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Assessing Sustainability Strategic Alignment in Automotive Product Development Decision-Making

Master's thesis in Industrial Ecology

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SUMMARY

The integration of environmental considerations into product development has been discussed in literature with particular attention to approaches related to Life Cycle Assessment (LCA). While these approaches aim to inform more sustainable products and business, a particular gap is the alignment between corporate sustainability strategies and operational decision-making. This study investigates how sustainability goals are operationalized in practice by assessing the strategic alignment between corporate targets and decision-maker priorities, exemplified by a Volvo Cars case study.

This study applies the Analytic Network Process (ANP), a Multi-Criteria Decision Analysis (MCDA) method, to two decision cases involving polymeric automotive parts. Six criteria were evaluated: cradle-to-gate carbon footprint, end-of-life circularity, recycled content, biobased content, weight and cost. Data from 79 decision-makers in product development were used to quantify priorities, enabling assessment of strategic alignment. These findings were complemented with interviews with company sustainability experts and participating decision-makers to enable triangulation between strategic ambitions and operational practices, complemented with literature to assess the integration efforts in the case company and synthesize complementary improvement actions.

The findings indicated several instances of internal and external misalignment, and misalignment between decision maker preferences and sustainability targets. The integration of environmental considerations into product development decision making was found to be relatively poor, with environmental aspects generally not viewed as an integral part of product development activities. Supplementary interviews and observations revealed that integration efforts from central sustainability functions addressed many of the prescriptions in literature, subsequently addressing much of the identified misalignment. However, a need was identified for top management support and allocation of resources, as well as the creation of dedicated collaboration spaces, to complement central sustainability efforts and to effectively motivate product development staff taking ownership of environmental considerations

This study is a relevant example of current challenges present in environmental work and green product development, with a particular focus in the automotive industry. It also demonstrates how a quantitative method like ANP can be combined with qualitative analysis and an extended scope of respondents to assess misalignment between sustainability strategy and decision-making practices in complex industrial contexts.

Keywords: environmental product development, sustainability, decision making, automotive, polymeric materials, Multi-Criteria Decision Analysis (MCDA), Analytic Network Process (ANP), Life Cycle Assessment (LCA), Life Cycle Management (LCM).

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1 Introduction

There are many reasons for companies undertaking consideration of environmental aspects in product development. For example, environmental improvement of products can bring competitive advantages, improve branding and public image and help meet regulatory requirements (UNEP, 2009). Design and product development processes are highly important for improving the sustainability of products because a lot of the environmental impact is decided in this phase (Baumann & Tillman, 2004). For effective environmental improvement of business practices and products, environmental considerations must be integrated into existing organizational systems, tools, processes and decision making, ideally as early as possible in the product development process (Baumann et al., 2002; Baumann & Tillman, 2004). Early integration of environmental aspects into product development decision making is key for achieving sustainability ambitions, because early phases allow for more design freedom and less costly changes (Baumann & Tillman, 2004; Zarte et al., 2019).

Specifically, material selection decision making is one of the major aspects of product development and has the most impact on product sustainability (Zarandi et al., 2011). Such decision making is an example of the complex decision making in environmental product development where conflicting decision criteria have to be simultaneously considered, thus constituting a multi-criteria decision problem (Kandakoglu et al., 2019).

The integration of environmental considerations into product development has been discussed in literature with particular attention to approaches related to Life Cycle Assessment (LCA). This is because LCA and product development shares the focus on a central product and because of LCA providing a holistic perspective that allows for insight into trade-offs when considered in combination with other aspects (Baumann & Tillman, 2004). While these tools aim to inform more sustainable products and business practices, a particular gap is the alignment and integration between corporate sustainability strategies and operational decision-making. This study investigates how corporate environmental sustainability goals are operationalized in practice by assessing the strategic alignment between corporate targets and decision-maker priorities in product development, exemplified by a Volvo Cars case study.

The aim of this study is to investigate how different decision makers prioritize sustainability related and other criteria in product development material selection decisions. Specifically, the study assesses misalignments between different decision makers' priorities, and between decisions on part system level and higher-level strategic targets, to identify and suggest improvement actions for addressing the identified misalignments and improving integration of environmental considerations in product development (also referred to as a sustainability steering process).

In accordance with the aim, the following three research questions are covered in this study.

1. What similarities and differences can be identified in decision makers' prioritization of sustainability criteria, and what implications do these have for the ranking of material alternatives?
2. What misalignments can be identified between different decision makers' priorities and between component level choices and higher-level strategic sustainability targets?
3. What improvement actions can mitigate the identified misalignment risks and improve integration of the sustainability steering process?

This study applies the Analytic Network Process (ANP), a Multi-Criteria Decision Analysis (MCDA) method, to two material selection decision cases involving polymeric automotive parts. Six criteria were evaluated: cradle-to-gate carbon footprint, end-of-life circularity, recycled content, biobased content, weight and cost. Data from 79 decision-makers in product development were used to quantify priorities, enabling assessment of strategic alignment between and within different groups of decision-makers, and with regards to sustainability strategic targets. These findings were complemented with interviews with company sustainability experts and participating decision-makers. This enabled triangulation between strategic ambitions and operational practices, complemented with green product development and life cycle management literature and regulatory pressures, to assess the environmental product development integration efforts in the case company and to synthesize complementary improvement actions.

This study is a relevant example of current challenges present in environmental work and green product development, with a particular focus in the automotive industry. It also demonstrates how a quantitative method like ANP can be combined with qualitative analysis and an extended scope of respondents to assess misalignment and integration between sustainability strategy and decision-making practices in complex industrial contexts.

Section 2 presents the theoretical background related to life cycle management and green product development literature, findings from previous studies and some contextual background related to regulatory pressures in the proposed End-of-Life Vehicles Regulation. Section 3 present the methodology, including a detailed description of the case company, the main steps for conducting an MCDA using ANP and how this was applied in this study, as well as the method used for collecting supplementary inputs via interviews, observation and reviewing relevant literature. Section 4 presents and analyses the results of the study. Section 5 discusses the results and method of the study and suggests some potential future research directions, before concluding the study.

1.1 Limitations and Assumptions

The two decision cases studied include only polymeric interior and exterior parts, although many of the aspects of the studied decision making also apply to metallic materials. The specific decision process studied is the R&D material choice in product development, thus excluding subsequent sourcing processes and decisions made by Procurement functions. This exclusion is motivated by the fact that it is currently the R&D department at the case company that takes criteria into account and makes material choices, while Procurement more so ensures that the R&D choice is within budget. Thus, decision makers in R&D are also the targeted group for the MCDA, excluding other departments' decision makers.

The weight criterion has very different implications depending on whether the vehicle is an internal combustion engine vehicle (ICEV), hybrid electric vehicle (HEV) or battery electric vehicle (BEV). Weight plays a much more important role in material choices for BEVs, where the driving range is heavily impacted by the weight of the vehicle (Pollock et al., 2025). Therefore, all cases considered in this study are done with the assumption of being BEVs.

2 Background

This section presents the relevant background for the study, specifically within the two areas of life cycle management and green product development. Also, in terms of regulatory measures and associated pressures, the End-of-Life Vehicles directive is highly relevant for the automotive industry context of this study.

2.1 Life Cycle Management

In contrast to traditional corporate environmental management, which focuses mainly on a company's own production sites and processes, life cycle management (LCM) incorporates life cycle thinking to expand the focus on the impact of products over their entire life cycle, from cradle-to-grave (Nilsson-Lindén et al., 2021; UNEP, 2007).

Specifically, LCM can be defined as “...not a single tool or methodology but a management system collecting, structuring and disseminating product-related information from the various programs, concepts and tools incorporating environmental, economic, and social aspects of products, across their life cycle” (UNEP, 2007, p. 18). LCM has also been referred to as a toolbox, within which LCA is a common tool (Nilsson-Lindén et al., 2021).

As all functions in an organization need to collaborate actively in LCM, product development is a key part of this (Nilsson-Lindén et al., 2021; UNEP, 2007). An example of an approach for incorporating social and environmental considerations into the traditional product development process is Design for Sustainability (DFS), which then needs to be integrated in existing processes and business strategy (UNEP, 2007). Examples of DFS actions include selection of renewable, recycled and recyclable materials and reduction of weight (UNEP, 2007). As such, the studied sustainability steering process for material selection at Volvo Cars can be considered as a part of typical LCM activities. Thus, literature on LCM provides relevant background for this study.

Some of the motivations for organizations implementing LCM given in literature include branding and public perception, stakeholder and shareholder impacts and adaption to the regulatory landscape (UNEP, 2007). From a sustainable development perspective, some see LCM as a means of transitioning towards the circular economy (Nilsson-Lindén et al., 2021).

But, to achieve more sustainable business practices, LCM concepts and tools must be practically translated and integrated into the daily operations (Nilsson-Lindén et al., 2021). Nilsson-Lindén et al. (2021) explain this translation as combining idealistic motivations for change with contextualizing and legitimizing strategies for the new actions. In a case study of LCM work at a manufacturing company with global operations, Nilsson-Lindén et al. interestingly found that not only idealistic aspirations motivated life cycle work, but also a desire to avoid negative outcomes. Another key success factor for the implementation of LCM presented in literature is support from top management and other key employees throughout the organization (UNEP, 2007). Clearly communicating about LCM throughout

the organization and connecting LCM activities to economic gains are other reoccurring prescriptions in literature (Nilsson-Lindén et al., 2021).

Nilsson-Lindén et al. (2018) expands on the common focus on tools and prescriptive success factors in LCM literature to detailed findings in a globally operating manufacturing company. In addition to those previously described, success factors commonly mentioned in LCM literature include cross functional integration, alignment with the overall business strategy and not having LCM as a separate add-on, knowledge building such as education and training, importantly having enough time and resources for education, collaboration within the product chain, integrating LCM into the early stages of product development, spreading responsibilities throughout the organization and including environmental aspects in company branding and marketing (Nilsson-Lindén et al., 2018). With regards to LCA as an LCM tool, previous studies indicate that rather than rational judgment or LCA knowledge, individual understanding, personal values and organizational culture might affect managerial action or inaction in environmental issues (Nilsson-Lindén et al., 2018).

In addition to these literature success factors, Nilsson-Lindén et al. found from the empirical company study that not only top management support, but also middle management support is crucial, and difficult to achieve, for line organization integration of LCM activities. An example of handling the middle management challenge was found to be directly connecting top management with operational levels (Nilsson-Lindén et al., 2018). Other challenges were integrating LCM among procurement and sales departments, measured environmental targets having to be complemented with follow up and other compliance accountability efforts in order for staff to take ownership of environmental activities, and concerns about lack of customer interest in environmental product marketing (Nilsson-Lindén et al., 2018). Other ways of improving LCM integration found at the studied company included integration into tools and processes and creating cross functional networks to enable further interaction, knowledge sharing, and creative problem solving in a dedicated arena (Nilsson-Lindén et al., 2018).

2.2 Green Product Development

There are many different but related terms for green product development (GPD) such as environmental product development (EPD), sustainable product development (SPD), design for sustainability (DFS) and ecodesign (UNEP, 2009). The main difference is that SPD or DFS has a slightly more encompassing scope, including both a life-cycle perspective and social and economic sustainability in addition to environmental aspects, which are the sole focus in GPD, EPD and ecodesign (UNEP, 2009). Historically, it was mainly environmental product sustainability that was highlighted in concepts popularized in the 1990s such as ecodesign and GPD, which were then later expanded into the broader DFS and SPD concepts (UNEP, 2009).

As described in Section 2.1, there are many parallels between the studied Volvo Cars sustainability steering process for material selection and DFS activities. However, most of

the applicable DFS activities are related to environmental sustainability, so GPD and EPD literature is also relevant for this study.

Many of the motivations for organizations undertaking DFS are similar to those mentioned for LCM (see Section 2.1). For example, competitive advantages, branding and public image, and regulatory requirements (UNEP, 2009). In terms of regulation, Extended Producer Responsibility and recycled content requirements (such as those proposed in the End of Life Vehicles (ELV) directive, see Section 2.3) are specifically highlighted as motivations for DFS (UNEP, 2009). Additionally, a motivation for ecodesign and GPD is that the environmental impact of a product is largely set in the design and product development phases, necessitating integration of environmental considerations into these phases (Baumann et al., 2002; Baumann & Tillman, 2004).

Similar to the success factors for LCM described in Section 2.1, Pujari et al. (2003) found both literature and empirical support for aspects that positively influence the environmental performance of EPD. These aspects are top management support, integration of environmental coordinators for issuing guidelines, driving the implementation process and providing environmental assessments at each product development gate, involvement of suppliers via monitoring, auditing or partnerships, integration of environmental impact databases into existing information systems provided to EPD teams, and cross-functional coordination (Pujari et al., 2003).

Baumann et al. (2002) describe a common view in literature on strategic decision making in product development, focusing on prescriptive tools and techniques, and that environmental aspects need to be integrated into existing organizational systems for the environment to be considered in business decisions. Furthermore, the importance of learning and communication is highlighted in literature on decision making in GPD (Baumann et al., 2002).

A challenge for engineers in GPD is that environmental concerns are outside their usual areas of expertise, and require much longer term perspectives than what is usual in product development (Baumann et al., 2002). The engineer's perspective on GPD is characterized by a focus on tools and a view of environmental tools as "add-ons" to conventional product development (Baumann et al., 2002). The timing of tool use in product development is crucial, with the concept phase being pointed out as key for the environmental impact of products, and early phase tools are called for (Baumann et al., 2002). In general, environmental aspects should be integrated as early as possible in product development, due to increasing costs of design changes in later stages, making only incremental changes feasible later (Baumann & Tillman, 2004). Product developers might have a harder time using and understanding environmental tools compared with existing technical evaluation tools, requiring instruction and training in the use of environmental tools, and support from environmental experts (Baumann et al., 2002). However, availability of tools does not guarantee environmental improvement,

management and organizational efforts such as those previously mentioned are also required, and may be even more important than tools (Baumann et al., 2002; Baumann & Tillman, 2004).

LCA is one of the most important GPD tools, and is also common in combination tools together with technical and economic aspects (Baumann et al., 2002; Baumann & Tillman, 2004). It can be used in tools creatively for generating product concepts or analytically for evaluating impacts of said concepts (Baumann & Tillman, 2004). One of the main applications of LCA that has received the most attention in the past is indeed design and product development (Baumann & Tillman, 2004). This is because, like in product development and design, LCA centers around products, and because the design phase, including material selection, is seen as crucial for deciding the environmental impact of products (Baumann & Tillman, 2004). Also, LCA is useful for ecodesign because of its holistic perspective that enables insight into trade-offs between e.g. different ecodesign strategies and product concepts, especially when used in combination tools (Baumann & Tillman, 2004). Like the case for any environmental tool, LCA is not enough to ensure EPD activities in an organization – consistent management behavior, motivation and support for product developers via training, knowledge building and clear responsibility assignments are crucial (Baumann & Tillman, 2004).

2.2.1 Decision Making in Green Product Development

An important part of integration discussed in GPD literature concerns decision making, where a key success to profiting from environmental objectives is making it a core part of the business strategy and all associated decision making processes (Baumann et al., 2002). As mentioned previously, integrating environmental concerns into the organizational learning and communication processes contributes to integration in business decisions (Baumann et al., 2002). The concept of ecodesign can be closely linked to decision making, where the environment defines the direction of ecodesign decisions in product development, to the same extent as for example profit and functionality (Baumann et al., 2002).

Decision making in sustainability contexts and sustainable product development is particularly complex (Kandakoglu et al., 2019; Zarte et al., 2019). Specifically, this kind of decision making constitutes a multi-criteria decision problem with conflicting decision criteria, quantitative and qualitative, that all have to be simultaneously considered in the decision making (Kandakoglu et al., 2019). The importance of timing previously mentioned is also highlighted with regards to decision making, with early integration into product development decision making enabling more design freedom and easier sustainability improvements (Zarte et al., 2019). Particularly, considering trade-offs in early product development decision making, for example by applying multi-criteria decision analysis (MCDA) methods, enables environmental improvement of products (Xu et al., 2023). Analytic Hierarchy Process (AHP) and Analytic Network Process (ANP) are some of the

most common MCDA methods in sustainable product development decision making (Xu et al., 2023; Zarte et al., 2019).

Material selection decision making is one of the major topics of product design next to part and assembly design, and has the most impact on product sustainability (Zarandi et al., 2011). Material selection decision making in particular is a multidisciplinary consideration of functional, economic and environmental objectives (Zarandi et al., 2011). AHP and ANP are frequently used for material selection decision making in environmental product development (Xu et al., 2023).

2.3 End of Life Vehicles Directive

The End of Life Vehicles (ELV) directive first entered into force in the European Union in 2000, and regulates the role of vehicle and equipment manufacturers in ensuring recyclability, reusability and recoverability of vehicles at end-of-life and limiting use of hazardous substances (European Union, 2023). Within the ELV directive, a new End of Life Vehicles Regulation (ELVR) was proposed in 2023 (European Commission, n.d.). In terms of product development and design, the new proposal includes requirements for developing circular strategies and circular design requirements (European Commission, 2023). Also, the proposal includes mandatory recycled content targets for new vehicles (European Commission, 2023). In the latest update of the proposal these targets are 15% recycled plastic content, of which 20% from ELV sources, within six years of the regulation entering into force, and 25% recycled plastic content, again of which 20% from ELV sources (i.e. 5% of the total material content), within 10 years of the regulation entering into force (Plastics Today, 2026). This update allows only post-consumer recycled material to be counted towards the targets, but it can be either mechanically or chemically recycled (Plastics Today, 2026). The latest update does not accept counting of biobased content towards the recycled content targets, but it requires the European Commission to review the state of biobased materials and propose requirements and targets including potential acceptance of counting biobased content towards recycled content targets within 72 months of the regulation entering into force (Victory, 2026).

3 Methodology

This section presents the methodology of the study, including the case company studied, the main steps for conducting an MCDA using the ANP methodology, and the various ways that data was collected for the study and results derived.

3.1 Description of Case Study

Section 3.1.1 below presents the case company studied. To capture the spread of the different kinds of sustainable polymeric material alternatives in automotive parts, two different material selection decision cases were studied at the case company: one from the exterior product area and one from the interior product area, presented in Section 3.1.2 and 3.1.3 below.

3.1.1 Case Company

Volvo Cars is a car manufacturer based in Gothenburg, with global operations and markets (Volvo Cars, n.d.). Sustainability is an integral part of the company strategy, as seen for example in the company purpose introduced in 2018: “*Freedom to move in a personal, sustainable and safe way*” (Volvo Car Group, 2019), putting sustainability on the same level as safety, a decades long guiding principle for the company (Volvo Car Group, 2025). Since then, Volvo Cars has adopted many strategic targets related to environmental sustainability within two key areas: climate action and circular economy (Volvo Car Group, 2025). For example, a CO₂¹ reduction per car of 65-75%, compared to a 2018 baseline, as well as 90-100% electrified share of global sales, by 2030 (Volvo Car Group, 2025). Other strategic goals, for 2040, include net zero greenhouse gas emissions across the value chain and becoming a fully circular business (Volvo Car Group, 2025).

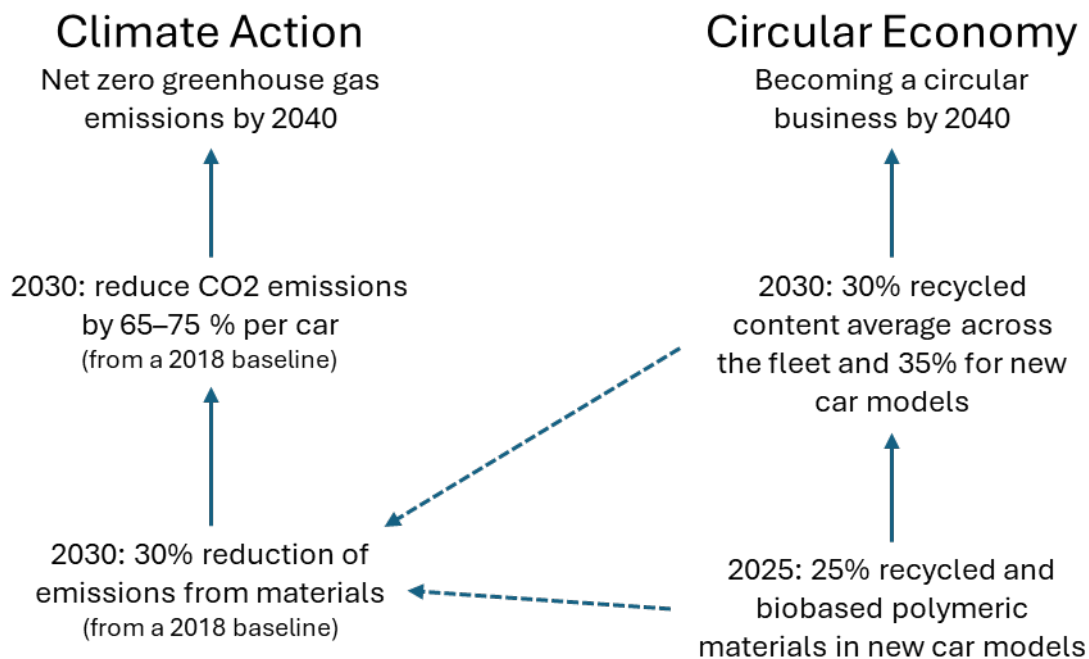
An important part of reaching the CO₂ reduction target per car and subsequently the net zero emission target, is to reduce the CO₂ emissions from materials, for which a target of 30% reduction compared to 2018 has been set (Volvo Car Group, 2025). Indeed, reducing emissions from material production for Volvo’s cars is one of three main focus areas, the others being electrification and minimizing operational emissions, for reaching the goal of net zero by 2040, and all intermediary targets (Volvo Car Group, 2025). The main strategy for meeting the emission reduction target for materials is to increase the use of recycled content (Volvo Car Group, 2025). In turn, increasing use of recycled materials is also a key strategy in reaching the goal of becoming a circular business by 2040, especially for the focus area of minimizing primary resource use (Volvo Car Group, 2025). To this end, there are strategic targets also relating to recycled material use, specifically, fleet average of 30% recycled content and 35% recycled content in newly released car models, by 2030 (Volvo Car Group, 2025). Furthermore, this target is broken down between different kinds

¹ CO₂ as used by Volvo Cars refers to a measure of the climate impact in terms of Global Warming Potential over 100 years, including also the effects of greenhouse gas emissions other than CO₂, sometimes referred to as carbon footprint and measured in CO₂ equivalents. In this report, CO₂ or “carbon footprint” is used interchangeably, to refer to this climate impact measure.

of materials, with a target of 25% recycled and biobased polymeric materials in new cars by 2025 (Volvo Car Group, 2025). See Figure 1 below for an illustration of how select sustainability goals and targets are interrelated.

Figure 1

Select Volvo Cars environmental sustainability goals and targets of relevance to the issue studied



Note. Arrows indicate how lower-level targets contribute to higher level targets. Dashed arrows indicate how targets within the key area of Circular Economy also contribute to Climate Action targets. Based on Volvo Car Group, Annual and sustainability report 2024, pp 140-141.

Polymeric materials constitute around 19% of the weight of an average car (Volvo Car Group, 2025), and have many unique properties that make them essential in vehicle manufacturing (Volvo Car Corporation, 2024c). In their use of polymeric materials, Volvo Cars does not only strive to increase recycled and biobased content, but also recyclability, although no formal target has been set (Volvo Car Group, 2025). Specifically, the company defines sustainable materials as materials that are “*responsibly sourced, non-hazardous, recyclable and have a lower environmental impact than those from primary sources*” (Volvo Car Group, 2025, p. 160). This includes material feedstock types such as recycled, biobased (renewable) or derived from greenhouse gases (Volvo Car Corporation, 2024b).

The reasons for undertaking the above-mentioned strategic goals and targets for climate action are that the public's expectations in light of global climate change pose a threat to brand reputation and risk of sales loss if Volvo Cars does not transition its business sustainably, as well as regulatory pressures presenting financial risks in case of non-compliance (Volvo Car Group, 2025). Similarly, the goals and targets for circular business are motivated by financial and reputational risks in case of non-compliance with regulatory pressures, such as the EU End-of-Life Vehicles (ELV) directive (see Section 2.3), which has current requirements for end-of-life circularity and proposed requirements on recycled content (Volvo Car Group, 2025). Additionally, implementing circular strategies and increasing end-of-life circularity is also seen as an opportunity for financial gain and competitive advantage (Volvo Car Group, 2025).

Even if the motivations behind the strategic goals and targets are clear, meeting them requires operationalizing the strategies by integrating sustainability considerations into the day-to-day actions and decisions, especially for the product specific targets on CO₂ and recycled content. To this end, CO₂ and recycled content considerations need to be integrated into the product development cycle, *“from concept phase to end-of-life”* (Volvo Car Group, 2025, p. 168). This has been attempted by adding CO₂ and recycled content performance steering to the existing cost steering model for product development and sourcing (Volvo Car Group, 2025). This is implemented by setting car program specific targets also for sustainability performance, which are then divided further into component and system specific targets early in the program cycle (Volvo Car Corporation, 2024b; Volvo Car Group, 2025). The idea is that such system level sustainability steering will enable integration of CO₂ and recycled content into all decision making and ensure targets are met in a cost efficient way (Volvo Car Group, 2025).

As for the end-of-life circularity, since no quantitative targets are set, the main action in product development is to *“value longevity”* (Volvo Car Group, 2025, p. 179), for example avoiding downgrading of materials at the vehicle end-of-life, ensuring reusability and recyclability (Volvo Car Corporation, 2024b) and *“consideration of the entire lifecycle”* (Volvo Car Corporation, 2024a, p. 3). For Design, requirements on factors such as durability and repairability are set, and both Design and R&D are seen as key in enabling circularity (Volvo Car Group, 2025).

The importance of including strategic sustainability considerations as early as possible in the product development process is commonly highlighted in literature (see Section 2.1 and 2.2) on life cycle management and environmental product development (Baumann & Tillman, 2004; Nilsson-Lindén et al., 2018). This is because of the design and product development conditions changing as the product development process proceeds, with the amount of design freedom and influence decreasing over time, and more and more of the environmental impact of the product being locked in as more and more of the product design is set (Baumann & Tillman, 2004). Concurrently, making changes in the product design becomes increasingly more expensive over time (Baumann & Tillman, 2004).

This can be seen in the Volvo Cars product development cycle, where in the earliest product cycle phase of concept development, initial material choices and recommendations for sourcing are made, thus locking in the possible sustainability performance of a component or system already at the concept phase. Considering the importance of timing highlighted in literature, this means that integrating considerations of CO₂ and recycled content into early product development decisions related to materials is of particular importance, especially for meeting the corporate targets on CO₂ per vehicle, emissions from materials and recycled and biobased content. Also, to avoid more costly changes in later phases of product development, it is necessary for decision makers in both early and later phases to be aligned in their priorities.

However, there are many uncertainties regarding sustainability related and other data when making material choices in product development. For example, since the decision makers are typically R&D engineers without significant sustainability knowledge, the meaning of different sustainability data and potential interlinkages or trade-offs between them can be difficult to interpret. Another difficulty lies in how to compare and prioritize data with widely different scales and units, especially since in the past, cost has been the only deciding factor. Also, when different decision makers make decisions for specific components or systems in isolation and often with a great degree of personal judgement, there are risks of misalignment in how sustainability data is considered and valued, and that targets are not met in the most cost-efficient way when considered at component or system level. For the goal of increasing end-of-life circularity, since no targets are set and this aspect is thus not measured in any quantifiable way, it presents additional complexities in the decision making, regarding how to balance such values with quantified targets and budgets.

