CHALMERS
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Reducing the Carbon Footprint of Automotive Electronics

The Role of Product Development and Purchasing Integration in ECU Sourcing Processes

Master's thesis in Supply Chain Management

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CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2023
www.chalmers.se
Report No. E2023:069

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SUMMARY

In response to a heightened awareness of environmental issues, automotive OEMs have increasingly embraced sustainability trends. Due to the trend of electric and autonomous vehicles, more electronic components are needed to manufacture a single vehicle, contributing significantly to global warming. This necessitates the implementation of mitigation strategies to restrict their adverse environmental effects. Procurement, being responsible for managing the company's inbound material flow and acting as the initial interface with suppliers, plays a crucial role in a company's environmental performance. Consequently, it is essential to implement green sourcing practices, such as LCAs, and use their results to inform future sourcing processes. Furthermore, by promoting integration between purchasing and R&D departments, supplier involvement in product development can be facilitated, enabling early response to sustainability issues. Thus, the thesis motivation originated from an automotive company's ambition to deepen its understanding of sustainable electronics as part of its efforts to manage Scope 3 emissions, with a particular focus on an ECU, which is a complex component integral to vehicle functionality.

This single case study endeavors to investigate the sourcing process and the interdepartmental collaboration between R&D and procurement with the aim of minimizing the carbon footprint of the electronic components in ECUs, thereby promoting a proactive approach towards sustainability. To fulfill the research objective, an existing PCF analysis of an advanced ECU was used to pinpoint the environmental hotspots, in this case, logic ICs. In addition, this aspect was further explored by conducting 24 interviews with 22 representatives from the case company and its first-tier supplier. A theoretical framework was devised to guide the development of interview questions. An as-is analysis was undertaken to establish the current status of the case company, serving as a basis for empirical findings and discussions. The empirical data highlighted three main themes: green sourcing strategies, procurement and supplier involvement in product development, and top management support, with the latter being a prerequisite for the successful implementation of the former two. These findings, coupled with the consequent discussion, led to the identification of areas for improvement aimed at enhancing the ECU's sustainability. Suggestions include reinforcing top management commitment, developing green sourcing collaboration strategies and an electronics-specific supplier environmental questionnaire.

Keywords: Green sourcing strategies, Cross-functional collaboration, supplier involvement in product development, PCF, electronics, ECU

ACKNOWLEDGEMENTS

This master's thesis has been carried out at the Department of Technology Management and Economics at Chalmers University of Technology in collaboration with an automotive OEM during the spring semester of 2023. We wish to express our sincere appreciation to these institutions that have facilitated this final project within our academic education, equipping us for future endeavors. We extend our deepest gratitude to our supervisor and examiner, Ala Arvidsson, whose insightful feedback and encouraging guidance have substantially enriched the quality of this thesis. Her expertise in the field of procurement and ECUs has been of immense value.

Moreover, we wish to direct a special thanks to our supervisors and the team manager at the automotive company for their welcoming demeanor and for making this thesis possible. Thank you for supporting us and for your continuous guidance throughout the course of this research project. Finally, we thank the representatives from the tier-one supplier who graciously contributed their time for the interview process.

Ali Afshari & Erna Ramic, Gothenburg, June 2023

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1. Introduction

The following chapter provides a comprehensive overview of the topic, including background, aim and delimitations of the study and lastly presents the research questions that are to be investigated.

1.1 Background

As the requirement for corporate accountability is increasing (European Parliament, 2022), companies must take responsibility for their impact on the environment. Additionally, accountability requires accounting for the interests of stakeholders. It also entails reporting on the company's strategy and advancement in reaching its targets, as well as being transparent about the company's environmental effects (Lowe, 2019). The increased environmental consciousness has led to a green trend (Blome et al., 2014), which automotive OEMs (original equipment manufacturer) are increasingly acting upon.

With the electrification trend, connectivity and autonomous drive vehicles (Insights, 2022), an increasing quantity of electronic components are required to assemble a single vehicle. For instance, a vehicle may consist of more than 100 electronic control units (ECU), which in turn are made up of several different electronic components (Aptiv, 2020). Therefore, electronics have a significant impact on the carbon footprint, due to the rapid increase in the quantity of electronic components and the energy-intensive manufacturing processes, which often occur in Asia that has restricted access to sustainable resources (Vasan et al., 2014; King, 2021).

A growing number of OEMs are placing greater emphasis on reducing their indirect Scope 3 emissions, which constitute approximately 80 percent of a company's overall climate impact and originate from activities in the upstream and downstream value chain (Huang, 2009; Spiller, 2021). Addressing Scope 3 emissions is a complex issue, which includes carbon-accounting and monitoring activities, as well as collaborating with suppliers (Spiller, 2021). Huang's (2009) findings demonstrate that firms can reduce a substantial proportion of their upstream carbon footprint by acquiring complete emissions data from a few direct suppliers. As stated in Sarkis & Dou (2017, Chapter 3), procurement can be employed as a tool to green the entire supply chain, even extending to the management of sub-suppliers and multiple tiers. Schneider and Wallenburg (2012) support this claim, suggesting that sustainable sourcing is heavily dependent on the purchasing function's adoption of corporate sustainability.

1.1.1 Green Sourcing and Product Development

With the increased environmental awareness (Cohen, 2014), automotive manufacturers are emphasizing sustainability to a greater extent due to customer pressure and governmental legislation to develop more environmentally friendly vehicles (PwC, 2023). Organizations are primarily concerned with reducing their environmental impact and CO_2-footprint, by e.g. including various environmental criteria in their product development (PD) and procurement practices (Spiller, 2021; Zsidisin & Siferd, 2001). To achieve corporate sustainability, Schneider and Wallenburg (2012) propose that organizations review their supplier performance protocols, to involve the suppliers more and define environmental criteria. Therefore, implementing sustainable sourcing through the purchasing department is essential for corporate sustainability. Generally, green sourcing is characterized as the incorporation of environmental considerations into purchasing practices, which promote sustainability without impacting the upstream supply chain (Pelton & Smith, 2015; Min & Choi, 2020).

Schneider and Wallenburg (2012) further argue that the collaborative efforts and alignment of many departments are vital for corporate sustainability; however, the purchasing department has the potential to influence overall organizational environmental performance. This is due to the department being linked to the initial handling of upstream material flows. Moreover, various corporate departments have an impact on what and how purchasing sources, as they are the purchasing department's “internal” customers whose demand requirements must be met (Schneider and Wallenburg, 2012). Thus, for example, purchasing may need to adjust its sourcing in accordance with sustainability requirements. This is consistent with Carter et al. (2000) findings, that a company’s environmental initiatives are unlikely to succeed if they do not have specific goals related to environmentally responsible procurement.

To construct a sustainable supply chain, sustainability must be incorporated into R&D’s (research and development) product development process (Reitsma et al., 2023). Therefore, the connection between product design and supply chain is essential to comprehend. A specific supply chain approach for particular product designs and characteristics contributes to improved operational performance (Reitsma et al., 2023; Pero et al., 2010). The reverse is also applicable, i.e., product design influences the design decisions of the supply chain. Consequently, supply chain costs and sustainability are largely dictated in the design phase (Pero et al., 2010). Thus, there is potential value to be realized by integrating PD and purchasing. For instance, such integration facilitates early supplier involvement in new product development (NPD), which may assist with their expertise regarding, e.g. design decisions and material selection, in order to develop more sustainable products (Lakemond et al., 2001; Pero et al., 2010).

1.1.2 Environmental Impact of Electronics

The electronics industry is a substantial and rapidly expanding worldwide sector, with new methods and equipment continually being introduced (O’Connor et al., 2016). According to estimates, the global GHG emissions of the electronics sector are equivalent to 2% of those of the aircraft sector (Vasan et al., 2014). Rapid technological progress brought about by the desire for new and improved technology has distracted attention from material management, which encompasses sustainable material extraction and end-of-life management.

The life cycle of an electronic component involves stages of raw material extraction, manufacturing, distribution, usage, and end of life. This requires the extraction and processing of various minerals, such as copper, plastic resins, gold, and silicon. The material mining and manufacturing process contributes to GHG emissions, as found in Vasan et al. (2014).

Sustainability in PD may be attained by applying life cycle thinking. This is because identifying hotspots throughout a product's life cycle allows for efficient environmental impact reduction (Kara et al., 2014). The same concept applies to green sourcing (Finnveden et al., 2009). Findings from life cycle assessment (LCA) studies may be used as a foundation for sourcing decisions, for encouraging supplier participation in supplier development and learning how to minimize their environmental impacts, and for supplier comparison purposes based on sustainability performance (Agarwal et al., 2012). This suggests that PD and procurement are related in this regard as well and that both might benefit from LCA to meet sustainability goals.

The product carbon footprint (PCF), a particular form of LCA practice, is the subject of this study (Yung et al., 2018). Hence, PCF and LCA will be used interchangeably but PCF is being referred to in this case. Using the LCA as a basis, PCF exclusively addresses climate change and the global warming potential (GWP). The GWP index for greenhouse gas (GHG) calculates the amount of energy that is absorbed by one ton of gas over a predetermined time (usually 100 years) in contrast to one ton of CO_2-emissions (EPA, 2022). Therefore, unlike an LCA, it is limited in the number of impacts it takes into account. However, PCF is a valuable tool for guiding sustainable procurement decisions, facilitating buyer-supplier dialogue on sustainability topics, and promoting supplier innovation, ultimately leading to investment opportunities in sustainability through sourcing and procurement (Pelton & Smith, 2015; Agarwal et al., 2021).

1.1.3 Case Situation

The present study constitutes a case study examining the procurement of electronic components within the context of an automotive OEM. The focal company is a global automotive manufacturer that has shifted its focus to providing high-technology electric vehicles. With that, increased utilization of ECUs and subsequently electric components follows. However, there is limited documented data on these types of components and the sustainability focus around them has recently emerged. Thus, there is an initiative to improve sustainable sourcing regarding a specific ECU, as an action to reduce the carbon footprint. These initiatives can be related to the OEM's sustainability ambitions. By 2040, the company seeks to both be circular and climate neutral. Additionally, the firm has three main ambitions for 2025 (Case Company, 2023). One of these objectives relates to scope 3, which this study targets:

- Reduce tailpipe emissions per car by 50%

- Reduce operational emissions per car by 25%
- Reduce supply chain emissions per car by 25%

This study's motivation originated from the automotive company's procurement department for software and electronics. The particular ECU is the primary research subject due to its crucial role in vehicle function, its high complexity involving numerous components, and the case company's desire to enhance its comprehension of sustainable electronics. Sustainability goals have led to a need for investigating the carbon footprint from purchased materials, that is to find critical hotspots as a measure to provide proposals to reduce the CO_2-emissions. Additionally, there are new company-specific sustainability targets for electronics, such as renewable energy and material selection, that need to be accounted for. These ambitions require collaboration and transparency with suppliers, which has also been recognized by Lamming and Hampson (1996). They found that firms with closer collaboration with suppliers had a better understanding of the environmental impacts throughout the supply chain. To reach sustainability goals, the focal company must set clear design specifications and environmental requirements for suppliers, as stated by Zsidisin and Hendrick (1998). Thus, the incentive to investigate the product development process emerges. In conclusion, collaboration and transparency with suppliers, along with clear environmental requirements, are essential for reducing CO_2-emissions and meeting sustainability goals.

1.2 Aim

The purpose of this master thesis is to examine the sourcing process of the ECU and the role of R&D in it, to make suggestions for sustainability improvements. This would involve cross-functional collaboration in order to modify the sourcing process, resulting in the eventual reduction of the ECU's carbon footprint and the promotion of a proactive approach toward sustainability. The master's thesis will investigate the carbon dioxide hotspots in an existing supplier PCF analysis of an advanced ECU, which a global automotive company sources. Thus a PCF will not be conducted by the authors, as the existing one has already been validated by the case company. This will serve as the foundation for the identified hotspot, specifically logic ICs, which constitute a category of semiconductors, exhibiting potential for improvement throughout the ECU value chain.

1.3 Limitations

The primary research focus is on the R&D and procurement departments, specifically their processes, collaboration and potential benefits of "greening" their operations. Given that electronic components have a significant carbon dioxide impact, as indicated by the PCF of the ECU, this area is of particular concern. The PCF report exclusively examines the cradle-to-gate stage, which refers to the carbon impact of the ECU from the point of production to its delivery to the focal company. This means that the report does not consider the use phase and end-of-life stage. Furthermore, the report excludes raw materials and components such as aluminum housing, as the case company is already knowledgeable in those areas and working towards improvement. Therefore, the primary focus is on the surface mount technology (SMT) process, which involves mounting electronic components onto the printed circuit board (PCB) to form a complete ECU without its housing. The electronics of interest are semiconductor components since they have been identified as a hotspot.

1.4 Specification of Issue Under Investigation

Based on the aims of the thesis, two research questions have been developed. These are:

RQ1: How can automotive OEMs utilize ECU product carbon footprint results as an input in their sourcing processes to reduce the electronic component CO_2-footprint and what are the potential challenges associated with such integration?

RQ2: What efforts can automotive OEMs implement to facilitate collaboration between the procurement and R&D departments to streamline the sourcing process, i.e., to fulfill company-specific sustainability goals regarding CO_2-impact?

2. Theoretical Frame of Reference

This chapter highlights the theories that were used as a base for the research. This section covers various aspects of the electronics industry, including procurement, green sourcing, R&D and sourcing, supply chain management, and the environmental impact of electronics.

2.1 Procurement

According to Van Weele and Rozemeijer (2022), procurement constitutes a crucial catalyst for business success, encompassing a broad spectrum of activities concerned with acquiring goods, services, capabilities, and knowledge from external sources for integration into the firm's value chain. Procurement has evolved into a strategic business domain, and achieving operational excellence is one of its primary responsibilities, ensuring that the best products are delivered to internal customers on time, with the best quality and price. Additionally, strategic alignment of procurement objectives with overall business objectives has become important as suppliers play an increasingly significant role in a company's competitive positioning.

Procurement is predicated upon the principles of the total cost of ownership (TCO) thinking, whereby the comprehensive view of an asset is taken into account and the purchase price and operational costs are collectively evaluated. This approach encompasses both direct and indirect costs associated with the procurement of goods and services. Thus, the procurement decision-making process requires buyers to undertake a long-term outlook and incorporate expenses incurred over the product's lifetime (Van Weele & Rozemeijer, 2022).

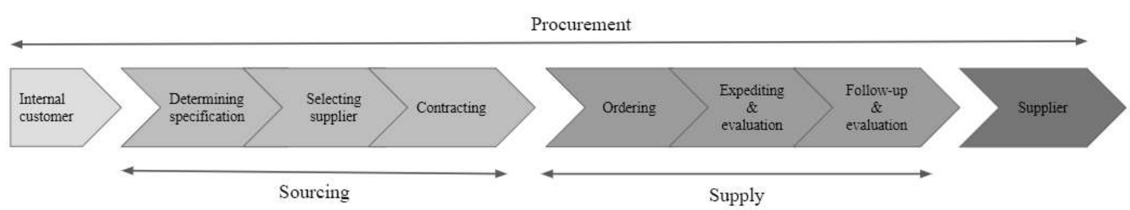

Figure 1*: Own adaptation of Van Weele & Rozemeijer's (2022) linear procurement process model.*

Van Weele and Rozemeijer's (2022) procurement process model, as shown in Figure 1, depicts the various activities involved in the procurement function, with a particular emphasis on sourcing - the focal point of this study. Procurement refers to the entire process of acquiring goods or services from suppliers. It begins with the collection of business needs and requirements, in order to determine specification. The subsequent stage involves supply market research to select adequate suppliers, capable of delivering the required quality at the best price. When a supplier is selected, a legal contract is drawn up. These three steps constitute the sourcing process, while the supply phase is more focused on operational aspects such as establishing ordering, monitoring, and controlling routines, which are necessary for ensuring timely deliveries and payments. Finally, the supplier's performance is evaluated through follow-up and measurement. This information is documented to maintain quality and delivery records, competitiveness, and innovativeness, as it affects the vendor rating. Consequently, the authors (Van Weele & Rozemeijer, 2022) argue that firms concentrate their collaboration among suppliers with demonstrated capabilities, often leading to a reduction of the supplier base.

2.1.1 The Sourcing Process

As mentioned above, the sourcing process consists of three phases; determining specifications, supplier selection and contracting (see Figure 2). Firstly, the collection of business needs and requirements is done, which entails defining the specifications of the goods, services, and solutions needed. This step often addresses make-or-buy decisions. R&D, or more specifically PD, is involved in determining the specification. Functional and technical specifications are used to define the requirements of a product. The functional specification outlines the product's intended use, while the technical specification outlines the product's properties, characteristics, and supplier activities. However, Van Weele and Rozemeijer (2022) warn that over-specification can lead to increased costs without improving functionality. During the technical specification phase, it is common to select basic technologies with a limited number of pre-determined suppliers in mind. If technical specifications change during the sourcing phase, the responsibility falls upon the buyer to convey any alterations to the supplier and ensure that they are implemented accordingly.

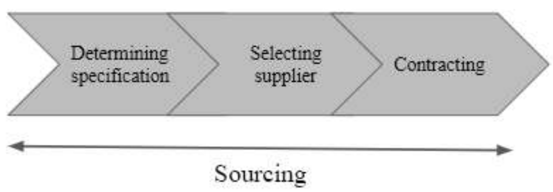

Figure 2*: The three steps of the sourcing process.*

The subsequent stage is considered to be a crucial step in the sourcing process and involves several activities that influence supplier selection. It involves supply market research to select adequate suppliers, capable of delivering the required quality at the best price. Requests for information (RFI) are typically issued to suppliers with excellent vendor rating scores, which may be eligible for a possible tender. The purpose of the RFI is to gather supplier-related data, including past projects and relevant experience, to assess their qualifications and capabilities. Typically, supplier visits or audits are conducted during this stage (Van Weele & Rozemeijer, 2022). Here, buyers may include environmental criteria to assess sustainability performance (Seuring and Müller, 2008). Upon acquiring the necessary information, the suppliers that show the most potential are chosen and subsequently contacted through the means of a request for proposal (RFP) and request for quotation (RFQ) (Van Weele & Rozemeijer, 2022). A review conducted by McKinsey of the RFQs from automotive OEMs has revealed an increasing trend of including specifications for the use of renewable energy sources, recycled materials, and commitments to science-based targets as a means to reduce greenhouse gas emissions (Fredershausen et al., 2022). Next, the buyer compares supplier bids and negotiates delivery with the chosen supplier. Lastly, a legal contract is created, specifying compliance procedures and routines such as payment, delivery terms, penalty clauses, and warranty conditions (Van Weele & Rozemeijer, 2022).

2.1.2 Cross-functional Approach

Van Weele and Rozemeijer (2022) propose that procurement decisions should not solely prioritize optimizing procurement performance but also consider their implications on other departments such as product development and logistics. Thus, instead of focusing on securing the lowest price, procurement decisions should prioritize optimizing TCO or maximizing the value of procurement expenditure, which includes future costs beyond the initial investment, such as those related to packaging materials, spare parts, and technical services. This requires careful decision-making that integrates cross-functional teams from all business disciplines involved. Only through close collaboration with all relevant disciplines and top management can effective procurement strategies be established. The study by Brandmeier and Rupp (2010) affirms the cross-functional approach, indicating that the efficacy of procurement activities is significantly impacted by the level of integration of the procurement unit within the organization and the extent of cross-functional interaction with other units. Additionally, Schneider and Wallenburg (2012) suggest that corporate sustainability necessitates collaboration and alignment among many departments, thereby urging procurement to broaden its scope of activities to include active consideration of various stakeholders and breaking down functional silos by enhancing internal cooperation.

2.2 Green Sourcing

Organizations have adopted green procurement as a means to address sustainability requirements and minimize their environmental impact, which involves taking environmental factors into account while making procurement decisions (Min & Galle, 2001; Pelton & Smith, 2015). Green purchasing refers to an environmentally-conscious initiative that ensures the products or materials purchased by a company meet specific environmental standards, as defined by Carter et al. (1998) and Zsidisin and Siferd (2001).

