECU Supplier (Tier 1)
11	2/3/2022	Procurement High-Level Training	180	Several Interviewees	Competence Developers	Competence Development: Procurement Processes & Tools	Focal Automotive Company
12	3/3/2022	Environmental Impact of Semiconductors	60	Interviewee C	Category Buyer	Procurement: Software & Electronics	Focal Automotive Company
				Interviewee L	Category Buyer	Procurement: Software & Electronics	Focal Automotive Company
				Interviewee M	Principal Engineer	R&D: System Team	Focal Automotive Company
				Interviewee N	Analysis Engineer	Sustainability Centre: Environmental Attribute & Material	Focal Automotive Company
				Interviewee O	Category Buyer	Procurement: Propulsion	Focal Automotive Company
				Interviewee P	Sales Representative	Sales	Semiconductor Supplier (Tier 2)
				Interviewee Q	Sustainability Manager	Sustainability Centre	Semiconductor Supplier (Tier 2)

3.1.3 Thesis Aim and Scope

During the literature review and unstructured interviews, the thesis aim and scope were discussed and reviewed. The literature review made it possible to see gaps in the existing research and increase the understanding of the topic. When the unstructured interviews were conducted at the same time, the aim and scope were formulated accordingly to the different stakeholder's interests. For instance, was the initial and broad topic of the study to investigate the industry sustainability standards for purchased components. However, this topic was continuously refined and specified by the discussions and literature, and this finally resulted in the establishment of the three research questions for this study.

3.2 Phase 2: Design Selection

The second phase mentioned by Yin (2018) is the case study design, this phase aims at defining and bounding the case to be studied. According to Yin (2009) shall this step act as a link between the data that will be collected and the research questions together with the reasons for why the case study is conducted. In this phase, the theoretical frame of reference of the thesis was decided and developed from phase 1. When the theoretical

frame of reference was established, the design of the case study began, both those sub-phases will be described in the following sections.

3.2.1 Theoretical Frame of Reference

At the beginning of phase two, the theoretical frame of reference was decided and thereafter developed. To understand the daily work of the buyers in the procurement department, the theoretical frame of reference aims to first introduce what procurement is and what processes that are involved in this concept. This enhances the knowledge of where in the process and how the buyers can influence the suppliers to consider the sustainable aspects of their business. Furthermore, green sourcing practices are described in the aspect of how these can be incorporated in the sourcing processes.

Furthermore, the theoretical frame of reference was developed to include how to conduct PCFs in sourcings. The reason for this is since the procedure was mentioned early in the unstructured interviews with the company due to its well-recognized and structured process of defining the CO2 equivalent impacts in kilograms of a product. Additionally, the procurement department expressed that it would be helpful to have the actual CO2 equivalent impact quantified in real numbers because it would facilitate the comparison between different suppliers products in the future.

3.2.2 Case Study Design

As earlier mentioned, Yin (2018) describes the importance of bounding and specifying the case to be studied. This study is designed as a single case study, analysing the sourcing of electronics between a global automotive company and one of its first-tier suppliers. The case has been limited to only focusing on one sourced ECU and one first-tier supplier. The specification and boundaries of the case have been defined in Figure 5 below. The figure visualises the two companies and the departments within them that have been studied. At a later stage, the semi-structured interviews were conducted with employees working in these departments.

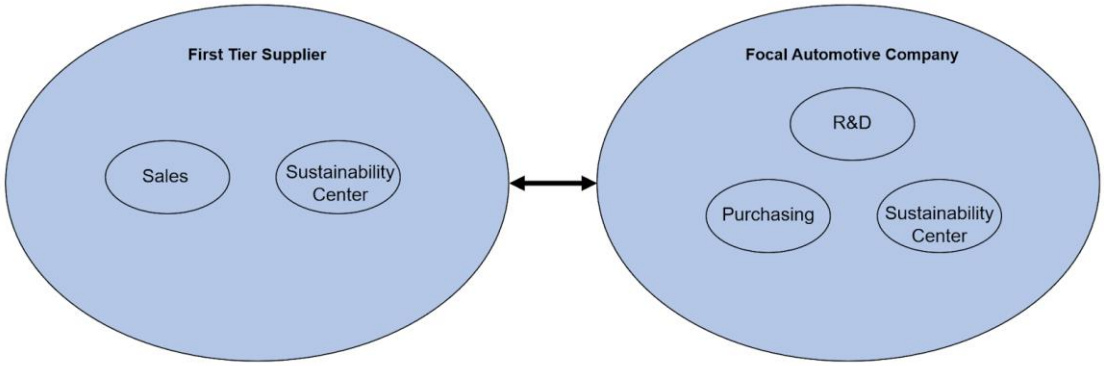

Figure 5: A picture of the boundaries for the data gathering in this case study.

According to Yin (2018), it is also important to test the quality of the case study. Yin (2018) further explains that the case study design can be tested against four criteria developed from social science research: construct validity, internal validity, external validity, and reliability. Since the entire thesis work has been designed as a case study, those tests will be discussed in the last part of this chapter in order to cover all the aspects of the methodology.

3.3 Phase 3: Prepare for Data collection

Yin (2018) mentions several aspects that are important in the preparation phase of a case study, before starting the data collection. In this study, the focus has been on the following aspects which Yin (2018) suggests: honing skills and training for the specific case study, gaining approval for human subjects protections, and screening candidates and selecting final cases for the data collection.

As previously mentioned, an ongoing literature review has been conducted throughout the whole study with the aim of enhancing the knowledge of the researchers. Additionally, the researchers have been involved in several interactive trainings provided by the focal automotive company to increase the understanding of the procurement processes within the company and the work with sustainability. Furthermore, to enhance the knowledge even more, videos presenting the company's PCF process characteristics and sustainability tools in the sourcing process have been viewed.

Moreover, Yin (2018) points out the importance of gaining approval for human subjects' protection before starting with the data collection. In this study, this was mainly performed by signing confidential contracts with the focal company and having ongoing dialogues regarding which type of information that could be included in the study. The focal automotive company's name, its supplier and the employees' names have been anonymised for purpose of protection. The work with confidentiality was

also carried out in the semi-structured interviews, and this will be described in combination with them in the next phase: collect.

Furthermore, the screening of candidates and selection of the final case for the data collection were conducted in this phase. An interviewee list was established containing representatives from the focal automotive company and the first-tier supplier. The initial selection of relevant interviewees was decided through discussions with the supervisor from the company, however a snowball effect was also present to some extent. This snowball effect primarily arose from the first interviews held, meaning that the interviewees gave further suggestions on other relevant persons to interview from the focal company or from the supplier.

3.4 Phase 4: Data Collection

According to Yin (2018), case study evidence can be collected through several sources. In this study, semi-structured interviews and PCF have been chosen to act as sources of evidence. The semi-structured interviews have been chosen due to the possibility of analysing a real case scenario with primary sources in a neutral way. Furthermore, the PCF approach has been chosen due to its widely accepted methodology of investigating the environmental impacts of products. It also gives a comprehensive and detailed understanding of where in the product's chain most of the CO2 equivalent contributions exist. The two approaches will be further described in the following sections.

3.4.1 Semi-structured interviews

Semi-structured interviews with experts from the company were chosen for this qualitative study. According to Bell et al. (2019), semi-structured interviews are a flexible method allowing the researcher to have an open mind regarding what knowledge that is needed, hence theories and concepts can emerge from the collected data. This is a primary reason for why this method has been chosen, in other words, it enables a neutral analysis of all emerging aspects mentioned by the primary sources in the case study. Furthermore, every single interview can be adapted to treat the most interesting topics, since the follow-up questions can be formulated with this in mind. Additionally, the interviews held at a later stage in the process could also be designed to continue on interesting topics mentioned in the earlier stages of interviews. The semi-structured interviews mainly focus on analysing the aspects of RQ2 and RQ3, since the method enables the interviewees to express their views on important aspects, i.e., drivers and barriers as well as sourcing capabilities, when incorporating PCF in the sourcing processes.

All interviews were conducted by both authors of the thesis to ensure that all prepared questions were asked and to ensure a high quality of the gathered data. A mixture of physical interviews at the company's office together with remote interviews through the video-conferencing tool Microsoft Teams was used. The interview list can be found

in Table 5. During the interviews, notes were taken, and the dialogues were recorded. The two primary languages used during the interviews were Swedish and English depending on the interviewees' preferences. Transcription of the recordings into texts was also conducted in order to analyse the data at a later stage.

Table 5: The list of interviewees for the semi-structured interviews.

Interview	Date	Length (min)	Subject	Role	Department	Company
1	3/21/2022	60	Interviewee 1	Procurement Director	Procurement: Software & Electronics	Focal Automotive Company
2	3/24/2022	60	Interviewee 2	Category Buyer	Procurement: Software & Electronics	Focal Automotive Company
3	3/29/2022	60	Interviewee 3	Category Buyer	Procurement: Software & Electronics	Focal Automotive Company
4	3/4/2022	60	Interviewee 4	Senior LCA Engineer	Sustainability Centre: Environmental Attribute & Material	Focal Automotive Company
5	3/15/2022	60	Interviewee 5	System Architect	Sustainability Centre: Sustainability Architecture	Focal Automotive Company
6	3/16/2022	60	Interviewee 6	Analysis Engineer	Sustainability Centre: Environmental Attribute & Material	Focal Automotive Company
	3/16/2022	60	Interviewee 7	Analysis Engineer	Sustainability Centre: Environmental Attribute & Material	Focal Automotive Company
7	3/25/2022	60	Interviewee 8	Industrial PhD Candidate	Sustainability Centre: Environmental Attribute & Material	Focal Automotive Company
8	3/18/2022	60	Interviewee 9	Strategic Innovation Manager	R&D: Core System Platform Development	Focal Automotive Company
9	5/18/2022	60	Interviewee 10	Director of Global Sustainability	Sustainability Centre	ECU Supplier (Tier 1)
			Interviewee 11	Global Sustainability Manager	Sustainability Centre	ECU Supplier (Tier 1)
			Interviewee 12	Commercial Manager	Sales	ECU Supplier (Tier 1)
			Interviewee 13	Account Manager	Sales	ECU Supplier (Tier 1)

The selection of relevant interviewees was decided by the thesis authors together with the supervisor from the company. Moreover, the selection consists of people working within the procurement department or in close vicinity to it, but also employees working more centrally with sustainability within the company. Additionally, representatives from suppliers that work closely with the company were also interviewed. The interviews held with the focal department had a focus on the procurement processes, the purchased components and the current integration of sustainability into this work. Before each interview, open-ended questions were designed and follow-up questions were asked during the interviews depending on the answers given. Furthermore, the focus of the interviews with the suppliers was on how they work with sustainability and the different impacts of the components they produce.

3.4.2 Product Carbon Footprint

According to Yung et al. (2018), the PCF has four phases as earlier mentioned: the definition phase for the scope and goal, the inventory analysis phase, the impact assessment phase and the interpretation phase (ISO, 2006). In the definition phase, a PCF was decided to be conducted to analyse the CO2 equivalents in kilograms, from cradle to gate for a specific sourced ECU. The reason for choosing this method is due to its widespread recognition throughout the research on how to calculate the CO2 equivalent emissions in a standardised way. Moreover, the outcomes of it will help the involved organisation to understand where in the product's chain the hotspots of emissions exist. The cradle to gate analysis in this case refers to the analysis of the component from raw material extraction until it is finalised and exits at the first-tier supplier's gate. Furthermore, the PCF will be used as a tool for mainly answering RQ1 since the methodology will result in numbers on the CO2 equivalent emissions throughout the product's supply chain.

For the inventory analysis phase, the chosen ECU was studied on a deeper level. In the beginning, the general parts of it were analysed through a bill of material (BOM) provided by the focal automotive company. However, since this BOM was on a relatively general level, a detailed material report from the first-tier supplier was requested. This material report was extracted from The International Material Data System (IMDS), which is a database developed by automotive manufacturers (de Oliveira et al., 2022). According to de Oliveira et al. (2022), IMDS has a list of all subcomponents and detailed material composition of all the components and therefore it can be used as a data source in the PCF studies. When this report was extracted from the IMDS database, the different materials of the ECU could be identified in grams. From the IMDS report, the sub-components were categorised into six groups: populated printed circuit board (PCB-P), housing, gore, adhesive, screw and others. The PCB-P could further be categorised into 10 groups: resistor, capacitor, diode, IC, crystal, thermistor, solder, unpopulated printed circuit board (PCB-U), inductor and common mode.

In the impact assessment phase, a software program provided by the focal automotive company was used. The program is called Gabi and is widely known and used by PCF practitioners. It is worth mentioning that the impacts for each material in the database of Gabi only consider averages based on numbers from many different sources. This data was the primary source for the analysis, although supplier specific data was used in the case of understanding the exact material composition of the component.

To receive a PCF result that was as accurate as possible, each subcomponent was built up in the software. These sub-components were built up by adding material and electricity as the input. The exact amount of material was extracted from the IMDS report and then added to the process. A limitation was added here by excluding the materials that represented less than one percent. There was not any supplier specific data regarding the electricity required for the different processes collected from the

first-tier supplier. Therefore, inspiration was taken from the already existing aggregated processes in the software Gabi. Some conservative assumptions were made during the PCF calculation. For instance, the energy source used for electricity was assumed to be a global average mix of energy sources. Furthermore, the component group which was categorised as others was assumed to have the same CO2 contribution as the IC. The reason for this is that ICs has generally a high CO2 contribution. Aggregated processes were used for the raw material extraction and refining of the different materials.

The interpretation phase of the PCF was conducted to combine, summarise and discuss the results from the two previous phases. In this phase, recommendations and conclusions could be formulated by including the focal automotive company's and first-tier supplier's thoughts on some big CO2 equivalent contributors. The software program was beneficially used in this phase, to visualise the results from the PCF in charts and graphs. This facilitated the recognition of the CO2 equivalent hotspots within the cradle to gate scope.

3.5 Phase 5: Analyse & Share

In the last phase of the study, the empirical findings from the semi-structured interviews and the experience gained from conducting the PCF on the ECU were compiled and compared with the theoretical frame of reference. One common analytical tool used when analysing the case study data is pattern matching (Yin, 2018). This tool was used in this thesis to structure the findings from the semi-structured interviews. Hence, in the beginning the interview questions were designed to fit into the categories of the identified theory. Afterwards, when the answers from the interviews had been transcribed, they were arranged under the different theoretical concepts. For instance, there is a section regarding drivers and barriers in the theoretical frame of reference and thus the interviewees were asked to define the main challenges and drivers for incorporating PCF in the sourcing process. Thereafter, when the answers had been grouped into a category, they were compared against each other to find similarities and differences between the interviewees' thoughts. Moreover, the results from the PCF conducted on the ECU were analysed by looking at the graphs and tables generated from the Gabi software. When conducting the PCF, the researchers gained an understanding of how such a process works and the challenges of conducting one. Therefore, this experience could be used in order to compare this with theory and the empirical findings from the semi-structured interviews in the discussion. In the discussion, the empirical findings were discussed in comparison with the theory to find similarities and differences, but also to identify the key findings of this study.