The problematic uncertainties described above are especially relevant for polymeric materials, where not only recycled but also biobased content is considered towards the same target, and downgrading of end-of-life material is quite common. Also, polymeric materials are frequently used for lightweighting, an important strategy for reducing environmental impact from the use phase and extending the range of electric vehicles (Lyu & Choi, 2015), adding yet another aspect for which potential trade-offs need to be handled.

Therefore, there is a need to investigate deeper the decision-making process for material selection in product development at Volvo Cars R&D, especially for polymeric materials. By gaining insight into how the decision makers consider and integrate sustainability performance data, both quantitative and qualitative, next to other data such as cost and weight when making material choices, it can be evaluated whether the potential misalignment risks described above are present in current decision making at Volvo Cars R&D. Additionally, common areas of uncertainty among decision makers and areas of possible improvement can be identified. As such, Volvo Cars can gain insight into how well current R&D decision making practices live up to the strategically desired operationalizing

of the corporate sustainability strategy via integration of the sustainability steering process, and what improvement actions are recommended.

3.1.2 Exterior Decision Case

The exterior material selection decision case consisted of three material alternatives for the frunk (front trunk) part system, which consists of the frunk itself and cover panels. The three material alternatives considered for the case were a recycled polypropylene alternative (Recycled PP), a mass balance biobased polypropylene alternative (Bio PP) and a lightweight, recycled polyester alternative (Lightweight PET).

All three material alternatives were based on what company experts on the frunk system considered realistic for this particular part system and examples of materials that had in the past been considered for these parts. The biobased PP material alternative was considered as somewhat less realistic according to the frunk experts, since it would not usually be considered when there already existed feasible recycled material alternatives, due to the expected higher cost of biobased materials. However, the Bio PP alternative was mechanically equally feasible as the other two materials, and therefore it was still included in the decision case to ensure that both studied decision cases included both recycled and biobased material alternatives.

3.1.3 Interior Decision Case

The interior material selection decision case consisted of three material alternatives for the luggage trim side panel part, which consists of a polymeric carrier and a polyester felt surface. Since the polyester surface material was identical for all three alternatives, only the plastic carrier material alternatives were included in the final decision case. The three material alternatives considered for the carrier were a natural fiber filled polypropylene bio composite alternative (NFPP), with both biobased and recycled content, a cotton fiber filled polypropylene bio composite alternative (PP/cotton), also with both biobased and recycled content, and a polyester mono material (Mono PES), with only recycled content. Similarly, for the exterior decision case, the three alternatives were based on what company experts on the luggage trim parts considered as realistic material alternatives for the luggage side panel.

3.2 Multi-Criteria Decision Analysis

MCDA was chosen as the main methodology for this study because of its ability to realistically model complex decision making with multiple, conflicting objectives and multiple alternatives among which none can be identified as the optimal solution (Guitouni & Martel, 1998). MCDA is “a set of methods that can be used to compare alternatives from a product level to a policy one, by covering one or more sustainability pillars” (Cinelli et al., 2014, p. 139). MCDA is also used to quantitatively model decision maker preferences, making it suitable for this study where a large number of decision maker preferences need to be compared.

For this study, the scope of sustainability assessment with MCDA was limited to environmental and economic considerations on a product level scale. Social sustainability aspects were not considered because they are prerequisites in the studied cases. Specifically, Analytic Network Process (ANP) was chosen as the MCDA method used.

3.2.1 Analytic Network Process Methodology

The ANP methodology is an extension of the Analytic Hierarchy Process (AHP) (Otay & Kahraman, 2019; Taherdoost & Madanchian, 2023). Both methods were proposed and developed by Saaty (1980, 1996) and can be used to identify the criteria weights as well as the ranking of alternatives according to decision makers’ preferences (Otay & Kahraman, 2019; Vaidya & Kumar, 2006), both of which are necessary in order to answer the first research question (see Section 1) of this study.

However, AHP, which structures a decision problem in terms of a strict hierarchy of the goal, criteria, sub-criteria and alternatives (Vaidya & Kumar, 2006), assumes that all criteria have inner and outer independence, and is unable to handle qualitative criteria (Guitouni & Martel, 1998). For this study, ANP was chosen over AHP due to its ability to structure a decision problem as a network and consider both inner (between the elements of a cluster) and outer (between elements of different clusters or between clusters) dependence of all elements (i.e. all criteria and alternatives) (Otay & Kahraman, 2019; Saaty, 2008). ANP includes pairwise comparisons of alternatives with criteria (Otay & Kahraman, 2019), capturing not only how different criteria priorities affect rankings of alternatives, but also how the specific criteria values of the alternatives affect criteria priorities (Saaty, 2008; Taherdoost & Madanchian, 2023). Therefore, applying ANP enables more realistic modelling of the Volvo Cars product development decision making situation, since these decisions are usually made based on (some) criteria information of alternatives. Therefore, it is possible to assume that the priority of different criteria is dependent on the actual criteria scores or values of the alternatives, i.e. there is an outer dependence between criteria and alternatives.

The inclusion of the qualitative criteria of end-of-life circularity presents further motivation for using ANP, because it can handle both quantitative and qualitative criteria (Taherdoost & Madanchian, 2023). Another advantage of ANP is its' ability to handle different units for inputs, which is also the case for the criteria considered in this study (Taherdoost & Madanchian, 2023).

Another motivation for using ANP is that the decision maker preferences, expressed for each pairwise comparison, can be collected using questionnaires (Jorge-García & Estruch-Guitart, 2022). Therefore, this allows for collecting a large number of responses from many different decision makers in the company in a relatively time efficient manner, which is necessary for generating a large enough collection of data for subsequent analysis of patterns in the decision maker' priorities and rankings.

ANP has in the past been applied to a wide range of decision-making problems, including environmental product development material selection in particular (Xu et al., 2023) and the engineering and environmental science fields in general (Taherdoost & Madanchian, 2023), making it a suitable choice for this particular study context.

3.2.1.1 Structuring the Decision Problem

The first step of any MCDA, and indeed also in ANP, is to structure the decision problem, deciding which criteria and alternatives to consider (Guitouni & Martel, 1998; Taherdoost & Madanchian, 2023). A general way to do this in MCDA is to put together a performance table, where the evaluations of each alternative (the table rows) are expressed for each criterion (the table columns) (Guitouni & Martel, 1998). See Table 1 below for a general performance table of the decision making situation considered in this study.

Table 1*Performance table of the decision problem*

Material alternatives	CO₂ (kg CO ₂ eq)	RC (kg)	Bio (kg)	Cost (SEK)	Weight (kg)	EOL circularity (qualitative)
Alternative 1	e_{11}	e_{12}	e_{13}	e_{14}	e_{15}	e_{16}
Alternative 2	e_{21}	e_{22}	e_{23}	e_{24}	e_{25}	e_{26}
Alternative 3	e_{31}	e_{32}	e_{33}	e_{34}	e_{35}	e_{36}

Note. The six criteria are the carbon footprint (CO₂), Recycled Content, Biobased content, Cost, Weight and end-of-life (EOL) circularity.

Four of the criteria: carbon footprint (CO₂), recycled content, cost and weight, can all be connected to existing quantified targets (or budget in the case of cost) as described in Section 1. Therefore, these four represent criteria that are currently often considered in Volvo Cars product development decisions. Biobased content is included as an additional criteria in order to evaluate whether decision makers prioritize biobased and recycled content equally, considering that the corporate strategic targets for polymeric materials treat them as equal, with a single, common target for both material feedstock types (Volvo Car Group, 2025). Finally, end-of-life circularity is included as the only qualitative criteria, which as described in Section 1 can be connected to the corporate goal of enabling circularity. This criterion is included in order to evaluate how qualitative criteria lacking quantitative targets in the sustainability steering process are prioritized by decision makers.

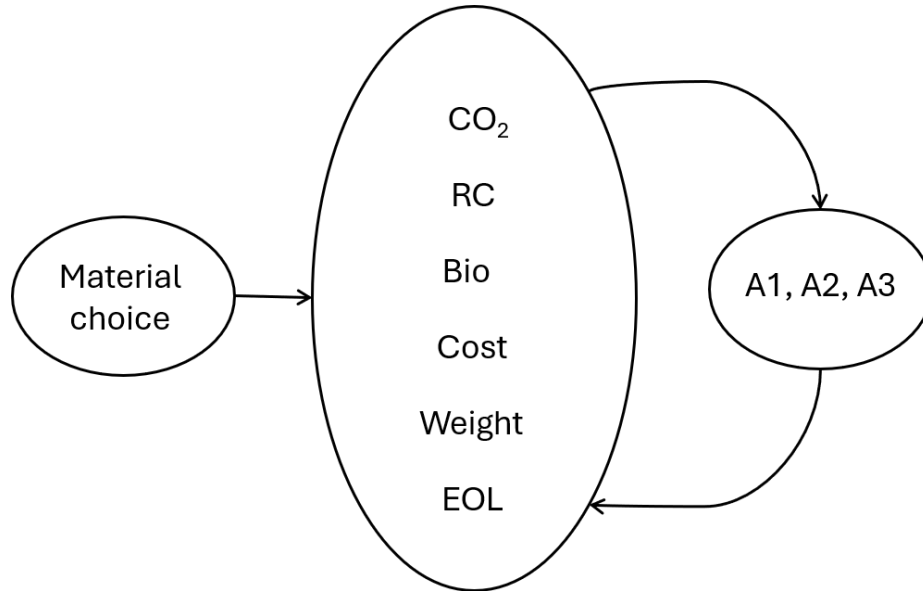
The evaluations e_{ij} of each alternative i for each criterion j in Table 1 were calculated and estimated for each specific decision case based on input collected from company experts on each decision case part. See Section 3.3.1 for the decision case performance tables.

In ANP, after defining the alternatives and criteria for the decision problem, next, the inner and outer dependence of all elements are identified (Otay & Kahraman, 2019). These are then illustrated in a network model with arrows indicating inner (between the elements of a cluster) and outer (between different clusters) dependence relationships (Al-Hawari et al., 2014; Otay & Kahraman, 2019).

A network model of the specific decision problem studied is presented in Figure 2 below.

Figure 2

Network model of the decision problem



Note. The cyclical arrows indicate the presence of mutual outer dependence between the two clusters: alternatives A1-A3 (right), and the six criteria (left). Material choice is the overall goal of the decision problem. Note that if not for the arrow from the alternatives cluster to the criteria cluster the decision problem would simply be a hierarchy model as in AHP, instead of an ANP network model.

3.2.1.2 Pairwise Comparison

After the problem structuring, the next step in ANP is to have the decision makers carry out pairwise comparisons of all elements in accordance with the dependence relationships of the network model (Taherdoost & Madanchian, 2023).

The overall objective of the studied decision problem, which guides the pairwise comparisons between elements, is also referred to as a control criterion (Al-Hawari et al., 2014). As seen in Figure 2, the control criterion is material choice or, simply expressed, “selecting the best material alternative”. As it is included in the network model, it is a so-called comparison linking criterion (Al-Hawari et al., 2014; Saaty & Vargas, 2013).

For the specific decision problem studied, modeled as in Figure 2, this entails having the decision makers’ make pairwise comparisons a) between the criteria, with respect to which is more important for selecting the best material alternative (which would be the only step done in AHP), b) between the alternatives with respect to which is more important for each criterion in selecting the best material alternative and c) between the criteria with respect to which is more important for each alternative in selecting the best material alternative.

Adapted from Saaty & Vargas (2013), an example of a question to be answered by decision makers in the pairwise comparison of type c) is: “Given the control criterion of selecting the best material alternative, the alternative A1 and the pair of criteria C1 and C2, how much more than C2 does C1 influence A1 with respect to selecting the best material alternative?”

Conversely, a type b) example is “Given the control criterion of selecting the best material alternative, the criterion C1 and the pair of alternatives A1 and A2, how much more than A2 does A1 influence C1 with respect to selecting the best material alternative?”

Finally, for type a) “Given the control criterion of selecting the best material alternative and the pair of criteria C1 and C2, how much more than C2 does C1 influence selecting the best material alternative?”

The pairwise comparisons can be collected using questionnaires (Jorge-García & Estruch-Guitart, 2022), where decision makers express the relative importance for each pair of compared elements in linguistic terms with corresponding numerical values as defined in Saaty’s fundamental scale, presented in Table 2 below. See Section 3.3.2 for how the questionnaires were constructed and used to collect the pairwise comparisons for the studied decision cases.

Table 2

Fundamental Scale (Saaty, 2008)

Linguistic term	Value
Equal Importance	1
Moderate Importance of one over another	3
Strong or Essential Importance	5
Very Strong or Demonstrated Importance	7
Extreme Importance	9
Intermediate values	2,4,6,8
Use reciprocals for inverse comparisons	

3.2.1.3 Matrix Operations

Once the decision makers’ pairwise comparisons are collected, the corresponding numerical values as defined in the fundamental scale (Table 2) are used to construct pairwise comparison matrices, where the row elements are compared to each column element, and reciprocal values are used for inverse relationships (Saaty & Vargas, 2013; Taherdoost & Madanchian, 2023).

Table 3 shows a general example of the pairwise comparison of six criteria (C1-C6) (as was, for example, done in this study with respect to the control criterion of selecting the best material alternative).

Table 3

Pairwise comparison matrix of six criteria with respect to a control criterion

Control Criterion	C1	C2	C3	C4	C5	C6
C1	1	a_{12}	a_{13}	a_{14}	a_{15}	a_{16}
C2	$a_{21} = 1/a_{12}$	1	a_{23}	a_{24}	a_{25}	a_{26}
C3	$a_{31} = 1/a_{13}$	$a_{32} = 1/a_{23}$	1	a_{34}	a_{35}	a_{36}
C4	$a_{41} = 1/a_{14}$	$a_{42} = 1/a_{24}$	$a_{43} = 1/a_{34}$	1	a_{45}	a_{46}
C5	$a_{51} = 1/a_{15}$	$a_{52} = 1/a_{25}$	$a_{53} = 1/a_{35}$	$a_{54} = 1/a_{45}$	1	a_{56}
C6	$a_{61} = 1/a_{16}$	$a_{62} = 1/a_{26}$	$a_{63} = 1/a_{36}$	$a_{64} = 1/a_{46}$	$a_{65} = 1/a_{56}$	1

Expressed generally, a_{ij} is the importance of element i compared with element j , and the inverse comparisons are then assigned the reciprocal value $a_{ji} = \frac{1}{a_{ij}}$ (Taherdoost & Madanchian, 2023).

The consistency of the comparison matrices needs to be verified. By calculating the consistency index using Eq. 1 below and dividing it with the random index (Table 4) for the number of elements in the matrix, the consistency ratio is calculated (Saaty, 2008). The consistency ratio should be ≤ 0.10 (Saaty, 2008). If it is larger than that, the pairwise comparisons may need to be repeated until appropriate consistency is reached. However, consistent pairwise comparisons are mostly relevant if using ANP as grounds for making a decision, thus wanting rational evaluations as the basis of alternative rankings. In this study, however, the ANP results are used to represent decision maker priorities for internal and external comparison, and not for making any actual decisions, why it is not considered necessary to repeat the comparisons in case of inconsistency. Instead, the inconsistency check is used only to identify where human error in the questionnaire responses might have resulted in mistakenly inputting reciprocals instead of the 1-9 values or vice versa.

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad 1$$

Table 4*Random Index for $n \leq 10$ elements (Saaty, 2008)*

n	Random Index
1	0
2	0
3	0.52
4	0.89
5	1.11
6	1.25
7	1.37
8	1.40
9	1.45
10	1.49

Next, local priority vectors are derived from the pairwise comparison matrices by solving Eq. 2 below for the eigenvector ω of the pairwise comparison matrix A with maximum eigenvalue λ_{max} (Taherdoost & Madanchian, 2023).

$$A = \lambda_{max} \times \omega \quad 2$$

One way of determining the priority vector ω is to first normalize the columns j of the comparison matrix A (n elements) using Eq. 3 below, and then the priority vector is obtained by calculating the arithmetic mean of each row i using Eq. 4 below (Alinezhad & Khalili, 2019).

$$a_{ij}^* = \frac{a_{ij}}{\sum_{i=1}^n a_{ij}}; j = 1, 2, \dots, n \quad 3$$

$$\bar{a}_i = \frac{1}{n} \sum_{j=1}^n a_{ij}^*; i = 1, 2, \dots, n \quad 4$$

Once the priority vectors for all pairwise comparison matrices have been calculated, they are compiled, constructing the unweighted super-matrix W (Saaty, 2008).

For a decision problem with six criteria (C1-C6) and three alternatives (A1-A3), and one control criterion (CC) with a network model like Figure 2 the corresponding unweighted super-matrix takes the shape of Eq. 5, where w_{xyi} is the i th element of each priority vector ω_{xy} , derived from the pairwise comparison matrix A_{xy} , where x denotes the type of comparison (see Section 3.2.1.2) and y denotes with respect to which element the comparison was done. All other entries in the super-matrix are zero entries, because the corresponding elements have no influence relationships (Taherdoost & Madanchian, 2023), as seen in Figure 2.

$$W = \begin{matrix} & \begin{matrix} CC & C1 & C2 & C3 & C4 & C5 & C6 & A1 & A2 & A3 \end{matrix} \\ \begin{matrix} CC \\ C1 \\ C2 \\ C3 \\ C4 \\ C5 \\ C6 \\ A1 \\ A2 \\ A3 \end{matrix} & \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ w_{aCC_1} & 0 & 0 & 0 & 0 & 0 & 0 & w_{cA1_1} & w_{cA2_1} & w_{cA3_1} \\ w_{aCC_2} & 0 & 0 & 0 & 0 & 0 & 0 & w_{cA1_2} & w_{cA2_2} & w_{cA3_2} \\ w_{aCC_3} & 0 & 0 & 0 & 0 & 0 & 0 & w_{cA1_3} & w_{cA2_3} & w_{cA3_3} \\ w_{aCC_4} & 0 & 0 & 0 & 0 & 0 & 0 & w_{cA1_4} & w_{cA2_4} & w_{cA3_4} \\ w_{aCC_5} & 0 & 0 & 0 & 0 & 0 & 0 & w_{cA1_5} & w_{cA2_5} & w_{cA3_5} \\ w_{aCC_6} & 0 & 0 & 0 & 0 & 0 & 0 & w_{cA1_6} & w_{cA2_6} & w_{cA3_6} \\ 0 & w_{bC1_1} & w_{bC2_1} & w_{bC3_1} & w_{bC4_1} & w_{bC5_1} & w_{bC6_1} & 0 & 0 & 0 \\ 0 & w_{bC1_2} & w_{bC2_2} & w_{bC3_2} & w_{bC4_2} & w_{bC5_2} & w_{bC6_2} & 0 & 0 & 0 \\ 0 & w_{bC1_3} & w_{bC2_3} & w_{bC3_3} & w_{bC4_3} & w_{bC5_3} & w_{bC6_3} & 0 & 0 & 0 \end{bmatrix} \end{matrix} \quad 5$$

With the priority vectors ω_{xy} , Eq. 5 instead takes the shape of Eq. 6.

$$W = \begin{matrix} & \begin{matrix} CC & C1 & C2 & C3 & C4 & C5 & C6 & A1 & A2 & A3 \end{matrix} \\ \begin{matrix} CC \\ C1 \\ C2 \\ C3 \\ C4 \\ C5 \\ C6 \\ A1 \\ A2 \\ A3 \end{matrix} & \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ \omega_{aCC} & 0 & 0 & 0 & 0 & 0 & 0 & \omega_{cA1} & \omega_{cA2} & \omega_{cA3} \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & \omega_{bC1} & \omega_{bC2} & \omega_{bC3} & \omega_{bC4} & \omega_{bC5} & \omega_{bC6} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \end{matrix} \quad 6$$

The unweighted super-matrix W is then weighted, by normalizing the columns of W , using Eq. 3, making it column stochastic (Saaty, 2008). Finally, the weighted super-matrix W_w is raised to exponential powers by multiplying with itself, until all row values converge to a single value, at k exponential powers (Otay & Kahraman, 2019). Once the values have converged, by normalizing separately over each cluster column in the limit matrix W^k (i.e. the criteria column and the alternatives column), the final priority weights of the criteria, and of the alternatives, are obtained, showing also the final ranking of alternatives (Saaty, 2008; Taherdoost & Madanchian, 2023).

Due to the relatively simple structure of the network model (Figure 2) with a limited number of criteria, alternatives and dependency relationships, all the matrix calculations were able to be carried out in a regular spreadsheet environment in Microsoft Excel.

3.3 Data Collection

The four main data collection processes for the study were i) collecting and calculating the data for the decision cases, including criteria values for each material alternative and target information, ii) collecting the decision maker preferences in questionnaires for pairwise comparison and deriving ANP results, iii) collecting further input related to the ANP results and about the sustainability steering process via supplementary interviews, and iv) collecting relevant background information from literature and previous studies to contextualize findings and identify relevant improvement actions. Each of these data collection points are described in more detail in the following sections.

3.3.1 Decision Problems

To structure the decision problem for each of the two decision cases by populating the performance tables, data was collected from various sources. The company experts on each studied part (or part system) were consulted regarding the part price (cost) and asked to provide a Bill Of Materials (BOM) for all alternatives. This BOM was populated by the engineers with supplier data, data extracted from technical systems and some expert judgment estimations, in accordance with the type of data sources usually available for this type of decision making situation. The values for the recycled content, biobased content and weight criteria for each material alternative were collected directly from the BOMs. For the qualitative criteria of end-of-life circularity, in addition to the part experts, a polymeric material expert at Volvo Cars R&D was consulted. For the carbon footprint criterion, cradle-to-gate values were calculated for the exterior case based on the BOM data using an internal company calculation tool that is usually available to R&D staff for supporting this kind of decision making. Due to limitations in the modelling capabilities of the internal company tool, it was not possible to use this approach for the carbon footprint values for the interior case, as the interior material alternative types were not included in the database of the tool. Instead, cradle-to-gate values were retrieved from the material supplier for the interior case, because that is according to the part expert realistically what would be done when the company tool is insufficient.

See Table 5 and Table 6 below for the populated performance tables for each decision case.

Table 5

Performance table of the decision problem for the exterior decision case (frunk part system)

Material alternatives Frunk system	CO₂ (10 ¹ kg CO ₂ eq)	RC (kg)	Bio (kg)	Cost (10 ² SEK)	Weight (10 ⁰ kg)	EOL circularity (qualitative)
Recycled PP	1.9x	4	0	y	1.6z	Mechanically recyclable with downgrading
Bio PP	2.0x	0	3,5	1.25y	1.6z	Mechanically recyclable with slight or no downgrading
Lightweight PET	x	3	0	1.3y	z	Chemically recyclable with slight or no downgrading

Note. The values for all quantitative criteria, not just recycled and biobased content, were stated in absolute terms in the performance tables presented to decision makers. Here, the carbon footprint, cost and weight criteria values of each material alternative are instead expressed in relation to the lowest value (x, y, or z) for each criterion, to protect the internal, sensitive data.

Table 6

Performance table of the decision problem for the interior decision case (luggage trim side panel)

Material alternatives Luggage trim	CO₂ (10 ⁰ kg CO ₂ eq)	RC (kg)	Bio (kg)	Cost (10 ² SEK)	Weight (10 ⁰ kg)	EOL circularity (qualitative)
NFPP	2.9x	1,5	1	1.03y	z	Incineration
PP/cotton	x	1	1	y	1.1z	Incineration
Mono PES	2x	2	0	1.2y	z	Mechanical recycling with downgrading

Note. The values for all quantitative criteria, not just recycled and biobased content, were stated in absolute terms in the performance tables presented to decision makers. Here, the carbon footprint, cost and weight criteria values of each material alternative are instead expressed in relation to the lowest value (x, y, or z) for each criterion, to protect the internal, sensitive data.

Additionally, status and target information for related strategic targets at the department level were collected from internal reporting systems for a project currently in development at Volvo Cars. The status values were adjusted so that none of the material alternatives would allow complete fulfilment of either target, to ensure that there was no easy, intuitive

choice, thus further motivating decision maker participation in the ANP. Also, the weight status was adjusted so that all material alternatives were within the allowance of the weight target, in accordance with past experiences of the R&D engineers consulted for this data collection process, that sustainability criteria would never even be considered as basis for the decision if the weight target or cost budget were over target, due to the current landscape of the automotive industry creating huge cost and weight pressures. This is also the motivation for assuming that there is still room left in the budget. See Table 7 and Table 8 below for the status and target information tables for each decision case. These were provided to participating decision makers along with the performance tables because they contain contextual information that is often considered by decision makers in material choices, thus making the decision cases as realistic as possible. The decision makers were instructed to consider the target information as much or as little as they would if the provided decision case was real, to again ensure as realistic of a representation of the decision making situation as possible.

Table 7

Department level status and target information for existing, quantified strategic targets, for the exterior case department

Program target information (Department level)	Status Exterior Front & Rear	Target Exterior Front & Rear
CO ₂	1.1x 10 ² kg CO ₂ eq	x 10 ² kg CO ₂ eq
Recycled/Bio Content	0.8y 10 ¹ kg	y 10 ¹ kg
Weight	0.9z 10 ¹ kg	z 10 ¹ kg
Cost	There is still room in the program budget	

Note. All of the quantitative status and target values were stated in absolute terms in the materials presented to decision makers. Here, the status values are instead expressed in relation to each target value (x, y, or z), to protect the internal, sensitive data.

Table 8

Department level status and target information for existing, quantified strategic targets, for the interior case department

Program target information (Department level)	Status Interior Trim	Target Interior Trim
CO ₂	1.2x 10 ² kg CO ₂ eq	x 10 ² kg CO ₂ eq
Recycled/Bio Content	0.8y 10 ¹ kg	y 10 ¹ kg
Weight	0.9z 10 ¹ kg	z 10 ¹ kg
Cost	There is still room in the program budget	

Note. All of the quantitative status and target values were stated in absolute terms in the materials presented to decision makers. Here, the status values are instead expressed in relation to each target value (x, y, or z), to protect the internal, sensitive data.

3.3.2 Analytic Network Process Questionnaires

The questionnaire for collecting data of pairwise comparisons by decision makers was constructed in Microsoft Excel, for easy dissemination and because of the high level of familiarity with the Excel environment among decision makers. The questionnaire consisted of three parts, each containing the pairwise comparison matrices of type a), b) and c) (see Section 3.2.1.2).

Each pairwise comparison matrix cell was filled out by selecting the decision maker numerical evaluation of each pairwise comparison from a dropdown list according to a response key based on Saaty's (1996) fundamental scale, see Table 9. To simplify completion of the questionnaire, only the bottom diagonal half of each comparison matrix was open for input, while the corresponding reciprocals in the top diagonal half were automatically populated with the inverse relationship values using Excel formulas, see Figure 3.

Table 9*Response key for pairwise comparison*

Response key		
Numeric value	Linguistic term	Explanation
1	Equal Importance	The row element and the column element contribute equally to the objective
2		Intermediate value
3	Moderate Importance	Experience and judgment slightly favor the row element over the column element
4		Intermediate value
5	Strong Importance	Experience and judgment strongly favor the row element over the column element
6		Intermediate value
7	Very Strong Importance	The row element is strongly favored , and its dominance over the column element is demonstrated in practice
8		Intermediate value
9	Absolute Importance	The highest possible order for the importance of the row element over the column element is considered
1/x	Inverse importance	Used when the column element is more important than the row element

Note. Based on Saaty (1996), explanations adjusted to refer explicitly to the row and column elements of pairwise comparison matrices and emphasis added.