According to Rusinko (2007), companies recognize the positive outcomes associated with green sourcing, such as eco-efficiency, cost savings, and improved reputation (Walker et al., 2008). The drivers for green sourcing can be divided into internal and external ones. Among the internal are organizational factors such as the desire to reduce costs (Walker et al., 2008) and quality improvements (Ruskino, 2007). External drivers include regulations (Min & Galle, 2001), customer expectations, societal ideals, supplier collaboration as well as obtaining competitive advantage (Walker et al., 2008). However, literature provides several barriers to implementing green sourcing, such as limited knowledge (Adham & Siwar, 2012; Buniamin et al., 2016), insufficient resources and alignment across departments (Bowen et al., 2001), lack of involvement from top management (Blome et al., 2014; Salam, 2008), poor supplier commitment, regulatory constraints (Walker et al., 2008), costly environmental programs (Min & Galle, 2001), and differences across industries (Zhu & Sarkis, 2006). In addition, the implementation of green sourcing may pose difficulties in terms of supplier selection, since more stringent environmental quality standards lead to a reduction in the number of eligible suppliers, which, in turn, raises the threshold for supplier qualification criteria (Min and Galle, 2001).

2.2.1 Green Sourcing Strategies

Studies have discussed various strategies to adopt green purchasing to influence suppliers' environmental behavior and performance. These strategies can be categorized into three dimensions, namely product standards, behavior standards, and collaboration. While product standards, such as eco-labelling, may not necessarily lead to changes in suppliers' behavior, some firms rely solely on integrating environmental criteria in their purchasing policies, without taking active measures to ensure progress. In contrast, the other two dimensions, behavioral standards and collaboration, require more extensive participation and exertion. Therefore, it is pertinent for buying firms to conduct a cost-benefit analysis to ascertain the degree to which suppliers should improve environmentally (Sarkis & Dou, 2017, Chapter 3).

Lloyd (1994) presented external certification of suppliers and the use of questionnaires and audits as two types of green sourcing strategies. Lamming and Hampson (1996) have extended the proposal with five strategy types, which include the use of vendor questionnaires, environmental management systems, product stewardship, life cycle analysis, and collaboration and relationships. Meanwhile, Tachizawa et al. (2015) grouped the various green sourcing strategies, based on their distinctive features, into either monitoring or collaboration. Monitoring strategies involve the practice of scrutinizing suppliers' environmental compliance, including environmental audits and product labeling, while collaboration strategies entail working jointly with suppliers to enhance their environmental performance, such as developing cleaner production processes and eco-friendly products and advocating for environmental legislation. These categories are depicted in Table 1. Furthermore, the monitoring and collaboration strategies are related, with monitoring serving as a foundation for implementing collaboration strategies (Tachizawa et al., 2015).

Table 1: *Monitoring and collaboration strategies of green sourcing.*

Green sourcing monitoring strategies	● Product content requirements ● Supplier environmental questionnaires ● Product eco-labeling ● Requirements for environmental management systems ● Supplier compliance auditing
Green sourcing collaboration strategies	● Product stewardship ● Supplier collaboration in product design ● Educating suppliers about sustainability ● Joint development of sustainable production ● Influencing legislation together with suppliers

The implementation of monitoring strategies is mostly reactive, while collaboration strategies usually require proactive measures. To effectively implement the above strategies, particularly those of a more collaborative nature, entails accounting for several factors when managing the supplier-customer relationship. These factors include establishing long-term strategic relationships and contracts, involving both the supplier and customer early on, trust building, fostering cross-functional alignment among different management levels and functions, engaging suppliers early in the product and process design phase, forming joint teams and encouraging collaborative problem-solving, and prioritizing value over cost (Sarkis & Dou, 2017, Chapter 3).

Fredershausen et al. (2022) argue that implementing green sourcing practices often requires significant innovation and collaboration across value chains to overcome supply chain constraints and achieve cost savings. These initiatives are typically concentrated on developing market insights to manage uncertainties, taking a strategic and long-term approach to sourcing decisions, and building new capabilities beyond supply chain management. The latter indicates the elimination of supply chain emissions related to the acquisition of new capabilities, such as design skills to modify product materials or engineering capabilities necessary to switch to product-as-a-service business models. Examples of long-term approaches include decarbonizing suppliers' energy use through the adoption of renewable energy sources or energy-efficient processes, adjusting the materials mix through product redesign or circular design, and partnering with suppliers to increase production capacity for sustainable materials or low-emissions processes.

2.2.2 LCA as a Tool in Green Sourcing

According to Pelton and Smith (2015), hotspot analysis is an effective tool for guiding buyers in sustainability purchasing criteria, and its results can form the basis for supplier questionnaires and dialogue between buyers and suppliers on sustainability improvements. To enhance credibility, supplier-specific information should be integrated into hotspot analysis. Agarwal et al. (2021) suggest that LCA can aid in making sustainable design decisions and lead to better procurement decisions by promoting joint cost and impact reduction efforts among several suppliers and ease supplier innovation. LCA results can be applied to assess which supplier and/or product is most capable of contributing to sustainability objectives and determining from what manufacturing site to source in order to reduce environmental impact. By performing regular benchmarks and following up on sustainability initiatives, businesses can achieve quantifiable benefits and identify opportunities for investing in sustainability through sourcing and procurement.

2.2.3 Supplier Relationships in Green Sourcing

The engagement of suppliers is deemed crucial in achieving environmental sustainability goals and improvements (Awan et al., 2019; Walker et al., 2008). Awan et al. (2019) suggest that innovative thinking should be in the context of green innovation, to facilitate knowledge-sharing in the supply chain network. Moreover, through supplier collaboration, joint development can be achieved which both parties can benefit from (Sarkis & Dou, 2017, Chapter 3). Sarkis & Dou (2017, Chapter 4) argue that firms have moved away from mere compliance to supplier engagement, to create sustainability along the whole supply chain. Green supplier development, according to the authors, entails establishing a collaborative partnership between the supplier and the buyer to foster increased adaptability and responsiveness towards enhancing environmental performance and achieving economic profitability.

Hamner (2006) and Charter et al. (2001) contend that developing collaborative relationships with suppliers is the most effective green sourcing strategy for improving suppliers' sustainability behavior. Implementing sustainable sourcing may be considered a challenging situation that promotes close collaborations, which is likely to further enhance purchasing's reliance on suppliers (Schneider & Wallenburg, 2012). However, buyers must invest more resources in terms of cost and effort to implement a sourcing strategy that advocates for sustainable practices among suppliers (Hamner, 2006). Schneider & Wallenburg (2012) similarly suggest that sustainable sourcing should involve selecting suppliers that offer competitive costs, adhere to high environmental standards, and the focal organization's standards and values. According to Ghosh et al. (2021), green approaches in sourcing are essential, and they recommend using CO_2-emissions as a determining factor in supplier selection.

Finally, it is worth noting that numerous suppliers in emerging economies, which constitute a significant portion of the supplier base, face resource and technological limitations in dealing with environmental issues. This also applies to smaller and medium-sized manufacturing firms. Therefore, an increased number of purchasing organizations are collaborating with suppliers to enhance their environmental performance, thus contributing to addressing serious environmental problems in emerging economies (Sarkis & Dou, 2017, Chapter 4).

2.2.4 Sustainability Reporting

For firms to be transparent about their environmental impact, they provide sustainability reports that detail their business model, strategy, and method of risk and viability management (Lowe, 2019), which serves as a form of corporate communication (Rhoden et al., 2022). This trend of addressing sustainability issues is crucial in the automotive industry, where some OEMs are leaders and others are falling behind (Sukitsch et al., 2015). Procurement teams need to acquire the skill of assessing the sustainability efforts of potential suppliers. One such skill is the use of carbon accounting principles to compare the environmental impact of various supply options. This is to identify suppliers that align with the organization's sustainability objectives or that have sustainability measures in place, resulting in favorable footprints or innovative technologies aiding in the achievement of sustainability targets (Cherel-Bonnemaison et al., 2021). Thus, sustainability reports are commonly utilized as a means for supplier selection, i.e., evaluating the sustainability ambitions and roadmaps of different suppliers.

Sustainability reporting is a managerial strategy that aims to improve market shares and stakeholder relationships (Daub. 2007; Morhardt et al., 2002). Information disclosure leads to an enhanced reputation (Sukitsch et al., 2015) and increases company value (Rhoden et al., 2022), consequently contributing to increased turnover (Sukitsch et al., 2015). Corporate sustainability initiatives are frequently used as a tool for efficiency, cost savings, and risk management (Sukitsch et al., 2015; Rhoden et al., 2022), allowing businesses to be more proactive and adopt more externally oriented methods. This indicates that the report should clearly describe how targets have been accomplished and cover both short- and long-term goals (Sukitsch et al., 2015). This is to avoid so-called greenwashing and facilitate supplier evaluation.

2.3 R&D and Sourcing

Research and development (R&D) can be defined as a range of activities a company undertakes to generate new knowledge or utilize pre-existing knowledge, to innovate and introduce a new product or service. Hence, R&D is essential for a company to be a leader and stay competitive (Roussel et al., 1991; Chiesa, 2001). Manual (2005) provides another definition of innovation: the introduction of a new product or modification of an existing one, to enhance its performance or functionality.

To improve operational efficiency and effectiveness, firms are promoting interdepartmental collaboration where synergies can be realized, such as between the R&D and procurement groups. The procurement team can contribute valuable input to the acquisition of product components during the product development phase. In contrast, the R&D department can assist the procurement function in the identification of the most suitable suppliers and guarantee the optimal supply of components and materials (Partida, 2016). Behncke et al. (2014) emphasize that procurement plays a crucial role in establishing a value-added relationship with suppliers in the procurement market, as well as timely identification of market trends to leverage technical potential for success. These objectives warrant the involvement of procurement in development activities.

In essence, R&D in procurement refers to the systematic exploration and development of new products or services that a company intends to procure. The process involves the commencement of market research and a comprehensive needs assessment, wherein the organization identifies potential areas of improvement and current technological advancements. Subsequently, the organization performs research to identify viable solutions. When suitable solutions are recognized, they are developed and tested, before being procured by the company (Behncke et al., 2014). Figure 3 below pinpoints the steps in the sourcing process where R&D can influence and contribute with input. Schiele et al. (2021) argue that the responsibilities of the purchasing department vary across the different product life cycles.

Although the purchasing department is responsible for procuring parts and ensuring competitiveness throughout the product life cycle, the focus of the R&D function is predominantly on the initial stage.

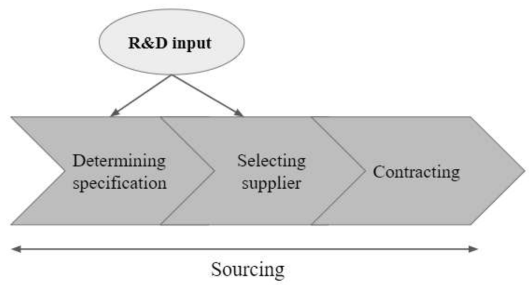

Figure 3*: Illustration of the sourcing process steps during which R&D contributes input.*

The integration of R&D and procurement can yield numerous advantages for companies. It can enable continuous development and enhancement of products and services, thereby maintaining a competitive edge and fostering business expansion and revenue growth. Moreover, R&D's involvement in supplier selection may contribute to reduced procurement costs and increased purchase value from certified vendors, while also identifying suppliers that align with the company's strategy and offer superior value and service. This collaboration can also lead to mutually beneficial improvements in the sourcing process (Partida, 2016). This reasoning can be applied in the context of sustainability, where R&D input can assist in identifying more sustainable suppliers that align with the company's values.

The procurement function is in an advantageous position, due to it being the organization's main point of contact with suppliers, responsible for managing purchasing costs and ensuring a continuous supply of necessary resources. Hence, it can contribute to the creation of new products and enhance customer value, leading to a competitive edge in the marketplace (Nijssen et al., 2002). As a result, the following chapters will delve into new product development and early supplier involvement.

2.3.1 New Product Development

Wheelwright and Clark (1992) define new product development as the activities undertaken by an organization to introduce a product to market, with low cost and short time-to-market. Loch and Kavadis (2008) argue that NPD includes more than just the creation of new products; it also involves the creation of possibilities that lead to the production of goods and services. A reworked version of an existing product with an improved or different function or design may be regarded as new product development.

During the development of a new product, the company must make critical decisions regarding both design and sourcing that shape the entire PD process (Wouters et al., 2009). NPD is also a phase in which product specifications are refined (Loureiro & Curran, 2007).

Sourcing decisions must be aligned with these specifications in order to ensure that the necessary materials, components, and resources are acquired. Thus, NPD serves as a means to analyze the product requirements and specifications, which in turn dictate the sourcing process (Wouters et al., 2009).

Product development processes are a part of the business process of supply chain management where an organization converts market and technological opportunities into information for the production of a commercial product. The development of a new product in relation to the product's lifetime, from planning and design to the end of the product's lifeline, is included in this process (Loureiro and Curran, 2007). Additional research has demonstrated the relationship between PD and the supply chain. As stated by Pero et al. (2010) this linkage is based on two factors: the design phase where the distribution and manufacturing of the product are decided, and the subsequent impact that the product has on supply chain management practices. Also, the product that the supply chain distributes is the outcome of the NPD process.

Regarding the supply and sourcing of a new product, the suppliers play a crucial role in the sourcing process as they significantly impact different aspects of the product, including its cost, quality and sustainability. To make any improvements in the product, it is essential to integrate suppliers into the product's supply process (Handfield et al., 1999). Applying changes in a product's NPD process becomes more challenging as the process moves forward and the design becomes more definite and established. This presents a constraint on procurement, as they may be limited in their ability to suggest changes based on suppliers and make adjustments as the NPD process proceeds. As a result, it is advised that procurement be included early in the NPD process (Van Weele & Rozemeijer, 2022).

2.3.2 Purchasing and Early Supplier Involvement in NPD

Supplier involvement entails the collaborative engagement between a corporation and its supplier towards achieving a common strategic goal for a product development project. According to Handfield et al. (1999), the more complex a product is, the earlier supplier involvement should occur. Whereas Schiele et al. (2021) have found a correlation between strategic suppliers according to Kraljic's matrix and early procurement involvement. Studies have shown that supplier involvement can provide the company with a more comprehensive understanding of the market, enabling them to obtain the necessary information to develop a product (Van Echtelt et al., 2008). Lakemond et al. (2001) and Schiele et al. (2021) suggest that the purchasing department must be integrated into the NPD process coherently to achieve successful supplier involvement. Purchasing involvement requires two key enabling factors: a collaborative organizational culture, where the internal organization must facilitate communication and coordination across departments involved in the PD process (Lakemond et al., 2001; Schiele et al., 2021; Van Weele & Rozemeijer, 2022), and the personnel involved in purchasing must possess the necessary education, skills, and experience to carry out their roles effectively (Lakemond et al., 2001; Nijssen, 2002).

The purchasing department acts as a relationship manager, serving as an intermediary between the organization and suppliers by leveraging their expertise in cost, quality, and availability of resources (Lakemond et al., 2001; Schiele, 2021). Thus, the buying firm can access additional and potentially better information from the suppliers (Petersen et al., 2005). To facilitate effective communication with suppliers and R&D experts, the purchasing department needs to coordinate the work of suppliers and convey potential design contributions (Lakemond et al., 2001). The level of involvement of the purchasing department is summarized in Table 2 below and can range from ad hoc to extensive participation in the development team.

Table 2*: Six different purchasing involvement types in product development projects, inspired by Lakemond et al. (2001).*

	Purchasing involvement type	**Description of purchasing involvement types**
A	Indirect purchaser involvement on an ad hoc basis	Engineers contact external purchasing specialists *as needed*.
B	Integrated purchaser involvement on a part-time basis	Purchasing specialists are incorporated into the project team and collaborate closely with an engineer on particular components, materials, or technologies on a *part-time* basis.
C	Integrated purchaser involvement on a dedicated basis	Purchasing specialists are incorporated into the project team and collaborate closely with an engineer on particular components, materials, or technologies on a *full-time* basis.
D	Purchasing coordinator	The project team includes a purchasing coordinator responsible for coordinating external purchasers.
E	Part-time integrated purchaser involvement in combination with purchasing coordinator	The project team is supported by a purchasing coordinator and *part-time* purchasing specialists.
F	Dedicated integrated purchaser involvement in combination with purchasing coordinator	The project team is supported by a purchasing coordinator and *full-time* purchasing specialists.

The complexity and size of a development project may require varying degrees of purchasing involvement. Figure 4 illustrates the preferred involvement type for each scenario.

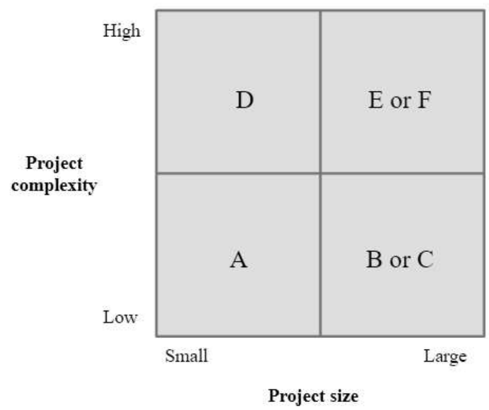

Figure 4: *Illustration of the purchasing involvement type's relationship between project complexity and size, adapted from Lakemond et al. (2001).*

While the extent of purchasing involvement varies, it is important to note that other functions, such as R&D, may also have knowledge of supplier markets and can coordinate supplier involvement. Therefore, supplier involvement is not solely managed by the purchasing department but carried out by several business functions in varying constellations (Lakemond et al., 2001). Furthermore, supplier involvement necessitates both internal and external cross-functional collaboration and communication. To facilitate such involvement, firms must have well-defined roles and a transparent organizational structure (Van Weele & Rozemeijer, 2022; Van Echtelt et al., 2008). According to Nijssen et al. (2002), Schiele et al. (2021) and Handfield et al. (1999), top management support for purchasing involvement in NPD is important for it to succeed and contribute to positive effects. Moreover, the authors emphasize the necessity of top management support to counteract the resistance from R&D towards purchasing involvement, stemming from conflicting priorities. Specifically, procurement's focus is on maintaining particular cost levels, whereas R&D seeks optimal technological product solutions.

Handfield et al. (1999) suggest that suppliers can be involved in various stages of new product development, from idea generation to prototype testing. Suppliers' involvement can vary from simple consultation to full responsibility for component or system design (Petersen et al., 2005). Although earlier integration is beneficial in cases of higher technology uncertainty, being "locked in" with a specific supplier can be a disadvantage, especially in the presence of multiple competing technologies (Handfield et al., 1999). Van Weele & Rozemeijer (2022) suggest that the term "timely supplier involvement" is more appropriate than "early supplier involvement" and emphasize that the degree of supplier involvement is crucial to NPD performance. In this regard, the involvement should align with the supplier's responsibility, which can vary from no involvement to black box design, as shown in Figure 5.

None	White box	Gray box	Black box
• No supplier involvement • "Make to print" • "Do as I order"	• Informal supplier involvement • Buyer "consults" with supplier on buyer's design	• Formalized supplier involvement • Joint NPD process between supplier and buyer	• Primarily supplier driven design • Based on buyer's functional/performance specifications

***Figure 5:** Degree of supplier involvement in NPD, adapted by Petersen et al. (2005) and Van Weele & Rozemeijer (2022).*

Supplier engagement presents both benefits and drawbacks. Empirical research reveals that it can result in reduced time-to-market, improved quality, decreased manufacturing costs, and easier sourcing of components, yet other studies have shown opposing outcomes (Handfield et al., 1999; Partida, 2016; Schiele et al., 2021; Van Weele & Rozemeijer, 2022). Connected to time-to-market, Partida (2016) argues that the involvement of suppliers in the design and sourcing phase of PD may increase the likelihood of launching product development projects on budget and within the specified timeframe. This is because supplier involvement allows for necessary modifications at a more cost-effective stage, rather than making changes later in the process, which may result in rework. Other advantages of supplier involvement are the sharing of risks and leveraging the supplier's expertise and knowledge. However, a potential disadvantage is the constraint on autonomy due to exclusive supplier partnerships, as well as the intricacy of the collaborative process, which can impede progress (Handfield et al., 1999).

Partida (2016) suggests that involving suppliers in product cost management from the early stages of product development is beneficial. Suppliers can offer insight to the R&D team on whether the needed materials for a product are available and the best source for them, taking into account trade agreements and duty rates. This input can lead to the identification of alternative materials or careful sourcing of materials by the procurement group to minimize production costs. Additionally, it can help organizations identify reliable locations to source from and avoid supply disruptions. This approach can also be relevant in sustainability efforts, as it can help identify sustainable regions for sourcing and highlight regions that pose risks such as child labor or lack of access to renewable energy sources.