Lastly, the main findings from the thesis work were presented to four different audiences, one was performed at the university and the additional ones were performed at the case company. After the presentation at the university, feedback was received from an opponent group and the thesis was refined based on this. The aim of the three presentations at the focal company was to spread knowledge and learnings among the

personnel. However, the audiences were requested to provide feedback on the findings as well. This made it possible to validate and refine the thesis before it was finalised.

3.6 Research Quality

Since a research design is supposed to reflect logical statements, certain logical tests can be used to verify its quality (Yin, 2018). Throughout the years, the following four tests have been widely known for their usage in verifying empirical social research: construct validity, internal validity, external validity, and reliability. Yin (2018) means that case study research is a type of social research, and consequently, the tests should be used for this type of research as well. Furthermore, Yin (2018) highlights the importance of using the tests throughout the entire case study and not only in the design phase. In the following sections, the four tests including their tactics are being applied to this thesis work. The four tests including their tactics that have been used in this thesis can be seen in Table 6 below.

Table 6: The four logical tests including their tactics based on Yin (2018).

Tests	**Case Study Tactic**
Construct Validity	Use multiple sources of evidence
	Maintain a chain of evidence
	Involve key informants to review the case study
Internal Validity	Pattern matching
	Address rival explanations
External Validity	Use theory in single-case studies
Reliability	Clearly present the methodology used
	Develop a case study database

3.6.1 Construct Validity

The construct validity tests to which level a case study investigates what it claims to be investigating (Denzin and Lincoln, 1994). In other words, it measures the extent to which a process results in accurate and valid observations of reality (Denzin and Lincoln, 1994). Gibbert et al. (2008) emphasise that construct validity must be considered during the data collection phase. According to Yin (2018), the test is especially challenging in case study research since researchers tend to be subjective and use operational measures that confirm their own predefined ideas when collecting data. There exist three tactics that can be used to ensure a high level of construct validity in a case study (Yin, 2018). The first one is to use multiple sources of evidence, the second one is to maintain a chain of evidence and the last one is to involve key informants whose main task is to review the draft of the case study report.

The usage of multiple sources of evidence implies that a researcher must look at the same phenomenon from different perspectives by using different data collection procedures and data sources (Gibbert et al., 2008). Accordingly, several sources of evidence have been used in this thesis work. In the data collection, semi-structured interviews were used to collect data from internal employees at the focal company and the first-tier supplier. Internal documents were also reviewed to increase the understanding of the organisation and the procurement processes. Furthermore, a PCF was performed in the data collection phase, where the main sources of evidence originated from a material report provided by the supplier and generic data in the software program Gabi. Worth mentioning is that the interviewees for the semi-structured interviews were chosen to represent different angles and perspectives of the key topic. Although the representatives working at the focal automotive company could be biased, the supplier's perspective was also considered to attain multiple sources of evidence.

To maintain a chain of evidence it is vital that the reader of the study can follow the derivation of any evidence from initial research questions until the final case study findings (Yin, 2018). Yin (2018) further explains that the reader must be capable of tracing the steps in either direction, both from initial research questions to findings and in opposite direction. In alignment with this, the research questions in this study have first been developed and always been present throughout the execution of the study, resulting in findings reflecting those in a consistent manner. For instance, the research questions were used as a guiding star in the semi-structured interviews and afterwards, the interviews were transcribed and stored. When analysing the transcriptions, similarities and differences between the interviews were noted, ideas were linked to the main topics of the study and quotations were marked. Consequently, the empirical findings could be linked to the research questions through a clear chain of evidence.

Moreover, Yin (2018) states that not only should peers review the draft of the case study to enhance the accuracy, but key informants and participants of the case study should also be involved. The supervisor from the university reviewed the process on a weekly basis and peers reviewed the report three times to provide feedback on the work. Additionally, the supervisor at the focal automotive company who also acted as a participant in the case reviewed the report continuously. The team manager for the software and electronics procurement team also reviewed the report a couple of times to provide new insights and ensure an accurate level of confidentiality. Lastly, the thesis was presented internally in the focal automotive company for three different audiences consisting of participants in the study.

3.6.2 Internal Validity

Internal validity refers to the causality of the relationships between analysis units and results (Gibbert et al., 2008). Yin (2018) describes that the study needs to consider certain conditions leading to other conditions, without involving false links between

those. The internal validity should be considered in the data analysis phase and the tactic used in this thesis encompasses pattern matching and addressing rival explanations.

When a pattern can be found and compared between the case study's empirical findings and a predefined assumption or belief, the study is using the logic of pattern-matching (Yin, 2018). The methodology of this thesis implies that the theoretical framework was developed before and during the data collection, hence theoretical assumptions were grasped before analysing the empirical findings of the semi-structured interviews. Thus, pattern matching was used to increase the internal validity by analysing the patterns between the literature and the interviewees' beliefs. In addition, Yin (2018) states that rival explanations should be addressed, meaning that explanations competing with the provisionary explanation of the data must be investigated. The rival explanations were addressed in the data analysis in this study by discussing the validity of the interviewees' arguments based on their experiences and backgrounds.

Additionally, pattern matching was used in the impact assessment phase of the PCF. The software program Gabi builds on the practices of the CML 2001 method, which is a method developed by the Institute of Environmental Sciences at Leiden University (Sphera, 2022). CML 2001 considers numerous studies conducted to find correlations between emissions and environmental impact potentials, which in this case is GWP of GHGs (Sphera, 2022). Hence, this strengthens the internal validity of the PCF results.

3.6.3 External Validity

According to Yin (2018) and Gibbert et al. (2008), external validity is a test which shows if and how a case study's findings can be generalised beyond the case in focus. Yin (2018) explains that this test must be considered already during the research design, and especially in the design of the research questions. Furthermore, Yin (2018) separates analytic generalisation and statistical generalisation and means that the first one is desirable in case studies, whereas the latter is present in surveys and experiments. To achieve analytic generalisation, it is important to use theory about the topic and discuss the potential findings and generalisations of the study, instead of just stating them (Yin, 2018). A case study should not be treated as a sample and cannot be statistically or numerically generalised, therefore claims and flaws of the study must be discussed thoroughly.

In accordance with Yin's (2018) research, this study has been designed to demonstrate an accurate level of external validity. To achieve the analytic generalisation of the findings, a theoretical frame of reference has been developed regarding the subject. This theory was then used to discuss the findings of the semi-structured interviews and PCF, hence generalisations could be found and stated in the discussion and conclusions of the study.

3.6.4 Reliability

The objective of the reliability test is to ensure that the case study can be repeated at a later occasion and result in the same insights and conclusions as the first time (Yin, 2018). It means that another researcher should be able to follow the steps of the methodology and arrive at the same results again (Gibbert et al., 2008). According to Gibbert et al. (2008), transparency and replication are essential in this test. Yin (2018) shares the same opinion and means that it is important to keep clear documentation and make as many procedures as explicit as possible.

To ensure a high level of reliability in this study, a methodology with defined steps was developed in the beginning. The steps of the methodology can be seen in Figure 4 as earlier mentioned. Hence, by presenting this procedure to readers, anyone should be able to conduct the same phases and arrive at the same results. Furthermore, questions were developed before the semi-structured interviews and those can be found in Appendix A and B. By following these questions another researcher could hopefully arrive at the same answers and insights as the authors of this study. Moreover, all evidence such as for instance transcriptions of the semi-structured interviews, research articles and public documents with information regarding the case company have been gathered in a Google drive. Thus, the Google drive acts as a case study database, which according to Gibbert et al. (2008) is an enabler for replication of a case study and this further improves the level of reliability.

4. Case Study

In the following section, the case study will be described. Firstly, the procurement department for software and electronics is introduced. Secondly, the case company's general work with PCFs is presented. Thereafter, an introduction to the studied component is presented and lastly, the CO2 equivalent hotspots of the component are explained.

4.1 Procurement Department for Software and Electronics

The procurement department for software and electronics in the focal company is responsible for supporting the running issues in production and securing the production with parts. One of their main tasks is to source electronic components, e.g., sensors, wire harnesses and control units, used for the infotainment systems and body electronic systems in the vehicles. They work in global category teams consisting of buyers, supply quality managers, global category managers and team managers.

Buyers have the responsibility for commercial and quality deliveries for running business and aftermarket. Furthermore, their task is to industrialise new vehicle programs by creating commodity business plans. These plans include the scope of what is needed to be sourced for the new vehicles, what strategy to be used and the time frame for the achievement of the goals. In order to manage the commodity business plan, buyers need to work cross-functionally with different stakeholders.

The category teams work closely with R&D at the focal company to ensure that the components are designed in alignment with the manufacturing of the vehicles. Cost engineers are considered to be a supporting function for the procurement department, by delivering a cost estimate. The cost estimate is a bottom-up calculation made to create an estimate of what the cost of a certain component should be. This provides a common ground and allows the buyers to compare different suppliers.

The buyers need to manage the supplier relationships and performance for the entire product life cycle. This includes managing topics such as sustainability and quality targets. They also have the responsibility to perform all the activities required for the commodity such as sourcing, re-sourcing, projects, risk management and developing the supplier base to be more efficient. Yearly cost negotiations are performed for all running projects, which include different cost saving programs and negotiation events with the suppliers.

Global category managers are responsible for the overall backlog, which is the list of tasks required to support a larger strategic plan. Furthermore, they determine what should be in the backlog for the next program increment, i.e., usually 12 working weeks, and the prioritisation of these tasks. They also provide guidance to the buyers regarding procurement strategies and should ensure that the team is working according to the focal company's policies and ethics. Every team member has a team manager

who supports their competence and personal development. Team managers and global category managers work together to support the team in achieving high performance.

4.1.1 Sourcing Process

The focal company has built and designed the sourcing process for buyers to master, which can be seen in Figure 6. Commodities for the infotainment systems and body electronic systems in the vehicles are developed by R&D. When the commodity has been developed, the product owner will create an engineering state of work which consists of a drawing, a 3D model with all dimensions included and all the technical requirements. The technical requirements include areas such as material, temperature and sustainability. A sourcing need is created during the development of the product and the task is given to the global category managers in the procurement department of electronics. The global category manager will then delegate the responsibility for the sourcing to a buyer in the team.

Figure 6: The sourcing process for electronics.

The first step in the sourcing process is to start to create a commodity business plan, which is a comprehensive strategic document overview of a commodity. It is created collaboratively between procurement and R&D throughout the sourcing process to describe the scope of the commodity from a technical, sustainability, supplier and strategic point of view. The next step in the sourcing process is to create a sourcing strategy by identifying potential sourcing candidates. Buyers can use the supplier bank to find suppliers that the focal company is currently working with. Otherwise, they need to search for new ones. The supplier's location and their previous performance are taken into account when searching for potential candidates. The strategy has to be presented and approved by the global council which consists of directors and head of software and electronic procurement. For larger businesses or more strategic commodities, an approval from the head of procurement has to be notified as well.

Once it has been approved, a request for quotation will be sent out to the candidates chosen for this project. At this stage, suppliers need to provide several documents such as cost breakdown, sustainability questionnaire, packaging suggestions, quality performance from their manufacturing site, and sign that they shall follow the requirements set in the engineering state of work. The negotiations with the suppliers start in the request for quotation phase, where the desire is to reach a mutually satisfactory agreement. The aim of the negotiation is to reduce the cost by achieving a

lower price. In this process stage, it is also possible to negotiate the sustainability requirements.

An internal quotation is also performed, to receive calculations on the logistic costs and the CO2 emissions emitted during shipment from the supplier to the focal site. This is because the focal company is responsible for the shipment of the commodities. These calculations are performed by the logistics team. After receiving the quotations, the buyers can make a TCO calculation by including the purchase price and logistics costs. Another internal quotation is made to receive a cost estimate of the commodity. The guideline suggests that the gap between the cost estimate and the purchasing price delivered by the supplier should not exceed five percent. Supply quality managers are also involved during the quotation phase by providing information about how well the suppliers meet the focal company's standards. Audits are made by the supply quality managers by visiting the suppliers manufacturing site and evaluating their performance regarding quality and sustainability. After collecting all these quotations, a comparison of the suppliers is made by looking at the cost, quality and sustainability aspects.

Once the supplier has been nominated, the decision has to be presented to the global council again. Here it is important to argue why the chosen supplier was selected by taking cost, quality and sustainability into consideration. The next step in the sourcing process is to sign an agreement. The chosen suppliers have to accept the focal companies' general purchasing conditions.

4.1.2 Sustainability Initiatives in Sourcing

The focal company has developed several corporate sustainability targets and has recognised that their CO2 footprint is dependent on their suppliers' emissions (Case Company, 2022b). Because of this, the focal company has recognised the importance of working with suppliers who are on the same sustainability journey as them and share the same ambitions. As mentioned by the head of procurement at the focal company's website "We're calling on our suppliers to help us achieve our climate neutral by 2040 ambition - now sustainability is as important as cost and quality" (Case Company, 2021c).

The procurement department of software and electronics has therefore implemented green sourcing practices to reach these targets, means interviewee C (personal communication, 28 January 2022). The interviewee further explains that employees at the department are encouraged to take procurement sustainability training offered by the focal company. The aim of the training is for the employees to gain more knowledge about the sustainability tools available in sourcing. Furthermore, the purpose of the training is to develop a common understanding within procurement of the ongoing sustainability initiatives and goals that they want to achieve. It also aims at clarifying the buyers' roles in the area of sustainability and the responsibility that comes with this position.

According to interviewee C (personal communication, 28 January 2022), suppliers need to fill in a sustainability questionnaire during the sourcing phase which evaluates their performance and their commitment to the sustainability targets. Furthermore, the interviewee means that the suppliers need to be ISO 14001 certified, to ensure that suppliers meet established standards related to environmental management. Additionally, a self-assessment questionnaire is required by the suppliers, to evaluate their sustainability performance. The assessment is conducted by using a platform from a third party organisation which automates the suppliers' identity and compliance management. This platform is recognised as world-leading and is used across the automotive industry.

Interviewee C (personal communication, 28 January 2022) explains that the procurement department for software and electronics has a transformation team focusing on sustainability topics. This team consists of buyers and one procurement director. Their main task is to drive sustainability topics within the department and support buyers in implementing green practices. A sustainability checklist has been created by the team, which involves all the sustainability related activities to be performed by the buyers in the sourcing phase. According to interviewee C (personal communication, 28 January 2022), the aim of the checklist is for buyers to incorporate green practices during sourcing and dialogues with suppliers. For instance, one of the points in the list is to ask the suppliers if they have conducted PCFs on their products, and another one is asking the suppliers how much renewable energy they use in their manufacturing processes. Furthermore, they support the process of collecting environmental assessments that are performed by all relevant suppliers and are updated once per year. Once the assessment has been received by the focal company's data system, it will be reviewed by the department of sustainability. The purpose of this assessment is to track the suppliers' progress towards the focal company's supplier targets and try to identify hotspots and improvement areas. Additionally, interviewee C (personal communication, 28 January 2022) states that the buyers together with the department of sustainability have dialogues with first-tier suppliers to increase green collaboration and become more sustainable throughout the supply chain. A summary of the sustainability initiatives performed by the software and electronics department during sourcing can be found in Table 7.

Table 7: Summary of the sustainability initiatives in sourcing.