Part 1 (P1) of the questionnaire, type a) pairwise comparisons, consisted of one comparison matrix comparing the different criteria with respect to the control criterion of “selecting the best material alternative” (and the response key for reference). As such it covered the AHP type comparison, resulting in criteria priorities for general material selection decision making. The Part 1 comparison matrix is pictured in Figure 3 below.

Part 2 of the questionnaire, type b) pairwise comparisons, consisted of six comparison matrices comparing the different material alternatives with respect to each criterion while still keeping the control criterion in mind, as well as the response key, decision case performance table and target information table for reference. The Part 2 comparison matrix is pictured in Figure 4 below.

Part 3 of the questionnaire, type c) pairwise comparisons, consisted of three comparison matrices comparing the different criteria with respect to each material alternative criterion while still keeping the control criterion in mind, as well as the response key, decision case performance table and target information table for reference. The Part 3 comparison matrix is pictured in Figure 5 below.

Figure 3

ANP questionnaire Part 1 pairwise comparison matrix

	A	B	C	D	E	F	G
1	"Selecting the best material alternative"	CO2	RC	Bio	Weight	Cost	EOL
2	CO2	1					
3	RC		1			1/6	
4	Bio			1			
5	Weight				1		
6	Cost		6			1	
7	EOL						1
8							
9							
10							
11							
12							
13							
14							
15							
16							
17							

Note. Questionnaire Part 1 consisted of one pairwise comparison matrix, comparing the six criteria with respect to the control criterion of “selecting the best material alternative”. Decision maker evaluations of each pairwise comparison were input into the corresponding white cell by selecting from the dropdown list of numeric values according to Saaty’s (1996) fundamental scale. Corresponding inverse comparisons in the grey cells were then automatically populated with the reciprocal value.

Figure 4

ANP questionnaire Part 2 pairwise comparison matrix

	A	B	C	D
1	CO2	Recycled PP	Bio PP	Lightweight PET
2	Recycled PP	1		
3	Bio PP		1	
4	Lightweight PET			1

Note. Questionnaire Part 2 consisted of six such pairwise comparison matrices, one for each criterion, comparing the three material alternatives in a decision case with respect to each criterion, here pictured for the exterior case material alternatives.

Figure 5

ANP questionnaire Part 3 pairwise comparison matrix

	A	B	C	D	E	F	G
1	Recycled PP	CO2	RC	Bio	Weight	Cost	EOL
2	CO2	1					
3	RC		1				
4	Bio			1			
5	Weight				1		
6	Cost					1	
7	EOL						1

Note. Questionnaire Part 3 consisted of three such pairwise comparison matrices, one for each material alternative, comparing the six criteria with respect to each material alternative, here pictured for the recycled PP alternative in the exterior case.

Each of the questionnaire parts were accompanied by another worksheet containing detailed step by step instructions, in writing and images, for how to complete that questionnaire part, so that decision makers could choose to complete the questionnaire on their own.

In addition to the ANP parts of the questionnaire, it included a link to an online form constructed in Microsoft Forms. In a mix of multiple choice and text response questions, supplementary input was collected about how much the decision makers considered the target information in their questionnaire completion and their usual decision making practices. For the complete set of questions posed in the online form, see Figure A8 in Appendix.

3.3.2.1 Questionnaire Testing

To evaluate the functionality of the questionnaire before dissemination to decision makers, it was tested by three different R&D engineers, all of which were largely unaware of the context of the study. Based on this, some clarifications to the instructions and the structure of the questionnaire were made. Primarily, the response key and pairwise comparison response cells were adjusted to include the fundamental scale numeric values in addition to the linguistic terms. This was done because the testers felt that only responding in linguistic terms (as is recommended by the ANP method) was too confusing, and thought that many of the R&D decision makers (who are more familiar with numbers than linguistic terms) might be discouraged from participating if not being able to respond in the numeric terms instead of linguistically. Collecting the responses numerically also made exporting the collected pairwise comparison responses to another spreadsheet for deriving the ANP results much easier, allowing collection of a higher number of results in the allotted time.

3.3.2.2 *Questionnaire Dissemination and Completion*

A person who can be considered a company expert deeply familiar with the different kinds of decision maker roles at Volvo Cars R&D was consulted regarding relevant participants for the study. Anyone who could be considered as a decision maker within hardware product development at Volvo Cars R&D was deemed a relevant study participant. This scope included many decision makers who usually would not be the ones that make the exact type of decisions covered in the cases (i.e. polymeric material selection, at component specific level, in early phase, at the exterior or interior departments) because a part of the misalignment assessment that is the aim of this study also includes misalignment between different product development phases and different levels of decision making in the organization. That the cases studied consist of polymeric material selection was also deemed less relevant for participant selection, since metal decision cases would include the same type of criteria (except for biobased content) and data. In summary, if the decision maker was somehow affecting the strategic target performance of the program targets in their usual decision making, they were deemed a relevant participant for the study. This resulted in a list of 204 names of potential participants.

These 204 decision makers were sent individual emails requesting their participation in the study. The ones who chose to participate in the study were given the choice to either complete the questionnaire on their own according to the written instructions, with on-demand support available from the practitioner of the study. They were given the alternative of booking an in-person meeting with the practitioner of the study for verbal instructions, where the study practitioner would be the one to continuously fill in the responses as given by the decision maker. The latter was presented as the recommended way of participating, since an in-person meeting allowed for greater insight into the decision makers' reasoning and also made it easier to avoid decision makers misunderstanding the ANP method.

Out of 204 contacted decision makers, 79 agreed to participate in the study within the timeline of the data collection phase. As for the other 125 contacted decision makers, the majority simply never responded to the emails sent out, some responded too late to be included in the ANP data collection and a few declined to participate either because of a lack of time or because they deemed their current role not a good fit for the study.

Out of the 79 ANP questionnaires collected, 5 were self-completed by the decision makers according to the written instructions. 5 were completed with a combined approach, where some instructions and start of the questionnaire responses were given in an in-person meeting with the practitioner of the study, but the rest of the questionnaire self-completed afterwards by the decision makers. The remaining 69 ANP questionnaires were fully completed in an in-person meeting, with the practitioner of the study guiding and interviewing the decision makers throughout the questionnaire completion process. 66 out of the 79 decision makers also responded to the supplementary questions online form.

Upon first contact with the 204 decision makers, an initial split into respondent groups for the exterior and interior decision cases was done, based on the desire to have representatives from all kinds of roles and departments for both decision cases. However, throughout the process of booking and meeting with decision makers, this decision case split was continuously revised depending on which decision makers ended up participating, to ensure that the desired representativeness was maintained among the final respondents. The final amounts of responses obtained for each decision case were 39 for the exterior case and 40 for the interior case.

3.3.2.3 Deriving ANP Results from Questionnaires

An automated template for deriving the ANP results was constructed in Excel according to the three-part structure of the questionnaire, to allow for easy exporting of the response data from the questionnaire to the results template. After inputting the questionnaire responses into the corresponding comparison matrices in the results template, the consistency ratios and priority vectors for each comparison matrix were calculated automatically by integrating the formulas presented in Section 3.2.1.3 into Excel. The supermatrix was then constructed by all of the local priority vectors using linking formulas in Excel. Finally, the supermatrix was raised to its powers using the matrix multiplication formula in Excel until the row values converged, thus obtaining the final criteria and material alternative priority weights in the limit matrix. In this way, the results for each decision maker were obtained by exporting the questionnaire responses into a copy of the results template.

3.3.2.4 ANP Results Visualization

The main results extracted from the ANP results template consist of two criteria priority vectors: one from Part 1 of the form, for the general material selection decision making (pairwise comparisons of type a), and the other from the final limit matrix covering all three parts of the form, i.e. both general material selection decision making and the specific decision case. The final part of the ANP results consists of the material alternatives preference ranking, extracted from the alternatives priority vector found in the limit matrix. These are the main results used to answer research question 1 and 2 (see Section 1) and they were visualized by plotting radar charts using Excel (see Section 4.1). See Table A1 in Appendix for the complete set of results extracted from the ANP results templates.

In some cases, transforming the alternatives priority vector from weights into a preference ranking caused very similar preference weights for two alternatives to appear as a larger difference, since they were separated by an equal distance in the ranking as for larger weights differences. Therefore, the alternatives priority vector weight results were for reference also visualized as radar charts, see Figure A1-A7 in Appendix. Additionally, some extra insights and ideas brought up by decision makers in the in-person meetings were collected during the ANP completion, but these results are presented together with other insights from the supplementary interviews in Section 4.2.1 below.

An important idea brought up by some decision makers in the in-person meetings is that it would make sense for the criteria priorities, particularly for the general material selection decision making in Part 1 (P1), to vary between different roles depending on what department they belong to since that affects what sort of material content the decision maker is used to. For example, since metals and electronics usually have much higher carbon footprint than polymers, it would make sense that those usually working with a lot of electronics or metal materials might prioritize carbon footprint over recycled or biobased content, especially since biobased content is only applicable as a criterion for polymeric materials. Those usually working with a lot of polymeric content, however, might be more likely to prioritize recycled content over carbon footprint, since the order of magnitude of differences in carbon footprint are generally smaller for polymeric alternatives than for metals or electronics. To analyze this theory, the ANP results were plotted for the main kinds of material content the respective decision makers are used to working with. A similar idea expressed by decision makers in meetings was that it would also make sense for priorities to vary depending on the type of manufacturing content that a decision maker usually works with. Specifically, a decision maker with mainly Full Service Supplier (FSS) content (meaning that an external supplier is responsible for the complete design, development, material selection and production of a certain part or part system) might prioritize sustainability criteria less because they have less information and less ability to affect the sustainability performance. Therefore, it would make sense to compare them with decision makers with mainly Built-to-Print (BtP) content, where Volvo Cars instead has full control over the product development process, or decision makers

with mixed FSS and BtP content. Thus, this kind of content difference was also used as a basis for the ANP results plots.

The other defining subgroups for the plotting of ANP results were based on expert judgement from the same company expert responsible for identifying relevant decision makers, complemented with how the decision makers described their own roles during in-person meetings, as exemplified above for the content definition groups. In addition to plotting the complete sets (ALL RESULTS) of criteria priority weights from Part 1 of the form (P1) and the final limit matrix (FINAL), as well as the complete sets of associated rankings from the exterior and interior decision case respectively, definition subgroups were based on the level at which the decision maker operates, the phase of the product development cycle in which the decision maker is involved, and as mentioned above, the main kinds of content that the decision maker usually works with.

For the level definition, two different groupings were made, one general and the other more specific:

- i) Whether the decision maker usually makes decisions at the detailed, component level (COMPONENT), or if they have a broader scope of their decision making, not necessarily being the main responsible in part or part specific level decision making (BROAD).
- ii) Whether the decision maker is operating at the team level, i.e. the most granular constellation within decision making at Volvo Cars R&D (TEAM), the department level, i.e. one step above team, covering all teams in a certain department (DEPARTMENT), the subunit or unit level, i.e. covering multiple departments in a subunit or unit (due to a relatively small group of respondents at the subunit level, these were grouped with the unit level decision makers) (UNIT), or at the highest level of the complete vehicle, i.e. covering all units in the complete vehicle (COMPLETE VEHICLE).

For the product development cycle phase definition, again, two different groupings were made, one general and the other more specific:

- i) Whether the decision maker is involved in a certain program, i.e. a certain car model project (PROGRAM), or is working in the line organization, i.e. being responsible for a certain area or content for all car programs (LINE).
- ii) Whether the decision maker is involved in the early phase of the program cycle, meaning before and up to the final definition of the product concept (EARLY), the late phase of the program cycle, meaning after the product concept has been finalized (industrialization and onwards) (LATE), or if they are working in the line organization as described above (LINE).

For the content definition, another two different groupings were made as described previously, one based on the material content, and the other based on the manufacturing type content:

- i) Whether the decision maker usually works with mainly polymeric content (PLASTIC), mainly polymeric and metallic content (PLASTIC & METAL), mainly polymeric content and electronics (PLASTIC & ELECTRONIC) or mainly all three kinds of material content (ALL MATERIAL).
- ii) Whether the decision maker usually works with mainly Full Service Supplier content (FSS), mainly Build-to-Print content (BTP) or both types of content (MIXED).

The ANP results charts for the complete sets of results and smaller groupings are shown in Figure 6-19 in Section 4.1 below.

3.3.3 Supplementary Interviews

Once the ANP results were compiled and visualized, supplementary informal interviews were held with decision makers to gain further perspectives related to the studied decision making situation and the obtained results. For further insight into the current state of the sustainability steering process and upcoming integration efforts, two company experts on the sustainability steering process, from the central sustainability function in the company, were interviewed. This interview revealed an upcoming training for R&D engineers about the sustainability steering process, and the first of these training sessions was observed along with training materials, allowing even further insight into the sustainability steering process integration efforts.

3.3.4 Literature Review

Review of literature and previous empirical studies was concentrated in the two research areas of life cycle management and sustainable (or green/environmental) product development because initial literature searches found that the studied decision making situation and the Volvo Cars sustainability steering process can be considered examples of typical life cycle management and environmental product development activities (see Section 2). Since the main focus of this study is on the empirical findings from applying the mixed method of ANP and supplementary interviews, the literature review was concentrated on review articles and select previous empirical studies at manufacturing companies. This was deemed sufficient to gain the necessary level of understanding of the main concepts and previous findings for utilizing previous literature and empirical findings for contextualizing the findings of this study and for identifying and evaluating potential improvement actions. The background of the ELV directive was also reviewed because it presents some of the regulatory type motivations for LCM and SPD mentioned in literature, and because it was found to be highly relevant for contextualizing the study findings and identifying and evaluating potential improvement actions related to the recycled content, biobased content and end-of-life circularity criteria.

4 Results and Analysis

This section presents and analyses the results of the study. First, the ANP results, visualized as radar charts, are presented and subsequently analyzed in Section 4.1, by identifying and analyzing similarities and differences and associated misalignment. Section 4.2 presents and analyses the results from supplementary interviews with decision makers and sustainability steering process experts. Finally, Section 4.3 combines insights from the previous sections to recommend improvement actions for addressing the identified misalignment and improving integration of the sustainability steering process.

4.1 Analytic Network Process Results

This section covers research question 1 and research question 2 (see Section 1) by presenting and visually analyzing the ANP results. Similarities and differences within and between the decision maker subgroup results are described and analyzed in order to identify areas of internal (within subgroups) and external (between subgroups) misalignment. Finally, similarities and differences between the ANP results and the strategic targets are analyzed and associated instances of misalignment are identified.

4.1.1 Subgroup Internal Misalignment

Figures 6-12 bring the perspective of subgroup internal misalignment. When looking at the criteria priority weights in these figures there is a noticeable variation in the criteria weights between the different decision makers, which can be visually identified in the difference of how dark the colored areas of the radar charts are. More overlap in priority weights corresponds to a darker, more filled in area in the chart, which in turn indicates a higher level of alignment of criteria priorities. This variation can be seen no matter if considering the complete sets of results in Figure 6 or any of the subgroup results shown in Figure 7-12, indicating the presence of misalignment in the priorities of decision makers even among those with similar roles. This indicates that differences in priorities might be caused by individual preferences rather than the type of role the decision maker has, presenting a possible misalignment risk, internally, within the different subgroups. This supports findings in previous LCM studies, that individual understanding and values affect managerial action in environmental matters rather than rational judgment (Nilsson-Lindén et al., 2018).

Figure 6

Criteria priority weights (Part 1 and final limit matrix) for all ANP results (a-b) and split between the two decision cases (c-f)

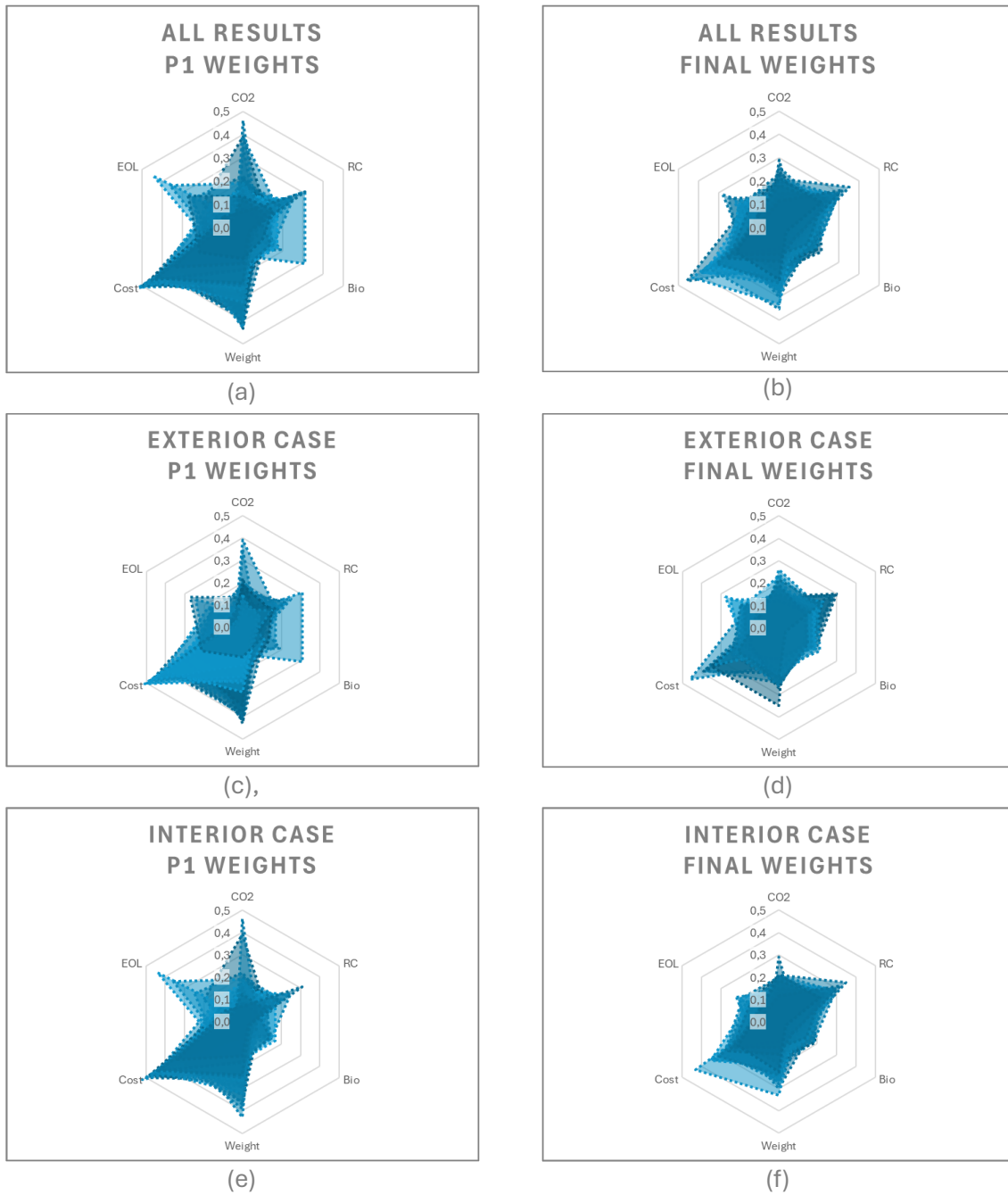


Figure 7

Criteria priority weights (Part 1 and final limit matrix) for all ANP results split between component level and broad level decision makers

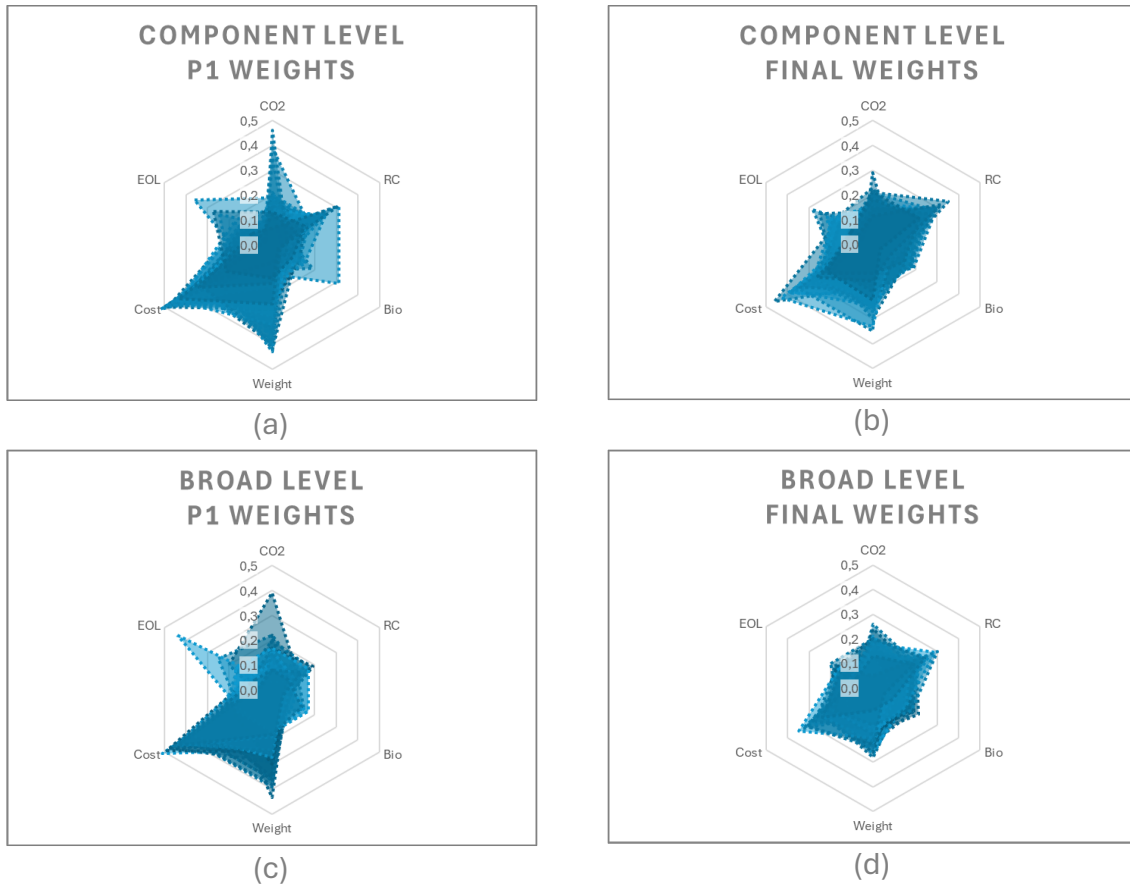
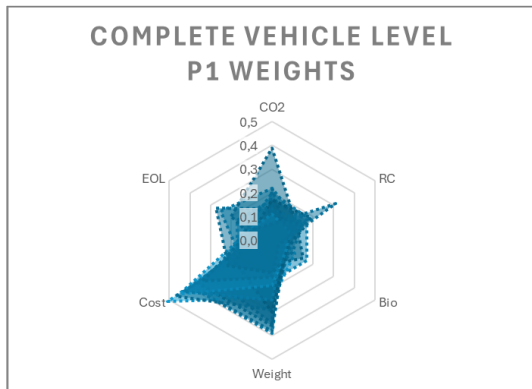


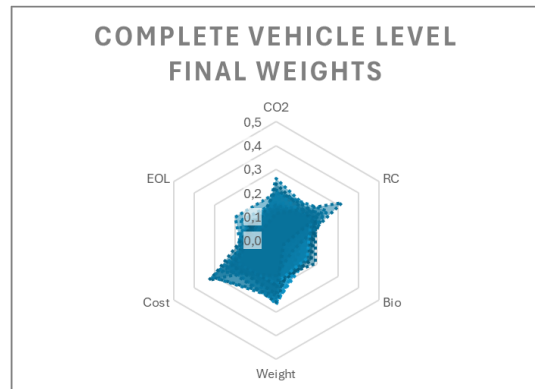
Figure 8

Criteria priority weights (Part 1 and final limit matrix) for all ANP results split between team level, department level, unit level and complete vehicle level decision makers.





(g)



(h)

Figure 9

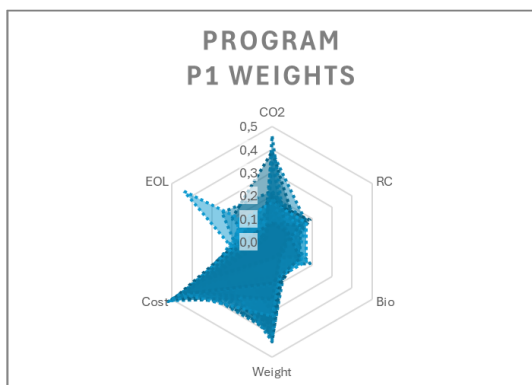
Criteria priority weights (Part 1 and final limit matrix) for all ANP results split between decision makers working in the line organization and decision makers working in specific car programs.



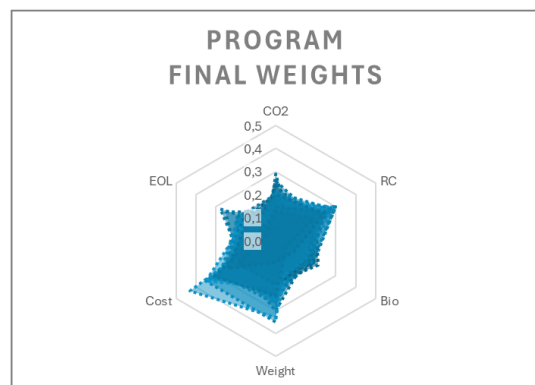
(a)



(b)



(c)



(d)

Figure 10

Criteria priority weights (Part 1 and final limit matrix) for all ANP results split between decision makers working in the early phase of the product development cycle, in the late phase of the product development cycle and in the line organization.