2.4 Supply Chain of Electronics

Baldwin and Clark (2006) state that the electronics industry has transitioned to a modular configuration where companies maintain a reduced number of in-house operations (i.e., a smaller physical presence) and delegate non-restrictive functions to outside parties to enhance their overall business performance. The electronics industry is characterized by a global supply chain network that includes separate component suppliers, contract manufacturers or original design manufacturers, branded companies, distributors, and retailers (Shin et al., 2009).

2.4.1 Semiconductor Components Supply Chain

The supply chain model of semiconductor components encompasses multiple activities, including R&D, manufacturing, design and branding, as well as distribution, sales, and service, as illustrated in Figure 6. These activities contribute to the creation of value, as goods move from component suppliers to end customers. Each participant in the supply chain acquires inputs, adds value, and passes the cost to the subsequent stage of production. The collective value added by all participants in the supply chain is equivalent to the final price of the product (Shin et al., 2009).

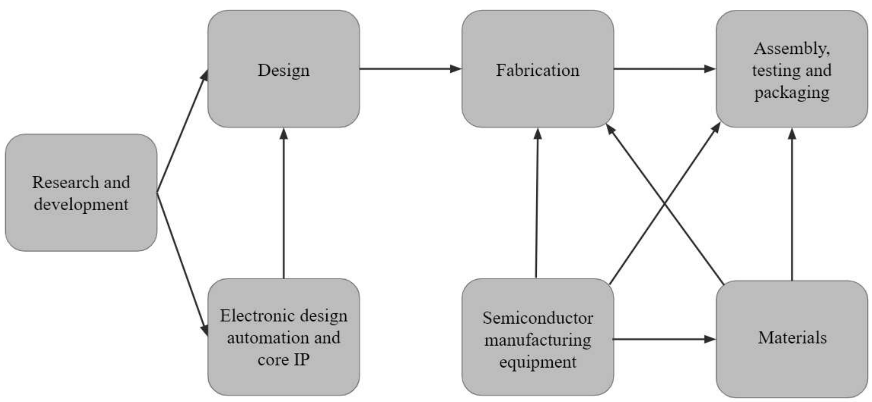

Figure 6: *Illustration of the semiconductor supply chain, inspired by Khan et al. (2021).*

For instance, at a high level, the supply chain of semiconductor production includes R&D and chip production (SIA, 2016). Research and development benefit all stages of the supply chain, encompassing both preliminary research into foundational technologies and competitive research that directly enhances semiconductor technology. The production process involves three main steps: design, fabrication, and assembly, testing, and packaging (ATP). These steps can either be performed by one company, known as an integrated device manufacturer (IDM) that sells the chip, or by separate companies, where a fabless firm designs and sells the chip while acquiring fabrication services from a foundry and ATP services from an outsourced semiconductor assembly and test (OSAT) company. To produce semiconductor components, several inputs are required, such as materials, semiconductor manufacturing equipment (SME), electronic design automation (EDA), and core intellectual property (IP). These inputs typically come from different companies, which makes the semiconductor supply chain complex (Khan et al., 2021).

Automotive electronics, which cover a wide range of in-car systems and displays, are projected to represent 45% of a car's manufacturing cost by 2030. With increased electronic content in vehicles and semiconductor shortages, automotive OEMs are becoming increasingly reliant on the semiconductor network for their supply since they do not have established direct relationships with semiconductor suppliers. Instead, a greater emphasis is placed on relationships with Tier 1 suppliers, and disruptions at semiconductor suppliers have highlighted how problems at various supplier tiers can result in supply chain disruptions for companies (King et al., 2021). Furthermore, Asia's largest chipmakers, TSMC and Samsung, do not have enough capacity to meet the increasing demand for these components, which poses bottleneck issues. Fabless companies, such as Qualcomm, Nvidia, and Apple, design semiconductors for these electronics, but their manufacturing occurs at advanced factories called foundries, and only a few foundries are responsible for the majority of global chip fabrication. The contract chipmaking business is mainly located in Asia, with Taiwan and South Korea being the two largest regions, home to TSMC and Samsung, respectively. King et al. (2021) state these issues as significant bottlenecks in the semiconductor supply chain.

Following the complexity of the semiconductor supply chain, Alam et al. (2020) argue that the supply chain for semiconductor components involves over 1000 steps that cross international borders at least 70 times before the product reaches its final customer. Since the supply chain of semiconductors involves several countries, policies that affect even a single firm or supply chain step can have global ripple effects with tremendous cost impact. For example, the advancement of China's semiconductor industry could reconfigure these supply chains, affecting international security and the competitiveness of incumbents (Khan et al., 2021).

2.4.2 Green Supply Chain of Electronics

The sustainability of electronics heavily relies on the supply chain. Nevertheless, the intricate nature of this supply chain poses challenges in identifying and implementing green supply chain management practices, which can be both difficult and costly (Hsu & Hu, 2008). According to Hsu and Hu (2008), there are three main categories of green supply chain management: management activities that involve working closely with suppliers, product-based practices that aim to manage the by-products of supplied inputs, and proactive approaches that entail the use of environmental criteria in risk-sharing, performance evaluation, and joint clean technology programs with suppliers. The most advanced organizations in terms of sustainability-oriented information sharing typically have cross-functional teams consisting of sales, environmental personnel, purchasing personnel, and other relevant departmental staff. These categories are closely related to the green sourcing strategies, which are presented in section 2.2.1.

2.5 Environmental Impact of Electronic Components

Component life cycles are divided into 4 stages: raw material, manufacturing, use and disposal. Through these phases, the environmental impact may differ. According to Alonso et al. (2007), the environmental impact hotspots of electrical and electronic components are the manufacturing and the use phase. Material production is the main reason for the high impact of the manufacturing process. The production of electronic components necessitates a substantial quantity of resources, including raw materials, energy, and water. These resources contribute significantly to emissions resulting from the manufacturing processes (Boyd, 2011).

The environmental impact can be assessed through PCF, which as previously described, is a particular form of LCA practice. The method of carbon footprinting is utilized to measure the direct and indirect greenhouse gas emissions caused by an individual, organization, product, or event throughout its life cycle (Vasan et al., 2014), and to find eventual hotspots. Hotspot analysis is employed to effectively pinpoint the areas in the supply chain with a high carbon footprint which can be targeted for reduction measures (Huang et al., 2009). Furthermore, PCF is significantly influenced by its supply chain, thus accurately estimating the PCF within a sustainable supply chain is critical. However, current research primarily focuses on calculating carbon footprint during the design and manufacturing stages and lacks specific guidance for consistent PCF calculation across the supply chain (He et al., 2019).

Electronic components are considered high GHG emission-intensive materials. Thus, the electronic industry is subject to GHG emission regulations, such as the Waste from Electrical and Electronic Equipment Directive (WEEE) and the Restriction of the Use of Certain Hazardous Substances legislation (RoHS). These regulations require electronics manufacturers to reduce waste and limit the use of hazardous substances that can cause harm to human health. In conclusion, the electronic industry is responsible for emission reporting and must comply with regulations aimed at reducing GHG emissions and protecting public health (Vasan et al., 2014). The electronics industry must also comply with other directives concerning greenhouse gas (GHG) emissions as electronic components are considered materials with high GHG emissions, exceeding 5 kg CO_2e/kg.

3. Methodology

By outlining the approaches that were used to address the research questions, the following chapter aims to convey the study's methodology. This chapter presents and discusses the approach taken in order to answer the research questions. The sections that follow, address the methodology of the study and how the research is structured.

3.1 Research Design

The focus of the research is the purchasing division for software and electronics at a global automotive manufacturer and their cross-functional communication with the R&D team in sourcing electronic components for a specific ECU. This study adhered to Bell et al. (2022) outline of qualitative research, which entails the formulation of broad research questions as the initial step. As indicated in Figure 7, the study was conducted in three phases: firstly understanding the problem and context, secondly data collection, and lastly analysis and recommendations. Recurring activities within the first phase consisted of unstructured interviews to understand the problem areas, and the development of preliminary research questions to establish a general study focus. These served to facilitate the development of research questions that were appropriate to the study. However, subsequent to consulting with supervisors, the research questions underwent several iterations and revisions.

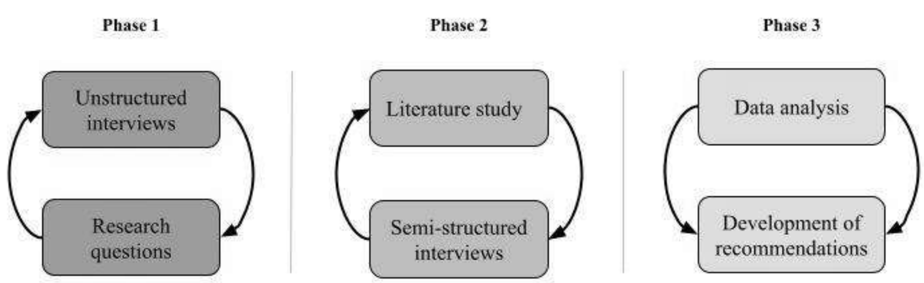

***Figure** 7: Illustration of the study's research process.*

Phase 2 comprised a literature study and semi-structured interviews. According to Yin (2018), a comprehensive literature review is an essential aspect of understanding the pertinent questions related to a particular topic. In line with this notion, a literature review was conducted based on the research questions to obtain a deeper understanding of the relevant themes. The literature study served as a foundation for developing an interview guide for the semi-structured interviews to ensure the inclusion of crucial areas of investigation (Bell et al., 2022). The use of semi-structured interviews is consistent with the qualitative research design and explanatory research questions. Moreover, it enables flexibility, facilitates respondent comparisons, and reveals patterns in the responses (George, 2022).

The interview process revealed certain irrelevant aspects of the literature study while necessitating further exploration of other areas. Thus, an iterative approach was utilized where theory and empirical findings complemented each other, constituting a “learning loop,” as identified by Kovács and Spens (2005). Abductive reasoning, which involves searching for suitable theories to explain empirical observations, is associated with so-called "theory matching" or "systematic combining" (Dubois and Gadde, 2002). This research approach is referred to as an "abductive process" (Spens and Kovács, 2006). In conclusion, the abductive process entails observing a real-life phenomenon and applying theoretical knowledge to it, resulting in an iterative and creative process of data collection and theory building.

The final phase entailed analyzing and discussing the gathered data, conducting a thematic analysis by coding data and drawing comparisons between the empirical findings and the literature. The as-is analysis formed the basis for developing recommendations aimed at reducing the carbon footprint of the ECU through practical actions.

3.2 Case Study

The primary research method is a case study of a specific ECU utilized in a global automotive company’s vehicles. Yin (2018) and Crowe et al. (2011) describe case studies as an in-depth analysis of a present-day occurrence within its authentic setting, particularly when it may be difficult to distinguish between the situation and its context. Moreover, case studies are preferred when addressing “what” and “why” issues (Yin, 2009). A case study, according to Patel & Davidsson (2019), provides a holistic view and enables the collection of extensive and detailed data. Moreover, it is useful for examining the processes and alterations in an organization or network. This is central to the study’s aim of obtaining an in-depth understanding of the case company’s current green sourcing and cross-functional practices with PD, to provide recommendations for sustainability improvements on how to reduce the CO2-footprint of the ECU.

In this thesis, the case study method was initially selected with the intention of exploring a contemporary phenomenon in the automotive industry. Additionally, the research questions posed were of an exploratory nature, which supported the choice of a large automotive company as a representative case. Further, the selection of a singular case was based on two factors. First, the perceived representativeness of the case company as a major automotive OEM, and second, time and resource constraints for undertaking multiple cases.

3.3 Data Collection

The purpose of this subchapter is to clarify the methods employed for data collection and analysis in the case study. Qualitative data is gathered through interviews with employees and managers from the procurement, sustainability, and R&D departments. This constitutes the primary data, which is according to Bell et al. (2022) collected specifically for research purposes. In contrast, secondary data corresponds to information obtained by other researchers for a variety of reasons (Bell et al., 2022). The procedures utilized to gather these two forms of data are detailed in this section, along with a description of how the collected data is analyzed.

3.3.1 Primary Data

The initial phase of the study is focused on acquiring relevant and valuable data and information. In order to gain a better understanding of the issue and how the case company is addressing it, various data collection methods were utilized as sources of evidence (Yin, 2018). According to Yin (2009), interviews are a critical source of case study data and can help understand why a process took place in a particular way. Unstructured interviews were conducted with employees to gain insight into the problem, which helped to focus the study's scope and objectives. These interviews were exploratory, encompassing open discussions conducted over four weeks with approximately ten employees from diverse backgrounds. Participant observation was also employed to comprehend the daily routines, communication, and departmental integration of the case study by participating in relevant meetings and presentations. Bell et al. (2022) contend that qualitative research methods, such as participant observation and semi-structured interviewing, enable researchers to maintain an open-minded approach towards their research questions, allowing for the emergence of new concepts and theories from the collected data.

Yin (2018) notes that case study interviews are comparable to guided conversations, rather than inflexible questionnaires. The key advantage of interviews lies in their ability to directly probe the topic under investigation and obtain personalized and insightful responses from the interviewees. However, it is essential to recognize the limitations of interviews, such as the potential for biased responses due to poorly framed questions, difficulties in accurately recalling the interviewee's statements, and the interviewee's inclination to provide answers that align with the researcher's expectations.

Semi-structured interviews have been selected as a suitable research method owing to their capacity to facilitate a neutral and unbiased analysis of a real-life case study, based on primary sources (Yin, 2018). It allows for an impartial examination of all emerging facets identified by the primary sources in the case study. Moreover, the flexibility of the semi-structured interview approach permits customization of the interviews to focus on the most compelling topics, as the follow-up questions can be tailored accordingly.

Together with the supervisor from the focal company, relevant interviewees were identified and selected using purposive sampling. The chosen participants primarily belonged to the procurement, R&D, and sustainability departments of the automotive OEM. Purposive sampling is a non-probability sampling technique frequently employed in exploratory and qualitative research to select pertinent cases or participants aligned with the investigation's objectives. The research questions determine which units need to be sampled strategically. Furthermore, snowball sampling was employed, which involves making initial contact with people who have a relevant connection to the research topic and leveraging those contacts to establish further connections with other people who possess relevant characteristics or experiences. This process continues until an adequate sample size is achieved (Bell et al., 2022).

The interviews were focused on the procurement processes of electronics, the involvement of R&D in the sourcing process, and the present integration of sustainability practices in these operations. The complete list of interviewees can be found in Table 3 below. All of the conducted interviews involved personnel from the focal company, except the final interview in the table, which was undertaken with representatives from the Tier 1 supplier of the ECU. Open-ended questions were prepared before each interview, and follow-up questions were asked as needed to obtain additional information. This approach highlights the flexible nature of semi-structured interviewing, as suggested by Bell et al. (2022). During the interviews, notes were taken, and the conversations were recorded. Additionally, the recorded data was transcribed to facilitate subsequent analysis.

Table 3: *Compilation of all semi-structured interviews. In total 24 interviews with 22 individuals.*

Interview type	**Respondent**	**Role**	**Department**	**Length**
Joint interview	R1 & R2	Category buyer and Global category manager	Procurement	120 min
	R3 & R1	Cost engineer and Category Buyer	Cost engineering and Procurement	120 min
Individual interview	R4	Analysis engineer	Sustainability Center: R&D	3 x 60 min
	R5	Analysis engineer	Sustainability Center: R&D	90 min
	R1	Category buyer	Procurement	90 min
	R6	Principal engineer	R&D	60 min
	R7	System architect	Sustainability Center: R&D	50 min
	R8	Category buyer	Procurement	60 min
	R9	Sustainability manager	Sustainability Center: Procurement	75 min
	R10	Hardware engineer	R&D	80 min
	R11	Business owner	Semiconductor team	45 min
Joint interview	R12 & R13	Global supplier owner & Category buyer	Semiconductor team & Procurement	25 min
Individual interview	R12	Global supplier owner	Semiconductor team	60 min
	R14	Top manager	Procurement	45 min
	R15	Supplier & partner manager	R&D	40 min
	R2	Global category manager	Procurement	90 min
	R16	Category buyer	Procurement	50 min
	R17	Team manager	Procurement	30 min
	R18	Product owner	R&D	30 min
	R19	Procurement director	Procurement	45 min
	R20	Category buyer	Procurement	30 min
Joint interview	R21 & R22	Project managers	**Tier 1 supplier**	60 min

3.3.2 Secondary Data

Saunders et al. (2009) observe that researchers commonly combine primary data with secondary data, which can be obtained in either written or non-written form. Written secondary data may comprise organizational documents, reports, emails, and newspapers, while non-written secondary data can take the form of audio and video recordings. Bell et al. (2022) support this view and report that documents are frequently used in case study research as a supplementary data source, alongside semi-structured interviews and participant observation.

In the study's first and second phases, secondary data was collected to complement the information gathered from the interviews. Various internal organizational documents, such as company websites, sustainability reports, powerpoints, and video recordings, as well as the PCF report and contracts with specifications of the studied ECU, were utilized as written secondary data sources. In addition, non-written secondary data was gathered from video recordings and participation in presentations on various topics. Table 4 outlines all presentations attended and their content. In the second phase, the collected secondary data was cross-checked during the semi-structured interviews by posing questions concerning the findings. The objective was to ensure the accuracy of the secondary data, thus strengthening the research's validity.

Table 4*: Compilation of all attended presentations.*

Topic	Department	Role	Company	Length	Subject
Sustainable electronics - future sustainability trends of IC manufacturing	Sustainability center: R&D	Analysis engineer	Focal company	55 min	P1*
ECU production process from a cost engineering perspective	Cost engineering electrical/software	Cost engineer	Focal company	120 min	P2
Sustainable electronics - electronics requirements	Sustainability center: R&D	Analysis engineer	Focal company	60 min	P3
Sustainability ambitions of a semiconductor manufacturer	Procurement: semiconductors	Company representatives	Semiconductor manufacturer	55 min	P4
Sustainable electronics - electrical hardware	Sustainability center: R&D	Analysis engineer	Focal company	60 min	P5
Electronics for procurement: basics of ECUs, ICs & semiconductors	Procurement: semiconductors	Senior manager	Focal company	90 min	P6
Sustainable electronics - CO_2 calculation estimates	Sustainability center: R&D	Senior manager	Focal company	30 min	P7

*P = presentation

3.3.3 Data Analysis

Bell et al. (2022) argue that qualitative analyses are characterized by an iterative process in which the collection and analysis of data are interdependent and repetitive. This implies that analysis commences after data collection, and the insights gained from the analysis influence the subsequent steps in data collection. This process is reflected throughout the study and is explained further in section 3.1.

In this study, the data analysis stage involves data reduction, where a large amount of data is condensed into a meaningful representation. The interpretation of secondary data is also considered a form of data analysis (Bell et al., 2022). Crowe et al. (2011) contend that utilizing various data collection methods should yield comparable conclusions. Further, they suggest that exploring a problem from multiple perspectives may facilitate the development of a comprehensive understanding of the phenomenon.

Thematic analysis, which involves identifying recurring topics related to the research focus, is one of the most commonly used approaches to qualitative data analysis (Bell et al., 2022). The authors searched for patterns, transitions (i.e., how topics shifted in the data), and similarities and differences to identify themes. Therefore, the interview questions were initially designed to fit within the categories of the theory section. Subsequently, the responses from the interviews were sorted into different theoretical concepts. This was accomplished through coding the data, wherein distinct pieces of information were assigned color codes according to the meaning they conveyed. Finally, the answers were grouped into categories and analyzed to determine similarities and differences between the participants' responses. The identified themes were green sourcing strategies, procurement and supplier involvement in product development and top management's support. Thus, the findings were derived from respondent quotes aligned with the identified themes. These were subsequently discussed and related to the theoretical frame of references, ultimately facilitating the answer to the research questions.

To be able to provide recommendations for improvement, the data analysis is essential in comparing the empirical findings with existing theory. In the present study, recommendations are proposed to the procurement and R&D departments, aimed at supporting the focal company's efforts to achieve its sustainability targets, particularly in terms of reducing the CO_2-footprint of a specific ECU during the sourcing process. Crowe et al. (2011) explain that the outcomes of case studies have the potential to enrich the development and examination of theories by validating, reinforcing, or weakening historical explanations of a case, and potentially facilitating the generalization of theories beyond the specific cases studied.