Sustainability Initiatives
Supplier Questionnaire
ISO 14001
Self Assessment Questionnaire
Sustainability Checklist
Sustainability dialogues with suppliers

4.2 Case Company's PCF Work

Currently, the company has conducted PCFs on two complete vehicle models. For one out of the two models, the electric version and the combustion type of the model have been compared (Case Company, 2021a). The company has also committed to conducting PCFs for all coming vehicle models in the future. However, PCFs have not yet been done on component levels, instead the materials have been consolidated into groups, and generic datasets for the emissions of these groups have mainly been used.

Although there does not exist any standardised method of conducting PCFs in the automotive industry, the focal company has followed the standards set by ISO (Case Company, 2021a). For the vehicles, they have focused on a cradle to grave approach and have only considered GWP potential (Case Company, 2021a). Most of the data for the materials included in the vehicles have been retrieved from IMDS reports according to the company. Furthermore, life cycle impact assessment phase databases containing general data on a variety of different materials, processes, energy, and logistics throughout the industry have been used to gather data about the materials and processes emissions (Case Company, 2021a). The company has also collected internal data over for instance the emissions from manufacturing and logistics, and energy and fuel consumption of the average vehicle. Moreover, supplier specific data for the battery modules of the electric vehicles were collected by providing methodological guidelines for the battery suppliers (Case Company, 2021a). The main reason for a deeper investigation of these components is because of their recognised harmful and big impact on the environment. The different data sources were then consolidated and used in the Gabi software and the results of the total emissions were then retrieved.

4.3 ECU

The chosen component for this thesis work is as earlier mentioned an ECU, which will be used in the case company's next coming vehicle models. The sourcing decision regarding the supplier of the component is already decided, but the component is currently not being manufactured. The main reason for choosing this specific electronic component is because of the detailed BOM that was received from the first-tier supplier. Due to confidentiality, the component will only be described on a general level with its main characteristics and sub-components. The main purpose of the ECU is to receive signals from smaller devices and sensors in the vehicle and convert those into signals which can be read by a central computer in the vehicle.

Although the ECU is quite small in size, it consists of approximately 1000 smaller sub-components. Those sub-components can roughly be divided into the housing, the PCB and mounted electronic components. The housing is a black box made of aluminium, and it is supposed to protect the PCB-P with smaller components. The PCB-U is firstly manufactured and on this board are smaller electronic components mounted. Instead of having a high number of cables and wires taking up space in the vehicle, the PCB-P

and its components can create closed electronic circuits in significantly smaller space. The smaller electronic components are for instance resistors, capacitors, diodes and transistors.

Since the ECU consists of many smaller sub-components, the supply chain is characterised as very complex according to interviewee E. It consists of many different actors and tiers of suppliers and because of this complexity, it is challenging to get the full visibility of the chain. However, a simplified model of the ECUs supply chain can be seen in Figure 7. Interviewee E describes the supply chain, and initially the wafer is produced. It is also usually packaged and tested by another company in this phase. Thereafter, a semiconductor company manufactures the ICs by processing the wafer in several steps and attaching for instance transistors and resistors. When the IC is finished it is distributed by another actor to electronic manufacturing service companies. The electronic manufacturing service companies assemble the ICs and additional smaller components on PCB-Us. The next step is the final assembly of the PCB-Ps into the housing. This is performed by the first-tier supplier before the final ECU is ready for transportation to the focal automotive company. In the focal automotive company, the ECU is integrated in the system of the vehicle and connected to other ECUs and the central computer means interviewee A.

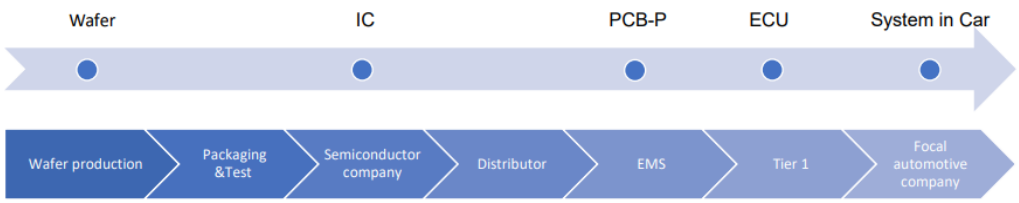

Figure 7: A simplified model of the ECUs supply chain.

The material report from IMDS indicated that the ECU's 1000 sub-components can be categorised into six groups: PCB-P, housing, gore, adhesive, screw and other. A list of the categories and the sub-components included can be found in Table 8.

Table 8: List of ECU's sub-components and its categorisation.

Category	Sub-component
Populated Printed Circuit Board (PCB - P)	Resistor
	Capacitor
	Diode
	Inductor
	Integrated Circuit (IC)
	Thermistor
	Unpopulated Printed Circuit Board (PCB - U)
	Crystal
	Solder
	Common mode
Housing	Top Housing
	Bottom Housing
Gore	Gore
Adhesive	Adhesive
Screw	Screw
Other	Connectors
	Semiconductors
	Suppressor
	Transistor

4.4 Flow Chart of ECU's Production Processes

This section will present flowcharts that give a visual overview of the ECU's production processes which includes material production and manufacturing. Figure 8 illustrates the flowchart for the PCB-P, which consists of ten sub-components. The first step in the PCB-P's supply chain is the extraction and processing of raw materials. Then, the material arrives at the manufacturing facility and is used for the manufacturing of the sub-components. Here, machines are used to carry out different processes and those are powered by electricity. Once the sub-components are manufactured, they are mounted onto the PCB-U to create a PCB-P. This process also requires electricity.

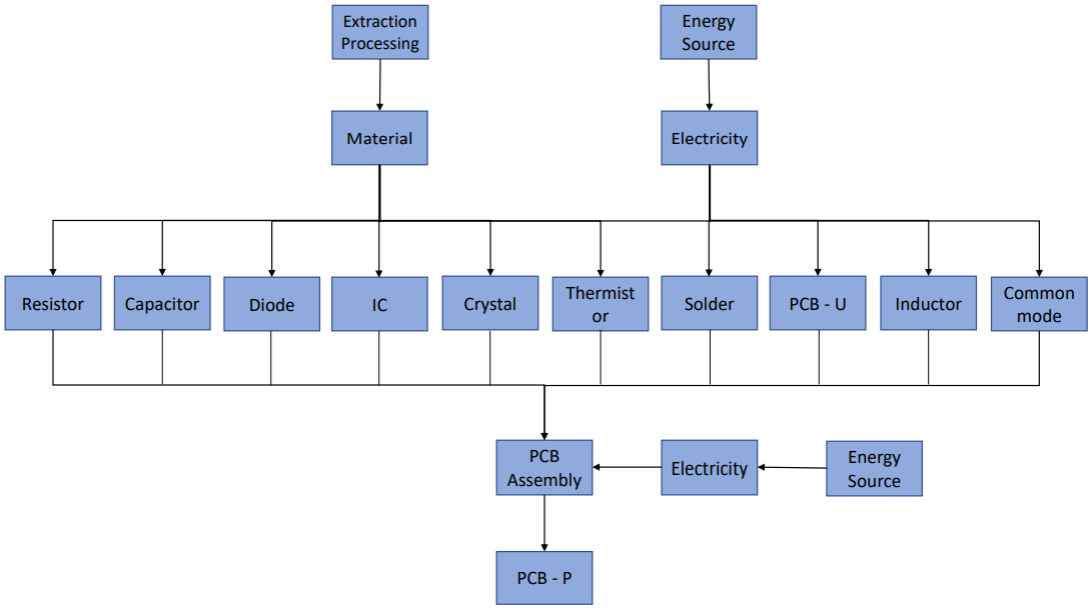

Figure 8: Flowchart of the PCB-P's production process.

The last step in the ECU's supply chain is the final assembly production process which is illustrated in Figure 9. Raw materials are extracted from the environment and then transformed into materials that are to be included in the product. The incoming material is thereafter used together with electricity to create the housing, screw, adhesive, gore and other components. These components are together with the PCB-P assembled into an ECU.

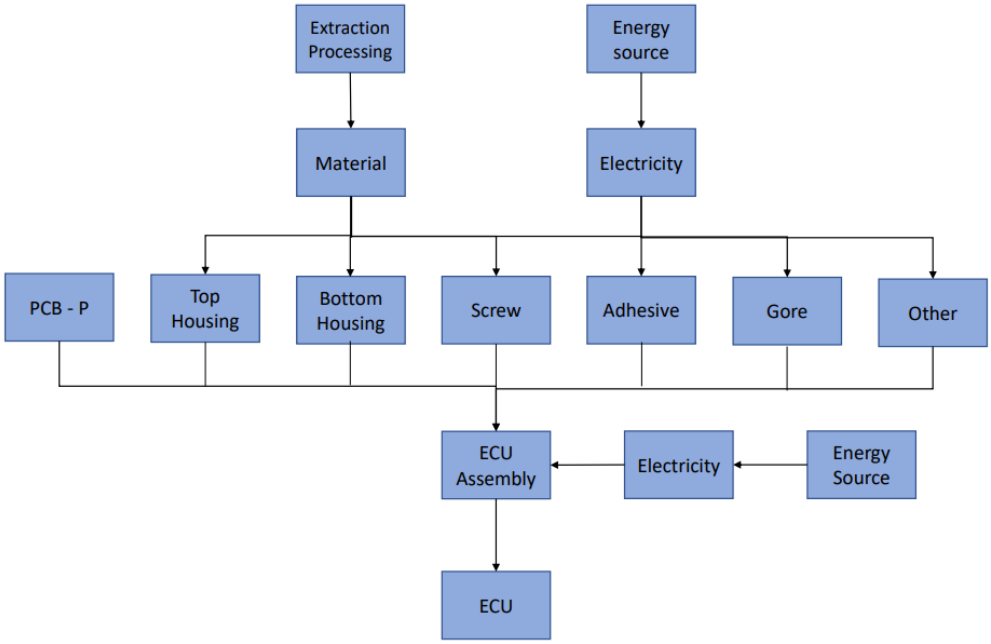

Figure 9: Flowchart of the ECU's final assembly production process.

4.5 CO2 Hotspots of the ECU

To answer RQ1 in this thesis, this section will aim at presenting the results of the conducted PCF on the ECU. Thus, the CO2 hotspots along the cradle to gate can be identified for the component. The result from the PCF can be seen in Figure 10. According to the diagram, the total GWP for the ECU is 14,8 kg CO2 equivalents. The diagram also illustrates the top five sub-components that contribute to global warming, which are the bottom housing, common mode, IC, PCB-U and top housing. These five sub-components together correspond to 88,5% of the total global warming emission for the ECU. The staple named "Rest" represents the other 14 sub-components and stands for 11,5% of the emissions.

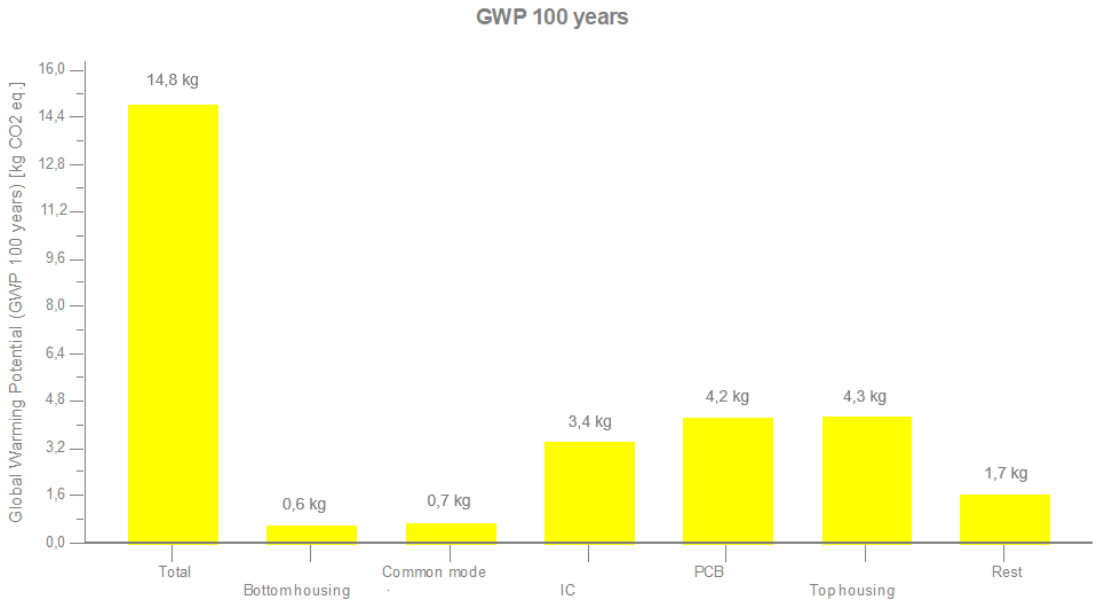

Figure 10: GWP for the ECU.

Table 9 illustrates the percentage of total emissions for different components and manufacturing processes. The red processes refer to the primary hotspots which stand for more than 10% of the total emissions. The yellow processes refer to the secondary hotspots, which stand for 3-10% of the total emission. The aim of this table is to identify sub-components and processes that are the top contributors to global warming. For instance, top housing has the greatest contribution to global warming by representing 28,9% of the total emission. The leading influential factor for this high contribution is the aluminium cast alloy production which stands for 28,9% of the total emission. Another great contributor is the PCB-U sub-component which stands for 28,3% of the total emission. According to the table, the electricity used during the PCB-U manufacturing is the primary cause to release emissions by representing 24,6%. Furthermore, based on the results shown in the table, the mining and production of gold for the IC has the third highest contribution to the total emission by representing 16,2%. By looking at the table it is possible to see that the electricity consumption in the

manufacturing across sub-components is a big CO2 equivalent contributor. For instance, the electricity required for manufacturing a PCB-U represents 24,6% of the total emissions. The sub-component with the second highest electricity consumption required in production is the IC, it represents 6,8% of the total emissions. In addition to this, the electricity in the common mode production stands for 2,6% of the emissions. In total, this adds up to at least 34% of the total emissions since the electricity required to for instance extract materials from the ground not is included in this number.

Table 9: Percentage of total emissions for components and processes.

Sub-components	Percentage of total emission (%) - component	Process	Percentage of total emission (%) - process
Top Housing	28,9	Cast aluminium alloy production	28,9
PCB - U	28,3	Electricity	24,6
		Tin plating production	2,6
		Lamination	1,1
IC	23,1	Gold mine and production	16,2
		Electricity	6,8
		Rest of material and processes	0,1
Rest	11,2	Inductor	3,8
		Diode	3,3
		X Conn	3,0
		Rest	1,1
Common mode	4,5	Electricity	2,6
		Copper oxide production	1,7
		Rest	0,2
Bottom Housing	4,0	Wrought aluminium alloy production	4,0

5. Empirical Findings from Semi-structured Interviews

This section aims at presenting the empirical findings from the semi-structured interviews conducted with the focal automotive company and the first-tier supplier of the ECU. Firstly, the representatives' view on drivers and barriers for incorporating PCF in the sourcing process of electronics is explained. Thereafter, their thoughts regarding the capabilities required by the focal company to incorporate PCF in the sourcing processes are presented.