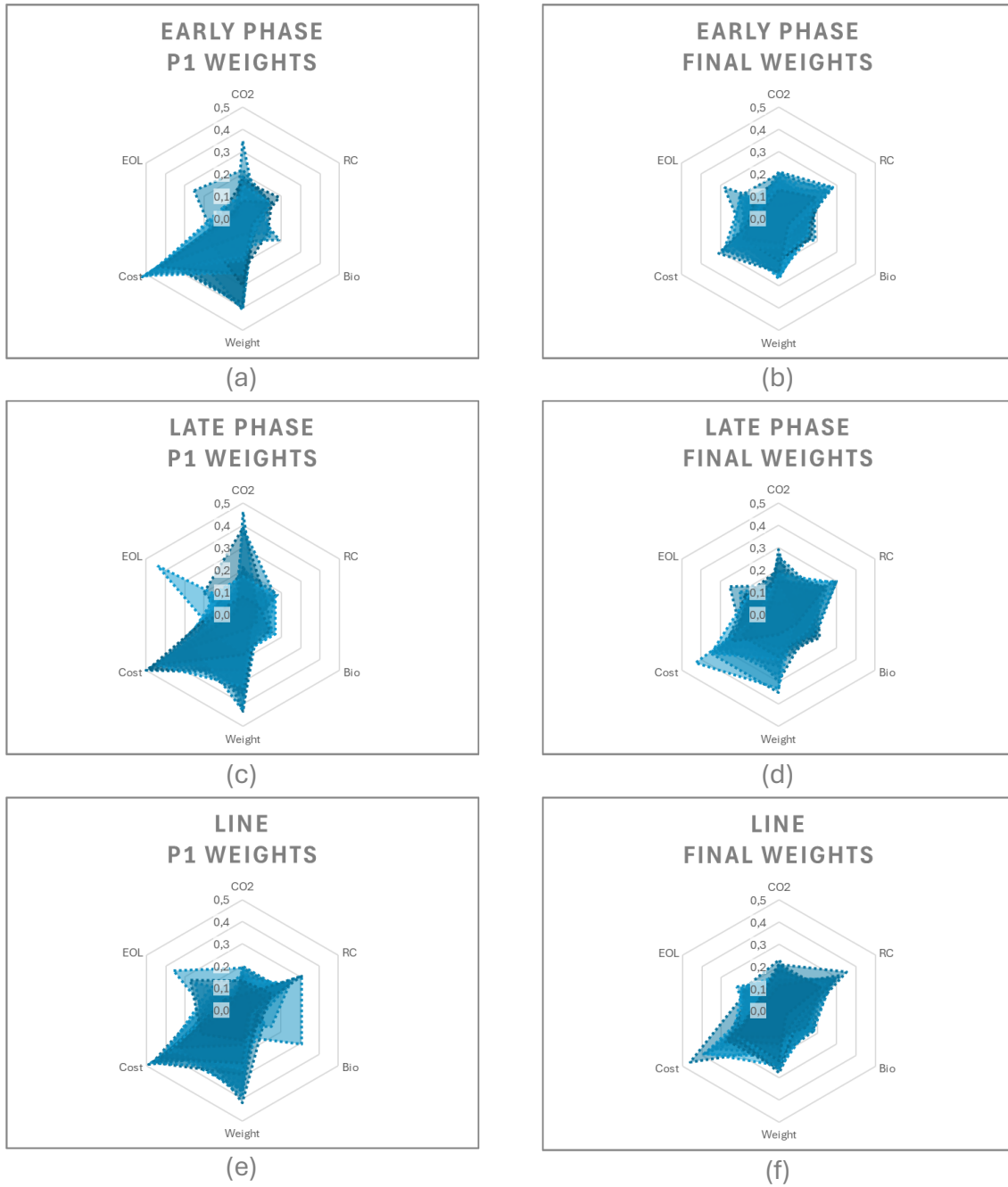
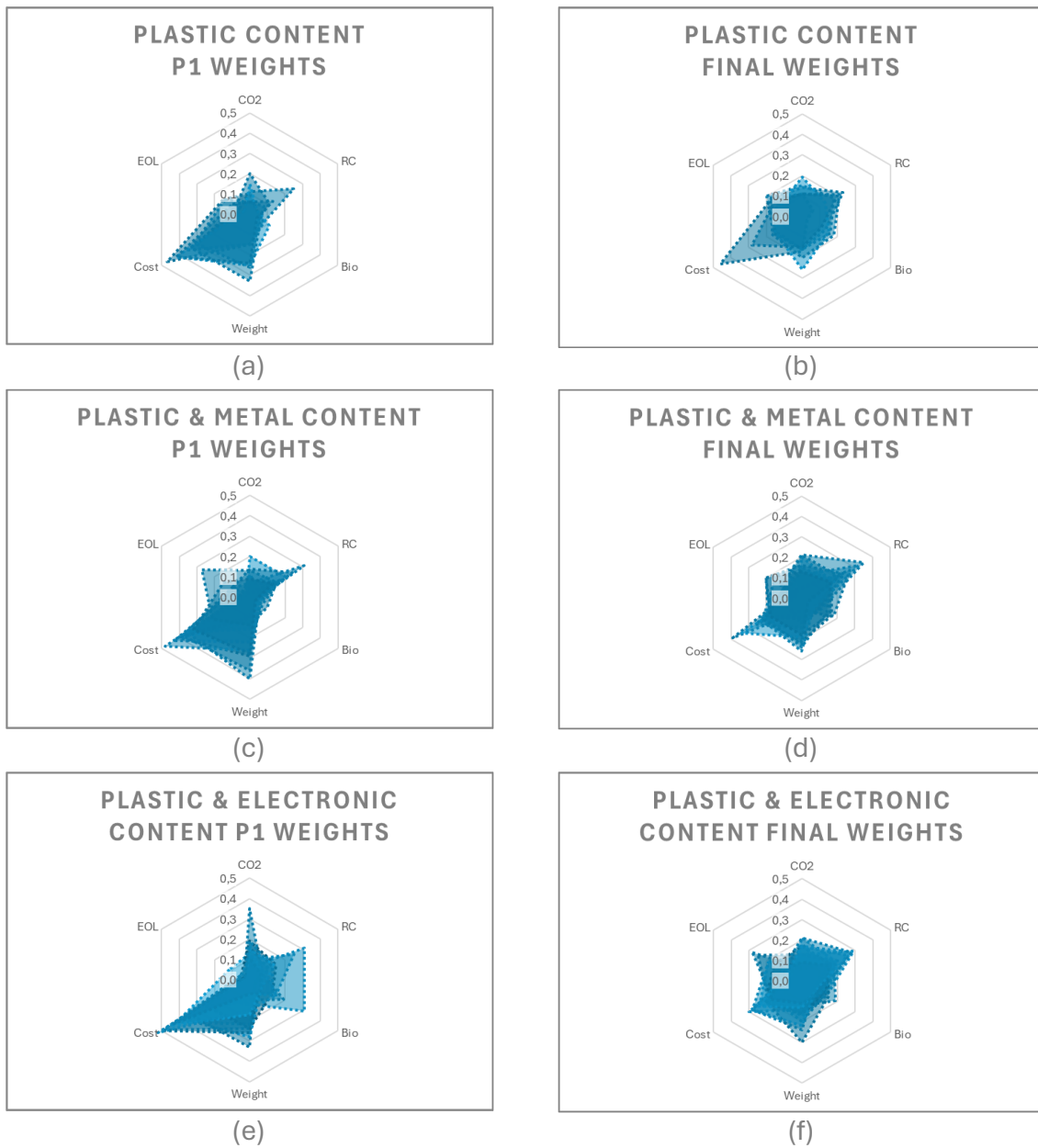
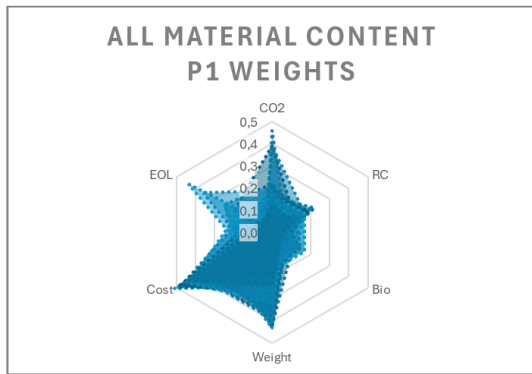


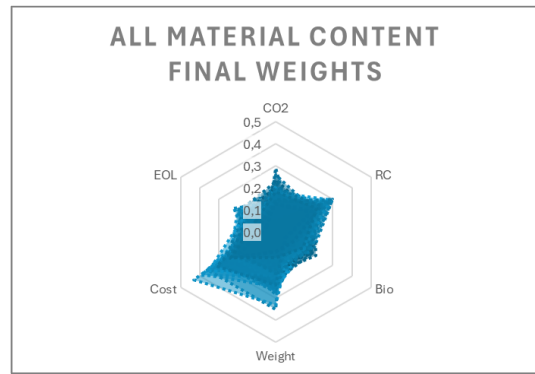
Figure 11

Criteria priority weights (Part 1 and final limit matrix) for all ANP results split between decision makers working with mainly plastic content, mainly plastic and metal content, mainly plastic and electronic content, and all kinds of material content.





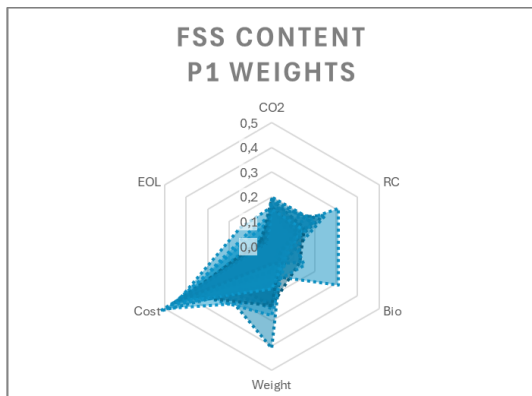
(g)



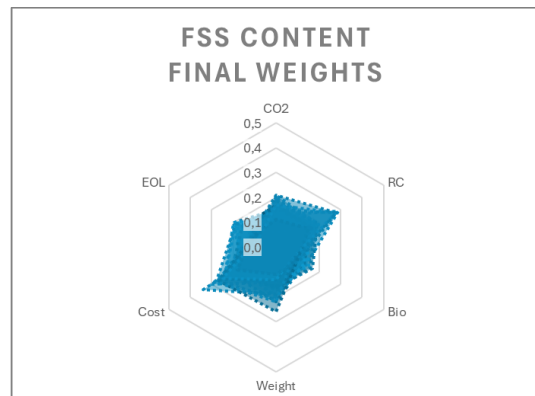
(h)

Figure 12

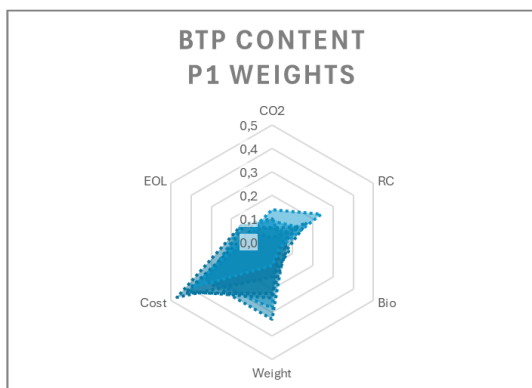
Criteria priority weights (Part 1 and final limit matrix) for all ANP results split between decision makers working with mainly Full Service Supplier content, mainly Build-to-Print content and mixed Full Service Supplier and Build-to-Print content.



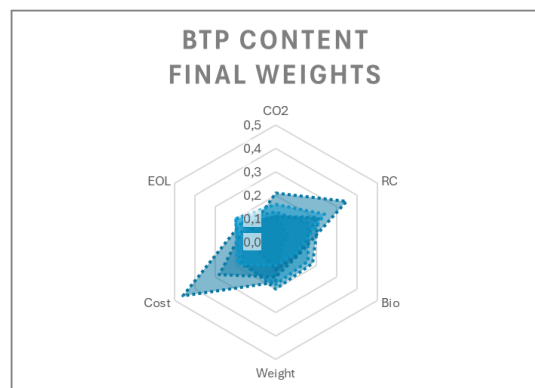
(a)



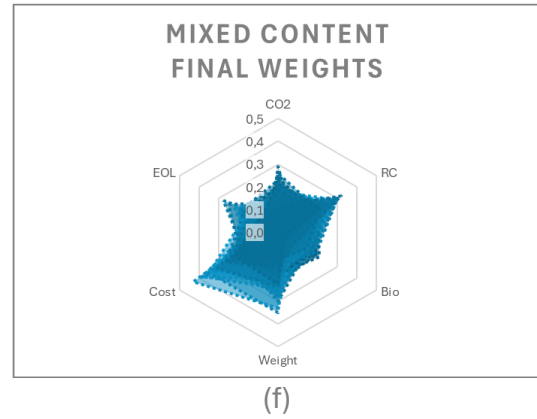
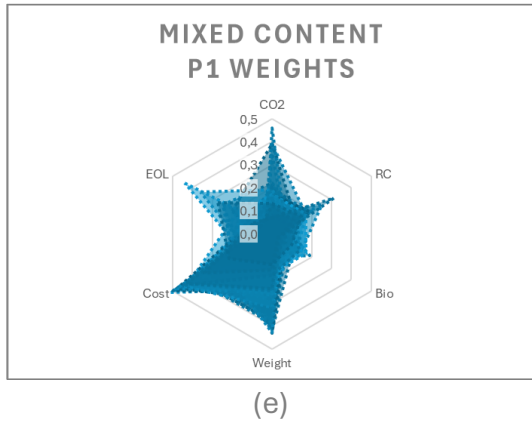
(b)



(c)



(d)



If comparing the P1 criteria weights with the final criteria weights for all subgroups in Figure 6-12, the resulting radar chart areas of the final weights seem to become more concentrated towards the middle of the chart, compared with larger peaks showcased in the P1 weight charts. Generally, this indicates that the priority weights of the different criteria become more similar, with less extreme preferences for one over the other, when looking at a specific decision case and having actual data to compare, in contrast to only being asked about the general decision making experience and preferences in P1. This is in line with what has previously been observed in ANP and is one of the key aspects of expanding AHP to ANP, that people become more willing to “pay” for certain criteria values when having actual numbers or data associated with the available alternatives (Colicchia, 2010). This example of the order of magnitude of the priority weights becoming more similar for the final weights compared to the P1 weights can be observed in all of the subgroup charts except the BTP content subgroup (see Figure 12c and 12d), i.e. in 18 out of a total of 19 subgroups.

4.1.1.1 Final Criteria Weights Results

Importantly, even though the difference between the criteria weights order of magnitude seems to generally decrease for the final weights compared to P1 for each individual decision maker, there is still substantial variation between different decision makers' priority weights showcased in many of the final weights charts (see Section 4.1.1).

For example, this variation can be seen in Figure 6b for the cost, weight, EOL and biobased content criteria. If instead looking at the subgroup results, similar levels of variations in the final weight for the cost criterion can be seen in Figure 6d, 6f, 7b, 8b, 8d, 9b, 9d, 10d, 10f, 11b, 11d, 11h, 12d, 12f, i.e. in 13 out of a total of 19 subgroups (Figure 9b and 10f show the same subgroup results). For the weight criterion, similar levels of variations in the final weights can be seen in Figure 6f, 7b, 7d, 9d, 9h, 10b, 10d, 11d, 11f, 12f and 12h, i.e. 11 out of 19. Again, for the EOL criterion final weights in Figure 6d, 7b, 8d, 8f, 9b, 9d, 10b, 10d, 11f, 12f, i.e. 10 out of 19. For the biobased content criterion final weights, in Figure 6d, 6f, 7b, 7d, 8f, 8h, 9b, 9d, 10b, 10d, 10f, 12b, 12d, 12f, i.e. 13 out of 19.

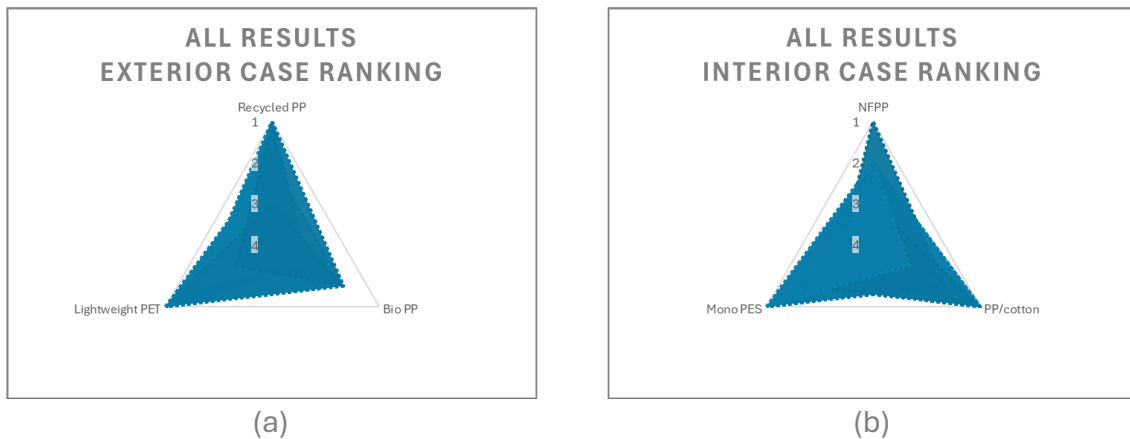
In general, for the recycled content and carbon footprint criteria, the final criteria weights have less variation in almost all charts in Figures 6-12, as most of the peaks for the carbon footprint and recycled content criteria have a darker, more filled-in area indicating more overlap and alignment in priorities between decision makers than for the other four criteria.

Since the final criteria weights analyzed here are obtained for the specific polymeric decision cases considered in this study, the above observations can be taken to indicate that end-of-life circularity, biobased content, cost and weight are misalignment areas for polymeric material selection decision making. However, when comparing these observations with the results for the P1 criteria weights, a general trend of preference weights for cost and weight decreasing between P1 and final weights can be observed in all pairs (e.g. a and b, c and d, e and f and so on) of P1 and final weight results in Figure 6-12. Combined with the misalignment areas identified for the final weights results this could indicate that the general internal misalignment is between how much of the cost and weight priority is sacrificed in favor of sustainability aspects, for the polymeric material decision case. Specifically, in favor of which sustainability aspects between biobased content and end-of-life circularity, with recycled content and carbon footprint final priorities being more aligned between decision makers in most subgroups. Perhaps the internal misalignment for the EOL criterion could be considered as slightly less than for biobased content, as substantial variations in priorities were observed in fewer subgroups.

4.1.1.2 Material Alternative Ranking Results

Figure 13

Material alternative preference ranking for all ANP results split between the two decision cases.

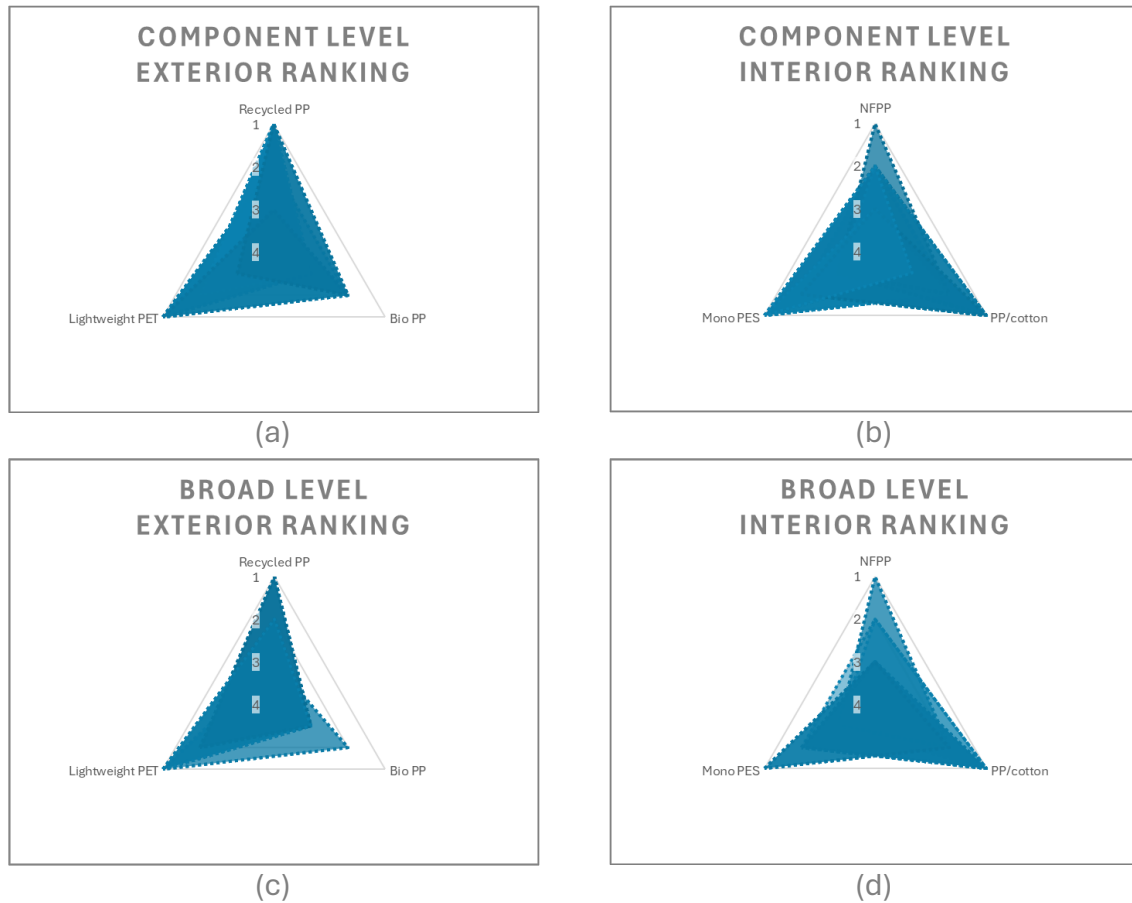


Note. The axes showing rankings from 1-4 are a mere visualization tool to make it easier to see the spread of preference rankings, since no alternative can be ranked fourth among three alternatives.

The complete results for the material alternative preference rankings in Figure 13 above support the above findings of internal misalignment. For the complete exterior case results in Figure 13a, there does seem to be one clear case of alignment, with the bio PP alternative not being ranked first among any of the decision maker respondents. This makes sense, since the bio PP was only really included in the exterior case as a hypothetical, to see the preferences for biobased content also in the exterior case, when it has in reality never realistically been considered for the Frunk part system due to the high cost compared to the recycled PP alternative (see Section 3.1.1). However, for the two remaining exterior case alternatives in Figure 13a, the results showcase very similar levels of preference for both recycled PP and lightweight PET as the first rank. Similarly, looking at Figure 13b for the complete interior case ranking results, all three alternatives showcase similar levels of overlap in the chart area, if slightly less for NFPP, and as such, similar levels of preference for all three as first rank among the complete set of decision maker respondents. These results, for both the exterior and the interior case, indicate that among all decision maker respondents, it is possible to expect different choices of material alternatives, even when provided with the same decision case data.

Figure 14

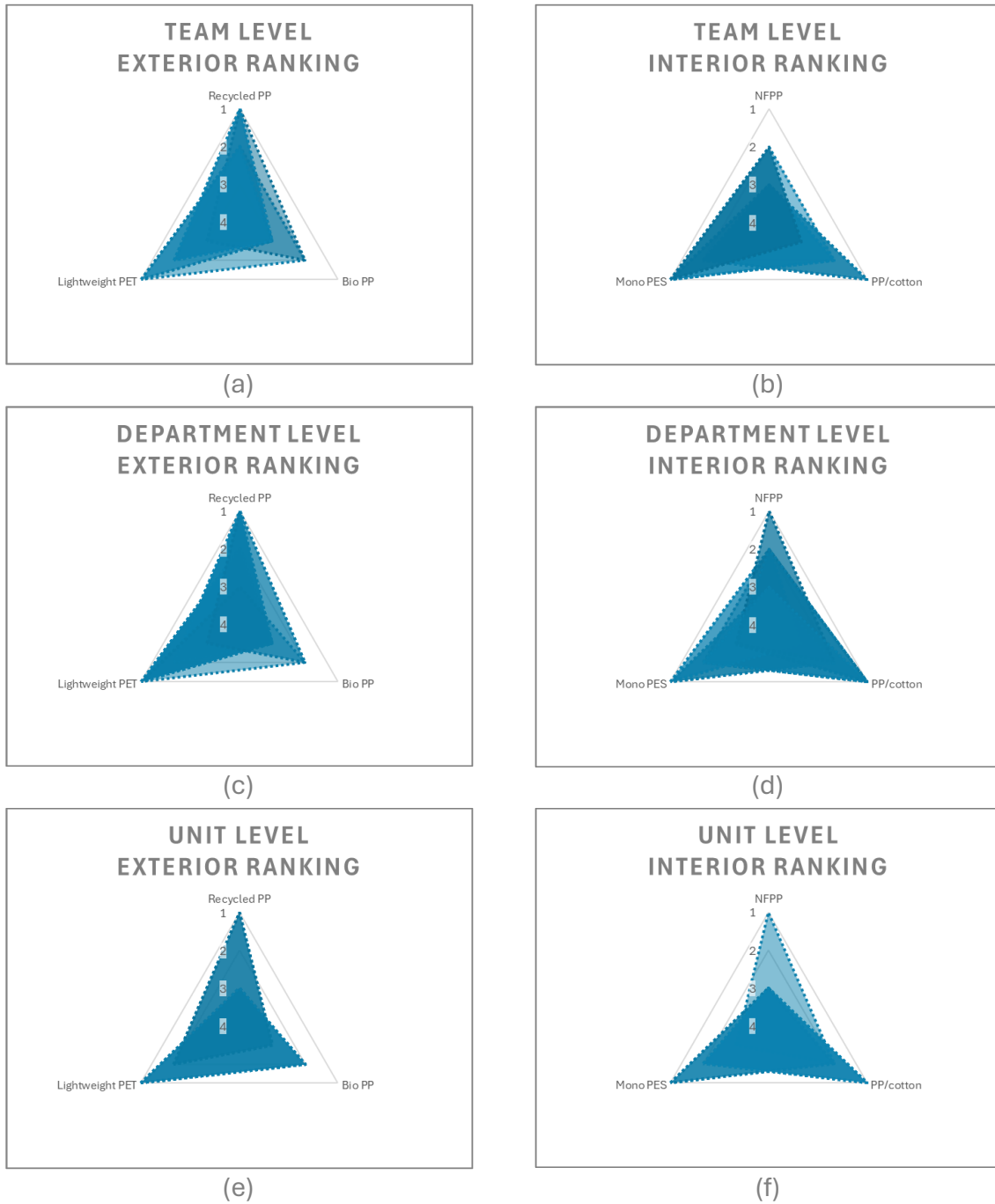
Material alternative preference ranking for all ANP results split between the two decision cases and between component level and broad level decision makers.



Note. The axes showing rankings from 1-4 are a mere visualization tool to make it easier to see the spread of preference rankings, since no alternative can be ranked fourth among three alternatives.

Figure 15

Material alternative preference ranking for all ANP results split between the two decision cases and between team level, department level, unit level and complete vehicle level decision makers.