3.3.4 Quality Assurance

Case study research has been criticized for its lack of scientific rigor and generalizability, as well as being difficult to replicate and lacking transparency (Crowe et al., 2011; Bell et al., 2022). Therefore, to assess the quality of research, Bell et al. (2022) highlight three key criteria: reliability, replicability, and validity. Reliability refers to the ability to replicate the results of a study and is closely linked to replicability. Replication is important for validating research findings, and for this to be possible, the study must be replicable, which requires a detailed description of the procedures. The most important criterion, according to the authors (Bell et al., 2022) is validity, which concerns the accuracy and integrity of the conclusions drawn from the research. However, qualitative studies are rather focused on trustworthiness as an evaluation criterion, which consists of four components: credibility, transferability, dependability, and confirmability.

In accordance with Crowe et al. (2011), various steps are implemented (see Table 5) to ensure the criteria above. These steps comprise theoretical sampling, which increases the rigor of the study, and respondent validation, which enhances the accuracy of the research. To achieve confirmability and credibility, data triangulation has been employed, which involves using multiple sources or methods of data to enable verification of the findings (Bell et al., 2022). To ensure valid data is obtained from individuals with extensive knowledge of the relevant topics, the supervisor from the focal company was advised to carefully select interviewees. Interviews are recorded, noted, and subsequently compiled to provide the participants with the opportunity to review and comment on preliminary findings. The extensive documentation of data relates to transferability. Transparency is crucial throughout the research process, and it is achieved by providing detailed descriptions of the case selection and data collection methods, as well as by presenting potential alternative explanations and being explicit about the interpretation of the data. This allows for a high degree of dependability and allows others to replicate the study. By following these steps, readers can evaluate the trustworthiness of the case study report.

Table 5*: Potential case study risks and mitigation actions to prevent them, inspired by Crowe et al. (2011).*

Case study risks	**Mitigation action**
Lack of generalization	Acquiring comprehensive knowledge of theoretical literature & justifying decisions made
Lack of rigor	Triangulation, theoretical sampling, respondent validation and transparency
Obtaining irrelevant or too little data	Concentrating on gathering data based on RQs while remaining adaptable to examining other topics.
Transparency issues	Detailed descriptions of all steps in the study
Difficulty to replicate	Ensure transparency

4. As-is Analysis

The following subsections will describe the present state of the focal company, with the case description portraying the context. This is followed by a detailed examination of the ECU under investigation and its corresponding supply chain. Additionally, offering a general overview of the procurement function for software and electronics, along with an exploration of its connections to R&D and the sustainability center. Finally, the sourcing process will be described, incorporating various sustainability aspects associated with it.

4.1 Case Description

The prioritization of core competencies and end product design, results in the automotive OEM extensively outsourcing the components, including electronics, used in its vehicles. This implies that the ECU under investigation is outsourced to a Tier 1 supplier. Outsourcing necessitates considerable supplier partnerships, with which the procurement function is often the primary point of contact. Hence, the focal company has ties with over 9000 suppliers worldwide and operates a purchasing organization with a workforce of approximately 850 individuals. The procurement department is strategically situated in proximity to other core departments and a vehicle production facility, emphasizing its strategic role due to the substantial influence of purchased components on the cost structure of the products.

Ambitious sustainability objectives have been established by the automotive OEM at an organizational level, and these are anticipated to be fragmented into department-specific sub-targets. However, determining the appropriate course of action and assigning departmental responsibility for each sub-target can often be ambiguous. For instance, a comprehensive set of sustainability-oriented supplier requirements has been developed, necessitating close monitoring. As a result, the procurement department is entrusted with the responsibility of addressing sustainability matters pertinent to the organizational and site levels, whereas the R&D department is accountable for sustainability concerns associated with a material and product level.

4.2 ECU

As previously described, the object under investigation is an advanced ECU with a critical vehicular function, designed to support the forthcoming generation of fully electric cars and enable greater technology customization. Centralizing complex computational tasks allows for software updates and continuous improvements throughout the vehicle's lifecycle. Additionally, the ECU undertakes intricate tasks, such as processing information from the extensive sensor array to construct a detailed representation of its surroundings, which is essential for safety systems. Furthermore, the integration of the ECU mitigates the complexities related to the numerous dispersed ECUs that previously managed individual features. This streamlining is expected to facilitate faster and constant development, allowing for the implementation of cutting-edge software and hardware in vehicles (Case Company, 2022).

To enable the above, a solution with distinct performance attributes also necessitated a specific chip. Approximately five years ago, the case company decided to source the ECU chip from a particular supplier. At that time, the market had a limited number of suppliers offering such solutions. Consequently, the company opted to proceed with the alternative that, in their estimation, best fulfilled the technical requirements. Hence, the choice was based on a reference design solution provided by the supplier. A reference design constitutes a pre-defined design embodying essential functionalities and characteristics pertinent to a specific application. In the context of an ECU, component selection entails choosing the specific electronic parts or elements that align with the recommendations and specifications provided by the reference design. The chip, in this case, plays a vital role not only in determining the compatible components but also in shaping the design of the PCB.

Considering that the ECU is designed for upcoming vehicle generations, which face stricter sustainability criteria, the procurement department must ensure that the Tier 1 supplier aligns with the goals encompassing Scope 3, specifically aiming to reduce supply chain emissions per vehicle by 25%. Consequently, a PCF analysis has been requested by the supplier. The findings have been validated and employed to identify hotspots where measures can be implemented as part of the climate action strategy. To begin with, the ECU can be broadly categorized into two components: the housing and the electronics, which comprise the PCB and various electronic components mounted onto it. These components include logic integrated circuits (ICs), memory ICs, and other electronic components. Among the roughly 400 components, there are 50 logic ICs, representing approximately 34% of the total CO_2-impact for the entire ECU, thereby constituting the most significant hotspot due to their energy-intensive manufacturing processes. Due to the aforementioned reason and the fact that logic ICs are a variety of semiconductors, increased focus has been directed toward how to secure a sustainable supply of these components.

4.2.1 ECU Supply Chain

From the perspective of the focal company, the Tier 1 supplier is considered the most crucial actor in the supply chain, as they serve as the primary contact for the ECU and are accountable for procuring all necessary electronic components. These components encompass not only semiconductors but also passive components such as resistors and transistors, as well as electromechanical parts such as PCBs, screws and connectors. However, the ECU supply chain exhibits a significantly more complex structure, primarily due to the multitude of component types, each possessing distinct characteristics and quantities, which calls for the involvement of multiple actors. Efficient coordination and communication among these actors are vital for ensuring the final product conforms to the stipulated specifications.

As depicted in Figure 8, utilizing some key actors, the ECU supply chain can be organized into five distinct steps, beginning with wafer manufacturing, which subsequently undergoes testing and packaging by a third-party foundry. The ICs are then produced by a semiconductor company, employing multiple steps. These two steps have lengthy lead times, often posing bottlenecks in the supply chain. Semiconductor companies are supplying semiconductors to the Tier 1 company. However, in some cases distributors are purchasing large volumes of semiconductors from semiconductor companies, thus functioning as a wholesaler, allowing the automotive OEMs to purchase from them. Subsequently, the Tier 1 companies mount the ICs and other components onto the PCB to finalize the assembly process. Ultimately, the fully assembled ECU is delivered to the focal company.

Figure 8*: The ECU supply chain.*

The shaded regions in Figure 8 represent where the purchasing department currently maintains direct contact, thus possessing the greatest insight into the value chain there. However, it is not the procurement for software and electronics that manages communication with certain semiconductor companies; rather, a dedicated semiconductor team within the focal company's procurement department handles this responsibility.

Though not illustrated in the figure, the procurement department for software and electronics maintains direct contact with the ECU chip supplier. This close interaction is necessitated by the strategic and critical nature of the component and the need for continuous discussions about design and future chip upgrades. Dialogues about sustainability with this supplier have only been initiated relatively recently, marking an effort to explore potential improvements in this area.

4.2.2 Semiconductor Supply Network

In the automotive sector, Just-in-Time (JIT) is a prevalent approach for sourcing materials. However, as a senior manager (P6) pointed out, semiconductor supply chains cannot be treated according to the JIT principles, due to the significantly longer planning horizons and lead times. Moreover, semiconductor manufacturing involves complex and time-consuming processes, which can span across several weeks, while the development of new chips and the expansion of production capacity can take several years. This extended time frame is a stark contrast to the quick turnaround JIT methodology employed in the automotive industry. In response to these challenges, the focal company has shifted its focus to the source, i.e., the Tier 2 suppliers, as elaborated by a senior manager (P6).

Owing to the critical role semiconductors play in the company's vehicles and the recent component shortage, the procurement department has introduced a dedicated semiconductor team as a measure to secure supply. In the long term, their ambition is to influence sustainability by engaging suppliers beyond the Tier 1 level. This involves cultivating robust relationships with semiconductor vendors in order to initiate sustainability dialogues and assess their sustainability roadmaps, which relates to the ultimate goal of finding vendors that align with the company's ambitions. According to a business owner, the selection of semiconductor manufacturers with which to enhance relationships is influenced by the potential synergies related to a semiconductor in an ECU that could apply to several other ECUs. However, the acquisition and pricing models for these vary significantly. The strategy, therefore, revolves around unifying procurement processes when a multitude of components are sourced from the same supplier, thereby enabling direct communication and potentially signing bespoke agreements.

The manager of the focal company's semiconductor team refers to the semiconductor market as a "roller coaster". This metaphor is used to signify its fluctuating nature, with periodic shortages arising due to factors such as changes in demand or lead times. To mitigate these occurrences, the semiconductor team concentrates on relationship-building with some semiconductor suppliers, intending to be prioritized during market disruptions and vulnerability. The supply chain for semiconductors and electronics constitutes a multifaceted network comprising numerous stakeholders operating across different tiers. These actors participate in diverse stages of the supply chain, including semiconductor design, manufacturing, and distribution, as well as electronics manufacturing. Figure 9 portrays a simplified model of the semiconductor network, which includes the automotive OEM. In the illustration, the information flow among the actors is depicted by the green arrows, while the blue arrows represent the physical flow.

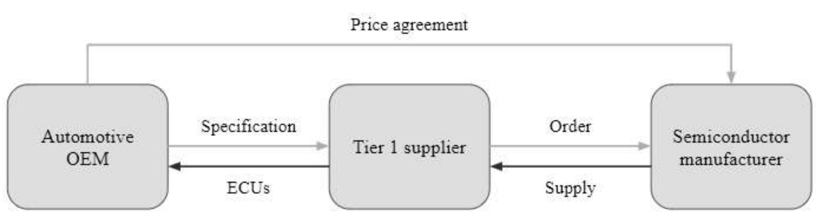

Figure 9*: Supply network for automotive electronics and semiconductors.*

The focal company provides the Tier 1 supplier with the necessary specifications for the semiconductor components. Despite the Tier 1 supplier's responsibility for supplying the semiconductors, the semiconductor team is engaged in direct communication with various semiconductor suppliers to establish pricing agreements and secure the sourced supply on behalf of the Tier 1 supplier, resulting in the delivery of ECUs to the Automotive OEM. This collaboration serves as a mechanism for fostering relationships with semiconductor vendors and increasing supply chain transparency, as per a global supplier owner. Additionally, the company utilizes this channel to encourage manufacturers to comply with sustainability requirements that align with the organization's strategic objectives.

4.3 Procurement Department for Software and Electronics

The procurement department for software and electronics' primary responsibility is to ensure a consistent supply of electronic components, such as control units for infotainment and vehicle body electronic systems. Procurement operates within global category teams composed of buyers, supply quality managers, and global category managers. Team managers are not a part of the global category team but they may be involved in discussions and provide viewpoints.

Buyers are responsible for the commercial and quality aspects of ongoing business and aftermarket operations. This entails contract management, i.e., negotiating and signing contracts and managing the day-to-day relationship with suppliers, which can include follow-up on sustainability objectives. Additionally, they are tasked with industrializing new vehicle programs by developing commodity business plans that outline the required scope, strategies, and timelines for sourcing new vehicles. Throughout the product life cycle, buyers are required to manage supplier relationships and performance, addressing e.g. quality and sustainability objectives. To conclude, buyers execute all activities related to the commodity, including sourcing, re-sourcing, project management, risk mitigation, and supplier base development for increased efficiency. To execute these plans, buyers must collaborate cross-functionally with diverse stakeholders. Category teams work jointly with R&D personnel to guarantee that component designs align with vehicle manufacturing processes. Figure 10 presented below serves as a simplified representation of reality, illustrating the interrelationships among key departments identified in this case. The simplification indicates that a degree of overlap in roles and responsibilities among departments exists, however, the primary emphasis remains as illustrated.

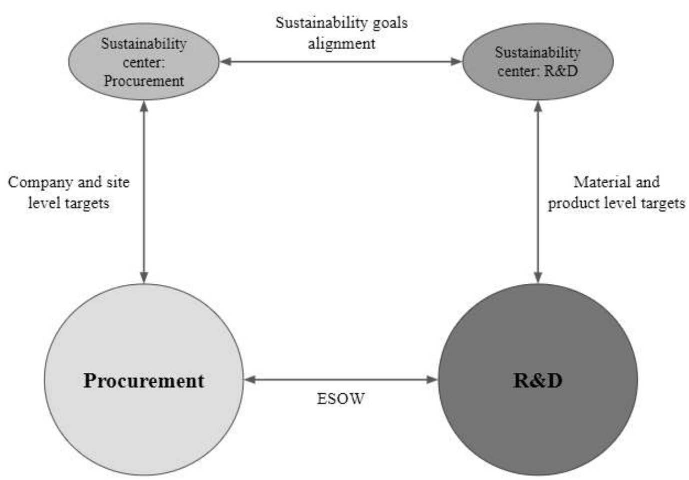

Figure 10: *Simplified illustration of the relationship and information exchange between procurement, R&D and Sustainability Center.*

The organization has a centralized Sustainability Center, which is divided into procurement and R&D segments, addressing sustainability concerns at distinct levels, ultimately producing diverse targets, processes and tools. Consequently, the communication between the two parties is largely focused on addressing the overlaps in their requirements, as highlighted by an analysis engineer, and determining who should be responsible for certain LCA hotspots, according to a sustainability manager. These segments have a support function for the company's standard procurement and R&D departments. Sustainability Center's procurement segment manages issues at the company and site levels, while its R&D counterpart is responsible for the material and product levels. Communication between procurement and the sustainability center primarily revolves around topics such as renewable energy and climate neutrality. Moreover, they assist buyers in mitigating climate impact, and how to evaluate supplier data. That is, determining when deviations from sustainability are acceptable, and establishing when it is justifiable to incur higher costs for sustainability purposes.

Sustainability center: R&D's responsibility for material and product may result in requirements communicated to R&D, which are integrated in product specifications, specifically within the Engineering Statement of Work (ESOW). The ESOW is an R&D document that is included as an appendix in the procurement contract. It addresses commodity information, technical specifications, expected deliverables, performance levels, roles and responsibilities, as well as cost split up. This information is subsequently exchanged between R&D and procurement to guarantee that suppliers fulfill the requirements. Procurement is responsible to ensure that both R&D and the supplier sign the ESOW.

As per the account of two buyers, the procurement department has introduced the concept of so-called "Sustainability Champions", which is a network of buyers with extended duties. This role involves the responsibility to stay informed of sustainability developments and to promote these issues with suppliers. Additionally, these champions are expected to regularly update their colleagues on the latest sustainability status and to advance the sustainability agenda along the supply chain and are tasked with tailoring the approach to their specific area to continuously improve and reach sustainability targets. It is primarily with these sustainability champions that the procurement sustainability center engages, informing them about the company's key sustainability focus areas, new tools, and processes. According to a sustainability manager, the champions are pivotal in distributing this knowledge to other procurement personnel. Two analysis engineers from the R&D sustainability center express that it is not their usual practice to collaborate directly with the procurement department. However, they would become involved in dialogues when specific questions related to sustainability arise from suppliers.

More details on the different roles in category teams: cost engineers serve as a support function for the procurement department by providing cost estimates, which are utilized to project the expenses associated with specific components. This information enables supplier comparisons based on the "should cost", supporting their efforts to negotiate cost-effective agreements. According to a senior manager (P7), cost analysis is not the only tool for evaluating suppliers; the team of cost engineers is expected to commence calculations on CO_2 estimates in the near future. Besides the cost breakdown, they will require suppliers to provide a more detailed accounting of their sustainability efforts and CO_2-emissions, such as the percentage of recycled content and the types of energy sources utilized. The manager emphasizes that considerable efforts remain to optimize this process, particularly with regard to electronics.

Fundamentally, global category managers serve a support function in eliminating barriers to enable buyers to execute their tasks efficiently. This entails providing guidance on procurement strategies, ensuring compliance with company policies and ethics, and encouraging continuous improvements. Global category managers bear the responsibility for end-to-end deliveries and the total backlog, with the aim of optimizing business value throughout the lifecycle by ensuring data transparency for all stakeholders regarding the deliverables. Consequently, managing stakeholder relationships is another crucial responsibility, involving identifying stakeholders and addressing their needs, concerns, and issues to facilitate informed decision-making. Team managers, on the other hand, concentrate on nurturing the competence and development of each team member. In cooperation with global category managers, team managers strive to cultivate a high-performing team atmosphere.

4.3.1 Sourcing Process

The core of the organization is its R&D function, which significantly impacts decision-making and the company's future trajectory. As a result, R&D is regarded as the project owner, initiating the sourcing process when a need emerges within the department. Needs are communicated to the procurement team in terms of budget allocation and project lead time, which initiates the planning phase of the sourcing process. This encourages cross-functional collaboration, with both parties adhering to a shared schedule. A critical aspect of the sourcing process lies in the product's requirements, as defined in the ESOW, which outlines expectations regarding functionality, material selection, responsibility, and cost distribution. Increasing supplier expertise in PD, design, engineering, testing, and manufacturing is the primary purpose of the ESOW process, thereby supporting global programs and assisting buyers in developing automotive products. In summary, R&D's contribution to the sourcing process includes fulfilling criteria, designing according to cost and budget constraints, and specifying product requirements, while procurement offers advice and ensures that R&D does not become exclusively dependent on a single supplier. However, the ECU examined in this report is an exception, as a specific supplier was strategically chosen, resulting in lock-in effects influencing sustainability which is detailed in Section 4.3.2. This situation arises from the product's complexity and its deviation from traditional build-to-print sourcing, a type of contract manufacturing that involves producing items based on client instructions in a competitive supplier environment. In contrast, for this particular component, the market demonstrated a scarcity of viable suppliers who could offer the desired solution.

In this case, the sourcing process was initiated in conjunction with R&D's development of an advanced ECU solution intended for future vehicle generations. R&D's initial step involved determining the ECU function based on anticipated output, leading to the creation of a product specification containing requirements. The sourcing process is depicted in Figure 11 and commences with the development of a commodity business plan, an extensive strategic document that provides a product overview. Jointly devised by procurement and R&D throughout the sourcing process, this plan comprehensively encompasses the commodity's scope, addressing technical, sustainability, supplier, and strategic dimensions.

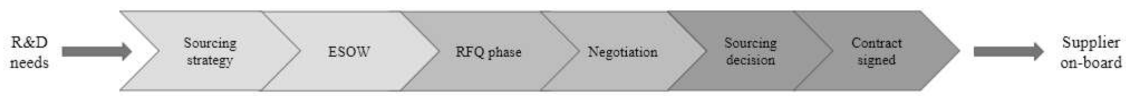

Figure 11*: The sourcing process of the ECU.*

As the ECU is not the company's core business, it was decided to outsource the design and manufacturing to a Tier 1 supplier. R&D participated in the design and testing phases to gather the supplier's input regarding content and to ensure that the ECU accomplishes the company's requirements. From the procurement perspective, a sourcing strategy must be aligned with all involved stakeholders. This particular strategy involved sourcing a black box solution from a Tier 1 supplier, responsible for the complete design development. Consequently, procurement must identify potential candidates capable of developing the solution. Some alternatives include evaluating suppliers with whom the focal company is already collaborating, or searching for new ones. Factors such as the supplier's location, previous operational performance, and sustainability record are considered when seeking potential candidates. Furthermore, a Sustainability Self-Assessment Questionnaire (SAQ) is employed, which has been co-developed with several global automotive OEMs and adheres to the Global Automotive Sustainability Guiding Principles. However, due to the company's strong emphasis on sustainability, the SAQ is considered insufficient, and a bespoke supplier sustainability questionnaire has been developed as a supplement.