5.1 Drivers of Product Carbon Footprint in Sourcing

The results from the semi-structured interviews indicated that there were both internal and external drivers to incorporate PCF in sourcing and this will be presented in this section. Internal drivers are referred to as the factors inside the business that can push the company into incorporating green sourcing and are usually factors that the company has control over. While external drivers are the factors outside the company providing reasons for them to incorporate green sourcing.

5.1.1 Internal Drivers

From an internal point of view, interviewee 6 explains that the focal company is relying more on outsourcing by purchasing most of the parts needed for the vehicles from suppliers. The company has realised that their CO2 footprint includes the emissions throughout the whole supply chain. Interviewee 6 mentions that it is important for the company to call on their suppliers to help realise their goals of becoming climate neutral by 2040. Incorporating PCF in sourcing, and adding requirements on suppliers to identify hotspots, could support the goal of reducing the CO2 footprint. A similar claim is made by interviewee 3, who mentions that incorporating PCF in the sourcing will support the company in reaching their environmental goals. Furthermore, interviewee 5 indicates that the focal company is currently seeking knowledge in where the main CO2 footprint contributors of electronics are in the supply chain. Receiving PCF reports from suppliers will allow the company to map out the CO2 footprint and gain a better understanding of the main contributors. Interviewee 5 indicates that the focal company needs to identify and evaluate the company's current state when it comes to the CO2 impacts of the purchased commodities, which the PCF can support with.

Interviewees 2, 3 and 5 mentions that it is essential to compare suppliers' CO2 impacts during sourcing and transform it into monetary terms. The monetary value is then added to the TCO, and a more comprehensive comparison can be made. According to interviewee 3, this might result in CO2 being the driving factor for some businesses by choosing the supplier with the least CO2 emission. Furthermore, by transforming the CO2 impact into monetary terms, buyers can choose the supplier with the lowest TCO.

5.1.2 External Drivers

From an external point of view, interviewee 8 mentions the necessity of incorporating PCF in sourcing, as the market is moving toward becoming more sustainable and customers are becoming more aware of environmental issues. According to interviewee 3, PCFs can be used as a tool to measure the reduction of CO2 made for each vehicle. The interviewee further claims that this can result in a competitive advantage for the company since they can market their vehicles as being more sustainable compared to other competitors.

Interviewees 3 and 5 believes that incorporating PCF in the sourcing process is a necessary step for the procurement department to accomplish. The reason is because the EU emissions trading system has set a carbon price to pay for each tonne of CO2 that the company emits. The carbon price is expected to gradually increase throughout the years, and therefore it is important that the company works proactively by trying to minimise the emissions now. Interviewee 3 explains that the focal company has set a higher price on carbon emission compared to the EU emissions trading system to work proactively with this topic and help to achieve their goals of becoming climate neutral by 2040.

Interviewee 5 mentions that the comparison of suppliers' CO2 emissions can also lead to an incentive for suppliers to produce more sustainable components if they want to create business with the focal company. Interviewee 2 explains that buyers today are mainly focusing on costs and reducing the purchasing price. Incorporating PCF in sourcing can encourage buyers to have a longer-term perspective on the business.

Since the complexity of the products has increased, it is important to have transparency with the suppliers. Interviewee 2 suggests that creating a partnership with the suppliers can increase the transparency. Interviewee 2 further states that the incorporation of the PCF in sourcing can increase the transparency between the focal company and their suppliers. By asking suppliers to perform PCFs during sourcing, the company will gain a better understanding of the product's lifecycle and its effects on global warming.

5.2 Barriers of Product Carbon Footprint in Sourcing

In the following section, the internal - and external barriers expressed by the interviewees from the focal company and the first-tier supplier will be presented.

5.2.1 Internal Barriers

From an internal point of view, interviewee 3 states that "Traditionally there has always been a focus on the cost perspective for the procurement – and R&D department. The solutions must not be too expensive." The interviewee together with interviewee 9 expresses that R&D takes technical functions and sustainability targets into

consideration. However, the technical functions are usually more prioritised. Interviewee 3 also gives an example of a situation when the R&D department made a technical specification of a product which could only be sourced from a specific supplier. Hence, a comparison of the best price and sustainability performance between suppliers could not be conducted. Furthermore, interviewee 1 complies with the statement expressed by interviewee 3 who also explains that price is the major KPI for the procurement department to look at. However, interviewee 3 believes that the sustainability work precedes in the right direction for sourcing and gives an example of when a supplier was selected due to its better sustainability performance rather than being the cheapest choice.

Several interviewees think that the incorporation of PCF in the sourcing will take time and be costly. Interviewee 9 explains that even if the sustainability centre wants to be available for direct contact with suppliers when it comes to sustainability issues, they do not have enough resources. This is aligned with what interviewee 6 explains when the interviewee expresses that six employees at the sustainability centre sometimes can be scarce. Interviewee 3 further expresses that if the focal company were to include more sustainable practices, more resources would be valuable. The interviewee explains “When I am thinking of it, we would need a sustainability expert in every department, but it is not so easy to realise".

5.2.2 External Barriers

Most of the respondents from the focal automotive company believe that challenges related to the specific industry exist when it comes to an incorporation of PCF in the sourcing processes of electronics. Four of the interviewees (Interviewees 1, 2, 5 and 8) think a major challenge is the complexity of the upstream supply chain for electronics. Since electronic components consist of many sub-components being supplied by various companies, the supply chain in this industry is characterised by numerous suppliers in different tiers. This means that it becomes problematic to find the root cause of problems since those can stem from a supplier located several tiers away in the chain.

The complexity of the supply chain results in problems with the data gathering means interviewee 2. Interviewee 8 who has been conducting PCFs in the company has a similar perception and explains “The data gathering was definitely the biggest challenge for my work”. The interviewees’ work has been conducted on components that are already in production, hence material reports with the complete recipe of the components have been available. Interviewee 8 together with the majority of the other interviewees within the focal company believes it would be interesting to see this in the sourcing phase, but thinks it can be difficult for the suppliers to find the specific data in such an early stage. Nevertheless, interviewee 2 clearly explains “The suppliers should be able to provide a PCF in the sourcing phase. If they are providing a quotation, then they should have a PCF since they have a BOM”. Interviewees 5 and 8 means it is

possible to do a general PCF with the data from the material reports and the BOM. However, to get the full picture it is also required that the suppliers provide information about for instance their specific production processes, the location of the facilities and their energy consumption.

In the same way, the focal automotive company describes that a major barrier is the complexity of the supply chain and the data gathering, interviewee 11 expresses similar thoughts from the supplier's perspective. Interviewee 11 explains "There are a lot of layers of suppliers below us in the supply chain, and all of these must develop competence and technology to have the right resources for collecting data for PCFs. It is a very complex situation". However, even if there may be a lack of specific data due to the complexity of the chain, interviewee 10 believes it is possible to conduct PCFs in a sourcing phase. The interviewee states "The PCFs in sourcings will be based on the available information at the time. All the materials will be known in this phase, but the suppliers might not be defined. Then it must be decided if we should wait on that information or continue with assumptions".

To overcome the problem where suppliers do not have all the information about their product in the sourcing phase, several interviewees (e.g., interviewees 6, 7 and 9) from the focal automotive company mean that using a PCF of a similar product can be a solution. Even if the products are not the same, it would be a way of getting a decent perception since many companies are at the beginning of their journey towards zero emissions. Interviewees 5, 6 and 7 believes that instead of asking the suppliers for comprehensive PCFs with all the details, a solution would be to start looking at the CO2 hotspots in the products' chains. Moreover, interviewee 3 thinks that the data used for PCFs in the sourcing phase will be generic since the full design of the products is not set. Nevertheless, the interviewee means this is a good start but that a revisitation of the PCF would be needed in a later stage when all the contracts are signed and the material reports are defined.

As earlier mentioned by the focal automotive company, several interviewees believe it may be wise to use already developed PCFs for similar products. This is aligned with the supplier's thoughts since interviewee 10 expresses "Unless something significantly changed in the material composition between a previous generation of a product and the current generation, the CO2 impacts would have been very similar". Another alternative mentioned by the focal automotive company was to work with the hotspots of the PCFs. The supplier believes this would be a valuable and interesting alternative. Interviewee 10 gives an example of this and explains "For instance, when a PCF was conducted on one of our components it turned out that gold had the biggest impact. Hence, instead of focusing on every single piece that goes into the product, the focus would be on the gold. I believe the biggest benefits can come from looking into the biggest impacts, instead of investing time in every detail".

Interviewee 4 explains that the focal automotive company has already started to develop an own PCF guideline, where the plan is to gather CO2 specific data from suppliers in

the future. Currently, a pilot study with a first outcast of the guidelines has been sent to 15 suppliers. Through this pilot, the company aims at collecting useful information on how the suppliers experience the guidelines and how they could be improved. In relation to this, interviewees 1, 2 and 3 believes it would be difficult to get acceptance throughout the industry of PCF guidelines developed individually by the focal automotive company. Interviewee 1 states "I would rather see a joint initiative between several original equipment manufacturers, where guidelines could be developed together to suit the whole automotive industry, or in this case, the electronics industry for automotive". Interviewees 6 and 7 mentions similar thoughts as well. Interviewee 1 further thinks it would be prudent to look at how ISO standards have been developed and create similar standards for PCF guidelines. Both interviewees 1, 2 and 3 express that in this case, they understand it may be better for the focal automotive company to start developing guidelines since there do not exist any industry specific standards. However, interviewee 1 explains it is important to lead it in some direction and try to get acceptance from other original equipment manufacturers or subcontractors. In line with this, interviewee 2 expresses "I think it is good that we are progressive with creating a PCF guideline. I mean we are challenging the suppliers every day, and we cannot just wait for a standard to come".

Supplier representatives 10 and 11, mention several times that the market for electronics has a low maturity of performing PCFs and that it does not exist any industry specific standards. They believe it is crucial to have a common way in the industry on how to conduct the PCFs, otherwise it is a waste of time performing PCFs that are not comparable. Interviewee 12 explains "We need to work together in the industry to develop a methodology that is suitable to use. The methodology needs to be simple enough but also robust enough, and it must be designed so it can be used across companies". However, the supplier representatives' further express that they will follow requirements for doing PCFs developed by the focal automotive company if they are standardised and cost-effective.

All the respondents from the focal automotive company believe barriers will come for the suppliers with the implementation of PCF guidelines which consequently can affect themselves. Interviewee 5 means some suppliers are afraid of presenting information regarding their suppliers, since they believe the focal automotive company can cut them out as a middleman from the chain. The interviewee means that transparency throughout the chain is crucial in the work with PCFs, however he means that some suppliers are afraid of presenting sensitive information. Interviewees 6 and 7 also believe the focal automotive company needs to have an open dialogue built on trust with the suppliers to receive information on CO2 impacts in the sourcing phase. Otherwise, they believe a catch 22-situation can occur, since suppliers do not want to disclose sensitive information which can portray them negatively in a sourcing process.

Moreover, several of the interviewees (Interviewees 2, 3, 6 and 7) claim that the suppliers do not have enough time and resources to perform PCFs on their products.

For instance, interviewees 6 and 7 explain that the focal automotive company is at the forefront of sustainability - and PCF work in the industry. The company has approximately six persons working with this fulltime and they express that this may be scarce from time to time. In comparison to this, many suppliers today only have one person dedicated to this work.

According to interviewee 11 from the supplier, conducting PCFs is time - and resource intensive. The interviewee explains that it would require considerable recruitment of personnel with the right competencies related to sustainability. The interviewee further explains that they may also have to do a restructuring of the organisation, and incorporate sustainability into their supply chain -, operational - and product perspectives. According to the interviewee, it takes approximately six months to do a proper PCF, therefore they are currently not doing PCFs on all of their products. Interviewee 11 believes that the process of conducting PCFs must be standardised to reduce the time. When it comes to the cost perspective of performing PCFs, interviewee 10 states that it costs many thousands of euros to conduct a PCF on one product. Therefore, the interviewee believes it is better to use already developed PCFs on similar products as well to save both time and money.

5.3 Sourcing Capabilities for Sustainable Sourcing of Electronics

In the following section, the interviewees' views on existing and required sourcing capabilities for incorporating PCF in the sourcing processes of electronics will be presented. The section is introduced by the findings on the liaison between procurement and other functions. Thereafter, detailed procurement policies and procedures are explained. Furthermore, the partnership approach with the supplier is described. Additionally, digital systems and technical skills of procurement are presented, and lastly, the advanced understanding of environmental issues in supply is explained.

5.3.1 Liaison between Procurement and other Functions

According to interviewee 1, the sourcing process today is performed by a team of engineers and buyers who together try to choose a supplier based on the best abilities given the criteria and requirements. In this subsection, the interviewees' views on the existing collaboration between the procurement department, R&D and sustainability centre will be described. Furthermore, suggestions on how this collaboration can be improved to ensure a successful incorporation of PCF are also presented

Interviewee 5 states that the sustainability centre is continuously having dialogues with the procurement department to initiate new ideas and projects. The sustainability centre works with identifying new areas that the organisations need to prioritise when it comes to sustainability and develops suggestions on how to handle the problems identified abundantly. Interviewee 6 mentions that the sustainability centre has meetings with the

procurement department every other week, where they can share knowledge about the electronics environmental impacts and what criteria that needs to be put on the suppliers. According to interviewee 6, it is important that the suppliers have a certain knowledge regarding sustainability. Since buyers are not experts on the topic of sustainability, people from the sustainability centre are invited to meetings with the suppliers, to support with knowledge and guidance.

Interviewee 6 stated that knowledge is also exchanged between the functions. For instance, the procurement department shares knowledge about how the suppliers are currently working with sustainability and what the supply chain looks like. Furthermore, they share knowledge about the information flow that runs to and from the supplier. According to interviewee 6, the collaboration between the sustainability centre and the procurement can promote more sustainability work towards their suppliers and increase the traceability further down in the supply chain.

According to interviewee 5, the sustainability team develops sustainability requirements that are added to the engineering state of work and these should be used by the R&D department during the design of the product. The sustainability team has a responsibility to see if these requirements are reasonable and relevant to be put into practice. They also need to investigate if the R&D department has enough tools and resources available to handle these requirements.

All the respondents from the automotive company state that there must be a collaboration between the procurement -, R&D - and sustainability departments for the incorporation of PCF in sourcing to be successful. However, interviewee 9 indicates that the collaboration between the sustainability team and R&D today has potential to be improved. The interviewee further states that a discussion between the functions needs to start at the beginning of the engagement, to settle down all the requirements and come up with an agreement before starting the design of a product. Interviewee 9 further states that the sustainability centre needs to provide documents or a compliance list to the different functions as a guidance to cover some of the sustainability concepts. The documents or the compliance list should be simplified and easy to understand by people that are involved in the sourcing project. Interviewee 9 states that “the simpler it is to understand, the better it will scale across the focal company”.

Interviewee 5 mentions that it is important that the functions are aligned. A similar statement is made by interviewee 1, saying that directors from the procurement and R&D must be aligned and mediate the importance of incorporating PCF in the sourcing phase. Interviewee 2 believes that the functions can be more connected even if they are moving in the right direction and more dialogues between the functions have started to occur. Interviewee 2 says “Give it some time, keep challenging, keep being interested, and the collaboration will come”. The interviewee thinks that the sustainability centre has a lot of knowledge that can be shared with other functions. Therefore, the interviewee sees the opportunities that can come with having more cross-functional collaboration.