(g)

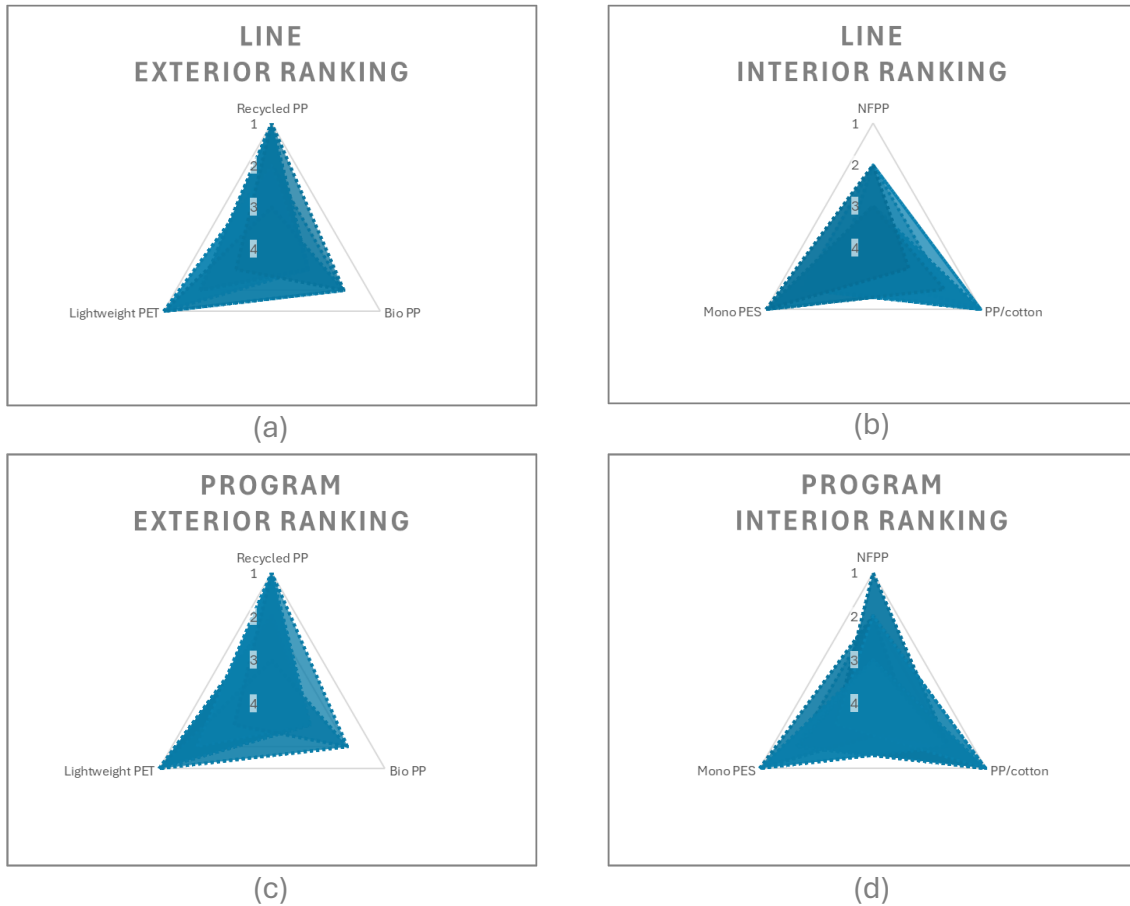


(h)

Note. The axes showing rankings from 1-4 are a mere visualization tool to make it easier to see the spread of preference rankings, since no alternative can be ranked fourth among three alternatives.

Figure 16

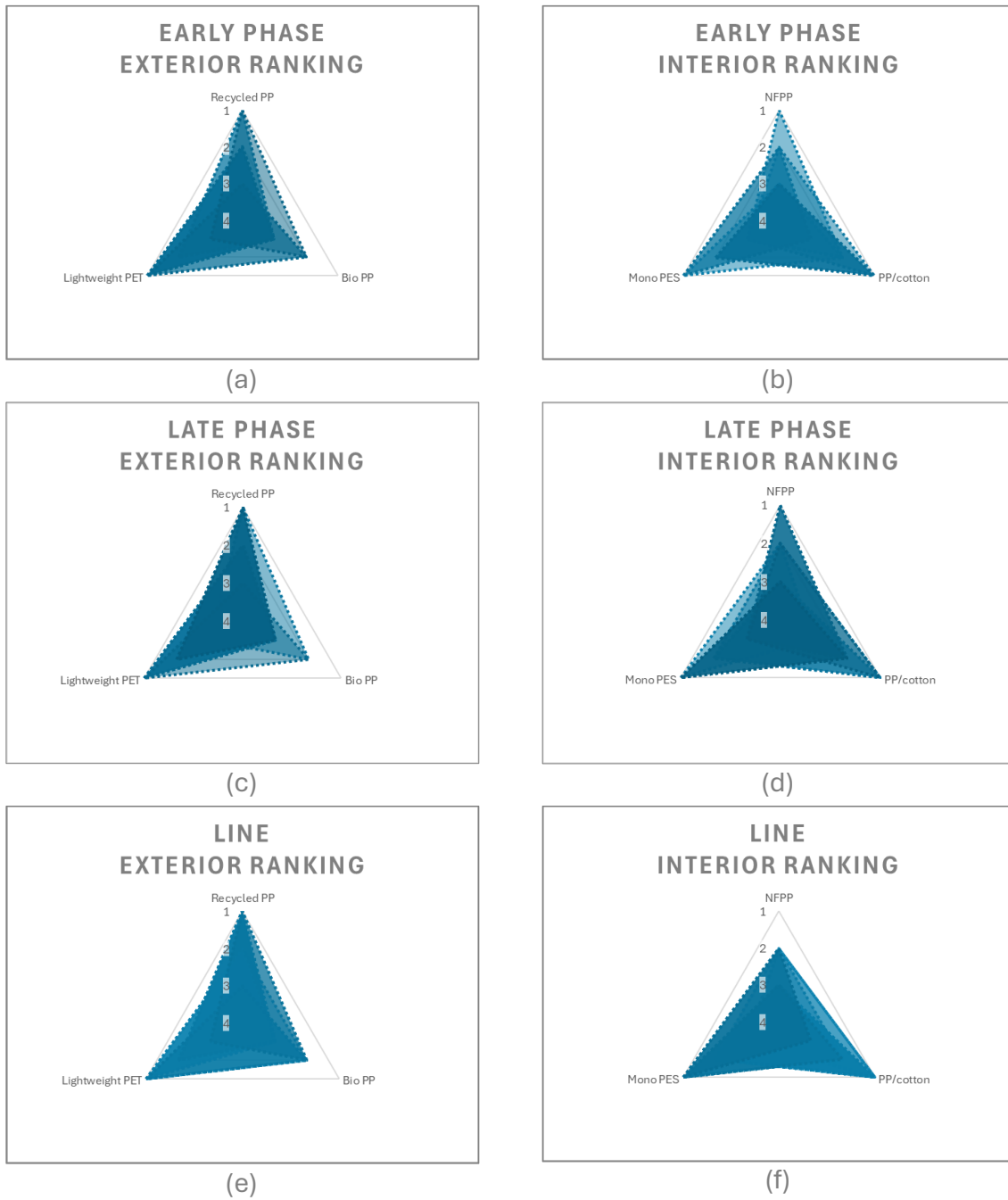
Material alternative preference ranking for all ANP results split between the two decision cases and between decision makers working in the line organization and decision makers working in specific car programs.



Note. The axes showing rankings from 1-4 are a mere visualization tool to make it easier to see the spread of preference rankings, since no alternative can be ranked fourth among three alternatives.

Figure 17

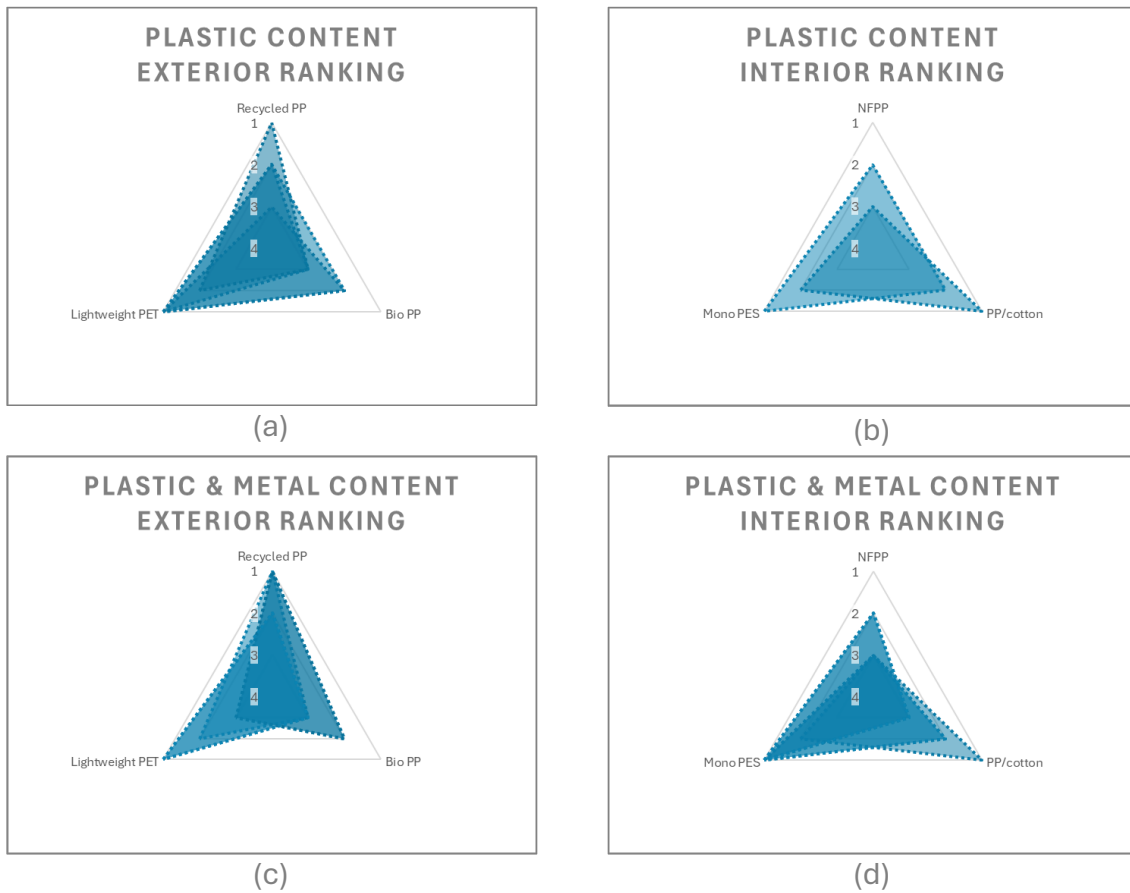
Material alternative preference ranking for all ANP results split between the two decision cases and between decision makers working in the early phase of the product development cycle, in the late phase of the product development cycle and in the line organization.

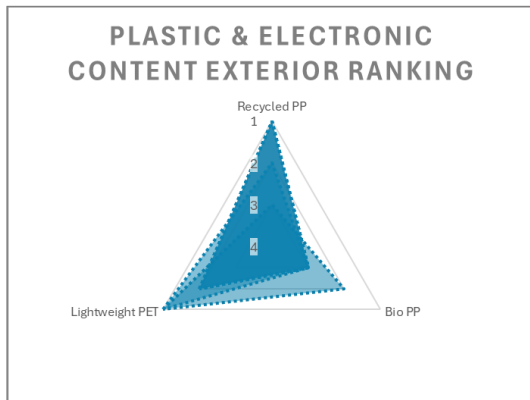


Note. The axes showing rankings from 1-4 are a mere visualization tool to make it easier to see the spread of preference rankings, since no alternative can be ranked fourth among three alternatives.

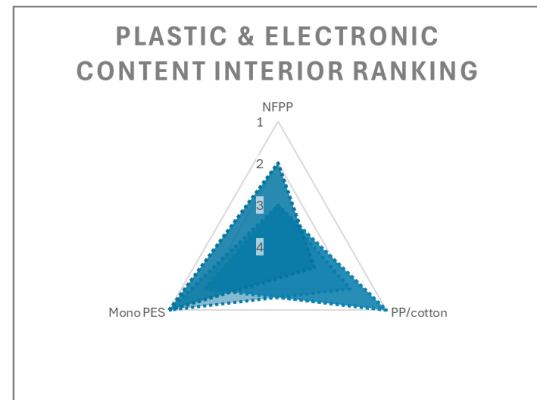
Figure 18

Material alternative preference ranking for all ANP results split between the two decision cases and between decision makers working with mainly plastic content, mainly plastic and metal content, mainly plastic and electronic content, and all kinds of material content.





(e)



(f)



(g)



(h)

Note. The axes showing rankings from 1-4 are a mere visualization tool to make it easier to see the spread of preference rankings, since no alternative can be ranked fourth among three alternatives.

Figure 19

Material alternative preference ranking for all ANP results split between the two decision cases and between decision makers working with mainly Full Service Supplier content, mainly Build-to-Print content and mixed Full Service Supplier and Build-to-Print content.



Note. The axes showing rankings from 1-4 are a mere visualization tool to make it easier to see the spread of preference rankings, since no alternative can be ranked fourth among three alternatives.

Diving deeper into the subgroup ranking results in Figure 14-19 above, again there are many instances of substantial internal misalignment. There is no clearly identifiable, single most preferred (first rank) alternative between the recycled PP and lightweight PET alternatives for the exterior case, with both alternatives having similar levels of overlap and alignment, in Figure 14a, 14c, 15a, 15c, 15e, 16a, 16c, 17e, 18g, 19a, 19c, 19e, i.e. 11 out of a total of 17 subgroups (Figure 16a and 17e show the same subgroup results). The trends for the remaining six subgroup results for the exterior case showcase a very slightly higher preference for either the lightweight PET alternative (Figure 15g, 17a, 18a) or recycled PP alternative (Figure 17c, 18c, 18e), but these differences in the trends are much too small that it can still be considered as clear instances of internal misalignment.

Compared to what was observed above for the complete ranking results for the interior case, when split into the subgroups, it becomes clearer that the NFPP alternative is generally less preferred than the mono PES or PP/cotton alternatives. Only a few outlier values (transparent areas, less overlap) of NFPP ranked first are showcased in Figure 14b, 14d, 15d, 15f, 15h, 16d, 16b, 16d, 17b, 17d, 18h, 19f, with the rest of the subgroups lacking any instance of NFPP being ranked first. Still, similarly to the exterior case analyzed above, there is no clearly identifiable, single most preferred (first rank) alternative between the Mono PES and PP/cotton alternatives, with both alternatives having similar levels of overlap and alignment, in Figure 14b, 14d, 15d, 15f, 16b, 16d, 17f, 18b, 18h, 19f, i.e. 9 out of a total of 17 subgroups. For the remaining eight subgroups, just as for the exterior case, the trends show only a slightly higher favor for the PP/cotton alternative in Figure 15h, 17b, 19b, and for the mono PES alternative in Figure 15b, 17d, 18d, 18f, 19d. These differences, just as for the exterior case, are small enough that it can still be considered as clear instances of internal misalignment. As such, all subgroup ranking results showcase at least some level of internal misalignment. Clearly, the internal misalignment identified for the final criteria weights results also translates into internally misaligned preference rankings of alternatives for virtually all subgroups and both decision cases.

4.1.1.3 Part 1 Criteria Weights Results

Applying the same visual analysis approach as previously to the P1 criteria priority weight results in Figure 6-12 (see Section 4.1.1), firstly, cost and weight criteria priorities appear to be more aligned than in the final weights results. For the cost criterion, there are darker, overlapping areas in not only the complete set of results in Figure 6a, but also in Figure 6c, 6e, 6c, 8a, 8c, 8e, 9c, 10a, 10c, 11a, 11c, 11e, 11g, 12a, 12c, 12e, i.e. 16 out of total 19 subgroups. This can thus be considered as one of the more aligned areas in the P1 criteria weights and by extension, in the general material selection decision case. For the weight

criterion, instances of similar, if slightly less, levels of alignment as for the cost criterion can be seen in Figure 6a, 6c, 6e, 7a, 7c, 8c, 9c, 10c, 11a, 11c, 11e, 11g, 12e, i.e. 12 out of 19 subgroups. In summary this is less evident alignment than for the cost criterion, but still more alignment than for the remaining four criteria. In the complete results in Figure 6a, a large variation in the P1 criteria priority weights can be seen for the EOL, carbon footprint, recycled content and biobased content criteria. Although, the biobased content criterion seems to have less misalignment than the other three criteria, considering that there is only one outlier value of a criteria weight greater than 0,2 for the biobased content.

Diving deeper into the subgroups, large variations in criteria priority weights can be seen for the EOL criterion in Figure 6c, 6e, 7a, 7c, 8c, 8g, 9a, 9c, 10c, 10e, 11g, 12e, i.e. in 11 out of a total of 19 subgroups. For the carbon footprint criterion, substantial variations are seen in Figure 6c, 6e, 7a, 7c, 8c, 8g, 9a, 9c, 10a, 10c, 10e, 11a, 11e, 11g, 12e, i.e. 14 out of 19 subgroups, with many variations even larger than for the EOL criterion. For the recycled content criterion, Figure 6c, 6e, 7a, 7c, 8c, 8e, 8g, 9a, 9c, 9e, 10c, 10e, 11a, 11c, 11e, 11g, 12c, 12e, i.e. 17 out of 19 subgroups showcase larger variations, although the order of magnitude of these variations is slightly less than for the carbon footprint criterion. Finally, for the biobased content criterion, variations are observed in Figure 6c, 6e, 7a, 7c, 8a, 8c, 8e, 8g, 9a, 9c, 10a, 10c, 10e, 11e, 11g, 12a, 12e, i.e. 16 out of 19 subgroups, although the order of magnitude of the variations is smaller than for the other three criteria.

To summarize, the four sustainability criteria of EOL circularity, carbon footprint, recycled content and biobased content can be identified as internal misalignment areas for the general material decision case covered in P1. The largest internal misalignment (combining the number of subgroups and order of magnitude of variations) is observed for the carbon footprint criterion, followed by the recycled content criterion, then the EOL criterion, and finally, the biobased content criterion.

4.1.2 Subgroup External Misalignment

In Section 4.1.1 above, the internal misalignment of the criteria priority weights within the different subgroups was analyzed. If instead considering the alignment between the different subgroups of decision makers, further patterns are revealed.

4.1.2.1 Level Subgroups (General)

Looking at the P1 weight results in Figure 7a and 7c (see Section 4.1.1), decision makers at the component level seem to have a slightly stronger preference for the sustainability criteria of carbon footprint, recycled content and EOL compared to decision makers with a broader level focus in their decision making. This might be because those at the component level are the ones that are primarily responsible for making part or part system level decisions that ensure that sustainability related and other targets are met, whereas those with a broader scope are more likely to only be involved in the cases where those at the component level are unable to make a decision on their own, or in later stages of product development if problems occur with regards to decisions previously made at the

component level. These findings seem to be slightly contrary to the importance of middle management support (like the broad level decision makers) for integration of LCM activities to operational levels (like the component level decision makers) described in previous studies (Nilsson-Lindén et al., 2018). The above findings instead indicate that operational (component) level decision makers have higher priorities for environmental aspects than middle (broad) level management.

If instead looking at the final weights in Figure 7b and 7d, it appears that the component level decision makers and broad level decision makers become more aligned when looking at a specific decision case. This would indicate alignment at least when given the same decision material, so although the trend for component level decision makers still shows slightly higher priorities for carbon footprint, recycled content and end-of-life than the broad level decision makers, there is no clearly problematic case of misalignment between these two subgroups.

Looking at the alternative rankings obtained for these subgroups in Figure 14 (see Section 4.1.1.2), it seems that the broad level decision makers have a slightly larger aversion to the exterior case bio PP alternative compared to the component level decision makers, but the preference trends for both the recycled PP and lightweight PET alternatives seem somewhat aligned between the two subgroups.

Again, looking at the interior case rankings in Figure 14, the broad level decision makers seem to have a slightly stronger preference for the PP/cotton alternative over the other two alternatives compared to the component level decision makers, but the difference between the two subgroups is very slight. So, similarly to the criteria weight results, the alternatives ranking results do not present any particularly evident instances of misalignment between the two subgroups.

4.1.2.2 Level Subgroups (Specific)

With the exemption of a few outlier values, comparing the P1 weights results for the different company hierarchy levels in Figure 8a,c,e,g (see Section 4.1.1) the priorities take a similar shape for all subgroups, with generally low priorities for all four sustainability criteria. The one exception is the carbon footprint weights trend for the department level decision makers being slightly higher than the rest of the subgroups in Figure 8. This might be because the sustainability targets are often set and followed up at the department level. Indeed, some team level decision makers expressed in the in-person meetings that they lack part or part system level carbon footprint targets, and tools for calculating carbon footprint, in order to consider it more in their usual decision making. This supports the engineers' commonly strong focus on tools described in GPD literature (Baumann et al., 2002).

Similarly to the broad and component level comparison, comparing the final weights results of the different subgroups in Figure 8, the trends take on similar shapes for all five subgroups, indicating alignment when given the same decision material and no evidently

problematic case of misalignment between these subgroups. The alternative ranking results in Figure 15a,c,e,g (see Section 4.1.1.2) support this as well, with all subgroups showing roughly the same trend, with only some slight variations in how strong the overall aversion to the least preferred alternative in each case is.

4.1.2.3 Phase Subgroups (General)

The P1 weights for the decision makers working in the line organization reveal stronger preferences for the recycled content and EOL criteria, compared to the decision makers working in specific programs instead having higher preferences for the carbon footprint criterion, in the general material selection decision making. This might be a case of problematic misalignment of priorities, since those working in the line organization are responsible for a lot of the decision making within the programs, but perhaps then might not make the same decisions as the decision makers with more final, encompassing responsibilities for the program. However, when looking at the final weights, again the two subgroups seem to become more aligned when given the same decision material, at least with less disparities than in P1.

The alternative ranking results for the exterior case in Figure 16a and 16c (see Section 4.1.1.2) show very similar preferences between the line and program decision makers. For the interior case alternative ranking results in Figure 16b and 16d there is an apparent difference, with the program decision makers having a clearly stronger preference for the NFPP alternative compared to the line decision makers, so this could again pose a potential risk of line decision makers sometimes making different selection than program decision makers. Although, this misalignment risk is likely not very substantial since it is only present for one alternative in one of the two cases.

4.1.2.4 Phase Subgroups (Specific)

Splitting the program subgroup into decision makers working in the early or late phase of the program, the P1 results in Figure 10a and 10c (see Section 4.1.1) showcase a higher preference for the carbon footprint criteria among late phase decision makers. This observation seems counterintuitive, because it is the decision making in the early (i.e. concept) phase that largely decides the carbon footprint performance. Perhaps it becomes more important for late phase decision makers because it is not until the late phase, when the product concept has been set, that more complete summaries are made and it thus becomes more apparent if the carbon footprint is too large, why it might become more prioritized. However, if this is the case, it is a highly problematic case of misalignment, because, as described in GPD literature, it will be much more difficult and expensive to mitigate a too high carbon footprint by making changes in the late phase, when the concept design and associated environmental impact is already locked in, than in the early phase (Baumann & Tillman, 2004).

Looking instead at the final weights in Figure 10b and 10d, again the alignment seems to increase when given the same decision material, but there is still a slight disparity between

the late phase and the early phase carbon footprint priority weights, and with the reasoning as above, it would likely make for a much more time and cost effective decision making if the carbon footprint criteria was instead prioritized higher in the early phase, before the concept is set and changes become much more expensive.

Misalignment is less evident in the alternative ranking results in Figure 17a-d (see Section 4.1.1.2), with the only noticeable difference being a slightly higher preference for the mono PES interior alternative among late phase decision makers compared to the early phase decision makers, which is likely caused by the somewhat lower final weights trend for the weight criterion in the early phase subgroup (Figure 10b). However, this difference is not enough to expect widely different decisions between the early phase and late phase subgroups.

4.1.2.5 Content Subgroups (Material)

The P1 weights for the different kinds of material content subgroups in Figure 11a,c,e (see Section 4.1.1) do not seem to support the idea expressed by some decision makers that those usually working mainly with plastics would prioritize recycled content over carbon footprint, and those usually working with metals or electronics prioritize carbon footprint over recycled and biobased content (see Section 3.3.2.4). Indeed, the recycled content weights trend for those working with both plastics and metals shows a higher weight than for those with only plastics, with the carbon footprint and biobased content weights being approximately the same order of magnitude for both subgroups. However, as there was only one decision maker respondent with only metal content, this is too small of a basis for an only metals subgroup, as opposed to the plastics and metals subgroup in Figure 11c. Thus, the idea about varying priorities between plastics and metal content decision makers cannot be completely disregarded based on the available results.

If instead comparing with the plastic and electronics subgroup (Figure 11e), there is somewhat higher priority for the carbon footprint criterion than for both the only plastics subgroup and the plastics and metals subgroup, which presents some support to the idea about varying priorities between plastics and electronic content decision maker. However, the recycled content priority weights trend for plastics and electronics are quite similar to the only plastics subgroup. The slightly higher preferences for the EOL criteria that can be seen when comparing the plastics and electronics group with the plastic only and the plastics and metals groups, do make sense if considering that electronics generally have poorer recyclability than plastics and metals.

For the final weights in Figure 11b,d,f,h, again, the trends take a somewhat similar shape for all four subgroups, particularly for the biobased content and carbon footprint criteria. Still, there is a slightly higher trend for the EOL criterion weights of the plastic and electronic subgroup, which makes less sense than for the P1 results, since the final weights cover the specific decision materials given, and thus differences based on usual content should not impact the results as much.

In the alternative ranking results in Figure 18 (see Section 4.1.1.2), the main difference observable for the exterior case results is the plastic content subgroup having a slightly less prominent preference for the recycled PP alternative compared to the other subgroups. A possible explanation is that the other subgroups showcase slightly higher trends for the final cost and recycled content criteria weights (Figure 11).

For the interior case, the main difference is that the all material content subgroup appears to have a slightly higher preference for the PP/cotton alternative and a clearly higher preference for the NFPP alternative, compared to the other subgroups in Figure 18b,d,f,h. The PP/cotton dominance compared to the other subgroups might be because of the slightly higher trend for the carbon footprint criterion in Figure 11h, whereas the slightly higher trend for the biobased content and cost criteria might be contributing to both the NFPP and PP/cotton preference. Again, these are likely not large enough differences to expect widely different decision making between the material content subgroups, at least not when compared to the internal misalignment risks described in Section 4.1.1.

4.1.2.6 Content Subgroups (Manufacturing)

Comparing the P1 weights in Figure 12a and 12e (see Section 4.1.1) there seems to be support for the idea that decision makers working mainly with FSS content prioritize sustainability aspects less than those with mixed FSS and BtP content (see Section 3.3.2.3). This is especially prevalent for the carbon footprint and EOL criteria in Figure 12a and 12e. However, if instead comparing Figure 12a and 12c, the trend for the two sustainability criteria of carbon footprint and biobased content is slightly higher for the FSS content group rather than the BtP content group. Thus, the results do not fully support the idea about varying priorities between BtP and FSS content.

Looking instead at the final weights in Figure 12b,d,f, like the case for Figure 11 described in the previous section, the trends seem to still display some of the variations present in the P1 weights, which make less sense considering that the decision makers received specific (BtP content) decision cases that is covered in the final weights. As such, it would be expected for the decision maker priorities to become more similar for the final weights. However, this observation for both Figure 12 and Figure 11 could be a mere consequence of the ANP method, because the P1 weights also influence the final weights, as all weights from the three parts of the ANP questionnaire are combined for the final weights.

The alternative ranking results in Figure 19 (see Section 4.1.1.2) showcase very similar trends for all three subgroups for the exterior case. For the interior case, the trends show a slightly higher preference for the mono PES alternative among the BtP content subgroup as opposed to a slightly higher PP/cotton preference among the FSS content subgroup, and the mixed content subgroup showcasing a clearly higher preference for the NFPP alternative compared to the other two subgroups. In this case, the differences still present in the final weights in Figure 12 have clearly caused some differences in ranking trends as well, at least for the interior case. The NFPP dominance might be because slightly higher

trend for the biobased and recycled content criteria weights in Figure 12f, while the difference between the FSS and the BtP subgroups might be because of the (with the exemption of two outlier values) slightly lower trend for the final cost and carbon footprint criteria weights for the BtP content subgroup (Figure 12d). For these subgroups, these differences in rankings for the interior case might point to a slight external misalignment risk, although the exterior case ranking trends being so similar reduces the amount of perceived misalignment risk.

4.1.3 Target Misalignment

As described in Section 3.3.1 the department level status and target information provided to decision makers when responding to the ANP questionnaire were realistically (although roughly) based on the existing ambitions in a car program currently being developed at Volvo Cars R&D, with the status adjusted so that no single alternative would be the self-evident choice. Additionally, the status information was adjusted so that both sustainability targets indicated significant need for improvement, whereas the weight and cost status information indicated already being within target or budget, no matter the alternative selected. Still, the final criteria weights results in Figure 6-12 (see Section 4.1.1) show cost and weight criteria dominating over the sustainability criteria in most subgroups.