After formulating a strategy, it must be submitted for review and endorsement by the global council, which comprises various directors. For extensive business cases or strategic commodities, notification of approval from the head of procurement is also required. Once approved, an RFQ is issued to the selected candidates for the project. During this phase, suppliers must present crucial documents, such as cost analyses, quality performance, sustainability questionnaires, and packaging proposals, while also pledging adherence to the requirements defined in the engineering state of work. In addition, the supplier negotiations process also occurs during the request for quotation phase, with the objective of reaching a mutually beneficial agreement. This stage further facilitates the discussion of sustainability prerequisites. After the nomination of a supplier, the decision necessitates reevaluation by the global council. Providing a rationale for selecting the specific supplier, based on factors such as cost, quality, and sustainability, is of importance.

4.3.2 Sustainability Aspects of Sourcing the ECU

The complexity of ECUs within vehicles has significantly increased compared to earlier models, a trend that a senior manager (P6) predicts will accelerate further with the advent of autonomous driving. This viewpoint is shared by an analysis engineer (P5), who recognizes that as vehicles evolve towards greater intelligence and digitization, the number of electronics is increasing. Thus, there is a need to assess and manage the environmental consequences of electronics as their continuous increase will account for a larger proportion of CO_2-emissions. As per a principal engineer's estimate, electronics account for 16% of the CO_2-footprint of a vehicle, despite constituting 1% of its total weight. It is assessed that the company's newer vehicles contain approximately 15 kg of electronic components, 10 kg of which is referred to as power electronics and the remaining 5 kg as signal electronics. The distinction between power and signal electronics is crucial due to their different contributions to carbon footprints, with signal electronics accounting for approximately six times the carbon footprint of power electronics, as per the company's calculations (P5). Generally, PCBs affiliated with signal electronics typically incorporate a greater number of circuits and systems and are thereby characterized by a higher density of ICs. The majority of emissions are primarily attributed to ICs and the PCB. Moreover, electricity accounts for over 50% of the carbon footprint in electronics, a consequence of energy-intensive production processes and the prevalent energy mix of different regions or countries (P5). Therefore, suppliers are encouraged to utilize renewable energy in their operations and strive towards achieving climate neutrality. A principal engineer argues that roadmaps and ambitions of Tier 2 suppliers regarding renewable energy are vital for influencing the company's carbon footprint.

Unlike the stringent sustainability standards of today, earlier vehicle generations did not prioritize sustainability, leading to various design considerations being overlooked. Presently, initiatives are being taken to correct these past oversights and reduce CO_2-footprints and waste generation. An example highlighted by a cost engineer (P2) is the chip upgrade in newer ECU generations. It has other dimensions, consequently affecting the PCB design, leading to less efficient space utilization and a reduction in the number of units manufactured per batch, thus creating more waste. Furthermore, the process of choosing and replacing ECU components is significantly influenced by the reference design, implying that the company is restricted to the chip supplier's design, limiting the ability to select alternative components with a smaller carbon footprint.

To mitigate these effects, the case company organizes weekly meetings that discuss various sustainability measures and the progress of Tier 1 supplier's sustainability journey, including ways to optimize the PCB to reduce waste and consequently, the carbon footprint. A PCF report provided by the Tier 1 supplier has enriched the sustainability discussion. However, as two analysis engineers and a principal engineer express, sustainability remains a relatively new concept within the electronics industry, which makes it challenging to implement sustainability measures for electronics, especially without a sufficient starting point. Previously, the emphasis within the electronics industry has predominantly been on materials usage and being at the forefront regarding optimization strategies. An analysis engineer affirms that the necessary knowledge already exists, but it must be redirected to prioritize sustainability as a key component of optimization efforts. As a result, it is crucial to evaluate the sustainability reports, roadmaps, and related documentation of various suppliers, to determine whether they conform to industry standards or are taking proactive steps to assume a leadership position. stand out as leaders in the field. A key area of interest in this examination is the supplier's approach to managing Scope 3 emissions, given its considerable influence on the overall environmental impact.

According to an analysis engineer (P3), more electronics-specific requirements have been established that concern varying degrees of climate-neutral energy in the upstream value chain. Should suppliers fail to meet these demanded criteria, they are expected to provide a roadmap detailing how they plan to meet these requirements. This includes how they intend to acquire information concerning the carbon footprint from sub-suppliers. Requirements related to recycled materials content are expected to be included in the ESOW, as per the analysis engineer (P3). These requirements, along with other company sustainability standards, are expected to be communicated to sub-suppliers by the Tier 1 suppliers. As per a category buyer and an analysis engineer, there are plans to collaborate with second-tier suppliers, aiming to enhance the effectiveness of sustainability efforts. An analysis engineer underscores the importance of data collection, suggesting that it outweighs the requirements themselves. They believe that fulfilling the goals is feasible, given that the necessary information is gathered. However, that is the main challenge, which necessitates an in-depth analysis of the supply chain and cooperation with procurement during sourcing. Key information includes where suppliers source from and the locations of their sites to understand the energy mix and estimate the CO_2-footprint. Such data can guide actions. For instance, discussing the possibility of suppliers sourcing from areas with a better energy mix, given the considerable impact of electronics.

On the other hand, some interviewees highlight the challenges associated with being a smaller player with a leading position in sustainability. These include investment in terms of time and resources for educating suppliers and additional costs in exchange for more sustainable products. For instance, many manufacturers within the semiconductor industry struggle to understand how to implement sustainability initiatives in their operations. An analysis engineer states that the automotive sector does not have a significant influence on the electronic industry, representing only approximately 10% of the market share. Thus, the shift towards climate neutrality and reduced carbon emissions is dependent on other market actors. In essence, semiconductor manufacturers align with the trends in consumer electronics and have consequently undertaken numerous modifications towards enhancing sustainability. This progression ultimately serves to the advantage of the automotive industry.

5. Empirical Findings

This section provides a comprehensive examination of the themes that have been identified: green sourcing strategies, procurement and supplier involvement in product development, and top management support. Initially, the approach to various green sourcing strategies, which are divided into monitoring and collaboration, will be described. Subsequently, the details of the ECU product development process are presented, shedding light on the extent of involvement of procurement and Tier 1 suppliers. Finally, the last theme elucidates the degree of support provided by upper management in facilitating cross-functional collaboration and achieving sustainability objectives. The nature of integration between the procurement and R&D functions is also accounted for.

5.1 Green Sourcing Strategies

A sustainability manager states that the company goal is to put sustainability on par with cost and quality, however, that is not always the case. For instance, sustainability cannot be prioritized if there is a trade-off in quality. When asked how procurement and R&D employees work with sustainability, the answers differed. It is an individual responsibility, resulting in some working with it more than others. A recurring problem seems to be as per a supplier & partner manager "*...there are probably 1000 people talking about sustainability and out of the 1000 there are probably 10 that are working very detailed with it*". However, there are several identified green sourcing strategies, both of monitoring and collaboration characteristics, which the focal company frequently utilizes. These are further presented in the forthcoming sections.

5.1.1 Monitoring Strategies

Table 6 demonstrates the prevalent green sourcing monitoring strategies that the focal company utilizes. One of these strategies is the implementation of sustainability requirements, which pertain either to the site and corporate level or the product and material level. As previously indicated, R&D is accountable for the latter category, and these requirements are to be incorporated into the ESOW and subsequently adhered to by the supplier. According to an analysis engineer, these requirements are generally broad in scope and are not explicitly tailored to individual products. These requirements primarily concern recycled material content, with the anticipation that new electronics-specific requirements will soon be incorporated into the ESOW. A supplier & partner manager believes that "*If you are after sustainability, the key thing is to bring it in as a requirement*", indicating that in order to achieve sustainability goals, the requirements must be included in the ESOW. While R&D formulates these requirements, procurement is often engaged in supplier dialogues due to its role and responsibility in ensuring supplier compliance with the ESOW. Therefore, the procurement department must stay informed of the requirements to effectively participate in supplier discussions and seek support from R&D when required. A hardware engineer affirms that sustainability is a topic addressed in discussions with procurement, thereby driving supplier conversations. These requirements can significantly influence supplier selection, as well as dictate the choice of materials, components, and design considerations for R&D. At the corporate and site levels, the procurement department bears the responsibility of ensuring adherence to sustainability requirements. These requirements encompass aspects such as renewable energy usage, waste elimination, approved smelters, conflict-free sites for conflict minerals. Moreover, the requirements are included in the company's two separate supplier environmental questionnaires.

Table 6*: Summary of employed green sourcing monitoring strategies.*

Tools	Reference
Sustainability requirements	R1, R2, R4, R5, R7, R10, R15, R16, R18
Supplier environmental questionnaires	R1, R2, R9, R12
Supplier auditing	R1, R2, R20
Environmental management systems	R1, R9, R12
Investigating roadmaps	R1, R2, R4, R5, R6, R7, R11, R12, R13

To monitor suppliers' sustainability practices, there are two different questionnaires that suppliers can respond to. One of these questionnaires is the Supplier Assessment Questionnaire (SAQ), which suppliers complete online independently. This questionnaire, developed in collaboration with other automotive manufacturers, addresses areas related to working conditions, human rights, health and safety, the environment, business ethics, supplier management, and responsible sourcing of raw materials. The procurement department utilizes the responses to this questionnaire, stored in a system database, to evaluate suppliers. A sustainability manager remarks, "*The SAQ contains general questions. The issue with it is that they are not climate-neutral. So, our sustainability questionnaire was created to direct it towards the company's sustainability goals, to gather and capture data.*" [Translated]. Consequently, since the information from the SAQ is considered insufficient, the company has developed its supplementary questionnaire with more company-specific questions tailored to sustainability goals, which is sent to suppliers for completion and is mandatory in the sourcing process.

Two category buyers explain that prior to the establishment of a supplier partnership, the company conducts supplier audits. These audits are executed by the company's quality engineers, who examine the supplier based on a variety of factors, including sustainability. The engineers must approve the supplier's conditions before any further steps can be taken. Operating its own environmental management system, the company also holds certifications according to various directives. Moreover, it is a member of several organizations such as the Responsible Business Alliance. Thus, the company requires its suppliers to be ISO 14001 certified, among other qualifications, and to have a plan on how to achieve their environmental goals and how to enhance their sustainability.

The case company also analyzes suppliers' sustainability roadmaps to ensure that their goals align with the company's long-term objectives. This activity serves dual purposes - determining prospective partnership alignments and observing the sustainable initiatives and goal timelines of suppliers. Meetings are often arranged to discuss suppliers' roadmaps, their ambitions, and what can be done to achieve them sooner. Adopting a proactive stance, the company's sustainability center reviews the renewable energy roadmaps of various semiconductor manufacturers, an area identified as a significant hotspot (P1). To aid employees in their supplier selection process, the company has constructed a map of prominent suppliers within the semiconductor industry, particularly focusing on those with a stronger commitment to sustainability and more ambitious targets. An analysis engineer highlights that the mapping assists in visualizing the influence of the sourcing location for semiconductors on the CO_2-footprint, due to the regional energy mix variations (P1). Additionally, the importance of assessing sustainability roadmaps is amplified in situations where a deviation is required to select a supplier. The company aims to ensure that such suppliers, although not meeting sustainability requirements at present, have a defined sustainability roadmap. As expressed by a category buyer: "*An action plan and roadmap are required when there is a deviation in sustainability*." [Translated].

5.1.2 Collaboration Strategies

Since the ECU sourcing started about 5 years ago, the company's sustainability requirements have changed. As stated by a category buyer and a global category manager, there were initially no specific sustainability requirements for the ECU, but new requirements have been added over time. This led to the case company becoming involved in aiding the Tier 1 supplier's initiatives to implement these requirements, necessitating the application of various collaborative strategies detailed in Table 7.

Being recognized for its leading position in sustainability, which is confirmed by the Tier 1 supplier, the focal company often assumes an educational role in which they teach and support suppliers towards enhanced sustainability. A category buyer states: "*We try to convince suppliers and respect countries on how far they have come in sustainability and educate them*." [Translated]. The case company typically shares its sustainability objectives with suppliers and frequently teaches suppliers how to accelerate the achievement of their goals, as a global supplier owner has commented. As pointed out in a semiconductor manufacturer's presentation on their sustainability efforts (P4), it was evident that the case company exhibited superior knowledge in this area, guiding the supplier on certain questions they had. However, representatives from the semiconductor company expressed an eagerness to receive feedback and understand their ranking, whether they are at the forefront or lagging behind according to the focal company's judgment. They consider these insights as internal motivation for enhancing their sustainability efforts. Fundamentally, there often exists a disparity between the objectives of the case company and various electronics suppliers. To address this, the case company aims for a mutually beneficial discussion, wherein the supplier offers counter-proposals on more feasible goals, potential adjustments to suit their situation, realistic timelines, and so on.

Another method of communicating and educating suppliers on sustainability topics involves having collective discussions on product analyses. An analysis engineer points out that after identifying hotspots, they liaise with the supplier to explore potential mitigation strategies This promotes a shared understanding of manufacturing processes, which subsequently aids in the achievement of sustainability goals, as noted by a business owner.

***Table** 7: Summary of employed green sourcing collaboration strategies.*

Tools	Reference
LCA/PCF analysis	R1, R2, R4, R5, R6, R12, R16, R18, R20
Educating suppliers regarding sustainability	R1, R4, R8, R11, R12, R16

In relation to collaborative strategies, the company is attempting to broaden its application of LCA, where the objective is to collect extensive LCA data from Tier 1 suppliers. As one category buyer suggests, the responsibility to procure an LCA from the supplier falls within the responsibility of procurement, given their role as the primary point of contact. However, the introduction and utilization of LCAs represent a new approach within the organization. Another category buyer disclosed that the company recently embarked on the implementation of LCAs at the component level, a deviation from their previous focus on entire vehicles. Consequently, they now demand that all suppliers conduct an LCA on the product they tender, enabling the comparison of different products and the evaluation of sustainability performance through cost engineer calculations. LCAs also reveal hotspots which can be leveraged to pinpoint potential areas for future improvements, where suppliers can be encouraged to incorporate measures to reduce their environmental impact.

An analysis engineer states: "*LCA is used to take measures to reduce CO_2-emissions and serves as a negotiation tool and educational instrument.*" [Translated]. The engineer also suggests that LCAs can be deployed to monitor outstanding hotspots for further investigation in the supply chain. This is a method to achieve the Scope 3 targets. Another analysis engineer asserts that such findings can be communicated to suppliers, emphasizing the importance of close dialogue and knowledge sharing regarding component sourcing and the potential benefits of sourcing from countries with e.g. access to renewable energy. That is to align with the company's sustainability objectives.

Internally, LCAs are utilized by the sustainability center to determine requirements for components and materials. According to a system architect, "*New sustainability requirements for electronics were established based on LCA analysis. The results and analysis have been communicated to both procurement and R&D to avoid misunderstandings.*" [Translated]. Conversely, there are certain challenges associated with LCAs for electronics. As per an analysis engineer, obtaining LCAs from all suppliers proves challenging as they may not consider it a priority and the creation of LCA is time-consuming, confirmed by a category buyer. The global category manager states: "*The idea is that you should conduct an LCA before you source. We have not reached that point yet and it is incredibly difficult…, since you do not source the finished product on a sourcing occasion.*" [Translated]. An analysis engineer adds that most products containing electronics are "black boxes", making it difficult to identify the constituent electronics due to the multitude of components and actors involved. They also note that hotspots for electronics typically reside further upstream in the value chain. Accordingly, the global supplier owner advocates for a shift from "black boxes" to a more transparent understanding of their ECUs to gain greater control. Therefore, a concurrent challenge when attempting to obtain LCAs earlier, preferably before sourcing, is the necessity to oversee the Bill of Materials (BOM), as highlighted by the global category manager and analysis engineer. This information is crucial to identify the constituent components and to perform an LCA. The challenge of obtaining transparent BOM lists, as emphasized by the global supplier owner, a category buyer and a product owner, is often due to confidentiality reasons. Given the existing difficulty in securing finalized BOM lists, obtaining preliminary BOMs several years before a vehicle is produced, as suggested by an analysis engineer for proactive carbon footprint management, may present even greater challenges.

5.2 Procurement and Supplier Involvement in Product Development

The case company maintains a strong and close relationship with the Tier 1 supplier, a sentiment also confirmed by the representatives of the supplier. Both the procurement team and the Tier 1 supplier have been involved at an early stage of the product development process due to the complexity of the ECU. A representative from the supplier acknowledges that there have been frequent in-depth discussions on various topics, primarily attributed to the ECU being a "cutting edge" product. They further state: "*If you take another example, a simpler ECU which we use in older cars, the developing process is not like that. It is quite different*". Table 8 shows the nature of the interactions during the PD process.

Table 8*: Different degrees of procurement and supplier involvement in product development.*

Degree of involvement	Reference
Close collaboration with Tier 1	R1, R4, R15, R18, R21, R22
Early supplier involvement	R1, R2, R20, R21, R22
Continuous procurement involvement in product development	R1, R2, R8, R20
Regular discussion with Tier 2	R8, R10, R18, R20, R21, R22

The procurement department was engaged at an early stage in the product development of the ECU, as indicated by a category buyer. Collaboration between R&D and the procurement team has been essential to establishing a mutual understanding of the product and the sourcing process. During the sourcing phase, discussions were held between R&D, the Tier 1 supplier and procurement to determine costs, detailed materials, and functionality. Eventual changes in the ECU may also result in alterations in the BOM which affect the cost, supplier selection for electronic components, and sustainability considerations. This, in turn, affects procurement as they are responsible for the cost and the signing of ESOW by the Tier 1 supplier and R&D.

The ECU chip selection was made before contracting the Tier 1 supplier. Subsequently, the case company considered suppliers experienced in working with the Tier 2 supplier's chips. According to a category buyer, the selection of the ECU supplier was primarily based on their design and manufacturing capabilities, especially as it is a complex component. Experience in providing similar solutions to other automotive OEMs was considered as well. Moreover, an existing agreement between the Tier 1 supplier and the Tier 2 chip supplier was acknowledged. Another important factor, as highlighted by the category buyer, was that "... *the supplier agreed to have a fully transparent BOM, which is important when it comes to engineering and also commercially*". This transparency was deemed important both from an engineering and commercial standpoint. However, at that time, the sustainability aspect of the BOM was not taken into consideration. Subsequently, the availability of a transparent BOM facilitated the sustainability center in modeling an LCA to validate the LCA conducted by the Tier 1 supplier. Transparency and openness have enabled improved communication regarding sustainability, material selection, and identifying areas of concern, as the supplier had conducted the LCA themselves and were aware of the hotspots.

According to a category buyer, the supplier involvement started early in the PD, "*Tier 1 started to be involved in the RFQ around the same time as it was decided to use the chip, so yes there is early supplier involvement*". It is characterized as early supplier involvement since the Tier 1 supplier was engaged in the sourcing process for the ECU before the case company had a complete specification. The Tier 1 supplier representatives conclude that the design specification and concept design provided by the case company were elaborated upon in detail. By adhering to the chip manufacturer's reference design, the resulting product encompasses predetermined components. According to the representatives, several components are single-sourced, which implies that they are not interchangeable. This, to some extent, explains why the case company maintains direct contact with the Tier 2 chip supplier from both the procurement and R&D sides. A product owner mentions that they organize three-way meetings involving the case company, Tier 1, and Tier 2 suppliers, to discuss potential changes that could impact the reference design, thereby necessitating validation from the Tier 2 supplier.

Another indication of the close collaboration with the Tier 1 supplier is their active engagement in sustainability discussions and their implementation of the focal company's requirements. The Tier 1 supplier representatives state that they do not have specific sustainability requirements but rather align with the customer's established criteria. Their perception of the case company is that they are leading within the sustainability field, with clear sustainability criteria. They further recognize the focal company's extensive knowledge of sustainability, noting that it was an early adopter of such practices. Tier 1, being unaccustomed to such relationships, relies on the case company's guidance through the process. Consequently, they are being steered on how to achieve the company's sustainability targets. The representatives appreciate the presence of a partner that can instruct and guide them in this respect, saving them considerable time and resources by preventing the need to conduct the research themselves. A representative praises the case company, stating: "*They are doing a good job to show how we can achieve the goal*".