Interviewee 3 states that the functions need to have more dialogues and work more cross-functionally. The interviewee further states that many teams in the procurement department should have more sustainability dialogues with the R&D department on how they should design a sustainable product. A suggestion to increase the collaboration is to have joint workshops to discuss sustainability topics and how this can be incorporated more into R&D practices and procurement practices. Interviewee 3 believes that the competence level regarding sustainability topics needs to increase both for R&D and procurement.

All interviewees indicate that roles and responsibilities need to be defined between the departments to create a well-functioning collaboration in the incorporation of PCF in sourcing. Interviewee 4 says that the buyer shall be responsible for the external connections and communications with the suppliers. They shall convey the requirements of the PCF guidelines to the suppliers and communicate what information that is expected to be received from them.

Interviewee 3 argues that R&D should be responsible for the product drawing and also the specifications for the products. They should also verify that the BOM that has been used for the PCF is correct. Interviewee 4 believes that the R&D team is responsible for defining the type of information that the supplier should exchange with the focal company and how this information is gathered and documented. They should also ensure that this information ends up in the right place in the organisation, so that the information can be useful. R&D and procurement should together have dialogues with suppliers, to inform them on how they will be evaluated after incorporating PCF in sourcing.

According to interviewee 1, the sustainability centre should be clear with the directives and requirements. Furthermore, they should develop the processes and instructions on the incorporation of the PCF in sourcing. These instructions should be available for the people that are involved in the sourcing process. Interviewee 3 also states that the sustainability team should support by verifying that the PCF conducted by the supplier is valid.

5.3.2 Detailed Procurement Policies and Procedures

Interviewees 1, 2 and 9 believe PCF guidelines developed for suppliers must be compressed and crisp, to the extent that only the most relevant questions are being asked. By compressing the requirements for the suppliers, the interviewee's mean that they hopefully will have time to include it in their tight time schedules. Interviewee 4 also means that the guidelines must be easy to understand and grasp. To avoid misinterpretations of PCF guidelines which can result in big differences between the outcomes of the CO2 numbers, interviewee 5 clearly expresses "It is impossible to compare apples and pears, instead we must have the possibility to compare apples and apples." Interviewees 3 and 9 also have the same thoughts regarding this, and refer to

the same expression saying “apples and pears cannot be compared”. Furthermore, interviewee 9 adds that clear and concise PCF guidelines would also simplify and facilitate the work for the internal buying teams and not only suppliers.

In alignment with what the focal company says about the guidelines, the supplier also expresses that the PCF guidelines must be simple and standardised. Interviewee 10 mentions the same expression as interviewees 3, 5 and 9 in the focal automotive company when interviewee 10 states “We expect you to set the rules, otherwise it will not be possible to compare apples and apples”. Additionally, interviewee 13 expresses a great interest in using PCF guidelines developed by the focal automotive company in their own sourcing processes. The interviewee says “If your company can establish standardised guidelines, then those can be copied and pasted into our own sourcing processes for our suppliers”.

5.3.3 Partnership Approach with Supplier

When it comes to the collaboration with suppliers on sustainability topics and PCFs, interviewee 2 means that dialogues with suppliers are increasing. In fact, the interviewee believes many good examples of successful collaboration between suppliers and the focal company have taken place lately. For instance, they have recently had follow up meetings with suppliers regarding sustainability questionnaires. In those meetings the focal automotive company tried to understand the suppliers’ answers to the questionnaires and tried to figure out plans for the suppliers to take to achieve the sustainability targets. Before these meetings were introduced, the questionnaires were usually only used to gather answers, with no further actions taken afterwards.

Sustainability topics and PCFs should be continuously discussed in the dialogues with suppliers, means interviewee 3. Additionally, the interviewee explains “These discussions take place on a varying level. Currently, it is a very hot topic since we are collecting the yearly environmental assessments from our suppliers”. However, the interviewee believes that it is important to continue working with these dialogues. Regarding the sustainability centre, the department is trying to be involved in direct dialogues with suppliers to support the buyers and help answering questions relating to sustainability means interviewees 5 and 6. Occasionally, they also have separate meetings with suppliers where sustainability topics and PCFs are discussed thoroughly.

From the interview with the supplier, interviewee 11 explains that the company is collaborating with the focal automotive company mainly in two ways. The interviewee means that they have a strategy aligned with the focal automotive company. Furthermore, they also share a similar sustainability roadmap, i.e., objectives and timelines. For instance, the interviewee explains that they share the same goal of reaching carbon neutrality by 2040 and some sub-goals on how to reach this.

By shifting the focus to how the collaboration could be improved, interviewee 2 means that the relationships between different actors in the automotive industry historically have been characterised as traditional. Products have been produced by suppliers and the original equipment manufacturers have bought them without any deep collaboration in between. However, the interviewee believes the digital transformation of vehicles will bring more complexity to the affairs. Furthermore, interviewee 2 believes the relationships need to become more of a partnership type, thus the interviewee states "When the vehicles are becoming more defined by software the complexity increases a lot. Therefore, the relationships need to go from more of a traditional silo to a partnership where actors work together". For an incorporation of PCF in the sourcing processes, the interviewee believes these closer relationships are the key to success. The majority of the other interviewees within the focal company agree that good collaboration is necessary for a smooth incorporation.

To decrease the pressure on the suppliers and create a closer relationship with them several interviewees (interviewees 2, 3, 5 and 6) believe more meetings besides the purchasing negotiations are needed. Interviewee 5 explains "What we want to do now, is to have contact with suppliers besides the pushed purchasing discussions to find relevant partners and learn from each other. We must find a forum for exchange of knowledge with the suppliers". This is however only an idea, and until now it has not been put into practice for electronics, means interviewee 4.

Interviewee 11 from the supplier expresses that to increase the collaboration with the focal automotive company, it is important to openly share methodologies and best practices for doing the PCFs in the industry. Interviewee 10 also believes they need to develop a roadmap on how to gather data for PCFs together with the focal automotive company. Furthermore, interviewee 11 thinks it is crucial that the focal company gives them a heads up if they update sustainability requirements and expresses "I think that one topic which can improve the collaboration between us, is if your company gives us an early notice when sustainability requirements are updated. This would facilitate our planification and we would be able to present better results for you."

In the context of how the focal automotive company can support the suppliers in conducting the PCFs, interviewee 3 states that it is crucial to first have internal knowledge. When there exists widespread internal knowledge, the employees would be able to support the suppliers when they have questions regarding PCFs. Interviewee 1 also explains that the focal automotive company needs to answer the questions coming from the suppliers and add meetings to clarify things if it is needed. Furthermore, the interviewee believes that people from the sustainability centre must be involved when the buyers cannot answer the questions by themselves. Interviewees 3, 4, 5 and 8 believes the focal company needs to provide the suppliers with training in PCFs. In addition to this, interviewee 4 also believes that it is resource ineffective to have separate education for the suppliers and explains "We need to provide many occasions

with education for our suppliers. However, we cannot talk to all suppliers individually because it must be resource effective".

From the supplier's point of view, interviewee 11 mentions the importance of getting clear guidance in the right direction from the focal automotive company. Interviewee 11 declares "There must exist a targeted guidance from the focal automotive company's side to excel us as the preferred choice of supplier from a sustainability perspective". Additionally, interviewee 11 adds that the automotive company must be able to assist when the supplier has questions.

In the matter of how the focal automotive company can motivate its suppliers to conduct PCF or collect data for them, interviewee 1 together with interviewee 2 thinks it is important that the management teams include this more in their communication. Interviewee 2 explains "I think that they get a lot of energy from when our management has press releases and conferences regarding sustainability topics that are going on. I think the suppliers really listen to what is being said in those channels. I can hear that they are taking pieces from this into their daily work". Interviewee 2 further believes a consequence of a partnership approach towards the suppliers will increase the communication with them, and hopefully also the motivation. It is also crucial that sustainability is a central part of the internal strategy at the focal automotive company, means interviewee 9. The interviewee emphasises that the company must be dedicated to their vision "We want to provide you with the freedom to move in a personal, sustainable and safe way". Thus, suppliers can sense how important sustainability is for the focal automotive company.

Interviewees shared various thoughts regarding how the focal automotive company shall approach the suppliers with the incorporation of PCF guidelines. Interviewees 2, 3 and 9 thinks the company shall be transparent in the beginning and explain that CO2 equivalent impact is a criterion the suppliers will be compared against. Interviewees 5, 6 and 7 believe the company shall be careful and explain to the suppliers that the company is here to support them in the PCFs. Thus, when the PCF work is more mature it can be more clearly expressed that this is a criterion for comparing suppliers.

Representative 11 from the supplier is presenting several factors that would motivate them to conduct PCFs in sourcings. Firstly, it will definitely motivate them if it comes with an economic reward. Secondly, they express that if it becomes a criterion to be awarded new and longer contracts it would also trigger them to perform the PCFs. Thirdly, if conducting PCFs would have given them an increased level of market recognition they would also be motivated. Another point which is not explicitly mentioned by the supplier representatives is that they are expressing great interest in presenting their work with PCFs and sustainability during the annual supplier conferences hosted by the focal automotive company. This goes in line with what interviewee 2 earlier mentioned regarding suppliers' interest in the focal automotive company's external events such as for instance conferences and press releases.

5.3.4 Digital Systems and Technical Skills of Procurement

Interviewees 1 and 4 are the only ones from the focal company mentioning the need for a digital system to make the incorporation of PCF in the sourcing process work. Interviewee 4 believes that it would be valuable to utilise the benefits of digitalisation and develop a joint system between the focal company, suppliers and other actors in the industry, which could generate sustainability data and communicate this throughout the supply chains. The interviewee expresses "In an ideal world, I want the PCF to be vivid, so it is possible to get the information in an early stage before the sourcing decision is taken. Because in this early stage, the information would be very useful for comparing different suppliers on their CO2 impact. That is why we need a digital system, where the updates of information can be done regularly". Furthermore, the interviewee expresses that there must be a collaboration between the internal R&D-, procurement- and digital departments together with external actors to create this digital system. One important aspect the interviewee wants to highlight is that the system should be able to present how the suppliers have gathered the data, because this would enable reviews of the validity. Interviewee 4 also believes that it is important to set crisp routines for using the system and have internal training for the personnel.

From the interview with the supplier, representative 11 mentions that a digital platform would have facilitated the work with PCFs in the sourcing process. According to the representative, the main reason for having the platform would be to record and gather emissions throughout the supply chain layers. However, the interviewee also explains that the automotive industry has a long way to go when it comes to incorporating such a system, hence it will probably occur in the future. Furthermore, the supplier representatives do not express how such a platform would work in practice.

5.3.5 Advanced Understanding of Environmental Issues in Supply

According to interviewees 6 and 7, the focal automotive company has previously had a focus on investigating the three major groups of parts (steel, aluminium and batteries) with the highest contribution to the CO2 equivalent impact of the complete vehicle Electronics is the fourth biggest impact category and recently the focus has been shifted towards this component group. Therefore, many of the employees have recently begun to work with this area.

An impact that seven out of nine interviewees from the focal automotive company highlight as a big contributor is the energy consumption needed in the production processes of electronic components. For instance, interviewees 6 and 7 estimates that energy consumption stands for approximately 50% of the total carbon emissions for electronics. Interviewee 8 explains that a high level of energy is required due to the many processing steps in electronics production, where materials need to be refined and purified. Furthermore, interviewee 3 believes the production processes of the wafers in the electronic components are the "energy thieves". To reduce the impacts

resulting from the energy consumption, interviewee 3 believes the company must push the suppliers to use renewable energy. Interviewee 2 agrees with this and adds that their first-tier suppliers must have similar requirements for their suppliers in turn. Furthermore, interviewee 3 also explains the importance of trying to reduce the energy consumption throughout the supply chain. The interviewee expresses "Overall, the reduction of CO2 emissions must start in reducing the energy consumption since this is a low hanging fruit".

All the employees in the central sustainability team (Interviewees 4, 5, 6, 7 and 8) and one of the buyers (Interviewee 3) mentions that gold is a high contributor to the GWP, although its mass often represents a small proportion of the total mass in the component. For instance, interviewee 3 explains this with an example of the complete vehicle and says that there is a relatively low proportion of gold in the vehicle compared to the copper that all the wire harnesses etc. is composed of. Hence, copper may contribute to a higher level of CO2 impact due to its large proportion, however by only looking at the individual materials, gold contributes to the impact significantly. According to interviewees 6's and 7's own estimations, primary gold can make up as much as 20% of the CO2 equivalent impact of electronics. They further explain that the use of recycled gold can reduce the impacts considerably.

Interviewee 9 who represents the R&D department has not analysed the CO2 impact of electronics on a deep level but speculates that transportation of the components and the soldering processes could be the major contributors. Interviewee 1 has similar thoughts regarding transportation, since it was stated that many of the electronic parts often are critical. Thus, the components are often shipped by aircraft, which is one of the transport modes with the highest CO2 contribution. For instance, that has been the case with the shortages of semiconductors in previous months. Interviewee 6 has recently conducted PCFs on the full vehicles and explains that transportation usually is a small part of the CO2 equivalent contribution. However, it is not clear if that is the case for electronics as well.

According to interviewee 10 representing the supplier, the primary contributor to CO2 equivalents in electronics is the metals and the second one is plastics. Copper is highlighted as being the main contributor within the metals by the interviewee and this is aligned with the reflections from the interviewees in the focal automotive company. Moreover, interviewee 10 believes the raw material extraction of the metals may stand for a higher contribution of the impacts in comparison to the manufacturing processes. To reduce the impacts of copper, interviewee 10 thinks it is crucial to investigate if recycled or sustainable copper can be used. The interviewee explains that sustainable copper is a type of virgin copper that has been produced in a new innovative way. However, interviewee 10 also expresses that they are currently focusing mostly on using recyclable copper. A process with a high contribution to the GWP is the moulding processes of plastics, interviewee 12 adds. However, since they are transitioning into only using renewable energy in 2030, this will not be an issue in the future.

6. Discussion

In this section, the semi-structured interviews conducted with the focal automotive company and the first-tier supplier will be compared with the theoretical frame of reference and the conducted PCF. This will be discussed to find barriers and drivers, but also required capabilities for a successful incorporation of PCF in the sourcing processes of electronics.

6.1 Drivers of Product Carbon Footprint in Sourcing

To answer the first part of RQ2, it was necessary to compare the results from the semi-structured interviews and the drivers of green sourcing. Therefore, the chapter starts with a discussion of the internal drivers for the focal automotive company. Thereafter, the external drivers will also be discussed. A summary of the drivers identified can be found in Table 10.

Table 10: The identified internal and external drivers.