Indeed, either the cost or weight criterion end up with the highest final weight of all six criteria for 49 out of total 79 decision makers (i.e. 62%), and if including also the next highest criteria weights, this increases to 63 out of 79 decision makers (i.e. 80%). Interestingly, 48 out of 66 (72%) of respondents to the supplementary questions form answered that they did consider the target and status information when responding to the ANP questionnaire. The final weight results seem to contradict this, since a majority of final weights still prioritized weight and cost over the sustainability related criteria. In the in-person meetings, some decision makers explained that this is because of weight and cost always being more important than sustainability, because even if the cost and weight targets are fulfilled, there is always additional value to reducing these criteria further. However, this can be considered as a strategic misalignment with regard to the targets, if a majority of decision makers prioritize criteria which are already within the bounds of their targets over those which still need to be improved towards the target values. These findings also support the common view presented in GPD literature of product developers seeing environmental aspects as add-ons to conventional product development (Baumann et al., 2002). Both LCM and GPD literature suggest that the environmental considerations instead need to be integrated into existing product development processes, systems and tools for the sustainability steering process to be successful.

Some decision makers did however mention, that the department level target and status do not show the complete picture, and that they still prioritized weight and cost because these criteria might need improvement at a broader scope than at a single department, or in a later phase of the program, and that optimizing for department level targets presented

risks for suboptimizing. In contrast, others mentioned needing even further broken down targets on the component level in order to fully incorporate the criteria into decision making. Others mentioned that due to the highly competitive landscape of the automotive industry today, they are never able to pay more for sustainability, because that doesn't affect the survival of the company as clearly as the economic costs. The general idea among decision makers is that customers are not willing to pay extra for a more sustainable product (other than choosing to purchase a BEV), and as such it becomes less important than, for example, weight, which has an impact on perceived quality and the driving range. This can be connected to how the LCM literature highlights the importance of environmental aspects and ambitions needing to be aligned with existing business strategy and not as mere add-ons (Nilsson-Lindén et al., 2018), which is clearly not the case expressed by the decision makers. Also, they mirror the concerns about lack of customer interest in environmental product marketing described in Nilsson-Lindén et al. (2018). Another input from decision makers was that the sustainability targets are seen as less defined and harder to grasp than cost and weight, because decision makers do not understand what risks and costs might follow from not meeting the sustainability targets, compared to the risks of not meeting cost and weight targets. This supports findings in Nilsson-Lindén et al. (2021) that desire to avoid negative outcomes motivates life cycle work, and LCM literature prescriptions about the importance of connecting environmental activities to economic gains. Clearly contextualizing and legitimizing (Nilsson-Lindén et al., 2021) of the consideration of sustainability targets in decision making is thus necessary, for example by providing clearer motivations, ideally connected to avoiding negative outcomes or by connecting to economic gains. Also, the difficulty in grasping sustainability targets expressed by decision makers supports GPD literature findings that product developers have a harder time understanding environmental evaluation compared to technical evaluation, and thus might need training and support from environmental experts (Baumann et al., 2002).

These reasonings show an internal preference among the decision makers for which targets are prioritized in the decision making, with cost and weight being seen as the most important, followed by all sustainability targets. This indicates further misalignment between the decision maker priorities and the strategic target steering, since no such internal priority is communicated along with the targets in the steering process.

With regards to the sustainability targets, some decision makers expressed that recycled content is an easier to grasp target, because it is easier for them to estimate in terms of kilograms of recycled content, compared to the carbon footprint target. Many decision makers expressed that they were unaware of the existence of internal tools for calculating carbon footprint. Those who were aware expressed some hesitancy regarding how to use the tools, especially in dialogue with material suppliers, or that the available tools might not be well suited enough to handle the existing diverse material content. This supports claims in GPD literature about the existence of tools not being enough to guarantee

environmental work (Baumann et al., 2002; Baumann & Tillman, 2004). In line with literature prescriptions, clearly education, training and support from environmental experts is needed for the decision makers to become aware of and learn how to use environmental tools, which according to GPD literature also should be combined with clear organizational and managerial efforts such as responsibility assignments to ensure implementation (Baumann et al., 2002; Baumann & Tillman, 2004). Also, this shows that decision makers feel some hesitancy about how to achieve supplier collaboration as called for in both LCM and GPD literature. Still, the recycled content target was criticized by some for being in kilograms instead of weight percentage, since this appeared to be in direct conflict with the weight target steering.

As for biobased content being in a combined target with recycled content, only 17 out of 79 respondent results (i.e. 22%) showcased equal P1 criteria weights for the recycled and biobased content criteria. For the final criteria weights, this dropped to 6 out of 79 respondent results (i.e. 8%). This is another instance of target misalignment, since a combined recycled and biobased content target indicates strategic equivalence between these two criteria. Indeed, many decision makers expressed a particular lack of knowledge about the implications of biobased material use, as is further reflected in the identification of the biobased content criterion as an area of internal misalignment in Section 4.1.1. Again, this supports the importance of building knowledge about environmental work as called for in both LCM and GPD literature.

4.1.4 Summary Misalignment Areas

Table 10 below summarizes the identified subgroup internal and external misalignment areas, as well as the misalignment areas identified with regards to the strategic target steering.

Table 10

Summary of the main misalignment areas identified based on the ANP results

Misalignment areas		Internal misalignment (Section 4.1.1)	External misalignment (Section 4.1.2)	Target misalignment (Section 4.1.3)
Part 1 (general material selection)	Criteria weights	• CO2 (largest misalignment), • RC, • EOL, • Bio (least but still present misalignment).	• Line (EOL, RC) & Program (CO2), • Late phase (CO2) & Early phase Generally less external than internal misalignment.	• Equal RC & Bio priorities in only 22% of results
Final (polymeric material selection case)	Criteria weights	• Bio, • EOL, • How much cost and weight to “pay” for Bio and EOL	• Late phase (CO2) & Early phase (but less than P1) Generally less external than internal misalignment.	• Cost and/or weight prioritized over sustainability in 80% of results • Equal RC & Bio priorities in only 8% of results
	Alternative rankings	No single, clearly preferred alternative in any subgroup, for both decision cases.	Generally less external than internal misalignment.	

Note. This table only includes the observed recurring instances of misalignment that can be considered as problematic from a perspective of strategic alignment. As mentioned in Section 4.1.1-4.1.1.3 there are other observed differences and instances of misalignment, but that are not considered severe enough to warrant improvement actions, or that have logical explanations based on, for example, different roles having different priorities that still make sense within a strategic perspective.

4.2 Supplementary Interview Results

This section presents the results from supplementary interviews with participating decision makers and with company experts on the sustainability steering process.

4.2.1 Decision Makers

Table 11 below shows the supplementary input collected from decision makers during the in person meetings for the ANP questionnaire completion, as well as additional, follow up interviews.

Table 11

Supplementary input from decision makers, split into two main topics of strategic targets and decision makers support needs

Decision maker	Strategic targets	Support needs
2	Not only department status/target, need to consider target fulfillment at higher levels: interior / exterior / complete unit	
4	Department level targets are too broken down, cost and weight always down prioritized when suboptimizing at component level towards other attribute targets than weight and cost.	
7		Needs more information, particularly estimates of the economic value of weight and sustainability improvements, how much (according to the company strategy) is it worth to pay for such improvements?
12	Sustainability targets are not useful for R&D engineers, how to work actively with them? Usually having the same supplier over the complete vehicle program lifetime, so it does not make sense to have carbon footprint targets set based on assumptions of yearly improvement.	R&D department / technical teams lack knowledge and education about CO ₂ , recycled and biobased content, and end-of-life: what do these aspects mean, how to communicate with suppliers and understand / make sure that supplier data is correct/truthful? Detailed education needs: What are the company definitions for the different sustainability aspects, including calculation methods? What other common definitions are there that Volvo R&D should be aware of to mitigate misunderstandings? What short- and long-term sustainability related requests should be highlighted in supplier dialogues? How to track that suppliers are fulfilling their sustainability roadmaps? What are the common sustainability ambitions for R&D and Procurement departments in sourcing processes?

13	Weight is highly prioritized within the company, and now also carbon footprint, previously it was only about cost. Today there is even (economic) value of weight estimates showcasing high importance of weight.	Needs (economic) value of CO2 and other similarly to existing value of weight estimates, kg of CO2eq is too one-sided and too difficult of a unit to interpret and trade-off against other targets. Biobased materials seem to be a hot topic right now, but are they valid alternatives long term? Needs more guidance, what are acceptable trade-offs among targets? Similar to existing picklists of approved materials, would need material strategic recommendations based on sustainability and other criteria, what general trade-offs exist and what should be prioritized?
16		Would have asked a colleague more used to questions about sustainable materials for guidance in selection, if this was a real decision case.
24	Sometimes the targets are too broken down, risk of suboptimization.	Would have sought input from others with expert sustainability knowledge if this was a real decision case.
31	The decision depends on the scope and status, are there other components (than the ones in the decision case) that can contribute to meeting the targets? Needs to consider a larger context and continuously sum up at a higher level at important milestones in the product development. Generally, cost, weight and recycled content are well measured and tracked today, not so much the carbon footprint. Today, it is mainly time, technology and cost that steer decision making, with sustainability falling to the wayside.	Needs more decision support for the different types of materials, for example, is recycled content more important than CO2 for plastics, and CO2 more important for metals than for plastics?
35	Needs to also know the status or possible improvement actions for other parts than the ones in the decision case – are all other departments or areas maxed out in possible improvement or are there cheaper options for meeting the targets?	
51	In reality, carbon footprint or end-of-life circularity are very rarely considered in decision making.	
52	Carbon footprint usually loses priority in later phases of product development. Current carbon footprint tools and steering processes might work in early phases, but for sourcing and later phases there needs to be more	Need clearer information and steering about the value of weight and CO2, what is acceptable to pay for improvements? Need better tools for tracking CO2, also in sourcing processes, better information about legality and how to make demands towards suppliers.

	legally binding demands or more certain ways of tracking CO2.	Sometimes noticing a big difference between company internal tools and supplier data for carbon footprint, how to manage this in supplier collaborations and sourcing?
58	Missing broken down targets at the component level, to properly consider the target priorities.	
60		In reality, would always seek and act according to the recommendations of experts. In general, would like more support from company experts regarding which type of end-of-life possibility is good or bad, for example, is incineration or recycling with material downgrading better?
64	Needs a larger context than the department targets and alternatives for just one component/part system.	
73	Difficult to make a decision at the component level, usually want to balance over multiple components so as to not suboptimize fulfillment of targets.	

The support needs expressed by decision makers show a high focus on environmental tools, just as described in GPD literature (Baumann et al., 2002). Particularly, tools for environmental impact estimation and for connecting environmental improvements with economic value, the importance of which is highlighted in LCM and GPD literature (Nilsson-Lindén et al., 2021; Pujari et al., 2003). However, the remarks about the strategic targets also show that many decision makers also do not see the sustainability targets as useful or well-functioning, either being too little or too much broken down, or not tracked or communicated well. In accordance with GPD literature, it might therefore not be the lack of tools that is the main issue, but rather the managerial and organizational efforts (Baumann et al., 2002; Baumann & Tillman, 2004) related to the setting and follow up of targets in the sustainability steering process.

The other two main support requests from decision makers relate to education and knowledge building and support from environmental professionals, the importance of both being supported by LCM and GPD literature.

4.2.2 Sustainability Steering Experts

The interview with two experts on the company sustainability steering process revealed that the sustainability professionals had similar impressions of the state of sustainability considerations in the company as was expressed by some of the decision makers. For example, the sustainability professionals felt that sustainability was still seen as an add-on, or something “on top” of usual cost and weight considerations. The sustainability experts also felt that the messaging around sustainability was much less in focus in the company, compared to cost and weight, and that roadmap follow up was lacking for sustainability. These problems relate largely to success factors and prescriptions called for in LCM and GPD literature, such as integration into existing processes and systems instead of environmental considerations being mere add-ons, clear communication about environmental activities and strategies throughout the organization and the need for following up environmental targets. Clearly these prescription and success factors at lacking at Volvo Cars R&D. An example of the uneven focus between cost and sustainability given by the sustainability professionals was the existence of controllers for cost but not so much for sustainability. The sustainability professionals called for increased high management support and communication about sustainability issues, and that middle management also needed to increase their ownership of sustainability questions and become the ones asking for sustainability status reports and roadmaps, rather than the central sustainability staff. These are all mentioned in literature as contributing positively to GPD and LCM activities.

When presented with some of the questions posed by decision makers about business risks and motivations for undertaking sustainability work, the sustainability professionals explained it in terms of three aspects: costs and risks for not complying with regulation as well as reputational risk if not living up to sustainable brand positioning, competitive advantage, and creating positive consumer value from branding and public perception, being trusted as a company making sustainable, safe and high quality products. This can be seen as providing the legitimizing and contextualizing motivations called for in LCM literature (Nilsson-Lindén et al., 2021). Particularly, these motivations can be related to both avoiding negative outcomes and connecting to creation of economic value, both of which are specifically presented as effective motivations for environmental activities in LCM literature (Nilsson-Lindén et al., 2021). Also, these were some of the motivations found to be lacking among R&D decision makers in Section 4.2.1, so they are clearly needed. Similar to concerns expressed by decision makers, the sustainability professionals agreed that missing or achieving sustainability ambitions is not what is going to bankrupt the company or make it “go down”, when compared to the criticality of cost and economic aspects. However, the most important reason for sustainability work according to the sustainability professionals was consumer value and the risk for backlash if not living up to previously communicated ambitions for sustainability, and that consumers choose a Volvo for its brand reputation, part of which is a strong sustainability position. Also, competitive advantage reasons for sustainability were highlighted,

particularly among premium European OEMs. Thus, the sustainability professionals do not seem to share the concerns of R&D decision makers about lack of consumer interest in environmental products (see Section 4.1.1.3). This is clearly an important point of communication between R&D and sustainability professionals, for addressing the perceived lack of motivation for GPD in R&D.

Finally, the sustainability professionals mentioned upcoming training sessions aimed at the R&D department, specifically focusing on a new version of the sustainability steering process with clearer division of responsibilities and education for engineers in product development. This can be considered an example of implementing the success factor of training and education as called for in LCM and GPD literature (Baumann & Tillman, 2004; Nilsson-Lindén et al., 2018).

Observation of one of these sustainability steering training sessions and associated materials showcased numerous efforts to address some of the needs expressed by decision makers and the sustainability professionals. The observed training instance was aimed specifically at project management and can thus be seen as an attempt at targeting middle management, this being one of the main challenges for integration of environmental activities found in previous LCM studies (Nilsson-Lindén et al., 2018). Other sessions of the same training aimed at design and product development engineers, and can thus be seen as attempts to also directly target operational levels, also in line with suggestions from previous LCM studies for handling the middle management challenge (Nilsson-Lindén et al., 2018). For the observed training, only 12 out of approximately 90 invited engineers accepted the invitation, and only a couple more than that ended up participating in the training session. Perhaps this might be a question of the engineers lacking sufficient time and resources for education, as called for in the LCM literature (Nilsson-Lindén et al., 2018), or it could indicate a lack of ownership of sustainability questions, that so few engineers took the time to participate in the training.

Knowledge Building and Motivation

In terms of knowledge building and motivation, the training included clear explanations of the main motivations for working with sustainability at Volvo Cars, both in terms of business risk and competitive advantage and consumer value gains, i.e. both motivations related to avoiding negative outcomes and creation of economic value, both of which are called for in LCM literature (Nilsson-Lindén et al., 2021). The highest level corporate sustainability targets and their relationship to the scope of the sustainability steering process were explained, particularly how the sustainability steering process focused on targets in the Climate action area (i.e. those related to carbon footprint, see Section 1). The sustainability targets and the steering scope were also explained in life cycle terms. The main strategies for meeting corporate sustainability ambitions were presented, as well as the specific strategies relevant for R&D product development (including material selection as one out of four main tactics). Specific tactics for improving the sustainability of materials were also presented, for engineers to bring into supplier discussions, i.e.

presenting some of the support requested by decision makers in Section 4.2.1 and promoting and supporting supplier collaboration as called for in LCM and GPD literature (Nilsson-Lindén et al., 2018; Pujari et al., 2003). The importance of cross-functional collaboration was highlighted, in line with literature prescriptions (Nilsson-Lindén et al., 2018; Pujari et al., 2003), and main expectations of different departments such as R&D, central sustainability, design, and procurement were explained. Some questions were raised by participating engineers during the training about further competitive advantage motivations, the competitive status of the corporate sustainability ambition, and whether sustainability is utilized to its full consumer value potential in existing launches and marketing strategies, showcasing that the motivations provided by the sustainability professionals were maybe not quite enough to calm R&D concerns about lack of consumer interest (see Section 4.1.1.3).

Process Timings and Responsibilities

Another part of the training focused on the sustainability steering process for product sustainability, by presenting in detail the different activities of the process and when and by whom they are to be done, in relation to the existing product development system. As such, both the timings of product sustainability activities and the responsibility divisions for each activity between different R&D, Procurement and central sustainability roles were explained in connection with specific phases and gates in the regular product development process. This shows clear attempts to improve the integration of these sustainability steering activities into the existing product development process, as is called for in much of the LCM and GPD literature. These efforts are especially in line with the importance of timing and clear assignments of responsibilities as called for in LCM and GPD literature (Baumann et al., 2002; Nilsson-Lindén et al., 2018). Also, the responsibility assignments can be considered as efforts to improve R&D staff taking ownership of the environmental activities as called for in LCM literature (Nilsson-Lindén et al., 2018), and by the sustainability professionals themselves. These activities included target setting at different levels of granularity from complete vehicle to components, as was pointed out as one of the aspects lacking in the sustainability steering process by R&D decision makers (see Section 4.2.1), status and roadmap estimation, follow up and reporting, as called for in LCM literature (Nilsson-Lindén et al., 2018), balancing between targets, sourcing, and supplier collaboration, data collection and legal agreements, as called for in LCM and GPD literature (Nilsson-Lindén et al., 2018; Pujari et al., 2003). Some questions raised by participants during this part of the training were questioning the responsibility division for some activities, between R&D and Procurement, between R&D project managers and R&D line managers, and particularly about the wording for different activities – “responsibility” as compared to “support”. This can be taken to indicate a hesitancy among the participating R&D project managers to take ownership and responsibility of the sustainability steering activities. This indicates that the motivations and education provided by sustainability professionals in the observed training session might not be

enough to fully ensure integration of the sustainability steering process in R&D product development.

Tools and Data

Finally, existing and upcoming tools for use in the sustainability steering process were presented, as well as what data to retrieve from each tool and at what phase(s) and activities in the general product development process to apply each tool. This can be seen as addressing the importance of timing in the use of environmental tools, as called for in GPD literature (Baumann et al., 2002). Importantly, many of the tools consisted of updated versions of existing steering tools, now extended to also include sustainability aspects in addition to previously tracked cost information. Thus, this constitutes integration of environmental aspects into existing tools as recommended in GPD literature (Baumann et al., 2002). Step by step instructions for using the different tools were either given in the training, or information about where to find such guidance was given, and for some, information on upcoming training and updates was provided. These efforts can be seen as providing instruction in the use of environmental tools and support from environmental experts as called for in GPD literature (Baumann et al., 2002). Tools, templates and systems for steering suppliers on sustainability targets were also explained, as well as the division of responsibility between R&D and procurement in the collaborative sourcing process. The relationship between carbon footprint and recycled content targets was also clarified, with component level carbon footprint targets set by R&D engineers being based on recycled content targets. The underlying steering documents and guides for the sustainability steering process were also presented, along with explanations of what they are based on, how to use them, and upcoming updates. Other planned updates in processes and tools were also presented. Finally, contact information in the form of one to two names per department (central sustainability, R&D, procurement and central materials engineering) was given in case of questions about sustainability and strategy. This can be seen as an attempt to provide the social network opportunities called for in LCM literature (Nilsson-Lindén et al., 2018). However, single contact persons are likely not enough to enable the networking arenas for collective sharing and creative problem solving called for in the literature, so more dedicated efforts at creating such meeting spaces and networks might be needed. It is also interesting that the tools are presented last in the training session, after the sustainability steering process and associated activities (i.e. management and organizational efforts) have been presented and motivated. This can be considered as in line with the GPD literature calling for organizational efforts such as motivation and responsibility assignments as crucial, because environmental tools alone are not enough to ensure GPD activities (Baumann & Tillman, 2004).

4.3 Improvement Actions and Recommendations

This section covers research question 3 (see Section 1.2) by combining insights from the previous sections to recommend improvement actions.

4.3.1 Internal Misalignment Improvement Actions

The internal misalignment found for the P1 weights of the carbon footprint, recycled content, EOL and biobased content criteria can be connected to the lack of knowledge, education, guidelines, expert support and tools for considering these aspects in product development decision making, as expressed by decision makers in supplementary interviews (see Table 11). Both the P1 criteria weights internal misalignment and expressed lack of resources are most prevalent for the carbon footprint criteria. Interestingly, the sustainability steering training described in Section 4.2.2 can be considered as addressing all of the lacking resources mentioned above for the carbon footprint and the recycled content criteria. As described in Section 4.2.2, this training can thus be considered as an attempt to implement many of the improvement actions recommended in literature. Of course, this means that the implementation of the training has to be effective and reach all of the relevant decision makers, for it to be able to improve the carbon footprint and recycled content internal misalignment.

However, for the biobased content and EOL criteria, for which internal misalignment was found both in the P1 and the final criteria weights, the lacking resources for R&D decision makers are not addressed in the sustainability steering training. Clearly, provision of such knowledge building, communication of guidelines and expert support is necessary to mitigate the internal misalignment. As suggested in GPD literature (Pujari et al., 2003), environmental coordinators issuing guidelines about biobased content and EOL aspects, in the same way as is done for carbon footprint and recycled content in the sustainability steering process (see Section 4.2.2). Considering the ELVR proposing ELV recycled content requirements, for which mechanically and chemically recycled (but not biobased) materials are allowed to be counted (Plastics Today, 2026; Victory, 2026), it would make sense to have guidelines related to this in the material selection process at Volvo Cars R&D. For example, in terms of EOL circularity, mechanically and chemically recyclable materials should be preferred over non-recyclable materials, but perhaps there is no need to make a difference between mechanical and chemical recyclability, in accordance with the proposed ELVR. Also in accordance with the proposed ELVR requirements, recycled materials should be prioritized over biobased materials, as they will potentially not be accepted for the ELV recycled content requirements nor the other recycled content targets (Victory, 2026). These guidelines should then be integrated in existing guidelines and tactics for recycled content, as called for in the GPD literature (Baumann et al., 2002). In order to ensure integration of the suggested guidelines in product development, perhaps motivations can be linked to expected costs of non-compliance to the ELVR, in line with motivations of the avoiding negative outcomes type found effective in previous studies (Nilsson-Lindén et al., 2018). By estimating such financial risks, perhaps it could also be

linked to a guide or tool for estimating the economic value of biobased content and EOL improvements to also improve this internal misalignment (see Table 10).

4.3.2 External Misalignment Improvement Actions

The sustainability steering training described in Section 4.2.2, although focusing on the carbon footprint criterion, might not be able to mitigate the external misalignment of line organization decision makers having lower carbon footprint priorities than program decision makers, because the training is so far targeting program management and operational level line staff, rather than line management. As middle management support is crucial for integration of environmental activities in the line organization according to previous LCM studies (Nilsson-Lindén et al., 2018), it will likely be necessary to also target line middle management, in order to increase ownership and integration in the line organization. Although connecting top management directly with operational levels can be seen as one of the strategies for handling the middle management challenge described in LCM literature (Nilsson-Lindén et al., 2018), in the case of the sustainability training, it is not coming from top management but rather environmental experts, and as such might not be as effective as top management communication for circumventing middle management. The external misalignment of program decision makers having lower recycled content priorities compared to line organization decision makers is addressed by the sustainability training clarifying the relationships between and tactics for recycled content and carbon footprint. However, the sustainability training is currently only targeting program management in some of the car programs and should in the future be extended to all program management for better integration. As for the program decision makers having lower EOL priorities, this could be addressed by the introduction of ELVR based guidelines, as described in Section 4.3.1 above.

The external misalignment of late phase decision makers showcasing higher carbon footprint priorities than early phase decision makers is clearly problematic when considering the importance of integration in early product development as called for in GPD literature (Baumann & Tillman, 2004), due to increasing costs of changes over time. Again, however, the importance of timing is clearly presented in the sustainability training, thus addressing this misalignment. Also, if this is caused by current lack of more complete carbon footprint summaries in the early product development phases, as theorized in Section 4.1.1, this is also mitigated by the sustainability training including information and instruction in available tools and clarifying responsibilities for setting, tracking and reporting carbon footprint statuses and targets at each stage gate in the product development process, from early concept phase to late industrialization phases. Again, it becomes a question of getting all relevant decision makers to take part in the training.

4.3.3 Target Misalignment Improvement Actions

Even though the lack of priority equivalence between the biobased content and recycled content criteria can be considered as clear misalignment with regards to the strategic targets treating the two as equivalent, perhaps it no longer makes strategic sense for this

equivalence in the targets, considering the proposed ELVR. Since the proposed ELVR might not accept biobased content to be counted towards the recycled content requirements for new vehicles (to be decided within 72 months of the regulation entering into force) (Victory, 2026), it does not make strategic sense for the Volvo Cars strategic targets to accept counting of biobased targets, at least in the same measure as recycled content. So, in this case, rather than trying to mitigate the decision maker misalignment, the target steering might need to be adjusted instead. Additionally, since the ELVR will only accept post consumer recycled content (Plastics Today, 2026), a difference should be made between post consumer and post industrial recycled content in the recycled content target steering. Also, if implementing the guidelines for biobased content and EOL circularity for mitigating internal misalignment proposed in Section 4.3.1 above it would make sense to adjust the strategic targets as described, to align recycled content target scopes with proposed guidelines. Additionally, the proposed ELV recycled content targets in the ELVR could also motivate the introduction of strategic targets for the EOL circularity. Either, requiring sourcing of a certain amount of ELV material in new car programs in product development, as done today for recycled content. Alternatively, since the regulation has not yet entered into force, perhaps it would be enough to require a certain amount of closed loop recyclable material in new car programs, to secure availability of ELV material from Volvo Cars products in the future.

For the target misalignment of cost and weight being prioritized over sustainability aspects, even when the decision makers were provided with status and target information indicating otherwise, as described in Section 4.1.1.3, this can be considered as evidence of the poor integration of the sustainability steering process among R&D decision makers and sustainability efforts being seen as mere add-ons to product development. However, as described in Section 4.2.2, the sustainability steering training aimed at R&D engineers addresses this lack of integration with many of the success factors, prescriptions and previous findings from literature. So, recommended improvement actions, like for the previously analyzed internal and external misalignment, largely come down to ensuring broad and effective implementation of the sustainability training.

As described in LCM literature (Nilsson-Lindén et al., 2018) it is crucial to have enough time and resources for education. Since less than 15% of invited R&D engineers participated in the observed sustainability training session, perhaps this indicates such a lack of time and resources. Something else that can be considered a lack of resources, is that there are only two sustainability professionals working with the sustainability steering process, which might be too little to provide the amount of training and support needed for all the relevant roles in R&D. Also, some of the questions posed by participants during the observed training session indicated that the motivation, education and support provided by the sustainability professionals might not quite be enough to ensure effective integration of the sustainability steering process in product development. One prescription common in both LCM and GPD literature (Nilsson-Lindén et al., 2021; Pujari et al., 2003;

UNEP, 2007) that cannot be considered as being addressed in the sustainability training is the importance of top management support. Perhaps clear communication and support for sustainability activities from top management, as called for in literature, is needed to motivate the allocation of resources and time necessary for effective implementation of the sustainability training and ensuring subsequent expected integration improvements.