5.3 Top Management Support

Overall, top management is deemed to treat sustainability issues with considerable priority and seriousness. The company is perceived as having ambitious goals and a strong desire for progress; however, the prioritization and breakdown of goals differ among departments. Consequently, there is ambiguity regarding the distribution of responsibilities, i.e., who is accountable for what goal. Another prevalent perception is that sustainability frequently becomes a secondary concern, as the case company is fundamentally a manufacturing organization, its primary focus will lie in vehicle production.

Regarding the cross-functional collaboration between procurement and R&D, historically, it has presented numerous challenges, particularly due to an individual responsibility to maintain a continuous and close dialogue. A prevalent issue arises from the perception of these departments as separate components within the same organization, instead of viewing themselves as integral parts of a collective entity. Moreover, a considerable consensus points to the necessity of dedicating substantial time and effort in order to cultivate relationships and facilitate efficient information exchange.

5.3.1 Top Management Support for Sustainability Efforts

Similar to the individual responsibility for sustainability initiatives among employees, a similar pattern is distinguishable among top managers, meaning that their motivation and interest in these issues dictate the degree of prioritization. A global category manager states: "*It varies from team to team what the managers are talking about and prioritizing*" [Translated]. This is related to unclear and divergent goals, as well as ambiguous distribution of responsibility, due to the absence of a unified set of goals. A category buyer's statement aligns with this, stressing that prioritization depends on the individual, and if they lack concern, sustainability will not be included in their agenda. Furthermore, a team manager expressed that: "*A lot regarding sustainability is individual. People have different interests…*" [Translated]. The team manager adds, "*The more curious the management is, the more they can influence the rest of the organization*" [Translated]. This poses certain challenges in how employees perceive top management's support for sustainability initiatives in their professional roles. These challenges are depicted in Table 9 below.

Table 9*: Perception of top management support for sustainability initiatives.*

Challenge	**Reference**
Sustainability tends to be deprioritized	R1. R9, R11. R14, R16, R17, R18
Unclear and uncoordinated goals	R1, R9, R11, R12, R15, R16, R19
Unclear distribution of responsibilities	R1, R10, R12, R15
Lack of resources	R10, R12, R14, R16, R18, R19

The four challenges presented in the table are closely interrelated and dependent upon one another. As described, some individuals perceive that securing production is of primary importance, consequently relegating sustainability to a lower priority. A sustainability manager notes: "*They [top management] are keen to work on sustainability, but they have other goals to consider…*" [Translated], which, according to the manager, makes it difficult to find a balance to fulfill all goals while ensuring that the factory continues to operate. One category buyer contends that if the development of technology is consistently deemed most important, sustainability could be overlooked. The buyer also states that:

> *If you look at purchasing, buyers are employed to do many different tasks and sometimes there are other things that are more important than sustainability. If you look at R&D, they are employed to develop a technology and so sustainability is not at the top of the list, rather at the bottom.*

Despite having clear corporate-level objectives, departmental goals are perceived as ambiguous. The breakdown of these goals is seen to be inconsistent. As per a global supplier owner, respective teams dedicate their efforts to achieving departmental-specific goals rather than pursuing aligned common goals that benefit the company as a whole. A top manager asserts that clarity is lacking in defining and interpreting the goals, stating: "*One can always question if we are focusing on the right things and whether there are other aspects that could have a larger impact*" [Translated].

Unclear goals also result in unclear responsibility distribution, leading to confusion about who is accountable for what. According to the sustainability manager and analysis engineer, R&D should be responsible for material and product requirements, whereas procurement should bear the responsibility at the site and corporate level, ensuring compliance from suppliers. However, this theory does not always translate into practice. For instance, it has been observed that R&D and the procurement department for software and electronics have differing views on the responsibility distribution for certain sustainability requirements. Based on the responses from some R&D employees, there seems to be a tendency for sustainability issues to be delegated to procurement, which is then tasked with addressing these with suppliers, often even when they apply to material and product-related questions that are part of the ESOW.

Moreover, there is a perception that procurement alone is responsible for sustainability tasks. This perception, as suggested by a category buyer, may stem from the historical context in which procurement has been subjected to more sustainability requirements and cannot finalize a sourcing task without declaring sustainability. Consequently, the awareness of buyers regarding these issues is automatically increased, thereby causing R&D to rely on them. Additional R&D feedback indicates that certain R&D teams are understaffed, thus restricting their capacity to address sustainability issues. For instance, a hardware engineer declares: "*Our management's assessment is that we lack the time to pursue these [sustainability] issues*" [Translated]. Therefore, it escalates into a resource-related concern as a category buyer points out, "*If we do not have the right conditions to do the job, it does not matter what goals we set, because if procurement is not working on it, who will?*" [Translated].

The common understanding is that the company has ambitious aspirations, but fails to recognize that there is a limited pool of individuals capable of executing the tasks. A procurement director comments: "*The goals are unclear, so it becomes challenging for me to say what resources are required.*" [Translated]. This lack of clarity results in a skewed view of the necessary resources, such as time, personnel, and expertise. The top manager explains: "*It is my responsibility to evaluate the resources I have and determine what we can deliver. I must be clear about the 80 tasks out of 100 that I can execute, and of the remaining 20, some may impact sustainability*" [Translated], which could contribute to the deprioritization mentioned earlier. Meanwhile, the global category manager maintains that their department has been allocated the necessary resources for success, as they have justified to the top management the resources required to deliver results and fulfill objectives. A category buyer argues that it is rather a matter of optimizing existing resources, implying that there might be overlapping responsibilities within R&D. A reallocation of tasks is suggested, with a particular emphasis on dedicating someone to manage sustainability issues. However, when it comes to integrating new sustainability requirements into the ESOW, the situation might be different. The buyer notes, "*...we are in a phase where we would have a launch phase for the initial projects that has not quite happened yet, and this results in resources not being released from the first project*" [Translated].

Some individuals express a perceived lack of support due to limited resources to manage all goals or a sense of inadequate knowledge of the topic, leading to a need for guidance. According to a category buyer, increased informational sessions are required, so individuals know who to consult when necessary. The hardware engineer, global supplier owner, and several category buyers have mentioned the need for more expertise and training in sustainability within teams to enable them to independently solve these issues. In line with this, a team manager states: "*... we do not have enough competence and resources on the R&D side. We would need to educate people more by showing how dire the environmental situation is*." [Translated].

On the other hand, various managers report that they attempt to support and encourage their employees to address sustainability issues through different approaches. For example, the top manager requires that potential sourcing must comply with the company's sustainability standards to gain approval. Meanwhile, the global category manager and procurement director provide a supportive role if their teams seek advice or help, acknowledging that employees already show considerable initiative regarding sustainability. Nevertheless, the procurement director expresses a desire for a more tangible comparison between two products during the sourcing process to facilitate sustainability considerations and discuss possible solutions. A product owner contends that the solution lies in effective collaboration and proper monitoring, ensuring compliance with requirements through cross-functional meetings, discussions, and follow-ups. The product owner states: "*It is the continuous improvement of the way of working and the collaboration, to look back to the previous period and see what lessons can be learned.*"

5.3.2 Top Management Support for Cross-functional Collaboration

An initiative exists, advocated by the company's management, that promotes cross-functional collaboration among various departments. This initiative accentuates the organization's commitment to sustainability, which necessitates the incorporation of new dimensions into the decision-making process, i.e., dimensions that may not have been as highly prioritized in previous instances of cross-functional collaboration. However, the procurement director argues that the initiative may be somewhat challenging to decipher in terms of what is truly being solicited.

How departments operate can fluctuate, based on a multitude of factors such as the topic under consideration, the project's phase, and the degree of individual accountability. Table 10 summarizes the employee's perspectives on the challenges associated with cross-functional collaboration between R&D and procurement departments. As presented by the global supplier owner, the extent of engagement in communication is largely a matter of personal responsibility, which might originate from a perceived lack of reception from R&D, thereby disincentivizing buyers from engaging and communicating with them. One of the recurring approaches towards collaboration has been that "*there is no time to consider it if you have problems today*" as per a category buyer.

Table 10: *Perception of top management support for cross-functional collaboration.*

Challenge	**Reference**
Level of effort is individual	R1, R12
Generally problematic communication between R&D and purchasing	R1, R2, R12, R17
Limited interdepartmental relationship-building	R1, R12, R14, R19

There is a prevailing sentiment that the communication between procurement and R&D is not optimal, with historical evidence suggesting less than satisfactory interdepartmental relationships. According to a global supplier owner, individuals operate within their respective teams with a primary focus on their specific goals. Apart from the lack of coordination in departmental goals, this leads to a mentality of fragmentation rather than unity towards shared corporate goals. Communication is a subjective matter, states the supplier owner, which can have different significance to different individuals. The procurement director further suggests that "*the perception between R&D and procurement can vary, and what is really requested is often unclear*." [Translated]. A global category manager indicates that the communication tends to be unstructured, while a category buyer highlights the lack of mutual support as a significant issue. Consequently, the global supplier owner advocates for improvements in internal relationships and stresses the importance of interpersonal relationship-building as a means to earn trust.

Given the occasionally complex relationship between procurement and R&D, many interviewees emphasize the significance of relationship-building, mutual understanding, and trust. The procurement director contends that reciprocal respect and understanding of each other's roles are essential, necessitating regular meetings and discussions and shared objectives. Similar notions are discussed by the global supplier owner, that there is a need for consistent engagement with internal stakeholders to foster a symbiotic relationship; "... *sitting with R&D, hanging out with them, knowing their kids' names, what they did over the weekend. That is what builds a relationship, so when you later call them and need something, they are there.*" [Translated]. A snowball effect will occur from activities that enhance communication, according to the top managers' beliefs. The approach to communication needs to be modified, by being inquisitive and curious, i.e., shifting towards how value can be collectively created, as noted by a global supplier owner. They further recommend that successful instances where the relationship between R&D and procurement is functioning efficiently should serve as examples for establishing well-functioning interdepartmental relations.

6. Discussion

As outlined in the theoretical section, the integration of procurement in R&D significantly facilitates supplier involvement in product development processes, a viewpoint supported by Lakemond et al. (2001) and Schiele et al. (2021). This aspect has also been observed through the conducted interviews, particularly concerning the ECU. The successful acquisition of such a product, which carries significant strategic value, requires integration between procurement and R&D. Based on the empirical evidence, there has been cooperation between the company's procurement and R&D departments, a necessary step for enabling supplier participation. However, there is a consensus among respondents that there is a need for improvement in terms of the efficacy of internal cross-functional collaboration and the distribution of responsibilities. Contrary, this collaboration has been essential owing to the complexity of the ECU and its status as an emergent technology. The company aspired to modify certain features, necessitating both internal and external input on their implementation. As the ECU functionalities are based on a specific chip, it leads to a reference design that constrains component selection and product design. Essentially, the use of a reference design, alongside the novelty and intricacy of the area, has led to a knowledge deficit, hindering comprehensive and long-term planning in all stages. For example, future upgrades of the chip and their impact on the PCB and surrounding elements, or the environmental impact of the ECU and its components, were not adequately taken into account. Early initiation of sustainability discussions during chip sourcing could have mitigated this. Yet, findings indicate that such dialogues were only recently introduced, largely due to the perceived power and influence of the chip supplier. Hence, this project provides learning opportunities, primarily the incorporation of proactive thinking, which can be leveraged for future sourcing success.

Given the aforementioned challenges, this section will draw comparisons between findings from the semi-structured interviews and the theoretical frame of reference. The aim is to discuss the employment of various green sourcing strategies and the cross-functional collaboration between procurement and R&D, focusing on possible improvements and the top management action towards these strategies. These themes overlap and have dependencies (see Figure 12), hence underscoring the need for effective cross-functional collaboration and well-defined sustainability goals supported by top management. Furthermore, the discussion will consider how the results of the PCF analysis can be incorporated into the sourcing process to reduce the carbon footprint.

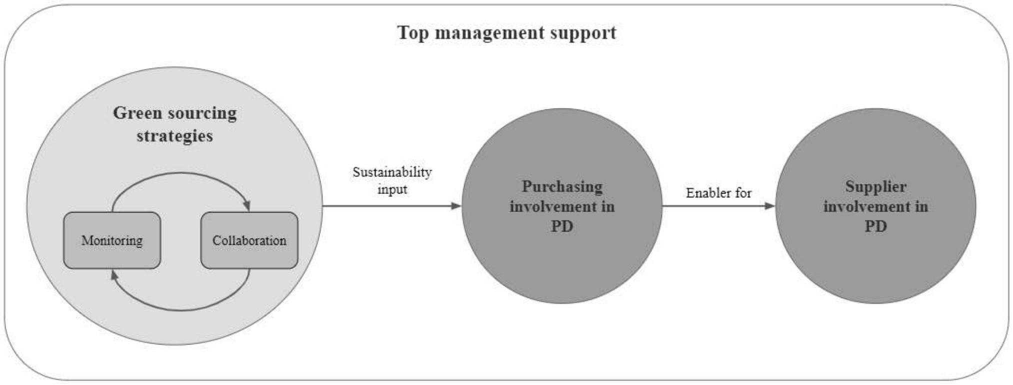

Figure 12: *Illustration of the connections between the identified themes.*

6.1 Green Sourcing Strategies

There exist both drivers and barriers to the adoption of green sourcing strategies. An internal driver that has been identified is the desire to enhance the organization's environmental performance. Among the external incentives are the expectations of customers and the need to maintain a competitive edge (Walker et al., 2008). Conversely, numerous barriers impede the firm's effective utilization of green sourcing strategies, including limited knowledge among employees (Adham & Siwar, 2012; Buniamin et al., 2016), insufficient resources and cross-functional collaboration (Bowen et al., 2001), varying degrees of top management support (Blome et al., 2014; Salam, 2008), as well as disparate characteristics between the automotive and electronics sectors (Zhu & Sarkis, 2006).

To address RQ1, a comparative analysis was conducted, incorporating findings from the semi-structured interviews and prevailing literature on green sourcing collaboration strategies. However, since the monitoring and collaboration strategies are related, the monitoring strategies will also be discussed. Thus, this chapter begins with an analysis of the monitoring strategies deployed by the focal company, which have a reactive character. Subsequently, the discussion advances to proactive collaboration strategies, encompassing LCA/PCF.

6.1.1 Monitoring Strategies

Due to the initial absence of specific sustainability requirements for the ECU, the identified green sourcing strategies have been retrospectively employed to reduce CO_2-footprint. These measures involve consistently incorporating sustainability prerequisites in the ESOW and the eventual inclusion of electronics-focused requirements. This strategy aligns with product content requirements as explained by Tachizawa et al. (2015). Further, the company employs monitoring strategies as described in the empirical data, such as supplier compliance audits and requirements for environmental management systems, aligning with the framework outlined by Tachizawa et al. (2015). Moreover, environmental questionnaires (Lloyd, 1994; Lamming & Hampson 1996; Tachizawa et al., 2015), of which the company utilizes two variants, serve as pre-sourcing supplier evaluation tools. However, certain company personnel express that these questionnaires may not be entirely appropriate for electronic suppliers. They suggest that more electronics-related questions or a separate questionnaire specifically tailored for electronic manufacturers might be more suitable. Nevertheless, this would require the existence of electronics-specific organizational requirements to formulate relevant questions for these questionnaires.

The evaluation of roadmaps appears to be an essential tool for the company, particularly since the electronics industry is not at the forefront of sustainability. This aligns with the findings of Sukitsch et al. (2015), indicating variability among OEMs, with some leading and others lagging in their response to sustainability issues. Cherel-Bonnemaison et al. (2021) indicate that roadmaps are used to pinpoint suppliers that conform to the company's sustainability ambitions, encompassing both short and long-term objectives (Sukitsch et al., 2015), which reflects the case company's practice. This methodology facilitates the selection of suppliers with favorable footprints or innovative technologies that contribute to meeting sustainability objectives. The company's sustainability center has started evaluating semiconductor companies' renewable energy roadmaps, which is beneficial as logic ICs pose a hotspot in the ECU. However, the full potential cannot be realized until the case company establishes which components, or more specifically semiconductors, can be substituted in the reference design. Upon this discovery, the company can optimally utilize the mapping and potentially switch to more advantageous suppliers. Meanwhile, they acquire knowledge about the sustainability perspectives of different suppliers. They can then exploit this information, particularly pertaining to the semiconductor suppliers of the ECU, to initiate direct contact, thus enabling sustainability discussions to enhance overall sustainability.

6.1.2 Collaboration Strategies

One of the company's key collaboration strategies involves obtaining LCA data from its first-tier suppliers, to identify and address environmental hotspots. This approach aligns with the findings of Pelton and Smith (2015), who propose that hotspot analysis effectively informs purchasers of their sustainability selection criteria. Aligning with the product stewardship concept highlighted by Tachizawa et al. (2015), this LCA utilization aids in reducing the environmental impact of the ECU during the manufacturing and final assembly stages. However, there is a notable misalignment since the ECU's PCF does not cover all life cycle stages, suggesting a misalignment from the comprehensive LCA utilization proposed by Tachizawa et al. (2015).

Agarwal et al. (2021) maintain that LCAs can enhance procurement, as their results can facilitate assessments of which suppliers or products are most likely to fulfill sustainability goals, and which manufacturing site to source from to minimize environmental impact. The company actively implements this strategy, especially regarding sourcing locations based on renewable energy use. According to Fredershausen et al. (2022), a long-term approach to sourcing decisions involves the decarbonization of suppliers' energy use through the adoption of renewable energy sources. Nevertheless, the company prioritizes this area, not just for its beneficial impact but also for the ease of measuring renewable energy, as indicated by a global category manager and an analysis engineer. From the company's perspective, its ambition to decarbonize the upstream supply chain may be considered a long-term strategy. Statements from a category buyer and an analysis engineer indicate a shift towards a focus on Tier 2 suppliers and climate-neutral energy in the upstream value chain. This aligns with the insights provided by Sarkis & Dou (2017, Chapter 3) and Schneider & Wallenburg (2012), who suggest that procurement acts as a catalyst in "greening" the supply chain by extending management to include sub-suppliers and multiple tiers.

Since the ECU is a tailored product and not an off-the-shelf solution, it is difficult to obtain an LCA before establishing sourcing and specifications. This challenge has constrained the company's capacity to work proactively with LCA results. However, since an LCA already exists, and new ECU generations do not substantially differ, according to a product owner and the Tier 1 supplier, it may be utilized to adjust certain parameters to estimate CO_2-emissions. This can then be employed for preliminary BOM/LCA, to enable the prediction of CO_2-footprint and plan mitigation strategies in advance. Agarwal et al. (2021) suggest that an LCA can serve as a tool for sustainable design decisions. Thus, R&D can examine components that constitute a hotspot to implement potential modifications in design, renewable materials usage, and the number of components. This approach corresponds with the theory presented by Awan et al. (2019), who advocate for innovative thinking to be oriented within the context of environmental innovation. For buyers, hotspot analysis serves as a mechanism facilitating meaningful dialogue between them and Tier 1 suppliers, intending to encourage the latter towards the adoption of more environmentally sustainable product development strategies, aligning with the theoretical findings (Pelton and Smith, 2015).

Transparency from Tier 1 suppliers is crucial for performing an LCA and for validating it, according to two analysis engineers from the company. Achieving transparency and obtaining BOM lists and LCAs necessitates relationship-building and a mutual understanding of the goals to be achieved, hence the importance of supplier engagement (Awan et al., 2019; Walker et al., 2008). Green supplier development, a strategy defined by Sarkis & Dou (2017, Chapter 4), is a collaborative partnership that effectively improves supplier sustainability behavior (Hamner, 2006; Charter et al., 2001). In this case, green supplier development could involve educating suppliers on environmental issues. Given the company's ambitious goals and leading market position in sustainability, the company often possesses more knowledge than its suppliers, leading to an educative role, confirmed by both Tier 1 representatives and company employees. The educational process usually centers around convincing suppliers of the significance of sustainable practices and the inherent benefits, which subsequently enhances their environmental competencies. The methodology adopted by the company is following the proposition set forth by Sarkis & Dou (2017, Chapter 3).