Internal	
Organisational factors	Improve organisations environmental performance
	Reduce organisational costs
External	
Regulation	Avoid wilful and negligent violations of environmental regulatory laws
Competition	Gain competitive advantage
	Improve organisational performance
Customer	Meet customer requirements
Society	Protect firms image and reputation
Supplier	Increase collaboration with supplier

6.1.1 Internal Drivers

According to Finnveden et al. (2009), one common tool used to map out the environmental impact of a product is using PCF. This tool is useful for the sourcing strategy to minimise the environmental impact of the purchased item. Similar statements were made by two interviewees, who claimed that incorporating PCF in sourcing could have several benefits. Incorporating PCF in sourcing, will support the company in mapping out the CO2 footprint and identifying the main contributors of electronics in the supply chain. This information can be used as a basis for defining prioritisation for the actions needed in the upstream supply chain. By defining the major improvement potential, the focal company can work with their suppliers to achieve a greener supply and reduce the environmental impact. Moreover, this can help realise

the focal company's goal of becoming climate neutral by 2040. Overall, the focal company seems to agree that the incorporation of PCF in sourcing is the next step for the procurement department.

The method can support in sourcing new suppliers, since actors can be compared against each other based on their environmental performance. According to interviewee 6, the company has realised that their CO2 footprint includes the emissions throughout the supply chain. It is therefore important for the company to choose suppliers based on their environmental performance, to improve their own organisational performance. This statement is justified by Walker et al. (2008) who are mentioning that green sourcing can result in companies improving their organisational performance.

Three interviewees mentioned the importance of comparing the supplier's CO2 impact during sourcing and transforming it into monetary terms. The monetary value is then added to the TCO, and a more comprehensive comparison including CO2 price can be made. A supplier that has a low purchasing cost, might not be the cheapest alternative because of the unforeseen CO2 expenses added to the purchase. A supplier that emits high levels of CO2 will have higher expenses compared to the one that emits low levels of CO2. With this said, the incorporation of the PCF can support the organisation in reducing their costs, by choosing the supplier with the lowest TCO. Another benefit of transforming the CO2 impact into tangible monetary figures is to help top management assess the real economic advantage of green procurement (Min and Galle, 2001). One could argue that this might lead to suppliers producing cheap products to compensate for their high CO2 emissions and thereby still having a low TCO. However, the supplier still needs to fulfil all quality requirements that are set by the focal company, thus not being able to produce cheap products with low quality and high emissions. Furthermore, the buyer has to consider the sustainability aspects and choose a supplier who is in line with the focal company's sustainability goals.

6.1.2 External Drivers

From an external point of view, interviewee 8 mentioned the necessity of incorporating PCF in sourcing, as the market is moving toward becoming more sustainable and customers are becoming more aware of environmental issues. This statement was justified by Carter and Carter (1998), who points out that customers are putting pressure on corporations to become greener. It has been found by Carter and Carter (1998), that customer demand is an external driver in firms' involvement with environmental procurement activities. According to interviewee 3, PCFs can be used as a tool to measure the reduction of CO2 made for each vehicle. This can result in a competitive advantage for the company since they can market their vehicles as being more sustainable compared to other competitors. Rusinko (2007) supports this claim by stating that green sourcing can work as a competitive advantage. One could argue that marketing their vehicles as more sustainable can result in increased sales thus improving organisational performance.

Min and Galle (2001) research revealed that environmental liability and penalty are the main drivers that affect supplier selections in a buying firm. This is the case for the focal company as well, where two interviewees stated that the carbon price set by the EU emissions trading system, is an external driver for incorporating PCF in the sourcing process. Using the PCF can support the company in working proactively by minimising emissions and thereby avoiding willful and negligent violations of environmental regulatory laws.

Incorporating PCF in the sourcing will require the focal company to increase their communication and collaboration with the suppliers to ensure transparency. This partnership with the supplier can be seen as a driver for the focal company to incorporate the green activity. Walker et al. (2008) found that suppliers are a key driver for incorporating green activities such as PCF. High supplier collaboration and great supply chain integration can result in more effective environmental practices.

6.2 Barriers for Product Carbon Footprint in Sourcing

Since RQ2 also includes identifying the barriers for an incorporation of PCF in the sourcing processes of electronics, this chapter aims at presenting those. In the beginning, the internal barriers will be discussed, and thereafter, the external barriers will be elaborated upon. A summary of the barriers identified can be found in Table 11.

Table 11: The identified internal and external barriers.

Internal	
Costs	PCFs are costly since it requires a lot of resources & take a long time to conduct
Other	Ensure that strategic goals are aligned
External	
Industry specific barriers	Complex supply chain
	Low maturity of using green sourcing practises
Poor supplier commitment	Lack of transparency with supplier
	Costs related to lack of time and resources

6.2.1 Internal Barriers

The two primary internal barriers identified are: PCFs are costly since it requires a lot of resources and takes a long time to conduct, and ensure that strategic goals are aligned. According to Min and Galle (2001), research has shown that one of the biggest barriers for incorporating environmental programs and green practices in sourcing is the companies' perception of increased costs. The authors' further explain that the rationale behind this is that many companies believe the increased investments in green practices will increase the total purchasing costs, and thus result in an economic disadvantage for

them. In accordance with this, several interviewees from the focal automotive company believe it will be costly to incorporate PCF in the sourcing processes of electronics. An underlying factor for this can be that the firm would probably need to hire more people with competencies regarding PCF and sustainability. Even if for instance interviewee 9 expressed that the sustainability centre wants to be involved in direct dialogues with the suppliers, they do not have enough employees to achieve this. Together with this, interviewee 6 explained that the central sustainability department consists of six people working full time with PCFs, and that this sometimes is scarce. Interviewee 3 also expressed "When I am thinking of it, we would need a sustainability expert in every department, but it is not so easy to realise". Undoubtedly, the personnel appear to have a positive approach to incorporating more resources to facilitate the incorporation of PCFs in the sourcing processes. Furthermore, even if there exists a perception that such an incorporation would be costly, the company should consider Zhu and Sarkis' (2007) argument that incorporation of green sourcing practices in manufacturing companies can be less costly compared to other green practices. Furthermore, translating environmental failures to tangible monetary figures will help the focal company see the real economic advantages (Min and Galle, 2001)

Another typical barrier identified by Salam (2008) is that goals within companies first must be aligned before an incorporation of a green sourcing practice takes place. This was also mentioned during the interviews held with the focal company. By looking at the different departments in the focal automotive company, it is possible to see that they have some different priorities. For instance, interviewee 3 explained "Traditionally there has always been a focus on the cost perspective for the procurement – and R&D department. The solutions must not be too expensive." The same interviewee also expressed that the R&D department has the technical functionalities prioritised. If the focal company were to include a KPI for CO2 equivalent impact in the sourcings, new processes and practices need to be established and this can be challenging. However, even if the sustainability perspective does not have the highest prioritisation within these two departments, their current KPIs seem to also have different priorities. For instance, interviewee 3 mentioned a situation where the R&D department made a technical specification of a product which could only be sourced from a specific supplier. Hence, any comparison of the best price and sustainability performance between suppliers could not be conducted. A conclusion that could be drawn from this is that the business units currently have different priorities and the sustainable perspective has not the highest prioritisation on the scale of importance. With this said, it is believed that the focal company shall continue working with aligning strategic environmental goals throughout the organisation.

6.2.2 External Barriers

When it comes to the external barriers, Zhu and Sarkis (2006) identified that different sectors often face various challenges in the incorporation of green sourcing. Additionally, Walker et al. (2008) mentioned that poor supplier commitment can be an external barrier as well. Both these external barriers were identified in this study.

The industry specific barriers can in this case be divided into the complexity of the electronics supply chain and the low maturity of conducting PCFs in the electronics industry. It was both expressed by the focal automotive company and the first-tier supplier that the supply chain is complex. A reason why the supply chain is complex mainly depends on the complexity of the composition of the electronic components. They often consist of many smaller sub-components sourced from different companies, and the high number of tiers of suppliers also increases the complexity of the chain. As a result of this, it becomes difficult to gather the required data for performing PCFs in the sourcing phase. Based on own experience of conducting a PCF on the ECU, the gathering of data was extremely challenging. At first, the goal was to gather supplier specific data for each component, but while the understanding of the supply chain became clearer, the complexity of the data gathering also increased. Therefore, the scope was redefined to only consider supplier specific data when it comes to the composition of the ECU. For instance, gathering energy and production data of the larger sub-components, e.g., housing and PCB-P, would have required surveying the buyers in the first-tier organisation. Based on own reflections, it is a challenging task to only map out the full supply chain of an electronic component.

Several interviewees from the focal automotive company together with the representatives from the supplier believed it is possible to conduct a PCF in the sourcing phase, even if there is a lack of detailed material reports and supplier specific data. For instance, representative 10 from the supplier said “The PCFs in sourcings will be based on the available information at the time. All the materials will be known in this phase, but the suppliers might not be defined. Then it must be decided if we should wait on that information or continue with assumptions”. Two interviewees from the focal automotive company also expressed that a general PCF could be conducted with the material report and the BOM, but to get the full picture it is important to consider supplier specific data in a later stage, e.g., the specific production processes, the location of the facilities and their energy consumption. By reflecting on the PCF conducted in this study, the material report was available one year after the supplier selection, and approximately nine months before the start of producing it. However, the BOM was established before the supplier selection. According to Pelton and Smith (2015), stakeholders often put pressure on buyers to work on a project during a certain time period and because of this, it is not possible to wait on a full PCF until selecting a supplier. Since Pelton and Smith (2015) also state that PCFs are specific to particular products, new PCFs must be conducted every time the product has changed design or

received new features. Both these aspects are identified in the case, and this makes it troublesome to conduct the PCFs in a sourcing phase.

However, two interesting options mentioned by the representatives from both the focal company and the first-tier supplier, is to use either hotspot mapping or PCFs of similar products in the sourcing phase to overcome the barrier of lacking data. Pelton and Smith (2015) mention that hotspot analysis can be an option instead of conducting comprehensive PCFs as well. Lamming et al. (2001) also stated that PCF is a useful tool if data, time and cost requirements are considered, otherwise a simplification of the method is needed. Identifying the CO2 equivalent hotspots and investigating them further seems to be a relevant alternative, instead of starting with incorporating comprehensive PCF analyses in the sourcing processes. For instance, interviewee 10 representing the first-tier supplier expressed "For instance, when a PCF was conducted on one of our components it turned out that gold had the biggest impact. Hence, instead of focusing on every single piece that goes into the product, the focus would be on the gold. I believe the biggest benefits can come from looking into the biggest impacts, instead of investing time in every detail". When the hotspots have been identified, these areas should be compared between the suppliers during the sourcing phase.

The alternative of using earlier established PCFs on similar products in the sourcing phase was also earlier mentioned by the focal automotive company and the supplier. For instance, interviewee 10 explained "Unless something significantly changed in the material composition between a previous generation of a product and the current generation, the CO2 impacts would have been very similar". However, it can be discussed which products that are similar or not. Electronic components are often unique, hence this could also result in a missinterception of where most of the impacts are coming from. For instance, the first-tier supplier has conducted three complete PCFs on different components, but when those are compared to the studied ECU, it would not be optimal to compare any of these since the material setups vary. Ideally, a PCF could be conducted on each new product and later generations of the same product series could perhaps be based on the first one with smaller updates. This would have resulted in the most valid representation of reality. However, since the market has a low maturity of conducting PCFs, a solution could be to ask the suppliers to conduct hotspot analyses and compare them on these in the sourcing phase. When a supplier has been selected, they should be able to complement the analysis in order to generate a complete and more comprehensive PCF. The result from the complete PCF can identify new improvement areas, and joint actions between the focal company and the supplier can be taken to reduce these impacts.

The second industry specific barrier identified is the low maturity of conducting PCFs in the electronics industry. For instance, Vasan et al. (2014) state that there is a lack of consistency in the PCF methods used by companies in the electronics industry. Thus, this can result in manufacturing companies conducting PCFs receiving incomparable results of the CO2 equivalent emissions. In light of this, two of the representatives from

the first-tier supplier also have a perception that there is a low maturity of conducting PCFs in the electronics industry. These two representatives together with three of the interviewees at the focal automotive company believe it is crucial to develop a common standard for PCFs in the industry, otherwise the outcomes cannot be comparable. Consequently, the actors in the electronics industry would benefit from developing a joint standard to save time and costs which can come from differently conducted PCFs.

However, since the industry currently is immature, the focal automotive company has started to establish its own standard. The representatives from the focal company believe it can be challenging to get acceptance from the suppliers of this standard, but the representatives from the first-tier supplier had a positive attitude towards this. A requirement the supplier had was however that the standard needs to be standardised and cost-effective. Concludingly, it can be stated that the optimal situation would be to have a jointly developed PCF standard throughout the electronics industry, but before this happens the focal company has started to put their touch on this. Many of the employees at the focal firm have a positive approach towards trying to develop guidelines instead of only waiting until it comes. This is highlighted by for instance interviewee 2 who explained "I think it is good that we are progressive with creating a PCF guideline. I mean we are challenging the suppliers every day, and we cannot just wait for a standard to come". Since they are a large global company, they also have a lot of bargaining power against other actors in the chain. Hence, if the focal company required a certain standard from their suppliers, many of them would certainly try to fulfil these. The first-tier supplier in this case also had a positive outlook on this, therefore it seems to be fruitful for the focal company to keep developing their own standard and use this until an industry standard has been established.

The second identified external barrier is poor supplier commitment. According to the interviewees, this can depend on two reasons. Firstly, three of the representatives from the focal company believed that there may exist a lack of transparency between the company and the suppliers. Interviewee 5 for instance mentioned the suppliers' fear of being cut out from the supply chain if they disclose sensitive information which can help the focal company to go directly and source from their suppliers. Interviewees 6 and 7 also thought a catch 22-situation could occur in the sourcing processes, since suppliers' may be afraid of presenting data about their products' emissions, because it can portray them negatively in the selection of suppliers. In alignment with this, Walker et al. (2008) argue that suppliers often resist increasing transparency due to the risk of exposing weaknesses. They further explain that the risk of showing weaknesses might give competitors a competitive advantage in the market. Since the sourcing phase means that suppliers will be compared against each other, the unwillingness to show weaknesses seems to be extra prevalent in this phase. Secondly, both representatives from the focal company and the supplier expressed the earlier identified internal barrier, which is the cost of incorporating PCF due to the current lack of time and resources. For instance, interviewee 11 explained that the supplier would have to conduct a considerable recruitment of skilled personnel and a restructuring of the company.

Furthermore, interviewee 11 expressed that it takes approximately six months to conduct a PCF, and interviewee 10 explained that it can cost many thousands of euros. Thus, they believe it is crucial to standardise and reduce the comprehensive process of conducting PCFs. Concludingly, it can also be said that the poor supplier commitment depends on the costs of conducting PCFs due to lack of resources and time.

6.3 Sourcing Capabilities for Sustainable Sourcing of Electronics

According to Bowen et al. (2001) it is crucial to develop certain capabilities to implement green supply practices including PCF. Once the capabilities are developed, they will act as support for the incorporation. Furthermore, Teece et al. (1997) mean that the capabilities are developed by the company's asset position and have a unique formation. This makes it challenging for competitors to imitate the company, thus providing them with a competitive advantage. To answer RQ3 and understand what capabilities that are required for the focal company to incorporate PCF in the sourcing processes of electronics, the following chapter will discuss the company's current capabilities and give suggestions on how these can be improved. The following capabilities mentioned by Bowen et al. (2001) will be discussed in this case: (1) Liaison between procurement and other business units; (2) Detailed procurement policies and procedures; (3) Partnership approach with supplier; (4) Digital systems and technical skills of procurement; (5) Advanced understanding of environmental issues in supply. Table 12 summarises the capabilities needed in the focal firm to ensure a successful incorporation of PCF in sourcing.