Another aspect found lacking in the sustainability training was the creation of social networks for collective sharing and creative problem solving related to the environmental activities, with the provision of only a couple of contact people likely not being enough to enable such networking arenas as called for in LCM literature (Nilsson-Lindén et al., 2018). Once the training has been increasingly implemented, more dedicated efforts at creating such meeting spaces might therefore be needed, to help provide avenues for those with newly assigned environmental responsibilities to turn to for further problem solving support and experience sharing.

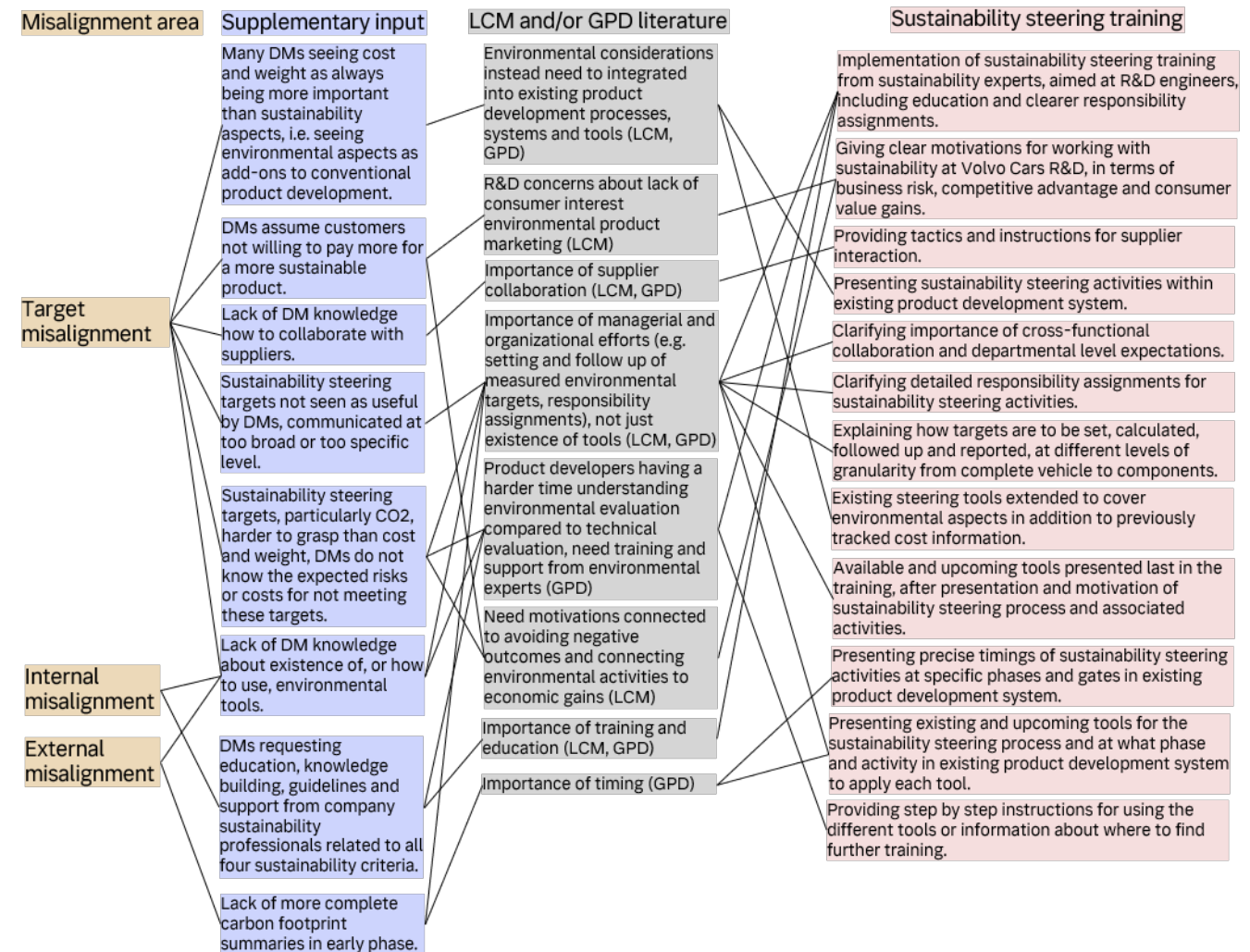
4.3.4 Summary Improvement Actions

Since the sustainability training was observed to already address a lot of the identified misalignment areas by implementing many success factors described in LCM and GPD literature, key improvement actions largely come down to complementing the sustainability steering integration efforts. The first is to ensure that the training reaches all relevant R&D roles, particularly line middle management as called for in LCM literature (Nilsson-Lindén et al., 2018). The second important improvement action is to ensure support and communication from top management regarding environmental considerations in product development, to complement and legitimize the existing support and communication from sustainability functions, as called for in both LCM and GPD literature (Nilsson-Lindén et al., 2018; Pujari et al., 2003; UNEP, 2007). The third is to create dedicated meeting spaces and arenas for collaboratively working with environmental product development, as called for in LCM literature (Nilsson-Lindén et al., 2018). Specifically for the misalignment areas of biobased content and end-of-life circularity, the most important improvement action comes down to adjusting existing recycled content target steering processes, guidelines and tactics to be in line with the ELV Regulation.

Figure 20 below summarizes how the sustainability training addresses the different types of misalignment by implementing success factors from LCM and/or GPD literature. Figure 21 and 22 below summarize how the complementary improvement actions are linked to currently lacking aspects.

Figure 20

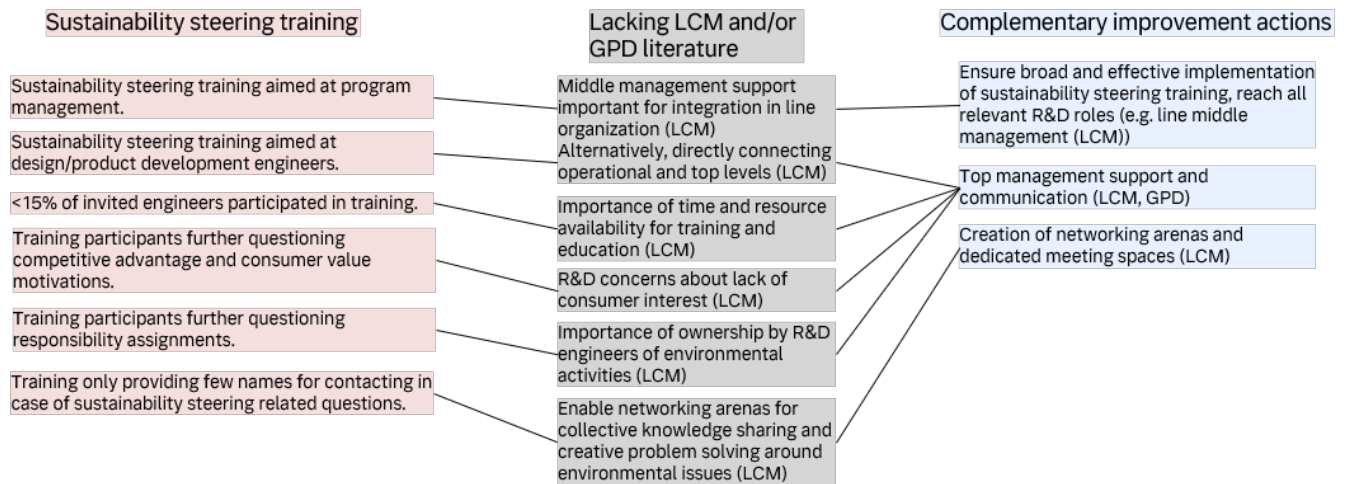
Results and analysis summary showcasing how the sustainability steering training addresses the different misalignment areas



Note. Connections (solid, black lines) between boxes indicate how identified misalignment areas (brown) are connected to the supplementary input from decision makers (blue) and recommendations from LCM and GPD literature (grey) as addressed in the observed sustainability steering training (red).

Figure 21

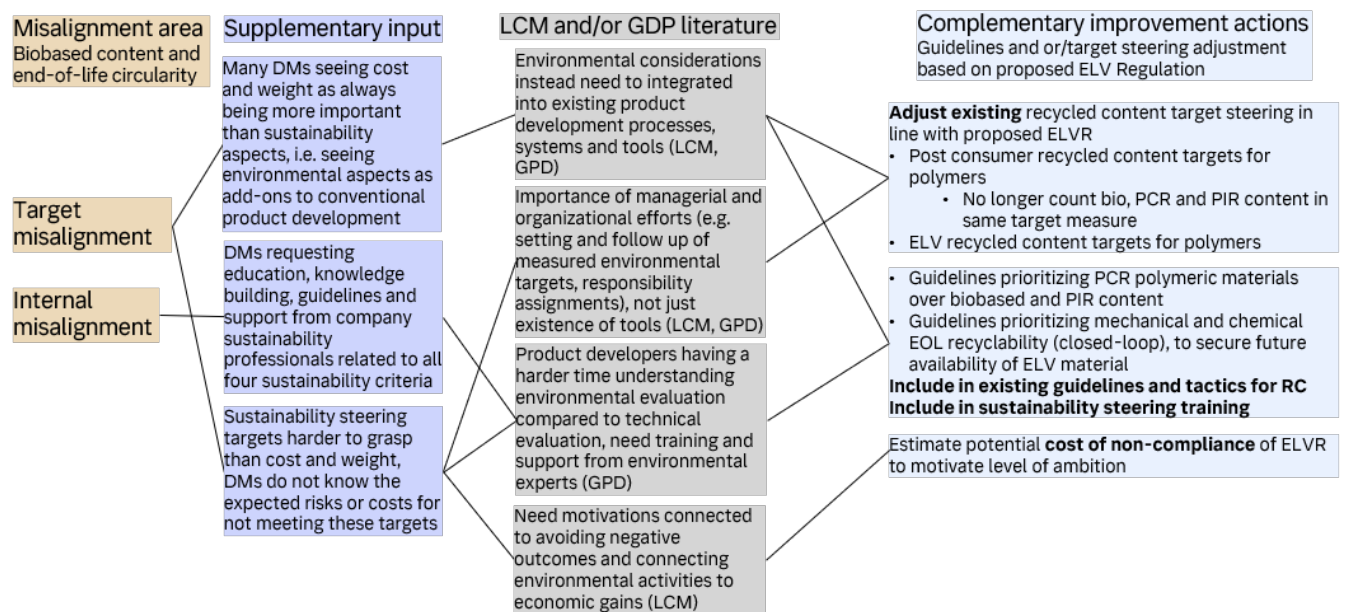
Results and analysis summary showcasing how recommended complementary improvement actions address aspects lacking in the observed sustainability steering training



Note. Connections (solid, black lines) between boxes indicate how recommended complementary improvement actions (pale blue) address the recommendations from LCM and GPD literature (grey) found to be lacking in the observed sustainability steering training (red).

Figure 22

Results and analysis summary showcasing how recommended complementary improvement actions address biobased content and end-of-life circularity misalignment areas not addressed by the observed sustainability steering training



Note. Connections (solid, black lines) between boxes indicate how the identified misalignment areas for biobased content and end-of-life circularity (brown) not addressed in the observed sustainability steering training are connected to the supplementary input from decision makers (blue) and recommendations from LCM and GPD literature (grey) as addressed in recommended complementary improvement actions for guidelines and target adjusted based on the ELV Regulation (pale blue).

5 Discussion and Conclusions

This final section discusses and concludes this study. Section 5.1 discusses the results of the study in relation to previous studies and literature related to LCM and GPD. Section 5.2 discusses the applied method and its' potential effects on the results obtained. In Section 5.3, the research questions posed in this study and how well they were covered is discussed, to identify potential future research directions. Finally, the conclusions of the study are stated in Section 5.4.

5.1 Results Discussion

The results of this study showcase the presence of internal and external misalignment in decision maker priorities at the case company. Internal misalignment was identified for all four sustainability related criteria, which can be taken to indicate that priorities are more so affected by individual understanding and viewpoints rather than the type of role a decision maker has. This is in line with findings in previous LCM studies, that individual understanding and values affect managerial action in environmental matters rather than rational judgment (Nilsson-Lindén et al., 2018).

As for external misalignment, component level decision makers were observed to have slightly stronger priorities for sustainability criteria, compared to broad level decision makers. Considering that the component level decision makers also can be characterized as the most granular, operational level decision makers at the case company, while the broad level decision makers consist of middle management roles, these findings are somewhat contradictory to previous LCM studies. Nilsson-Lindén et al. (2018) instead highlight the importance of middle management support for integration of LCM activities to operational levels, whereas the findings of this study instead indicate that operational (component) level decision makers have higher priorities for environmental aspects than middle (broad) level management.

A particularly surprising instance of external misalignment was found for the carbon footprint criterion, where late phase decision makers showcase higher priorities than early phase decision makers. This finding seems counterintuitive, because, as described in previous LCM studies and GPD literature (e.g. Baumann et al., 2002; Baumann & Tillman, 2004; Nilsson-Lindén et al., 2018; Zarte et al., 2019), it is the decision making in the early phase of product development that largely decides the carbon footprint performance. Once the product design and associated environmental impact already has been locked in in the early phase, it becomes much more difficult and expensive to mitigate a too high carbon footprint by making changes in the late phase (Baumann & Tillman, 2004). Therefore, this result is especially surprising considering the generally cost averse mindset emphasized by decision makers in supplementary interviews. A possible explanation is a

lack of knowledge of the carbon footprint status trends in the early phase. It is not until the late phase, when the product concept has been set, that more complete summaries are made at the case company, making it more apparent if the carbon footprint is too large and potentially leading to higher prioritization.

Misalignment was also identified between decision maker preferences and sustainability steering targets, with cost or weight taking priority over sustainability related criteria even when strategic targets indicated otherwise, in 80% of results. This can be explained by many decision makers expressing that weight and cost are always more important than sustainability and that there is always additional value to further reducing these criteria, even if the cost and weight targets are fulfilled. These findings also support the common view presented in GPD literature of product developers seeing environmental aspects as add-ons to conventional product development (Baumann et al., 2002). Further, decision makers thought that customers are not willing to pay extra for a more sustainable product (other than choosing to purchase a BEV), mirroring the concerns about lack of customer interest in environmental product marketing described in Nilsson-Lindén et al. (2018). Decision makers also described sustainability targets as harder to work with than cost or weight targets, because of unclear risks and costs of not meeting sustainability targets. This supports findings in Nilsson-Lindén et al. (2021) that desire to avoid negative outcomes motivates life cycle work and GPD literature findings that product developers have a harder time understanding environmental evaluation compared to technical evaluation (Baumann et al., 2002). Additionally, many decision makers were unaware of the existence of internal LCA tools for estimating carbon footprint, or were hesitant about how to use the tools, providing further support to GPD literature claims about the existence of tools not being enough to guarantee environmental work (Baumann et al., 2002; Baumann & Tillman, 2004).

In general, support needs expressed by decision makers in supplementary interviews focused largely on environmental tools, just as is common in GPD literature (Baumann et al., 2002). Also, some decision makers criticized the sustainability targets as not being useful or well-functioning, for example not being tracked or communicated well. This finding can be taken to indicate that it might not be the lack of tools that is the main issue, but rather the managerial and organizational efforts, thus providing support for previous GPD literature (Baumann et al., 2002; Baumann & Tillman, 2004).

The “add-on” view described previously, together with the many identified misalignment areas, can be taken to indicate that the integration of environmental considerations into product development decision making at the case company is relatively poor. Rather than the “add-on” view, both LCM and GPD literature (e.g. Baumann et al., 2002; Baumann & Tillman, 2004; Nilsson-Lindén et al., 2018, 2021) suggest that the environmental considerations instead need to be integrated into existing product development processes, systems and tools for the environmental integration and overall sustainability

steering process to be successful. Supplementary interviews with sustainability steering experts at the case company revealed that they shared the same view of the importance of integration and were aware of the currently dominating “add-on” view of environmental aspects in product development. Indeed, actions undertaken by the sustainability professionals to improve integration, in the form of a comprehensive sustainability steering training, was observed to implement many success factors and prescriptions in LCM and GPD literature, in turn addressing many misalignment areas. The training itself can be considered as implementing the success factor of training and education as called for in Baumann & Tillman (2004) and Nilsson-Lindén et al. (2018). Other instances of implementation of literature prescriptions in the training were, for example, explaining the main motivations for working with sustainability in terms of business risk, competitive advantage and consumer value gains, i.e. both motivations related to avoiding negative outcomes and creation of economic value, as called for in Nilsson-Lindén et al. (2021). Furthermore, promoting and supporting supplier collaboration and highlighting the importance of cross-functional collaboration as called for in Nilsson-Lindén et al. (2018) and Pujari et al. (2003), presenting the timings of product sustainability activities and clear responsibility divisions in connection with specific product development phases and gates, in line with the importance of timing and clear assignments of responsibilities as called for in Baumann et al. (2002) and Nilsson-Lindén et al. (2018). Also, explaining existing and upcoming tools, extending existing tools to also integrate environmental aspects, and presenting the specific phases and activities when to apply each tool, thus addressing the importance of timing in the use of environmental tools, integration of environmental aspects into existing tools, and providing instruction in the use of environmental tools, as called for in Baumann et al. (2002).

Because of the many integration efforts in line with literature recommendation already implemented in the observed training, suggested improvement actions largely come down to complementing and improving the existing integration efforts. For example, some more efforts might be needed to enable the social network opportunities and dedicated meeting spaces called for in Nilsson-Lindén et al. (2018), since the training only provided a few, individual contact persons. Also, the training needs to reach all relevant product development staff (for example line middle management as called for in Nilsson-Lindén et al. (2018)) to ensure wide effect of the implemented integration efforts. As a way to ensure this, top management support and allocation of time and resources might be necessary, as highlighted in Pujari et al. (2003) and Nilsson-Lindén et al. (2018), particularly since it was observed that only a small part of invited staff participated in the training. Furthermore, the sustainability training was not found to address any of the misalignment related to the criteria of biobased content and end-of-life circularity. Therefore, improvement actions for knowledge building, communication of guidelines and expert support related to these areas is necessary. As called for in Pujari et al. (2003) environmental coordinators issuing guidelines about biobased content and end-of-life

aspects is suggested. Since conforming to regulatory pressures is one of the most common motivations for LCM and GPD activities in companies (UNEP, 2007, 2009) and considering the ELVR proposing ELV recycled content requirements, for which mechanically and chemically recycled (but not biobased) materials are allowed to be counted (Plastics Today, 2026; Victory, 2026), it is recommended to adjust existing guidelines at the case company accordingly.

To conclude this section, the misalignment and integration challenges identified related to integration of environmental considerations in product development decision making at the case company mirror those commonly described in the GPD literature from over two decades ago, and in the more recent LCM literature. Clearly, many of the same challenges and prescriptions are still highly relevant, even in companies like the case company, who are considered ambitious in their sustainability goals and have already implemented some efforts to improve integration of environmental considerations in product development.

5.2 Method Discussion

The ANP decision model applied in this study was constructed to be as realistic as possible, but, like the case for any model, it is still a simplification of reality. This was found to especially be the case for the assumption made about fulfilment of technical requirements (for example related to mechanical properties) as a prerequisite for considering a material for selection. Although this assumption is idealistically desirable, it is not always the case according to participating decision makers. However, there are a myriad of technical requirements for automotive parts. Adding more criteria to the ANP model means an additional $n \cdot 4 + 3$, $n = 6, 7, 8, \dots$, pairwise comparisons for every criterion added to the six considered in this study (for which a total of 78 pairwise comparisons had to be done). If the ANP model included technical requirements it would therefore quickly have become unfeasible to collect all the necessary pairwise comparison judgements in a timely manner for a large number of decision makers. It can thus be reasoned that the assumption regarding fulfillment of technical requirements was necessary for achieving a representative number of responses.

The decision maker participants being given the choice of completing the ANP form on their own with written instruction or with in-person guidance might have had an effect on the results, since it is difficult to know whether a participant fully understood the method and filled out the ANP form correctly when self-completing it. However, since only 5 out of 79 participants (6%) chose to self-complete the form, the potential effect on the results should be minor.

The respondent group split between the exterior and interior decision cases was carefully done based on the different roles of contacted decision makers. Additionally, this split was continuously revised during the ANP data collection process to maintain the diversity and

representativeness of roles within each decision case respondent group. This resulted in 39 respondents for the exterior case and 40 for the interior case, with similar amounts of members of each subgroup used for plotting the ANP results (see Section 4.1) for both decision cases. As such, much care was taken to ensure the representativeness of responses. However, as discussed in Section 5.1, the internal misalignment findings of this study indicate that decision priorities might be more so affected by individual understanding and viewpoints rather than the type of role a decision maker has, and as such there is a possibility that the results could take a different shape with other respondents. Although, as shown in Section 4.1.2, trends for and between the different subgroups were still identifiable with the applied analysis approach. This allowed for deep and detailed analysis of research question 1 and 2 (see Section 1), ultimately making it a suitable method for the goal of the study.

5.3 Future Studies

Research questions 1 and 2 (see Section 1) of this study, about similarities and differences in decision maker priorities and subsequently identifiable misalignments, were explored and answered in depth in Section 4.1. This was done by analyzing the ANP results for numerous different constellations of respondent groups and at various levels of analysis, covering internal, external and target misalignment, considering both criteria priority weights and material alternatives rankings. To answer research question 3, about improvement actions, the misalignment trends identified in Section 4.1 were complemented with supplementary input from interviews with participating decision makers and sustainability professionals at the case company, as covered in Section 4.2. The purpose of this was to gain a more complete picture of the state of environmental integration in product development at the case company, which was further gained from direct observation of a training by sustainability professionals for product development staff. This allowed for deep understanding of the current challenges and improvement actions related to environmental integration already being implemented at the case company. Therefore, further improvement actions suggested in Section 4.3 in this study, as the answer to research question 3, were reduced to improvement actions needed to complement those already observed to be implemented in the sustainability training. However, this of course assumes that the sustainability training integration efforts are successful at mitigating misalignment and improving integration of environmental considerations in product development decision. This will require that all relevant product development staff takes part in the training and that all participants truly accept and adopt the new responsibility assignments, ways of working, tools and motivations. Some of the complementary improvement actions suggested in this study do take this into account, by highlighting the importance of, for example, wide dissemination and participation in the training and top management support and allocation of time and resources. Still, since the training is at the very initial phases of being implemented at the time of this study, its' success remains uncertain, especially if none of the suggested complementary

improvement actions are implemented by the case company. To see whether the improvement actions, both those already implemented at the case company and those suggested in this study, truly are successful at mitigating misalignment and improving environmental integration in product development, it would be interesting to repeat this study at the case company in the future. Then, one could compare the state of misalignment and environmental integration before and after the training (and other suggested improvement actions) are fully implemented, to assess whether the effects were as expected in this study.

This study was limited to a focus on R&D decision making, but as found in previous studies (Nilsson-Lindén et al., 2018; Pujari et al., 2003), cross-functional aspects are also very important for achieving environmental improvement and integration in product development. The importance of cross-functional collaboration, particularly with procurement functions and suppliers, was also highlighted in the supplementary interviews and sustainability training observed at the case company. In light of this, it would be interesting to further explore the role of procurement functions and how sourcing decision making integrates environmental considerations, since it might be expected that these functions have an even larger cost focus than what was observed in this study for R&D functions.

Overall, the many misalignment areas identified in this study, particularly between sustainability targets and decision maker priorities, show relatively little integration of environmental considerations in automotive product development. The study is contextually situated in the automotive industry, specifically covering a case of a European OEM in the premium segment, with a large focus on BEVs. This industry and market context is characterized by a highly competitive landscape with significant cost pressures, especially for BEVs, which generally have lower profit margins compared to ICEVs. The findings are likely influenced by this context, why it is recommended for future research to investigate these issues in other sectors. How are priorities and misalignment in product development in other sectors affected by, for example, different production and consumption patterns, supply chain structures, competitive landscapes or regulatory pressures?

5.4 Conclusions

This study set out to explore environmental integration in product development decision making, by assessing misalignment between decision makers' priorities and between operational decision making and strategic sustainability targets. By quantifying R&D decision makers' priorities for polymeric material selection decision cases at an automotive company, using the MCDA approach of ANP combined with qualitative analysis, several instances of internal, external and target misalignment were identified. Further contextual understanding was gained by complementing the quantitative results

with qualitative input from interviews with participating decision makers and sustainability professionals, and observation of integration efforts implemented in the form of a sustainability training. The findings revealed significant misalignment between decision maker priorities and sustainability targets, with the economic and technical criteria of cost and weight prioritized over sustainability criteria such as carbon footprint by a majority of decision makers, even when target statuses indicated otherwise. This view of environmental considerations as add-ons to conventional product development, rather than an integral part, was widely supported in interview results. Thus, the results of this study indicate that this “add-on” view commonly described in GPD literature from over two decades ago still persists in industry. The target misalignment findings could furthermore be linked to R&D decision makers lacking understanding of the business risks associated with failing to meet sustainability targets compared to cost or weight targets, and a general difficulty to interpret lifecycle data such as carbon footprint, providing further support to the challenge common in GPD literature, of product development staff understanding environmental evaluation.

Internal, external and target misalignment was particularly prevalent for the carbon footprint criterion. This can not only be linked to the lack of lifecycle knowledge and understanding described above, but also to a lack of knowledge of the existence of, and how to use, internal LCA tools that were already available at the case company. Thus, this study provides empirical support to one of the main points in LCM and GPD, that the existence of environmental tools is not enough to ensure environmental improvement, rather managerial and organizational efforts integrating environmental considerations into existing systems and daily operations are key (Baumann et al., 2002; Baumann & Tillman, 2004; Nilsson-Lindén et al., 2018, 2021). A surprising finding of this study was external misalignment for the carbon footprint criterion, where late phase decision makers showcased higher priorities than early phase decision makers, even though it is usually much more expensive to improve carbon footprint in later phases of product development. This again could be linked to a lack of organizational efforts, in this case related to lacking roadmap follow up of carbon footprint in the early phase.

Another important contribution of this study is a methodological one. By applying a quantitative decision analysis method such as ANP to a large scope of respondents, combined with qualitative inputs for contextual understanding, it was possible to identify specific areas of misalignment between operational R&D decision making priorities and higher-level corporate sustainability ambitions. This allowed for a detailed and nuanced evaluation of the state of environmental integration in product development. Because of this, improvement actions addressing the misalignment could be identified, enabling more targeted suggestions based on the current state and already implemented integration efforts at the case company, rather than the broad prescriptions common in LCM and GPD literature.

Notably, even though the study found that the sustainability training from central sustainability functions at the case company addressed a lot of the identified misalignment areas, some aspects were still considered to be lacking. For example, existing internal target steering processes and guidelines were found to not be well adjusted to upcoming external regulatory pressures from the ELVR. Importantly, the findings indicated that the motivations and training given by sustainability professionals needed to be complemented with support and allocation of time and resources from top management, for R&D staff to take part in, accept and start to embody the content of the training and the new responsibility assignments. This shows the importance of spreading responsibility of environmental matters from solely dedicated sustainability teams to other functions in the company, and making it a part of the core business strategy pushed by top management, for successful environmental integration and, in the long term, managing to actually meet corporate sustainability ambitions. This can be expected to matter not only for the automotive case company studied here but will likely be key in achieving environmental integration in the daily operations of many industries, enabling a transition from general sustainability ambitions to operationalized lifecycle practices throughout the organization.