Educating suppliers regarding sustainability has led to some joint development initiatives for cleaner production, following one of the collaboration strategies suggested by Tachizawa et al. (2015). A focus has been placed on waste management, an example being the impact of the upgraded chip on the design of the PCB, which has led to more scrap and impacted production efficiency. Reworking components to see which can be repurposed to save costs and reduce waste has also been explored, according to a category buyer and cost engineer.

There is a connection between the collaborative strategy of LCA and the monitoring strategy of supplier environmental questionnaires. As per Pelton and Smith (2015), the results of hotspot analysis can form the basis for supplier questionnaires and dialogues between buyers and suppliers about sustainability improvements. PCF results have led to weekly sustainability meetings with the ECU Tier 1 supplier in the focal company's case. According to Tier 1 representatives, they are already aware that logic ICs are a hotspot based on their own LCA. Therefore, they chose to send out the company questionnaire to the semiconductor vendors supplying the ECU, to understand the reasons behind the high CO_2-emissions and to investigate what measures can be taken before they start mass production. Moreover, they aim to base the next report on mass production to yield better figures, i.e., they want to improve their sustainability performance. This is a way, for both the focal company and Tier 1 supplier, to address their Scope 3 emissions, as it is a form of monitoring and supplier collaboration (Spiller, 2021). They target the activities of the upstream value chain, where a considerable part of emissions originate (Huang, 2009; Spiller, 2021). Moreover, Huang (2009) argues that the acquisition of emissions data from a direct supplier also plays a vital role in reducing the upstream carbon footprint. Hence, the data transparency between the company and Tier 1 supplier has significant potential in achieving the company's goal to reduce supply chain emissions per car by 25%, which pertains to Scope 3.

As the company predominantly employs monitoring strategies, its green sourcing strategy seems to be more reactive than proactive, according to Sarkis & Dou (2017, Chapter 3). This might suggest a need for the company to implement more collaborative strategies or to prioritize them. Alternatively, it could be an indication to further develop the existing monitoring strategies as they form the foundation for collaboration strategies. On the other hand, collaborative strategies demand more extensive participation and effort. A long-term strategic relationship is necessary, with the supplier being involved in the early stages (Sarkis & Dou, 2017, Chapter 3; Fredershausen et al., 2022). Cross-functional alignment among different management levels and functions is also a prerequisite (Sarkis & Dou, 2017, Chapter 3). These factors will be further discussed in detail in the following section.

6.2 Procurement and Supplier Involvement in Product Development

As previously emphasized, procurement must engage in PD to enable supplier involvement (Lakemond et al., 2001; Schiele et al., 2021). Two determining factors facilitate this purchasing involvement: the organizational culture fostering cross-functional collaboration (Lakemond et al., 2001; Schiele et al., 2021; Van Weele & Rozemeijer, 2022) and the presence of requisite competencies (Lakemond et al., 2001; Nijssen, 2002). Communication gaps, however, have been identified between procurement and R&D, despite the company's practices and interviews showing a close relationship between these departments. Uncertainty about responsibility distribution and support channels is a concern among employees. A global category manager points out the lack of clear structures for communication, despite the explicit initiative advocating for cross-functional collaboration between procurement and R&D. This indicates that there is a gap between the initiative and its implementation, suggesting room for improvement, particularly concerning individual accountability and, according to Van Weele and Rozemeijer (2022), in terms of close collaboration with all relevant disciplines and top management. These factors are linked to management support, i.e., to what extent cross-functional integration is encouraged, which is elaborated on in Section 6.3.

The connection between the company's procurement department for software and electronics and its R&D counterpart facilitated supplier involvement in PD. R&D communicates independently with the Tier 1 supplier concerning product technicalities, consistent with the literature (Van Weele and Rozemeijer, 2022). This highlights R&D's vital role in supplier communication, particularly in defining specifications given their knowledge of supplier markets (Lakemond et al., 2001). Emphasis on cross-functional integration is persistent, as several papers (Van Weele and Rozemeijer, 2022; Brandmeier and Rupp, 2010; Schneider and Wallenburg, 2012) validate the necessity of incorporating inputs from diverse departments prior to making procurement decisions, to ensure sustainability elements are considered. This is closely connected with green sourcing strategies, demanding alignment across functional boundaries, both internally and externally, for the effective deployment of collaborative strategies. However, it necessitates the establishment of well-defined roles and a transparent organizational structure (Van Weele & Rozemeijer, 2022; Van Echtelt et al., 2008), elements which are potentially lacking in the case company according to some employees. Furthermore, cultivating long-term strategic relationships with suppliers, where they are involved from an early stage, is required (Sarkis & Dou, 2017, Chapter 3). According to Tier 1 representatives, this is in accordance with the nature of their relationship with the case company. Given the necessity for tailored hardware to cater to specific software and specifications, there exists a close relationship between the Tier 1 supplier and the case organization to ensure the quality of ECUs, a statement brought forward by both parties. As indicated by the Tier 1 supplier representatives, the case company has been reportedly engaged throughout all phases of product development, closely overseeing all activities. Furthermore, several interviewees from the case company also indicate their positive experience with their Tier 1 supplier, appreciating their willingness to comply and their dedication to sustainable development.

According to Handfield et al. (1999) and Partida (2016), the active participation of suppliers is a crucial factor in improving a product. For instance, suppliers can provide input based on sustainability factors, such as design and material selection, as well as sourcing location. Nonetheless, empirical data suggests that in this case, the Tier 1 supplier appears not to have successfully provided insights regarding sustainability. This discrepancy is most likely due to the case company's dominant expertise in this area and the limited initial sustainability requirements. Yet, it could be argued that the company ought to have engaged in discussions concerning sustainability, grounded on their specific needs and expectations. It would permit an agreement with Tier 1 regarding what technical modifications can be made to the product, thereby ensuring the inclusion of a sustainability perspective in the design. Essentially, while this process should primarily rely on the case company's competence, the Tier 1 supplier should validate what can practically be implemented and/or amended. Contrarily, the existing relationship between the company and their Tier 1 supplier resonates with Sarkis & Dou's (2017, Chapter 4) observation, where the focus rests on fostering supplier engagement to improve sustainability throughout the entire supply chain.

Connected to the above observation, a similar pattern is identified with the Tier 2 supplier, which has not provided any sustainability insights. This is despite the case company's procurement maintaining continuous communication with the chip manufacturer, coupled with the R&D department scheduling three-way meetings with the Tier 1 and 2 suppliers. Sustainability has not been a prominent item on their meeting agenda, mainly due to the existing perception of the chip supplier having a power position, thereby limiting the influence of the case company. The focal company should reconsider this, perhaps by concentrating on ways through which the Tier 2 supplier can substantially contribute towards the sustainability aspect, particularly given their significant impact on the ECU.

The ECU is characterized as a "black box" solution wherein the design is supplier-driven, based on the specifications of the focal company, signifying increased supplier responsibility and correspondingly higher involvement (Petersen et al., 2005; Van Weele & Rozemeijer, 2022). The choice to adopt a black box solution stems from the fact that it lies outside the focal company's core competence, evidenced by a lack of relevant expertise and knowledge, as noted by a category buyer. Instead, the company seeks to leverage the supplier's core competencies to ensure a state-of-the-art solution. Taking this into account, coupled with the strategic significance of this area, the involvement of the procurement team is considerably high. Figure 13 provides a representation of the procurement department's participation in the ECU's PD process. Given the project's large scale and complexity, it is categorized as involvement type F, which suggests the presence of a dedicated procurement team for ECU-related activities, who continually monitor the project's progress through regular meetings with Tier 1 suppliers. As per Lakemond et al. (2001), this represents the highest level of purchasing integration in PD and therefore correlates with the supplier's PD responsibilities, arising from the level of supplier involvement (Van Weele & Rozemeijer, 2022).

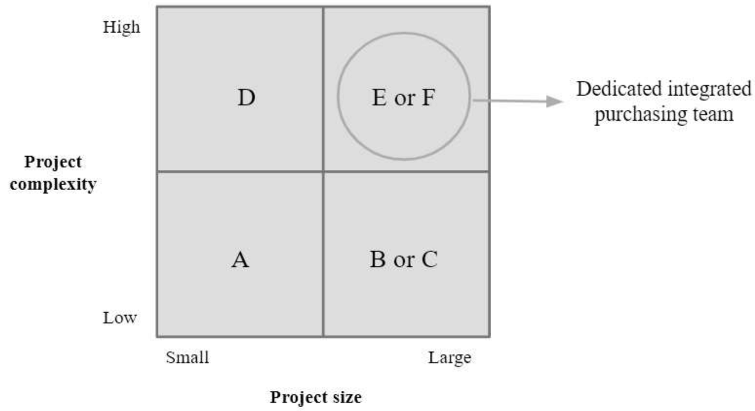

***Figure 13**: Level of purchasing involvement in the ECU product development.*

While early integration has its advantages, especially in scenarios comparable to the ECU, being overly dependent or "locked in" with a single supplier could lead to complications (Handfield et al., 1999). As established, by choosing a specific Tier 2 chip supplier, the company in question has limited its options concerning Tier 1 suppliers. Consequently, there is a secondary lock-in effect: the company is restricted to Tier 1 suppliers that have previously collaborated with the chosen Tier 2 supplier. Another potential lock-in situation may arise if other suppliers capable of providing superior ECU solutions enter the market (Handfield et al., 1999). This scenario highlights the importance of understanding the implications of the supplier gaining a power position, as a category buyer pointed out. Such a situation not only impacts the prospects for sustainability improvements, but could also lead to risks including increased costs, and supplier misconduct that may affect lead time, quality, or supply continuity.

6.3 Top Management Support

To answer RQ2, it is crucial to understand how the top management of the case company views sustainability and cross-functional collaboration, as they play a vital role in ensuring efficiency and fostering a shared vision within the organization (Salam, 2008; Blome et al., 2014; Schiele et al., 2021; Van Weele and Rozemeijer, 2022). This understanding becomes even more significant as the top management controls various parameters within these areas. While the company's top management maintains ambitious sustainability aspirations, there is a lack of distinct structures detailing how these goals are disintegrated and interpreted across various departments, resulting in ambiguity as numerous interviewees have noted, especially within electronics where sustainability is a relatively new concept. Top management must clearly define departmental responsibilities and goals. In addition, the company must transition from individual to collective accountability, emphasizing that everyone is responsible for the company's success.

6.3.1 Top Management Support for Sustainability

Based on the findings, there are four identified challenges related to top management support for sustainability: deprioritization of sustainability, unclear goals, unclear roles, and lack of resources. Figure 14 shows how they influence each other. For instance, the black arrows indicate that the challenges are interlinked, as the other three often lead to sustainability being deprioritized. Another explanation for the deprioritization is that manufacturing organizations are primarily concerned with securing production.

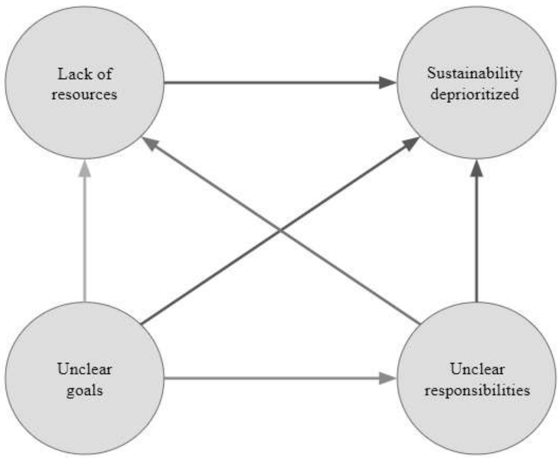

Figure 14: *Interdependencies between the identified sustainability challenges.*

However, as the number of electronic components in vehicles increases (P5, P6), sustainability in the electronics sector increasingly becomes an important factor to consider. To prioritize this topic, the focal company must first enhance its understanding of sustainability - a point highlighted by many within the organization and echoed by Adham & Siwar (2012) and Buniamin et al. (2016). Internal training initiatives in sustainability, which could be pushed by top management, could be instrumental in this regard. This would not only indicate a commitment to sustainability from the top management but would also facilitate the employees' work in this area by providing them with a clearer understanding of the organization's sustainability objectives. Moreover, passing this knowledge on to suppliers would contribute to the company's educational role. However, implementing such initiatives is resource-intensive, which highlights the need for allocating sufficient resources. Findings suggest that sustainability meetings, such as in the ECUs case, can have a positive impact, reinforcing the idea of extending such practices to other suppliers. But it is vital to have the right expertise and enough time to make this feasible.

In addition to education and knowledge, a robust framework for goal breakdown is crucial. This would clarify which goals are relevant to each department and would provide a better view of the resources needed to achieve these goals. The lack of clarity in goals often results in the inefficient allocation of resources, a point stressed by the procurement director (see the green arrow in Figure 14). Several employees and Bowen et al., (2001) have also identified insufficient resources as a barrier to addressing sustainability. Some sustainability champions state that they are the ones promoting sustainability issues to suppliers, as procurement is often considered responsible for these issues, which has to do with the unclear distribution of responsibility. However, there are concerns about the inadequacy of resources for the champions to drive the sustainability agenda effectively, as the champion's obligations are beyond their buyer responsibilities (see the blue arrow in Figure 14). These concerns reflect Hamner's (2006) view that buyers should invest more effort into promoting green sourcing strategies to ensure sustainability at the supplier level. One of these strategies is to investigate supplier roadmaps, which is a task that requires both time and resources. Lastly, the ambiguity in responsibilities often stems from unclear goals, as indicated by the red arrow in Figure 14.

6.3.2 Top Management Support for Cross-functional Collaboration

According to Van Weele and Rozemeijer (2022), effective procurement strategies can be established through close collaboration with relevant disciplines and top management. Further, managerial support is a key element for incorporating purchasing into product development (Nijssen et al., 2002; Schiele et al., 2021; Handfield et al., 1999). In the case of the focal company, it appears that the choice to interact with other departments is dictated by individual responsibility, despite an existing company-wide initiative encouraging interdisciplinary collaboration. Consequently, the question arises whether the level of commitment from the management is adequate, as suggested by Blome et al. (2014). In essence, it questions whether the management is putting forth enough effort to communicate the initiative and ensure its implementation. Drawing from the findings of Van Weele & Rozemeijer (2022) and Van Echtelt et al. (2008), creating a structured channel for communication may facilitate cross-functional collaboration. Furthermore, to enable purchasing involvement in product development, employees must possess the necessary education, skillset, and experience for cross-functional work (Lakemond et al., 2001; Nijssen, 2002). Implementing a basic course that encourages collaboration and relationship-building across various departments could prove beneficial. Such a course could result in an understanding of existing internal stakeholders, whose perspectives are vital in shaping a collective vision of the goals to be achieved. According to a top manager, activities that enhance communication can create a snowball effect that benefits future communication. Another approach to enhance cross-functional collaboration is to extrapolate lessons from successful collaborations and put them into practice.

Finally, top management's support for cross-functional integration and sustainability is intrinsically linked, with both requiring consistent management commitment (Blome et al., 2014). Establishing a solid foundation for effective collaboration cultivates a cooperative and supportive environment (Lakemond et al., 2001; Schiele et al., 2021; Van Weele & Rozemeijer, 2022). This environment has the potential to facilitate more open discussions about sustainability and subsequently lead to a shared drive towards attaining company objectives.

6.4 Areas for Improvement

Building on the identified themes, there exists a potential for improvement. Primarily, the organization would profit from adopting a more proactive approach. This entails conducting comprehensive analyses from various perspectives when making strategic, crucial decisions. For instance, in the case of the ECU, it was necessary to account for aspects that could affect the carbon footprint of the product throughout its entire life cycle. The preselected chip has once again led to locking effects, playing a significant role in the CO_2-footprint because the reference design constrains component replacement. Thus, there is potential in exploring which components within the reference design can be replaced, with sustainability as the basis, in order to mitigate the CO_2-impact of future ECUs. Component selection could be based on LCAs or the company's supplier sustainability roadmaps.

Given the finding that it is challenging to modify the reference design, meaning the majority of components are non-replaceable, it becomes crucial to explore possible ways of influencing electronics component suppliers. For example, by examining their roadmaps, possibly initiating sustainability conversations with them, or pushing more assertively at Tier 2, implying they should investigate the sustainability efforts of their sub-suppliers. This approach would benefit the key hotspot of the ECU, logic ICs, as the carbon footprint could potentially be reduced for this category. Since ECU generations are not notably different according to a product owner, there is an opportunity to be proactive by extracting lessons from previous generations and applying them to future ones.

Due to electronic-specific sustainability requirements being imminent, and because the electronics industry differs from the automotive sector (Zhu & Sarkis, 2006), it would be advantageous for the company to develop a supplier environmental questionnaire tailored to the electronics sector. Questionnaires represent a monitoring strategy (Sarkis & Dou, 2017, Chapter 3), and their progression could help strengthen existing collaboration strategies, thereby facilitating the case company's transition from a reactive to a proactive stance. To further expand the collaboration strategies, it must be ensured that the supplier is involved early on and that a close, long-term relationship is maintained (Sarkis & Dou, 2017, Chapter 3; Fredershausen et al., 2022). The following list summarizes the proposed improvement measures:

- Perform a detailed examination of the reference design to identify possible sustainability enhancements.
    - Conduct rigorous investigations to understand how updates to the ECU design (e.g., chip) will affect other electronic components and the PCB.

- Develop an electronics-specific supplier environmental questionnaire.

- Initiate sustainability discussions with the Tier 2 chip manufacturer to gain insights into their sustainability practices and correlate those with the reference design.

- Avoid overlooking the role of software in the CO_2-impact; hence, it is essential to examine how software and hardware interact and how they can be optimized to reduce their environmental impact.

- Assess the end-of-life potential of the ECU, to see if components can be reused and if the recycled materials content can be increased.

- Develop green sourcing collaboration strategies.
    - To become more proactive, try to incorporate LCA before sourcing to facilitate early mitigation actions on hotspots. Enhancing the progression of collaboration strategies could facilitate this process.

- Top management must demonstrate stronger commitment and promote alignment across departments for sustainability and cross-functional work, to ensure the achievement of company goals.
    - Implement mandatory sustainability training internally, as well as training in relationship-building and cross-functional work.
    - Review the resource availability for sustainability procedures. Consider introducing a role dedicated to pursuing sustainability discussions with suppliers and supporting employees.

7. Conclusion

This chapter will present the key findings which answer the research questions and lastly, suggestions on future research areas will be provided.

7.1 Key Findings

The company under investigation places a strong emphasis on sustainability and is consistently seeking ways to enhance its practices. Therefore, the firm is keen to discern strategies to reduce the carbon footprint of automotive electronics within its complex ECU. The purpose was to investigate the role of product development and purchasing integration in the sourcing process and explore how these interplay to fulfill corporate goals. The PCF of the Tier 1 supplier, with a particular focus on the logic ICs as a hotspot, is used as a basis to investigate how the results can be employed in future sourcing to mitigate environmental impact.

RQ1: *How can automotive OEMs utilize ECU product carbon footprint results as an input in their sourcing processes to reduce the electronic component CO_2-footprint and what are the potential challenges associated with such integration?*

In this particular case study, the PCF results highlight hotspots, to which the Tier 1 supplier has offered potential solutions. Conversely, it is the case company's responsibility to conduct a thorough analysis of these hotspots and determine what other variables could potentially affect them. Generally, the PCF can assist in identifying the critical components, i.e., those that generate a substantial impact. Furthermore, it can contribute to the decision-making process regarding future ECU solutions, how various alterations might influence the outcomes, and the optimization of future designs for the generation of improved PCF results. By receiving LCAs from all suppliers, OEMs can use the results as a comparison basis in sourcing, based on sustainability performance. However, obtaining LCAs and BOM lists from suppliers might pose challenges due to confidentiality concerns or the time-consuming nature of producing them. The same issue arises when trying to obtain an LCA in advance, which could be advantageous for the sourcing process and the final decision, considering that the final design might not yet be determined.