Table 12: Summary of the capabilities needed in the focal firm.

Capabilities	
Liaison between Procurement and other Functions	Increase liaison by having workshops
	Start liaison between business units early in the sourcing phase
	Define roles and responsibilities
Detailed Procurement Policies and Procedures	Well-defined procurement function and policies
	Experience of green sourcing practises to facilitate the incorporation of standardised PCF guidelines
Partnership Approach with Supplier	Frequent meetings focusing only on sustainability
	Keep involving sustainability topics and work with PCF in their external communication
	Motivate suppliers through economic reward
Digital Systems and Technical Skills of Procurement	Informing all functions involved in sourcing about the concept and the procedures for conducting a PCF
	Implementing a digital system to compile CO2 equivalent impact data from several actors in one joint system
Advanced Understanding of Environmental Issues in Supply	Training the personnel to understand the environmental issues in electronic supply and the benefits gained with using PCF sourcing

6.3.1 Liaison between Procurement and other Function

According to Bowen et al. (2001), managing the environmental impact of different products can be facilitated by a cross-functional team. The cross-functional team will consist of people from different business units and can thereby bring a range of skills and knowledge to the table. Furthermore, it can support green sourcing since it allows environmental impact to be considered in the product development phase. The design of a product will be performed by selecting materials and processes with low CO2 contribution. To understand what capability the focal company must develop, it is important to investigate the current collaboration between procurement, R&D and sustainability centre. Thereafter, suggestions on how this collaboration can be improved will be presented. Lastly, roles and responsibilities between the business functions will be determined to ensure a successful incorporation of the PCF in sourcing.

Based on the semi-structured interviews, it was found that there currently exists a cross-functional collaboration between procurement, R&D and sustainability centre during sourcing. The main purpose of this cross-functional collaboration is to choose a supplier based on the best abilities given the criteria. It was also found that knowledge is shared between the business functions during the sourcing phase, but also in other occasions.

It was primarily mentioned by people from the sustainability centre that they have started to have regular meetings with the procurement team and R&D to identify

materials and processes that have the highest CO2 contribution from electronics. The aim of these meetings is to spread knowledge to employees in the procurement department and R&D, and increase the understanding of environmental issues in the supply. It was also found that knowledge is spread from the procurement team to the sustainability centre by providing them with information about the upstream supply chain and how suppliers currently are working. The people from procurement and R&D that are joining these meetings are actively working with sustainability topics. The purpose is for them to spread the knowledge further to the rest of their department.

The benefit of having cross-functional collaboration is that it can promote more sustainability work towards their suppliers. It is also a strategy that can be used to spread information across the organisation. The interviewees seem to understand the benefits of using cross-functional collaboration and are aware that this has to be implemented more. All the respondents from the automotive company stated that there must be a collaboration between the procurement -, R&D - and sustainability departments for the incorporation of PCF in sourcing to be successful.

Based on the semi-structured interviews it was found that this collaboration has potential to be improved. More sustainability dialogues should start before the design of a product to settle down all the requirements. When designing the products, R&D should put requirements on where the different sub-components should be sourced. The R&D department should gain knowledge from procurement which suppliers further down in the supply chain that are using more green processes. Then put requirements in the technical specification that their first-tier suppliers can only source from these specific second-tier suppliers who are approved by the focal company. For instance, R&D can come up with suggestions on where the first-tier supplier can source the resistors and other sub-components from. However, according to Van Weele (2018), this way of working can lead to over-specification, which can inhibit innovation.

Furthermore, according to one interviewee, more workshops should be arranged so that people in these cross-functional teams can see each other in person and thereby stimulate more dialogues. Workshops activities can also be beneficial by building a sense of unity amongst participants. Additionally, it should be a place where the business units can discuss and develop strategies for conveying new processes such as the PCF incorporation. Another way to improve communication is to ensure that all business units have aligned goals and priorities. The aim is for all employees at every level in the company to work towards the overarching goals. One interviewee mentioned that it is important that managers communicate the company's visions and goals and ensure that the employees buy into these goals. The meetings currently happening between the business functions should continue and can be seen as an opportunity to provide updates on their sustainability work. These meetings should also cover the work of PCF in sourcing.

Procurement should be responsible for the communication part with the suppliers. The first step is to give the suppliers a heads up, and inform them that the PCF process is

going to be incorporated in sourcing in the near future. This will allow the suppliers to prepare and develop capabilities for conducting PCFs on the component level. The procurement department also has the responsibility to inform them on how they will be evaluated. Here it is important that the buyers are aware of the procedures and guidelines of the PCF, hence they can support the suppliers with knowledge. Furthermore, they have the responsibility to ensure that suppliers are delivering the PCF documents during the request for quotation.

The Sustainability centre should together with R&D develop the PCF guidelines. Through the pilot study, they should collect useful information on how the suppliers experience the guidelines. With this information, they should modify the guidelines to be crisp and easy to follow. R&D should also verify that the BOM that has been used for the PCF is correct. The sustainability centre should validate the PCF documents received from the suppliers and put requirements on R&D to design a more sustainable product.

6.3.2 Detailed Procurement Policies and Procedures

Having detailed procurement policies and procedures such as for instance well established sustainability procurement programs and supplier evaluation schemes etc. can support the incorporation of green supply (Bowen et al., 2001), and thereby the incorporation of PCF. Bowen et al. (2001) further mean that "The policies may allow environmental issues to be built into existing structures rather than bolted on, and facilitate the integration of environmental issues into the strategic supply process" (p.177-178). The focal company in this case has a clearly defined procurement function and procurement policies which have been developed over a long period of time. Additionally, they have in later years incorporated several green sourcing strategies such as supplier environmental questionnaires and code of conduct. Thus, according to Bowen et al. (2001), this facilitates the incorporation of PCF in the sourcing process since the method can be built into the already existing procedures and not be bolted on.

However, several interviewees from both the focal company and the first-tier supplier believed the procedures for conducting the PCF in the sourcing phase must be crisp and standardised. Otherwise, the outcomes of the PCF will not be comparable. In light of this, representatives from both the focal company and the supplier referred to the expression mentioned by interviewee 5: "It is impossible to compare apples and pears, instead we must be able to compare apples and apples". What speaks for the focal company when it comes to designing crisp and standardised guidelines is that they already have experience in setting other guidelines for their processes. Furthermore, they have started to develop an internal set of PCF guidelines which is currently being tested with a few suppliers, and this can help them in understanding what is needed from themselves when setting the scene. Concludingly, it can be said that attention must be directed towards creating standardised and crisp guidelines in the incorporation of PCF in the sourcing process of electronics. However, the focal company seems to have

a long experience in developing clear guidelines for other procurement procedures, which can beneficially help them in the incorporation.

6.3.3 Partnership Approach with Supplier

Bowen et al. (2001) mentions several reasons why building a partnership approach with the suppliers can support the incorporation of green sourcing practices. Firstly, it will increase the understanding between the focal company and its suppliers of their joint activities and the environmental impacts resulting from this. Secondly, a partnership will facilitate communication and improve the transferring of information between the actors. Lastly, it can build more confidence within the organisations and thus support the incorporation. Therefore, building a partnership approach with the suppliers should be considered by the focal company. In order to understand how this capability can be developed, the current collaboration between the focal company and its suppliers regarding sustainability issues will be discussed. Thereafter the improvements will be elaborated upon, together with how the focal company can support and motivate the suppliers.

The empirical findings showed that the focal company has dialogues regarding environmental issues with their suppliers. Currently, they have already established several green sourcing practices, such as environmental questionnaires and requirements on ISO standards for the suppliers. Interviewee 2 believed several initiatives had been taken lately to improve the sustainability dialogues. For instance, the focal automotive company has implemented meetings with the suppliers to review the answers from the environmental questionnaires. In those meetings, the actors together try to figure out a plan for the supplier to take in order to meet the targets from the focal company. Furthermore, interviewee 3 expressed that sustainability dialogues with suppliers takes place on a varying level. The representatives from the sustainability centre, means that they are trying to involve in direct dialogues with suppliers. Occasionally, they have separate meetings with the suppliers where sustainability topics can be discussed on a deeper level. Interviewee 11 representing the supplier means that they are collaborating with the focal automotive company in mainly two ways. Firstly, they have a strategy that is aligned with the focal company, and secondly, they share a similar roadmap for achieving sustainability goals. Therefore, it can be understood that the focal company and its first-tier supplier currently have discussions regarding sustainability issues in different ways. However, according to Bowen et al. (2001), it can always be beneficial to have a close relationship with the suppliers, since this facilitates the incorporation of green sourcing practices and thereby the incorporation of PCFs in the sourcing. Therefore, a suggestion would be to increase the frequency of these meetings where only sustainability is discussed, since this would increase the relation to the suppliers.

Many interesting examples were expressed by the interviewees on how the collaboration between the focal automotive company and its suppliers can be improved.

The majority of the representatives from the focal automotive company were aligned with Bowen et al. 's (2001) reflections implying that a partnership approach towards the suppliers is crucial in the incorporation of PCF. Interviewee 2 meant that the digital transformation of vehicles will promote the partnership approach in the automotive industry and stated "When the vehicles are becoming more defined by software the complexity increases a lot. Therefore, the relationships need to go from more of a traditional silo to a partnership where actors work together". Four of the representatives from the focal automotive company believed more meetings besides the purchasing dialogues are needed. For instance, interviewee 5 explained "What we want to do now is to have contact with suppliers besides the pushed purchasing discussions to find relevant partners and learn from each other. We have to find a forum for the exchange of knowledge with the suppliers". According to Gimenez and Tachizawa (2012) collaboration is about creating trust between the suppliers and the buyers, therefore it is recommended that the focal company tries to have more dialogues with the suppliers that do not only involve purchasing negotiations to build mutual trust.

From the suppliers' perspective, interviewee 11 expressed the importance of openly sharing methodologies and best practices for conducting PCFs in the industry. Furthermore, the focal automotive company must be fast in the communication of when environmental requirements are updated. Based on these thoughts, it is possible to say that both the focal automotive company and the supplier seem to be open to a closer relationship. To improve the relationship, trust must be built with the suppliers. Furthermore, the focal company must have more dialogues on the sustainability topics where the suppliers can articulate both their strengths and weaknesses, hence setting the base for how the focal company can support them in these topics.

The empirical findings also showed that the interviewees had many examples of how the focal automotive company could support the suppliers in performing PCFs to increase collaboration. Interviewee 3 highlighted the importance of having widespread internal knowledge about PCFs in order to support the suppliers if they have questions. This is always important when new practices should be implemented. The buyers must also be able to involve people from sustainability in questions they cannot answer themselves. Furthermore, four of the representatives also believed that the focal company needs to provide the suppliers with PCF training. The representatives from the supplier verified that they need assistance with the questions they have regarding PCFs. Furthermore, interviewee 11 explained, "There must exist a targeted guidance from the focal automotive company's side to excel us as the preferred choice of supplier from a sustainability perspective". If the focal automotive company supports the supplier in these aspects, it can build more confidence for the supplier in the area of conducting PCFs in the sourcing processes as was also mentioned by Bowen et al. (2001).

In order to understand how the focal company can improve the relationship with the supplier, the motivational factors of the supplier were also investigated. Two of the

interviewees from the focal automotive company thought it would motivate the suppliers if the management teams involved more sustainability topics in their communication. For instance, interviewee 2 explained "I think that they get a lot of energy from when our management has those press releases and conferences regarding sustainability topics that are going on. I think the suppliers really listen to what is being said on those channels. I can hear that they are taking pieces from this into their daily work". Accordingly, the supplier representatives expressed a great interest in being a part of the annual supplier conference and presenting their work with PCFs. Therefore, it is recommended that the focal automotive company keeps involving sustainability topics and work with PCF in their external communication, e.g., in conferences and press releases. In line with this, interviewee 9 expressed that it is beneficial to always have their vision in mind, which says "We want to provide you with the freedom to move in a personal, sustainable, and safe way". This can naturally lead to an increased involvement of sustainability topics in the daily contacts with the suppliers. In alignment with this, Sharma and Vredenburg (1998) argue that high priority of environmental issues and strategic incorporation of these can develop the capabilities. Hence, the company should continue to unify the organisation towards its vision which symbolises the importance of sustainability in the organisation.

The interviewees expressed various thoughts regarding how to approach the suppliers with the PCF requirements in the sourcing process. Three representatives from the focal automotive company believed it is crucial to directly communicate that the suppliers will be compared on the CO2 equivalent KPI in the sourcing processes. On the other hand, three other representatives expressed that it is a good idea to be careful and explain to the suppliers that the company is here to support them in conducting PCFs. Hence, when the PCF work is more mature, it can be articulated to the suppliers that they will be compared on this criterion. According to Bowen et al. (2001), it is crucial to have an open dialogue and be transparent to develop a partnership relation. In addition to this, Gimenez and Tachizawa (2012) explained the importance of building collaboration on mutual trust. Therefore, it is recommended that the focal company takes both the different perspectives expressed by the interviewees into account. Hence, the focal company is recommended to explain to the suppliers that they will be compared on the CO2 equivalent criteria in the future, however, they must also support the suppliers in this and show them that they are there for assistance. According to the supplier's perspective, they are mainly driven by economic rewards in different forms such as for instance longer contracts and increased market recognition. It would therefore be crucial to reward the suppliers who already now are ambitious with conducting PCFs. At this point in time, it is more about making the suppliers start conducting PCFs rather than comparing them on the CO2 equivalent numbers.

The development of a partnership relation with the suppliers could potentially also help the focal automotive company overcoming the external barrier of poor supplier commitment mentioned in section 7.2.2. In this discussion, there were two main barriers: lack of transparency and costs related to lack of resources and time of

conducting PCFs. Through a partnership relation with the supplier, the transparency could hopefully increase between the actors. For instance, Bowen et al. (2001) mentioned that a partnership will facilitate communication and improve the transferring of information between the actors and thus increase the knowledge of environmental concerns.

6.3.4 Digital Systems and Technical Skills of Procurement

Bowen et al. (2001) highlight the criticality of improving the technical skills and competencies of the procurement personnel since this makes the incorporation of green sourcing and consequently PCF more effective. Together with this, the implementation of a digital system has been added to this discussion, since several interviewees highlighted this topic during the interviews. Based on our own experience of conducting a PCF on the ECU, it was challenging to understand what type of data was needed in the beginning of the process. It was also difficult to know if the data was available or not. Hence, in order to support the process of conducting a PCF in the sourcing phase, it is required that the procurement personnel get clear directives and know how to gather the data in the most effective way. From our reflections, there existed a fundamental understanding amongst the procurement personnel of what a PCF is. However, Bowen et al. (2001) means that more training in this can support the incorporation even more. Hence, in order to make the incorporation of such a process effective, the company should start by informing all employees about the concept and the procedures they have for conducting PCFs. This will clarify the type of data that is required for the procurement personnel to gather.