Moreover, OEMs can leverage PCF results to establish internal sustainability requirements for the sourcing of electronic components. For instance, if a hotspot indicates that renewable energy is the constraining factor, the requirement could be put forth to mandate a minimum acceptable percentage for renewable energy usage. The main challenge here lies in the fact that sustainability is not as well-established in the electronics industry, with most roadmaps being considerably future-oriented. Hence, the challenge is to accomplish a balance between these two aspects. Another factor to consider is that the automotive sector is a relatively small player in the electronics industry, making it harder for these OEMs to influence suppliers. A potential solution could be to investigate trends in consumer electronics, a significantly larger segment of the market, to gain a comprehensive understanding. Alternatively, collaboration with other automotive OEMs might provide a stronger influence and pave the way for a more sustainable approach to automotive electronics.

RQ2: *What efforts can automotive OEMs implement to facilitate collaboration between the procurement and R&D departments to streamline the sourcing process, i.e., to fulfill-company specific sustainability goals regarding CO_2-impact?*

As emphasized before and reiterated here, it is imperative for a coherent integration between the procurement and R&D departments of automotive OEMs. This is vital for ensuring the success of supplier involvement and leveraging the advantages of this close and long-term relationship. The integration between purchasing and R&D is necessary because purchasing has to orchestrate suppliers' work to guarantee that the correct information is conveyed to the relevant internal teams. For instance, procurement can strive to cultivate relationships with their R&D counterparts, promoting open and continuous dialogues. Ideally, purchasing should be involved in PD before the finalization of the design, to benefit from R&D's market and component knowledge, enabling proactive efforts to reduce the carbon footprint. In many cases, involving the supplier earlier in PD, to facilitate information exchange and knowledge sharing, as well as discussing what sustainability-related modifications are feasible, is beneficial. However, the timing of the supplier's involvement depends on the complexity of the project and the responsibilities assigned to them.

For the above-mentioned integration to be successful, especially among larger OEMs, several other factors are crucial. For instance, there tends to be a lack of clarity around the distribution of responsibility and goal breakdown between departments, meaning it is not always clear who bears responsibility for certain aspects such as sustainability and whom to approach for assistance. Consequently, automotive OEMs need to strive towards achieving a mutual understanding of goals and the company's intended direction. This could be facilitated through internal training in cross-functional collaboration and sustainability. Furthermore, a clear communication structure between departments is needed, as essential information that procurement can utilize in their sourcing efforts must be available. Most importantly, this shift requires the full endorsement of top management, as they reflect the company's values. The primary issue that needs to be addressed is changing the culture where sustainability work is viewed as an individual choice; instead, it should be an integral part of daily business. Finally, clarity at all levels is fundamental because only then can change be achieved.

7.2 Future Research

The thesis aimed to examine how the cross-functional integration between purchasing and R&D may contribute to the carbon footprint reductions of the ECU. The findings of this thesis have established a basis for further exploration. Therefore, proposals for future research will be presented in this section.

An area for future investigation is to conduct a more detailed analysis of the upstream semiconductor supply chain, aiming to locate and suggest corrective measures to mitigate the hotspots. Alternatively, the exploration of other hotspots within the ECU could be a potential area of study.

As discussed earlier, the full potential of certain green sourcing strategies can only be realized by examining which components in the reference design are interchangeable. Thus, a future study could involve an examination of the reference design to evaluate its adherence to green product development practices and its potential for optimization concerning eco-design and assess if the ECU can be optimized with respect to eco-design.

References

Adham, K., & Siwar, C. (2012). Empirical investigation of government green procurement (GGP) practices in Malaysia. *OIDA international journal of sustainable development*, *4*(4), pp. 77-88.

Agarwal, S., Tanger, K., Linich, D., Madsen, J., Nicholson, A., & Martin, L. (2012). *Enhancing the value of life cycle assessment*. Deloitte. https://www2.deloitte.com/content/dam/Deloitte/us/Documents/process-and-operations/us-consulting-enhancingthevalueoflifecycleassessment-112514.pdf

Alam, S., Chu, T., Lohokare, S., Saito, S., & Baker, M. (2020). Globality and complexity of the semiconductor ecosystem. *Accenture and Global Semiconductor Alliance*.

Aptiv. (2020). *What Is an Electronic Control Unit?* https://www.aptiv.com/en/insights/article/what-is-an-electronic-control-unit

Awan, U., Sroufe, R., & Kraslawski, A. (2019). Creativity enables sustainable development: Supplier engagement as a boundary condition for the positive effect on green innovation. *Journal of Cleaner Production*, *226*, pp. 172-185.

Baldwin, C. Y., & Clark, K. B. (2006). Architectural innovation and dynamic competition: The smaller "footprint" strategy. *Harvard Business School, Boston, MA*.

Bell, E., Bryman, A. & Harley, B. (2022). *Business research methods.* (Sixth edition). Oxford: Oxford University Press.

Behncke, F. G., Eichinger, J., & Lindemann, U. (2014). Involvement of procurement in the product creation process: A systematization scheme of measures. *Procedia CIRP*, *17*, pp. 356-361.

Blome, C., Hollos, D., & Paulraj, A. (2014). Green procurement and green supplier development: antecedents and effects on supplier performance. *International Journal of Production Research*, *52*(1), pp. 32-49.

Bowen, F. E., Cousins, P. D., Lamming, R. C., & Farukt, A. C. (2001). The role of supply management capabilities in green supply. *Production and operations management*, *10*(2), pp. 174-189,

Boyd, S. B. (2011). Life-cycle assessment of semiconductors. Springer Science & Business Media.

Branham, M. S. (2008). *Semiconductors and sustainability: energy and materials use in integrated circuit manufacturing* (Doctoral dissertation, Massachusetts Institute of Technology).

Brink, C., Kamsties, E., Peters, M., & Sachweh, S. (2014, August). On hardware variability and the relation to software variability. In *2014 40th EUROMICRO Conference on Software Engineering and Advanced Applications* (pp. 352-355). IEEE.

Buniamin, S., Ahmad, N., Rauf, F. H. A., Johari, N. H., & Rashid, A. A. (2016). Green government procurement practices (GGP) in Malaysian public enterprises. *Procedia Economics and Finance*, *35*, pp. 27-34.

Case Company. (2022). *Annual and sustainability report 2022*.

Case Company. (2023). *Sustainability*.

Carter, C. R., Ellram, L. M., & Ready, K. J. (1998). Environmental purchasing: benchmarking our German counterparts. *International Journal of Purchasing and Materials Management, 34*(3), pp. 28-38.

Carter, C. R., Kale, R., & Grimm, C. M. (2000). Environmental purchasing and firm performance: an empirical investigation. *Transportation Research Part E: Logistics and Transportation Review*, *36*(3), pp. 219-228.

Cherel-Bonnemaison, C., Erlandsson, E., Ibach, B., & Spiller, P. (2021). *Buying into a more sustainable value chain*. McKinsey & Company. https://www.mckinsey.com/capabilities/operations/our-insights/buying-into-a-more-sustainable-value-chain

Charter, M., Kielkiewicz-Young, A., Young, A., & Hughes, A. (2001). *Supply chain strategy and evaluation*. London: Centre for Sustainable Design, University College.

Chiesa, V. (2001). *R&D strategy & organisation: Managing technical change in dynamic contexts* (Vol. 5). World Scientific.

Cohen, S. (2015, February 28). *The Growing Level of Environmental Awareness*. HuffPost. https://www.huffpost.com/entry/the-growing-level-of-envi_b_6390054

Crowe, S., Cresswell, K., Robertson, A., Huby, G., Avery, A., & Sheikh, A. (2011). The case study approach. *BMC medical research methodology*, *11*(1), pp. 1-9.

Daub, C.-H. (2007). Assessing the quality of sustainability reporting: An alternative methodological approach. *Journal of Cleaner Production, 15*(1), pp. 75– 85.

Dedrick, J., Kraemer, K. L., & Linden, G. (2010). Who profits from innovation in global value chains?: a study of the iPod and notebook PCs. *Industrial and corporate change*, *19*(1), 81-116.

Dubois, A. and Gadde, L.‐E. (2002). Systematic combining: an abductive approach to case research. *Journal of Business Research, 55*(7), pp. 553‐560.

EPA. (2022). *Understanding Global Warming Potentials*. https://www.epa.gov/ghgemissions/understanding-global-warming-potentials

European Parliament. (2022). *Companies to be more accountable for their social and environmental impact*. https://www.europarl.europa.eu/news/en/press-room/20220314IPR25409/companies-to-be-more-accountable-for-their-social-and-environmental-impact

Finnveden, G., Hauschild, M. Z., Ekvall, T., Guinée, J., Heijungs, R., Hellweg, S., ... & Suh, S. (2009). Recent developments in life cycle assessment. J*ournal of environmental management, 91*(1), pp. 1-21.

Fredershausen, A.-C., Hannon, E., Helmcke, S., & Nauclér, T. (2022). *It's not easy buying green: How to win at sustainable sourcing*. McKinsey & Company. https://www.mckinsey.com/capabilities/sustainability/our-insights/its-not-easy-buying-green-how-to-win-at-sustainable-sourcing

George, T. (2022, November 30). *Semi-Structured Interview | Definition, Guide & Examples*. Scribbr. https://www.scribbr.com/methodology/semi-structured-interview/

Ghosh, B., Kivimaa, P., Ramirez, M., Schot, J., & Torrens, J. (2021). Transformative outcomes: assessing and reorienting experimentation with transformative innovation policy. *Science and Public Policy*, *48*(5), pp. 739-756.

Hamner, B. (2006). Effects of green purchasing strategies on supplier behaviour. *Greening the supply chain*, pp. 25-37.

Handfield, R. B., Ragatz, G. L., Petersen, K. J., & Monczka, R. M. (1999). Involving suppliers in new product development. *California management review*, *42*(1), pp. 59-82.

He, B., Liu, Y., Zeng, L., Wang, S., Zhang, D., & Yu, Q. (2019). Product carbon footprint across sustainable supply chain. *Journal of Cleaner Production*, *241*, 118320.

Huang, Y. A., Weber, C. L., & Matthews, H. S. (2009). Categorization of scope 3 emissions for streamlined enterprise carbon footprinting.

Hsu, C. W., & Hu, A. H. (2008). Green supply chain management in the electronic industry. *International Journal of Environmental Science & Technology*, *5*, 205-216.

Insights. (2022). Transforming the automotive supply chain for the 21st century. *MIT Technology Review*.

Kara, S., Ibbotson, S., & Kayis, B. (2014). Sustainable product development in practice: an international survey. *Journal of Manufacturing Technology Management*, *25*(6), pp. 848-872.

Khan, S. M., Mann, A., & Peterson, D. (2021). The semiconductor supply chain: Assessing national competitiveness. *Center for Security and Emerging Technology*, *8*(8).

King, I., Wu, D., & Pogkas, D. (2021). *How a Chip Shortage Snarled Everything From Phones to Cars*. Bloomberg. https://www.bloomberg.com/graphics/2021-semiconductors-chips-shortage/

Kovács, G., & Spens, K. M. (2005). Abductive reasoning in logistics research. *International journal of physical distribution & logistics management, 35*(2), pp. 132-144.

Lakemond, N., Van Echtelt, F., & Wynstra, F. (2001). A configuration typology for involving purchasing specialists in product development. *Journal of Supply Chain Management*, *37*(3), pp. 11-20.

Lamming, R., & Hampson, J. (1996). The environment as a supply chain management issue. *British journal of Management*, *7*(1).

Linden, G., Kraemer, K. L., & Dedrick, J. (2009). Who captures value in a global innovation network? The case of Apple's iPod. *Communications of the ACM*, *52*(3), pp. 140-144.

Lloyd, M. (1994). How Green Are My Suppliers? Buying Environmental Risk. *Purchasing and Supply Management*. October 1994: 36-39.

Loch, C.H. & Kavadias, S. (2008). *Handbook of new product development management*. Amsterdam: Butterworth-Heinemann.

Loureiro, G. & Curran, R. (2007). *Complex Systems Concurrent Engineering: Collaboration, Technology Innovation and Sustainability.* London: Springer-Verlag London Limited.

Lowe, S. (2019, June 25). *Driving good governance through accountability*. Grant Thornton. https://www.grantthornton.co.uk/insights/five-principles-of-good-governance-accountability/

Manual, O. (2005). Proposed guidelines for collecting and interpreting technological innovation data. *OCDE: Statistical Office of the European Communities*.

Min, H., & Galle, W. P. (2001). Green purchasing practices of US firms. *International journal of operations & production management.*

Min, H., & Choi, S. B. (2020). Green sourcing practices in Korea. *Management Research Review*, *43*(1), pp. 1-18.

Morhardt, J. E., Baird, S., & Freeman, K. (2002). Scoring corporate environmental and sustainability reports using GRI 2000, ISO 14031 and other criteria. *Corporate Social Responsibility and Environmental Management, 9*(4), pp. 215– 233.

Nijssen, E. J., Biemans, W. G., & De Kort, J. F. (2002). Involving purchasing in new product development. *R&d Management*, *32*(4), pp. 281-289.

O'Connor, M. P., Zimmerman, J. B., Anastas, P. T., & Plata, D. L. (2016). A strategy for material supply chain sustainability: enabling a circular economy in the electronics industry through green engineering. ACS Publications.

Partida, B. (2016). Collaboration leads to clear benefits for procurement and product development: suppliers can inform product development and the R&D group can help select the best suppliers. *Supply Chain Management Review, 20*(3), 86.

Patel, R., & Davidson, B. (2019). Forskningsmetodikens grunder. Studentlitteratur AB.

Pelton, R. E., & Smith, T. M. (2015). Hotspot scenario analysis: Comparative streamlined LCA approaches for green supply chain and procurement decision making. *Journal of Industrial Ecology, 19*(3), pp. 427-440.

Pero, M., Abdelkafi, N., Sianesi, A., & Blecker, T. (2010). A framework for the alignment of new product development and supply chains. *Supply Chain Management: An International Journal*, *15*(2), 115-128.

Petersen, K. J., Handfield, R. B., & Ragatz, G. L. (2005). Supplier integration into new product development: coordinating product, process and supply chain design. *Journal of operations management*, *23*(3-4), pp. 371-388.

PwC. (2023). *Sustainability in the automotive industry.* https://www.pwc.de/en/sustainability/sustainability-in-the-automotive-industry.html

Reitsma, E., Hilletofth, P., & Johansson, E. (2023). Supply chain design during product development: a systematic literature review. *Production Planning & Control, 34*(1), 1-18.

Rhoden, I., Ball, C. S., Vögele, S., & Kuckshinrichs, W. (2022). Minding the gap‐relating disclosure to contexts of sustainability reporting in the automotive industry. *Corporate Social Responsibility and Environmental Management*, pp. 1-12.

Roussel, P. A., Saad, K. N., & Erickson, T. J. (1991). *Third generation r&d*. Harvard Business School Press.

Rusinko, C. (2007). Green manufacturing: an evaluation of environmentally sustainable manufacturing practices and their impact on competitive outcomes. *IEEE transactions on engineering management*, *54*(3), pp. 445-454.

Salam, M. A. (2008, September). An empirical investigation of the determinants of adoption of green procurement for successful green supply chain management. In *2008 4th IEEE International Conference on Management of Innovation and Technology* (pp. 1038-1043). IEEE

Sarkis, J., & Dou, Y. (2017). *Green supply chain management: A concise introduction*. Routledge.

Saunders, M., Lewis, P., & Thornhill, A. (2009). *Research methods for business students*. Pearson Education.

Schiele, H., Hofman, E., Zunk, B. M., & Eggers, J. (2021). Why and how to involve purchasing in new product development?. *International journal of innovation management*, *25*(03), 2150027.

Schneider, L., & Wallenburg, C. M. (2012). Implementing sustainable sourcing - Does purchasing need to change? J*ournal of Purchasing and Supply Management, 18*(4), pp. 243-257.

Semiconductor Industry Association. (2016). *Beyond Borders: The Global Semiconductor Value Chain*
https://www.semiconductors.org/wp-content/uploads/2018/06/SIA-Beyond-Borders-Report-FINAL-May-6-1.pdf

Seuring, S., & Müller, M. (2008). From a literature review to a conceptual framework for sustainable supply chain management. *Journal of cleaner production*, *16*(15), pp. 1699-1710.

Shin, N., Kraemer, K. L., & Dedrick, J. (2009). R&D, value chain location and firm performance in the global electronics industry. *Industry and Innovation*, *16*(3), 315-330.

Spens, K.M. and Kovács, G. (2006). A content analysis of research approaches in logistics research. *International Journal of Physical Distribution & Logistics Management, (36)*5, pp. 374-390.

Spiller, P. (2021). *Making supply-chain decarbonization happen*. McKinsey & Company. https://www.mckinsey.com/capabilities/operations/our-insights/making-supply-chain-decarbonization-happen

Sukitsch, M., Engert, S., & Baumgartner, R. J. (2015). The implementation of corporate sustainability in the European automotive industry: An analysis of sustainability reports. *Sustainability*, *7*(9), pp. 11504-11531.

Tachizawa, E.M., Gimenez, C., & Sierra, V. (2015). Green supply chain management approaches: Drivers and performance implications. *International Journal of Operations & Production Management, 35*(11), pp. 1546–1566.

Van Echtelt, F. E., Wynstra, F., Van Weele, A. J., & Duysters, G. (2008). Managing supplier involvement in new product development: a multiple‐case study. *Journal of Product Innovation Management*, *25*(2), 180-201.

Van Weele, A.J.V. & Rozemeijer, F. (2022). *Procurement and supply chain management*. (Eighth edition). Andover: Cengage Learning.

Vasan, A., Sood, B., & Pecht, M. (2014). Carbon footprinting of electronic products. *Applied energy, 136*, pp. 636-648.

Walker, H., Di Sisto, L., & McBain, D. (2008). Drivers and barriers to environmental supply chain management practices: Lessons from the public and private sectors. *Journal of purchasing and supply management*, *14*(1), pp. 69-85.

Wheelwright, S.C. and Clark, K.B. (1992) Revolutionizing product development quantum leaps in speed, efficiency, and quality. New York: Free Press u.a.

Wouters, M., Anderson, J. C., Narus, J. A., & Wynstra, F. (2009). Improving sourcing decisions in NPD projects: Monetary quantification of points of difference. *Journal of Operations Management*, *27*(1), 64-77.

Yin, R.K. (2009). *Case study research: Design and methods*. 4th ed. Los Angeles: Sage Publications.

Yin, R.K. (2018). *Case study research and applications: design and methods*. 6th ed. Thousand Oaks, California: SAGE

Yung, W. K., Muthu, S. S., & Subramanian, K. (2018). Carbon footprint analysis of printed circuit board. In *Environmental Carbon Footprints* (pp. 365-431). Butterworth-Heinemann.

Zhu, Q., & Sarkis, J. (2006). An inter-sectoral comparison of green supply chain management in China: drivers and practices. *Journal of cleaner production*, *14*(5), pp. 472-486.

Zsidisin, G. A., & Hendrick, T. E. (1998). Purchasing's involvement in environmental issues: a multi‐country perspective. *Industrial Management & Data Systems*, *98*(7), pp. 313-320.

Zsidisin, G. A., & Siferd, S. P. (2001). Environmental purchasing: a framework for theory development. *European Journal of Purchasing & Supply Management,* *7*(1), pp. 61-73.

Appendix

Interview Guide

General information

- What is your title and which department do you belong to?
- What is your responsibility area?
- Do you have contact with the purchasing department for software and electronics?
- What is your connection to R&D? What are your discussions about?
- What is your contribution to a sourcing process, i.e., what information from your department serves as an important input when sourcing electronic components?

Sustainability procedures and PCF

- How do you/your department work towards sustainability?
    - How do you feel top management approaches/manages the issue of sustainability?
- What's your outlook for electronic components in the future? How will they develop?
    - Do you know any regulations or environmental factors that can affect the development of electronic components?
- How will the new electronics sustainability requirements affect your work?
- What suggestions do you have in order to reach the sustainability goals for electronics?
- How are the results from an LCA (PCF) used?

Questions aimed towards the R&D department

- What kind of sustainability requirements are there for R&D?
- How do sustainability requirements affect different phases of R&D?
- Do different departments have the ability to affect the design of electronic components? In what way?
- Is the selection of what electronic components to source, solely decided by R&D or together with other departments? what about the supplier partner
    - Which departments can affect the selection and how?

Questions aimed towards the purchasing department

- What does the general sourcing process look like?
- What other departments might you need support from when sourcing? Why and what kind of support?
- How do the sustainability requirements affect supplier recruitment?

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