Furthermore, two of the representatives from the focal automotive company and one from the first-tier supplier mentioned the need for implementing a digital system to compile environmental impact data. The idea is to utilise the benefits of digitalisation and compile CO2 equivalent impact data from several actors including suppliers' in one joint system to communicate this throughout the chain and support the process of conducting PCFs in the sourcing. For instance, interviewee 4 expressed "In an ideal world, I want the PCF to be vivid, so it is possible to get the information in an early stage before the sourcing decision is taken. Because in this early stage, the information would be very useful for comparing different suppliers on their CO2 impact. That is why we are in need of a digital system, where the updates of information can be done regularly".

However, in order to create a digital system for this, the interviewee believed there must be a collaboration between the internal R&D-, procurement- and digital departments together with external actors. Thus, it seems to be a relevant idea to simplify the gathering of data which is one of the most challenging parts of conducting a PCF. However, it also requires that suppliers and other actors in the supply chain are willing and dedicated to develop this. The low maturity of performing PCFs in the industry has earlier been mentioned, and this could possibly be a challenge when it comes to

developing a digital system for environmental data. Realistically, a digital system can only be established when the maturity has increased, however, while waiting on this, the focal company shall definitely continue to work on their guidelines and try to find a way of gathering data effectively. If such a system could be established in the future, interviewee 4 means that it would be important to include how the suppliers have gathered the data, to increase the validity of the PCFs. Another requirement would also be to develop the technical skills of the procurement personnel in this program, since then they can communicate with the suppliers regarding which data they need to provide to the system.

6.3.5 Advanced Understanding of Environmental Issues in Supply

Historically, there has existed an "environmental illiteracy" among purchasing personnel according to Bowen et al. (2001). Therefore, it is crucial to provide training for personnel involved in the sourcing processes on basic environmental issues and the range of activities that can be used to increase green sourcing. To understand if the personnel have a basic understanding of electronics and specifically the ECU's environmental impacts, the interviewees were asked to provide their thoughts on the main impacts. To somewhat verify if the interviewees had an understanding of this, the results of the conducted PCF were used together with the answers from the experts in the focal automotive company's sustainability centre. Interviewees 4, 5, 6, 7, and 8 work full time with PCFs and sustainability issues, and especially interviewees 6 and 7 have started to dig deeper into electronic environmental impacts. Therefore, their answers are assumed to provide a valid picture of reality.

According to interviewees 6 and 7, a major CO2 equivalent contributor is the energy consumption required for the production processes of electronics. In addition to these two answers, from interviewees 6 and 7, five other representatives from the focal automotive company were aligned with this. Thus, there were only two of the interviewees from the focal automotive company who did not mention energy consumption as a big contributor. Based on the results of the PCF conducted on the ECU, it was shown that the electricity consumption required for manufacturing sub-components was a major contributor, by standing for at least 34% of the total emissions. Therefore, it can be concluded that almost all interviewees in the focal automotive company have a basic understanding implying that energy is a major contributor. Furthermore, some of the representatives also gave suggestions on how to reduce the impacts from the energy consumption. Interviewees 2 and 3 representing the buyers, were for instance mentioning that they need to push the suppliers' to use renewable energy sources. Interviewee 2 further stated that it must start with a reduction of energy consumption throughout the supply chain and the interviewee explained "Overall, the reduction of CO2 emissions must start in reducing the energy consumption since this is a low hanging fruit". This further implies that the buyers seem to have an advanced understanding of how to handle the environmental issues in supply.

The second major contributor highlighted by all representatives from the sustainability centre and one buyer was the gold. Even though the proportion of gold in electronics often is relatively small, it has a big CO2 equivalent impact. In alignment with this, the results from the conducted PCF showed that gold was the third biggest contributor to the CO2 equivalent impact. Hence, it means that it can be beneficial to provide the personnel with some more information regarding this issue.

Furthermore, two of the representatives for the purchasing department expressed that transportation may be a reason for a high CO2 equivalent impact on the electronics supply chain. However, both of them clearly express that this is only speculation. Interviewee 6 who has been conducting PCFs on complete vehicle models have seen that transportation only represents a small portion of the CO2 equivalent emissions. However, the fact that there has been a global shortage of semiconductors lately has created a perception of increased transportation with aircraft. Unfortunately, the performed PCF on the ECU was limited to exclude transportation due to a lack of data from the activities in the chain. Therefore, this factor could not be verified against the conducted PCF. Because of this, it is not possible to tell if transportation is a big contributor.

Generally, the perception is that the persons involved in the sourcing processes have a basic understanding of the biggest contributors to the electronics CO2 equivalent impact. However, according to Bowen et al. (2001), it is important that all personnel involved in the sourcing have an advanced understanding of the environmental issues in supply. Therefore, the focal automotive company can draw benefits from more advanced training of the personnel. Bowen et al. (2001) also stated that it is positive to provide the personnel with information regarding the activities that can be used to increase green sourcing. Thus, it will not harm the organisation to provide the personnel with more training about what PCF is and why it can help to make the sourcing process greener.

7. Conclusions

In this chapter, the key findings, and answers to the research questions will first be presented. Lastly, suggestions will be given on what future research can investigate in relation to incorporating PCF in the sourcing processes of electronics.

7.1 Key Findings

RQ1: What are the CO2 equivalent hotspots along the cradle to gate for the global automotive company's ECU?

The result from the PCF indicates that the total GWP for the ECU is 14,8 kg CO2 equivalents. The result also identified the top five sub-components that contribute to global warming which are the top housing, PCB-U, IC, common mode, and bottom housing. These five sub-components together correspond to 88,5% of the total global warming emission for the ECU. Furthermore, the leading influential factor for the high contribution of the manufacturing processes was identified. The main hotspot along the cradle to gate for the ECU is the aluminium cast alloy production which represented 28,9% of the total emission. Another hotspot found is the electricity required to manufacture the PCB-U. Lastly, the small amount of gold represented in the ECU contributed to a high contribution and is therefore a hotspot as well.

RQ2: What are typical drivers and barriers for incorporating PCF in the sourcing process of electronics?

Several drivers for the incorporation of PCF in sourcing were identified in this study. The result from the PCF allows the focal company to understand the actions needed to take in the upstream supply chain to minimise the environmental impact of the purchased item. The focal company can thereby improve its environmental performance. Furthermore, actors can be compared against each other based on their environmental performance. This allows the company to choose the supplier with the lowest TCO, thus reducing purchasing costs.

Customers are putting pressure on corporations to become greener, which is one driver identified for the focal company to incorporate PCF in sourcing. The focal company can use the PCF result to market themselves as sustainable and thereby gain a competitive advantage. Another positive aspect of using PCF, is the incentive of increased communication and collaboration with suppliers. It has also been found that the incorporation of PCF in sourcing can support the company in working proactively to minimise emissions, thus avoiding wilful and negligent violations of environmental regulatory laws. Lastly, the incorporation can be an incentive for increased collaboration with suppliers.

One primary internal barrier identified is that there exists a perception that the incorporation of PCF can be costly since the process requires a lot of resources and time. The study has shown that more time and resources would be valuable to support the incorporation of PCF in sourcing. The second internal barrier identified is that the business units currently have different priorities and the sustainable perspective can be given a slightly higher prioritisation on the scale of importance in practice. However, they have very clear sustainability goals and a defined roadmap to achieve these. The focal company shall continue working with aligning strategic environmental goals throughout the organisation.

When it comes to the external barriers, it was identified that the complexity of the electronics supply chain can result in difficulties when it comes to gathering data for the PCF. It has also been found that the market has a low maturity in conducting PCF. Due to the high complexity in the supply chain and low maturity of conducting PCF, a solution would be to ask the suppliers to conduct hotspot analyses and compare them in these specific areas. When a supplier has been selected, they should be able to complement the analysis in order to generate a complete and more comprehensive PCF. The result from the complete PCF can identify new improvement areas, and joint actions between the focal company and the supplier can be taken to reduce these impacts. The last external barrier relates to a relatively low supplier commitment, which can be explained by a lack of transparency from suppliers and their perception that PCFs also are costly and time-consuming to conduct and incorporate.

RQ3: What sourcing capabilities are required by the focal company to incorporate PCF in the sourcing processes of electronics?

In this study, it was found that five different sourcing capabilities are required by the focal company to incorporate PCF in the sourcing processes of electronics. These are: (1) Liaison between procurement and other business units; (2) Detailed procurement policies and procedures; (3) Partnership approach with supplier; (4) Digital systems and technical skills of procurement; (5) Advanced understanding of environmental issues in supply.

Firstly, there needs to be a cross-functional collaboration between procurement, R&D, and sustainability centre when incorporating PCF in sourcing. The collaboration that exists today has the potential to be improved through workshops and by creating discussions early in the sourcing phase. Clear roles and responsibilities need to be defined between the business units. Procurement should be responsible for being in the forefront and communicating what is expected from the suppliers and ensuring that they deliver the PCF documents. R&D and sustainability centre should together develop PCF guidelines and validate the PCF documents.

Secondly, the focal company has a well-defined procurement function and procurement policies, which have been established over a long period of time. In later years, they have also started to adopt several green sourcing practices. Thus, these well-defined

procedures and experiences with other green sourcing practices will facilitate the incorporation of PCF in the sourcing processes. Furthermore, a requirement for successful incorporation is that the procedures for conducting PCFs are crisp and standardised. Otherwise, the risk is that results from the suppliers' PCFs become impossible to compare. However, the focal company has as earlier mentioned a long experience in developing guidelines for other procurement procedures, which can beneficially help them in developing clear PCF guidelines.

Thirdly, it can be understood that the focal company currently has discussions regarding sustainability issues and PCFs with the first-tier suppliers. However, since these meetings occur occasionally and on a varying level, it is recommended to improve the partnership with the suppliers. For instance, this can be accomplished through implementing more meetings involving sustainability besides the purchasing negotiations. To support the suppliers, the focal company must start with developing an internal widespread knowledge regarding PCFs. Thereafter can the company support the suppliers with training and by answering questions. In order to facilitate the incorporation of PCF, the motivational factors for the suppliers were also discussed. The findings imply that they are mainly driven by economic rewards, therefore it is crucial to reward the suppliers who currently are ambitious with conducting PCFs. At this point in time, it is more about making the suppliers' start conducting PCFs rather than comparing them on the CO2 equivalent numbers. Furthermore, the suppliers showed a great interest in the focal automotive company's external press releases and conferences. Therefore, it is recommended that the focal automotive company keeps involving sustainability topics and work with PCF in their external communication. Additionally, it is important for the focal automotive company to continue working with their vision, which symbolises the importance of sustainability for them. Naturally, this will result in more involvement of sustainability topics in the external daily communication with suppliers.

Furthermore, there existed a basic understanding amongst the personnel involved in sourcing of what a PCF is, however, the knowledge of conducting one has improvement potential. Thus, to make the incorporation effective, the company should start with informing all employees involved in sourcing about the concept and the procedures for conducting one. This will clarify the type of data that is required for the procurement personnel to gather. Additionally, three of the interviewees gave a suggestion on implementing a digital system to compile CO2 equivalent impact data from several actors in one joint system, to communicate this throughout the chain and support the process of conducting PCFs in the sourcing. However, a digital system can only be established when the maturity has increased in the market, but while waiting on this, the focal company shall continue to work on its PCF guidelines and investigate effective ways to gather data.

Lastly, the perception is that persons involved in the sourcing processes have a basic understanding of the major contributors to electronics CO2 equivalent impact.

However, knowledge regarding environmental issues can always be increased. Therefore, the focal automotive company can draw benefits from training the personnel in both environmental issues in supply, and PCF in relation to how the method can make the sourcing process greener.

7.2 Future Research

The thesis aimed at examining the CO2 equivalent hotspots along the cradle to gate for the ECU. The result from this thesis has provided a foundation that can be further built upon. Hence, suggestions for future research will be presented in this section.

Firstly, due to time and resource limitations, the PCF conducted was primarily based on the data received from the IMDS report. Further research dedicated to the PCF of the ECU could map out the details of the supply chain and gather more supplier specific data. This includes data from low-tier suppliers. For instance, future research can focus on finding specific data regarding the energy sources used in the processing of the material and the manufacturing of the components. Furthermore, also the countries and regions where material extraction has occurred. Another suggestion would be to conduct a PCF on the ECU from cradle to grave and thereby include the use phase and end of life phase. This would have created an understanding of what the automotive manufacturing company could do to minimise its own direct environmental impact.

Secondly, a future study could perform a PCF on ECUs from other suppliers, thus allowing validation or refutation of the findings in this study. Lastly, while this thesis has provided knowledge of the drivers, barriers, and sourcing capabilities needed to incorporate PCF in sourcing processes of electronics, a future study could develop an action plan for how the incorporation would look like in practice.

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A Appendix - Interview Questions Focal Company

General Questions

- Can you tell us about your role (department) and what you work with?
- In what ways do you have contact with the general purchasing departments?
    - And more specifically, the purchasing department for software and electronics?
- Are you involved in any contact with suppliers focused on electronics?
    - If yes, in what ways do you work with sustainability in relation to these suppliers?
- Do you have an idea of where in the life cycle most electronics have the biggest CO2 impacts, both in terms of materials and processes?
    - If yes, how can those impacts be reduced?

Implementation of PCF guidelines - Internally

- Why do you believe that PCF guidelines are necessary to implement? What value will this bring to your company?
- What do you believe is important for making the implementation of the PCF guidelines successful?
- Which departments within the focal automotive company do you believe is important to include for the implementation?
    - What role does the purchasing department/ R&D/ sustainability centre have in the implementation?
    - What role does cost engineers and supply quality managers have in the implementation?
    - How can you create a good collaboration between the departments for this implementation?

Implementation of PCF guidelines - Externally

- What do you think will be the biggest challenges for your suppliers when they are presented to these requirements?
- How can the focal automotive company support the suppliers in doing their PCFs?
- How can the focal automotive company motivate the suppliers to do the PCFs?

Additional questions

- Will PCFs be conducted on products that are in production already, or products that you have decided to source or during the sourcing phase?
- Do you believe that it would be more beneficial to do the PCF during the sourcing phase? Why?
- What challenges do you believe that the focal automotive company will face if you push suppliers on conducting PCFs during sourcing decisions. Do you believe that the suppliers are willing to do this? Will the supplier have enough data to conduct a PCF during this early phase?

B Appendix - Interview Questions First-tier Supplier

Implementation of Product Carbon Footprint (PCFs) in sourcings

- How does the collaboration between the first-tier supplier and the focal automotive company look like today regarding sustainability topics? How can this be improved?
- Are you currently performing any PCFs on your products? If not, why?
- Are you asking your suppliers to perform PCFs on components that you purchase? If not, why?
- What do you think will be the biggest challenges (internal and external) for the first-tier supplier when conducting PCF on components that you sell to the focal automotive company, e.g., the ECU?
- Will the first-tier supplier manage to do PCF on components during the sourcing phase if such a requirement is implemented? What challenges do you think you will face?
- How can the focal automotive company support you as a first-tier supplier in doing their PCFs?
- How can the focal automotive company motivate you as a first-tier supplier to do the PCFs?
- Do you have an idea of where in the life cycle the ECU has the biggest CO2 impacts, both in terms of materials and processes?

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