Statement on the use of AI

The Scopus AI tool (Scopus, n.d.) was used to assist in the literature search for this report by generating keyword search strings based on questions input in natural language. No other generative AI was used for this study.

References

- Al-Hawari, T., Mumani, A., & Momani, A. (2014). Application of the Analytic Network Process to facility layout selection. *Journal of Manufacturing Systems*, 33(4), 488–497. <https://doi.org/10.1016/j.jmsy.2014.04.006>
- Alinezhad, A., & Khalili, J. (2019). ANP Method. In A. Alinezhad & J. Khalili (Eds.), *New Methods and Applications in Multiple Attribute Decision Making (MADM)* (pp. 115–125). Springer International Publishing. https://doi.org/10.1007/978-3-030-15009-9_17
- Baumann, H., Boons, F., & Bragd, A. (2002). Mapping the green product development field: Engineering, policy and business perspectives. *Journal of Cleaner Production, Integrating Greener Product Development Perspectives*, 10(5), 409–425. [https://doi.org/10.1016/S0959-6526\(02\)00015-X](https://doi.org/10.1016/S0959-6526(02)00015-X)
- Baumann, H., & Tillman, A.-M. (2004). *The hitch hiker's guide to LCA: An orientation in life cycle assessment methodology and application*. Studentlitteratur.
- Cinelli, M., Coles, S. R., & Kirwan, K. (2014). Analysis of the potentials of multi criteria decision analysis methods to conduct sustainability assessment. *Ecological Indicators*, 46, 138–148. <https://doi.org/10.1016/j.ecolind.2014.06.011>

Colicchia, C. (2010). *Analytic Network Process Decision making with dependence and feedback*.

European Commission. (n.d.). *End-of-Life Vehicles*. Retrieved May 25, 2026, from https://environment.ec.europa.eu/topics/waste-and-recycling/end-life-vehicles_en

European Commission. (2023). *Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on circularity requirements for vehicle design and on management of end-of-life vehicles, amending Regulations (EU) 2018/858 and 2019/1020 and repealing Directives 2000/53/EC and 2005/64/EC*.

European Union. (2023, March 30). *End-of-life vehicles summary*. <https://eur-lex.europa.eu/EN/legal-content/summary/end-of-life-vehicles.html>

Guitouni, A., & Martel, J.-M. (1998). Tentative guidelines to help choosing an appropriate MCDA method. *European Journal of Operational Research*, 109(2), 501–521. [https://doi.org/10.1016/S0377-2217\(98\)00073-3](https://doi.org/10.1016/S0377-2217(98)00073-3)

Jorge-García, D., & Estruch-Guitart, V. (2022). Comparative analysis between AHP and ANP in prioritization of ecosystem services—A case study in a rice field area raised in the Guadalquivir marshes (Spain). *Ecological Informatics*, 70, 101739. <https://doi.org/10.1016/j.ecoinf.2022.101739>

Kandakoglu, A., Frini, A., & Ben Amor, S. (2019). Multicriteria decision making for sustainable development: A systematic review. *Journal of Multi-Criteria Decision Analysis*, 26(5–6), 202–251. <https://doi.org/10.1002/mcda.1682>

- Lyu, M.-Y., & Choi, T. G. (2015). Research trends in polymer materials for use in lightweight vehicles. *International Journal of Precision Engineering and Manufacturing*, 16(1), 213–220. <https://doi.org/10.1007/s12541-015-0029-x>
- Nilsson-Lindén, H., Baumann, H., Rosén, M., & Diedrich, A. (2018). Organizing life cycle management in practice: Challenges of a multinational manufacturing corporation. *The International Journal of Life Cycle Assessment*, 23(7), 1368–1382. <https://doi.org/10.1007/s11367-014-0818-y>
- Nilsson-Lindén, H., Diedrich, A., & Baumann, H. (2021). Life Cycle Work: A Process Study of the Emergence and Performance of Life Cycle Practice. *Organization & Environment*, 34(1), 99–122. <https://doi.org/10.1177/1086026619893971>
- Otay, İ., & Kahraman, C. (2019). Analytic Network Process with Neutrosophic Sets. In C. Kahraman & İ. Otay (Eds.), *Fuzzy Multi-criteria Decision-Making Using Neutrosophic Sets* (pp. 525–542). Springer International Publishing. https://doi.org/10.1007/978-3-030-00045-5_20
- Plastics Today. (2026, March 2). *EU Vehicle Plastic Recycling Rules Set Targets*. Plastics Today. <https://www.plasticstoday.com/automotive-mobility/eu-publishes-provisional-end-of-life-vehicle-regulations>
- Pollock, J., Chong, P. L., Ramegowda, M., Dawood, N., Habibi, H., Hou, Z., Faraji, F., & Guo, P. (2025). Battery Electric Vehicles: A Study on State of Charge and Cost-Effective Solutions for Addressing Range Anxiety. *Machines*, 13(5). <https://doi.org/10.3390/machines13050411>

- Pujari, D., Wright, G., & Peattie, K. (2003). Green and competitive: Influences on environmental new product development performance. *Journal of Business Research*, 56(8), 657–671. [https://doi.org/10.1016/S0148-2963\(01\)00310-1](https://doi.org/10.1016/S0148-2963(01)00310-1)
- Saaty, T. L. (1980). *The Analytic Hierarchy Process*. McGraw Hill.
- Saaty, T. L. (1996). *Decision making with dependence and feedback: The analytic network process*. RWS Publications.
- Saaty, T. L. (2008). *The Analytic Network Process*.
- Saaty, T. L., & Vargas, L. G. (2013). The Analytic Network Process. In T. L. Saaty & L. G. Vargas (Eds.), *Decision Making with the Analytic Network Process: Economic, Political, Social and Technological Applications with Benefits, Opportunities, Costs and Risks* (pp. 1–40). Springer US. https://doi.org/10.1007/978-1-4614-7279-7_1
- Scopus. (n.d.). *Scopus AI*. Retrieved February 4, 2026, from <https://www.scopus.com/pages/home#scopus-ai>
- Taherdoost, H., & Madanchian, M. (2023). Analytic Network Process (ANP) Method: A Comprehensive Review of Applications, Advantages, and Limitations. *Journal of Data Science and Intelligent Systems*, 1(1), 12–18. <https://doi.org/10.47852/bonviewJDSIS3202885>
- UNEP. (2007). *Life Cycle Management: A Business Guide to Sustainability*. United Nations Environment Programme. <https://wedocs.unep.org/handle/20.500.11822/7894>
- UNEP. (2009). *Design for Sustainability: A Step-by-Step Approach*. United Nations Environment Programme. <https://wedocs.unep.org/handle/20.500.11822/8742>

Vaidya, O. S., & Kumar, S. (2006). Analytic hierarchy process: An overview of applications.

European Journal of Operational Research, 169(1), 1–29.

<https://doi.org/10.1016/j.ejor.2004.04.028>

Victory, M. (2026, February 26). Details of EU End-of-Life Vehicle Regulation Provisional Agreement published. *ICIS Explore*.

<https://www.icis.com/explore/resources/news/2026/02/26/11183225/details-of-eu-end-of-life-vehicle-regulation-provisional-agreement-published>

Volvo Car Corporation. (2024a). *Volvo Cars position on Circular Economy* [Position paper].

Volvo Car Corporation. (2024b). *Volvo Cars position on sustainable materials* [Position paper].

Volvo Car Corporation. (2024c). *Volvo Cars position on sustainable plastics* [Position paper].

Volvo Car Group. (2019). *Freedom to Move in a personal, sustainable and safe way* [Annual report 2018].

Volvo Car Group. (2025). *For life. Annual and sustainability report 2024*. [Annual report].

Volvo Cars. (n.d.). *Our story* | Volvo Cars. [volvocars.com](https://www.volvocars.com). Retrieved January 28, 2026, from <https://www.volvocars.com/intl/our-story/>

Xu, T., Liu, W., & Zhu, Z. (2023). MULTI-CRITERIA DECISION-MAKING METHODS APPLIED TO ACHIEVE SUSTAINABLE DESIGN: A SYSTEMATIC REVIEW. *Proceedings of the Design Society*, 3, 2725–2734. <https://doi.org/10.1017/pds.2023.273>

Zarandi, M. H. F., Mansour, S., Hosseinijou, S. A., & Avazbeigi, M. (2011). A material selection methodology and expert system for sustainable product design. *The International Journal of Advanced Manufacturing Technology*, 57(9), 885–903.
<https://doi.org/10.1007/s00170-011-3362-y>

Zarte, M., Pechmann, A., & Nunes, I. L. (2019). Decision support systems for sustainable manufacturing surrounding the product and production life cycle – A literature review. *Journal of Cleaner Production*, 219, 336–349.
<https://doi.org/10.1016/j.jclepro.2019.02.092>

Appendix

Table A1

Complete ANP results

Decision maker	Criteria	Part 1 weight	Final weight	Delta weight	Part 1 ranking	Final ranking	Delta ranking	Alternatives	Final weight	Final ranking
1	CO2	0,17	0,11	-0,06	1	6	5	Recycled PP	0,40	1
1	RC	0,17	0,19	0,02	1	2	1	Bio PP	0,27	3
1	Bio	0,17	0,15	-0,02	1	4	3	Lightweight PET	0,33	2
1	Weight	0,17	0,18	0,01	1	3	2			
1	Cost	0,17	0,22	0,05	1	1	0			
1	EOL	0,17	0,15	-0,02	1	4	3			
2	CO2	0,15	0,19	0,04	3	3	0	Recycled PP	0,31	2
2	RC	0,08	0,14	0,06	4	4	0	Bio PP	0,22	3
2	Bio	0,05	0,13	0,08	5	5	0	Lightweight PET	0,46	1
2	Weight	0,41	0,22	-0,19	1	1	0			
2	Cost	0,27	0,21	-0,06	2	2	0			
2	EOL	0,04	0,12	0,08	6	6	0			
3	CO2	0,11	0,15	0,04	4	6	2	Recycled PP	0,32	2
3	RC	0,25	0,18	-0,07	2	2	0	Bio PP	0,32	2
3	Bio	0,08	0,16	0,08	5	3	-2	Lightweight PET	0,36	1
3	Weight	0,15	0,16	0,01	3	3	0			
3	Cost	0,35	0,16	-0,19	1	3	2			
3	EOL	0,06	0,20	0,14	6	1	-5			
4	CO2	0,20	0,26	0,06	2	1	-1	Recycled PP	0,34	2
4	RC	0,18	0,20	0,02	4	2	-2	Bio PP	0,25	3
4	Bio	0,03	0,17	0,14	6	4	-2	Lightweight PET	0,40	1
4	Weight	0,19	0,11	-0,08	3	5	2			
4	Cost	0,28	0,19	-0,09	1	3	2			

4	EOL	0,12	0,07	-0,05	5	6	1			
5	CO2	0,20	0,14	-0,06	3	5	2	Recycled PP	0,33	2
5	RC	0,11	0,23	0,12	4	1	-3	Bio PP	0,29	3
5	Bio	0,05	0,13	0,08	6	6	0	Lightweight PET	0,37	1
5	Weight	0,26	0,16	-0,10	2	3	1			
5	Cost	0,30	0,15	-0,15	1	4	3			
5	EOL	0,08	0,18	0,10	5	2	-3			
6	CO2	0,19	0,14	-0,05	2	4	2	Recycled PP	0,35	2
6	RC	0,19	0,28	0,09	2	1	-1	Bio PP	0,27	3
6	Bio	0,07	0,17	0,10	5	2	-3	Lightweight PET	0,39	1
6	Weight	0,08	0,16	0,08	4	3	-1			
6	Cost	0,44	0,14	-0,30	1	4	3			
6	EOL	0,03	0,12	0,09	6	6	0			
7	CO2	0,10	0,11	0,01	4	4	0	Recycled PP	0,45	1
7	RC	0,04	0,06	0,02	6	5	-1	Bio PP	0,25	3
7	Bio	0,08	0,03	-0,05	5	6	1	Lightweight PET	0,30	2
7	Weight	0,15	0,17	0,02	2	2	0			
7	Cost	0,47	0,46	-0,01	1	1	0			
7	EOL	0,15	0,17	0,02	2	2	0			
8	CO2	0,16	0,10	-0,06	3	5	2	NFPP	0,33	1
8	RC	0,08	0,18	0,10	4	3	-1	PP/cotton	0,33	1
8	Bio	0,08	0,12	0,04	4	4	0	Mono PES	0,33	1
8	Weight	0,37	0,28	-0,09	1	1	0			
8	Cost	0,27	0,22	-0,05	2	2	0			
8	EOL	0,04	0,09	0,05	6	6	0			
9	CO2	0,11	0,15	0,04	3	4	1	Recycled PP	0,30	2
9	RC	0,05	0,17	0,12	4	3	-1	Bio PP	0,24	3
9	Bio	0,05	0,14	0,09	4	5	1	Lightweight PET	0,46	1

9	Weight	0,40	0,24	-0,16	1	1	0			
9	Cost	0,35	0,20	-0,15	2	2	0			
9	EOL	0,04	0,10	0,06	6	6	0			
10	CO2	0,13	0,12	-0,01	3	5	2	Recycled PP	0,42	1
10	RC	0,07	0,20	0,13	5	2	-3	Bio PP	0,28	3
10	Bio	0,07	0,12	0,05	5	5	0	Lightweight PET	0,30	2
10	Weight	0,22	0,13	-0,09	2	4	2			
10	Cost	0,41	0,24	-0,17	1	1	0			
10	EOL	0,11	0,19	0,08	4	3	-1			
11	CO2	0,09	0,13	0,04	5	6	1	Recycled PP	0,32	2
11	RC	0,13	0,16	0,03	4	4	0	Bio PP	0,31	3
11	Bio	0,03	0,16	0,13	6	4	-2	Lightweight PET	0,36	1
11	Weight	0,28	0,18	-0,10	2	2	0			
11	Cost	0,32	0,18	-0,14	1	2	1			
11	EOL	0,15	0,20	0,05	3	1	-2			
12	CO2	0,05	0,09	0,04	6	4	-2	Recycled PP	0,42	1
12	RC	0,11	0,13	0,02	4	3	-1	Bio PP	0,20	3
12	Bio	0,07	0,08	0,01	5	5	0	Lightweight PET	0,38	2
12	Weight	0,18	0,25	0,06	2	2	0			
12	Cost	0,41	0,38	-0,03	1	1	0			
12	EOL	0,18	0,07	-0,10	3	6	3			
13	CO2	0,08	0,15	0,07	5	3	-2	Recycled PP	0,48	1
13	RC	0,22	0,12	-0,09	3	4	1	Bio PP	0,15	3
13	Bio	0,04	0,04	0,00	6	6	0	Lightweight PET	0,37	2
13	Weight	0,23	0,20	-0,02	2	2	0			
13	Cost	0,20	0,39	0,19	4	1	-3			
13	EOL	0,25	0,09	-0,15	1	5	4			
14	CO2	0,10	0,17	0,07	4	3	-1	Recycled PP	0,39	1

14	RC	0,13	0,14	0,01	3	5	2	Bio PP	0,24	3
14	Bio	0,06	0,16	0,10	5	4	-1	Lightweight PET	0,38	2
14	Weight	0,19	0,25	0,06	2	1	-1			
14	Cost	0,48	0,24	-0,24	1	2	1			
14	EOL	0,04	0,05	0,01	6	6	0			
15	CO2	0,11	0,09	-0,02	3	6	3	Recycled PP	0,29	3
15	RC	0,10	0,21	0,11	4	2	-2	Bio PP	0,33	2
15	Bio	0,05	0,15	0,10	5	4	-1	Lightweight PET	0,38	1
15	Weight	0,36	0,24	-0,12	1	1	0			
15	Cost	0,36	0,14	-0,22	1	5	4			
15	EOL	0,02	0,17	0,15	6	3	-3			
16	CO2	0,12	0,15	0,03	4	4	0	Recycled PP	0,36	1
16	RC	0,12	0,22	0,10	4	1	-3	Bio PP	0,29	3
16	Bio	0,10	0,18	0,08	6	2	-4	Lightweight PET	0,35	2
16	Weight	0,26	0,14	-0,12	1	6	5			
16	Cost	0,24	0,17	-0,07	2	3	1			
16	EOL	0,16	0,15	-0,01	3	4	1			
17	CO2	0,06	0,13	0,07	5	5	0	Recycled PP	0,38	1
17	RC	0,31	0,29	-0,02	1	1	0	Bio PP	0,25	3
17	Bio	0,31	0,14	-0,17	1	4	3	Lightweight PET	0,36	2
17	Weight	0,12	0,17	0,05	4	3	-1			
17	Cost	0,18	0,18	0,00	3	2	-1			
17	EOL	0,03	0,09	0,06	6	6	0			
18	CO2	0,11	0,13	0,02	4	5	1	Recycled PP	0,30	2
18	RC	0,13	0,15	0,02	3	3	0	Bio PP	0,25	3
18	Bio	0,05	0,13	0,08	5	5	0	Lightweight PET	0,45	1
18	Weight	0,25	0,27	0,02	2	1	-1			
18	Cost	0,42	0,18	-0,24	1	2	1			

18	EOL	0,04	0,14	0,10	6	4	-2			
19	CO2	0,07	0,05	-0,02	4	6	2	Recycled PP	0,48	1
19	RC	0,13	0,27	0,14	3	2	-1	Bio PP	0,26	2
19	Bio	0,03	0,18	0,15	5	3	-2	Lightweight PET	0,25	3
19	Weight	0,36	0,06	-0,30	2	4	2			
19	Cost	0,38	0,39	0,01	1	1	0			
19	EOL	0,03	0,06	0,03	5	4	-1			
20	CO2	0,21	0,16	-0,05	2	3	1	Recycled PP	0,40	1
20	RC	0,13	0,22	0,09	3	2	-1	Bio PP	0,26	3
20	Bio	0,08	0,15	0,07	5	4	-1	Lightweight PET	0,33	2
20	Weight	0,42	0,11	-0,31	1	6	5			
20	Cost	0,13	0,23	0,10	3	1	-2			
20	EOL	0,03	0,14	0,11	6	5	-1			
21	CO2	0,39	0,14	-0,25	1	4	3	Recycled PP	0,39	1
21	RC	0,17	0,30	0,13	3	1	-2	Bio PP	0,33	2
21	Bio	0,13	0,19	0,06	4	2	-2	Lightweight PET	0,28	3
21	Weight	0,08	0,07	-0,01	5	6	1			
21	Cost	0,19	0,13	-0,06	2	5	3			
21	EOL	0,04	0,16	0,12	6	3	-3			
22	CO2	0,18	0,15	-0,03	3	3	0	Recycled PP	0,35	2
22	RC	0,06	0,07	0,01	4	4	0	Bio PP	0,17	3
22	Bio	0,03	0,03	0,00	5	6	1	Lightweight PET	0,48	1
22	Weight	0,34	0,35	0,01	2	1	-1			
22	Cost	0,35	0,35	0,00	1	1	0			
22	EOL	0,03	0,06	0,03	5	5	0			
23	CO2	0,35	0,06	-0,29	1	6	5	Recycled PP	0,30	3
23	RC	0,07	0,18	0,11	5	3	-2	Bio PP	0,34	2
23	Bio	0,19	0,19	0,00	3	2	-1	Lightweight PET	0,36	1

23	Weight	0,10	0,12	0,02	4	5	1			
23	Cost	0,27	0,17	-0,10	2	4	2			
23	EOL	0,03	0,28	0,25	6	1	-5			
24	CO2	0,06	0,16	0,10	3	5	2	Recycled PP	0,32	2
24	RC	0,06	0,17	0,11	3	3	0	Bio PP	0,27	3
24	Bio	0,06	0,12	0,06	3	6	3	Lightweight PET	0,40	1
24	Weight	0,39	0,19	-0,20	1	1	0			
24	Cost	0,39	0,18	-0,21	1	2	1			
24	EOL	0,06	0,17	0,11	3	3	0			
25	CO2	0,16	0,19	0,03	4	1	-3	Recycled PP	0,33	2
25	RC	0,22	0,19	-0,03	3	1	-2	Bio PP	0,27	3
25	Bio	0,05	0,17	0,12	5	4	-1	Lightweight PET	0,40	1
25	Weight	0,25	0,16	-0,09	2	5	3			
25	Cost	0,30	0,18	-0,12	1	3	2			
25	EOL	0,02	0,12	0,10	6	6	0			
26	CO2	0,16	0,13	-0,03	3	5	2	Recycled PP	0,30	2
26	RC	0,11	0,20	0,09	4	2	-2	Bio PP	0,17	3
26	Bio	0,03	0,08	0,05	5	6	1	Lightweight PET	0,53	1
26	Weight	0,33	0,16	-0,17	2	4	2			
26	Cost	0,34	0,19	-0,15	1	3	2			
26	EOL	0,03	0,25	0,22	5	1	-4			
27	CO2	0,11	0,23	0,12	3	1	-2	Recycled PP	0,26	3
27	RC	0,04	0,12	0,08	6	6	0	Bio PP	0,32	2
27	Bio	0,11	0,13	0,02	3	4	1	Lightweight PET	0,41	1
27	Weight	0,42	0,20	-0,22	1	2	1			
27	Cost	0,25	0,13	-0,12	2	4	2			
27	EOL	0,07	0,19	0,12	5	3	-2			
28	CO2	0,06	0,14	0,08	5	5	0	Recycled PP	0,32	2

28	RC	0,16	0,16	0,00	3	4	1	Bio PP	0,31	3
28	Bio	0,07	0,14	0,07	4	5	1	Lightweight PET	0,37	1
28	Weight	0,20	0,21	0,01	2	1	-1			
28	Cost	0,49	0,17	-0,32	1	2	1			
28	EOL	0,03	0,17	0,14	6	2	-4			
29	CO2	0,05	0,07	0,02	5	6	1	Recycled PP	0,30	3
29	RC	0,13	0,16	0,03	3	5	2	Bio PP	0,33	2
29	Bio	0,08	0,19	0,11	4	3	-1	Lightweight PET	0,37	1
29	Weight	0,26	0,22	-0,04	2	1	-1			
29	Cost	0,45	0,20	-0,25	1	2	1			
29	EOL	0,02	0,17	0,15	6	4	-2			
30	CO2	0,09	0,15	0,06	3	4	1	Recycled PP	0,36	2
30	RC	0,05	0,23	0,18	5	1	-4	Bio PP	0,25	3
30	Bio	0,03	0,14	0,11	6	5	-1	Lightweight PET	0,40	1
30	Weight	0,38	0,16	-0,22	2	3	1			
30	Cost	0,39	0,18	-0,21	1	2	1			
30	EOL	0,06	0,14	0,08	4	5	1			
31	CO2	0,11	0,12	0,01	4	5	1	Recycled PP	0,36	1
31	RC	0,17	0,20	0,03	3	2	-1	Bio PP	0,29	3
31	Bio	0,07	0,21	0,14	5	1	-4	Lightweight PET	0,35	2
31	Weight	0,43	0,18	-0,25	1	3	2			
31	Cost	0,18	0,17	-0,01	2	4	2			
31	EOL	0,04	0,11	0,07	6	6	0			
32	CO2	0,22	0,24	0,02	3	2	-1	Recycled PP	0,39	1
32	RC	0,07	0,18	0,11	4	3	-1	Bio PP	0,23	3
32	Bio	0,03	0,07	0,04	5	6	1	Lightweight PET	0,38	2
32	Weight	0,35	0,11	-0,24	1	4	3			
32	Cost	0,30	0,33	0,03	2	1	-1			

32	EOL	0,03	0,08	0,05	5	5	0			
33	CO2	0,17	0,15	-0,02	3	4	1	Recycled PP	0,40	1
33	RC	0,04	0,17	0,13	5	3	-2	Bio PP	0,29	3
33	Bio	0,04	0,14	0,10	5	6	1	Lightweight PET	0,31	2
33	Weight	0,21	0,15	-0,06	2	4	2			
33	Cost	0,47	0,22	-0,25	1	1	0			
33	EOL	0,06	0,18	0,12	4	2	-2			
34	CO2	0,19	0,17	-0,02	3	2	-1	Recycled PP	0,40	1
34	RC	0,15	0,16	0,01	4	3	-1	Bio PP	0,27	3
34	Bio	0,13	0,13	0,00	5	6	1	Lightweight PET	0,33	2
34	Weight	0,24	0,16	-0,08	2	3	1			
34	Cost	0,25	0,21	-0,04	1	1	0			
34	EOL	0,05	0,16	0,11	6	3	-3			
35	CO2	0,08	0,13	0,05	4	5	1	Recycled PP	0,37	1
35	RC	0,15	0,17	0,02	3	3	0	Bio PP	0,27	3
35	Bio	0,06	0,17	0,11	5	3	-2	Lightweight PET	0,36	2
35	Weight	0,29	0,21	-0,08	2	2	0			
35	Cost	0,40	0,23	-0,17	1	1	0			
35	EOL	0,02	0,09	0,07	6	6	0			
36	CO2	0,07	0,14	0,07	3	3	0	Recycled PP	0,36	2
36	RC	0,07	0,14	0,07	3	3	0	Bio PP	0,25	3
36	Bio	0,07	0,14	0,07	3	3	0	Lightweight PET	0,39	1
36	Weight	0,24	0,26	0,02	2	1	-1			
36	Cost	0,51	0,23	-0,28	1	2	1			
36	EOL	0,04	0,08	0,04	6	6	0			
37	CO2	0,11	0,15	0,04	3	4	1	Recycled PP	0,29	3
37	RC	0,09	0,15	0,06	4	4	0	Bio PP	0,30	2
37	Bio	0,06	0,13	0,07	6	6	0	Lightweight PET	0,41	1

37	Weight	0,17	0,20	0,03	2	1	-1			
37	Cost	0,47	0,17	-0,30	1	3	2			
37	EOL	0,09	0,18	0,09	4	2	-2			
38	CO2	0,13	0,12	-0,01	3	6	3	Recycled PP	0,40	1
38	RC	0,09	0,14	0,05	4	4	0	Bio PP	0,33	2
38	Bio	0,04	0,15	0,11	5	3	-2	Lightweight PET	0,26	3
38	Weight	0,22	0,14	-0,08	2	4	2			
38	Cost	0,50	0,24	-0,26	1	1	0			
38	EOL	0,02	0,20	0,18	6	2	-4			
39	CO2	0,15	0,19	0,04	3	2	-1	Recycled PP	0,14	3
39	RC	0,04	0,13	0,09	5	5	0	Bio PP	0,29	2
39	Bio	0,11	0,15	0,04	4	3	-1	Lightweight PET	0,57	1
39	Weight	0,25	0,26	0,01	2	1	-1			
39	Cost	0,42	0,15	-0,27	1	3	2			
39	EOL	0,03	0,12	0,09	6	6	0			
40	CO2	0,14	0,12	-0,02	3	3	0	NFPP	0,29	3
40	RC	0,11	0,26	0,15	4	2	-2	PP/cotton	0,38	1
40	Bio	0,02	0,12	0,10	6	3	-3	Mono PES	0,33	2
40	Weight	0,25	0,12	-0,13	2	3	1			
40	Cost	0,43	0,30	-0,13	1	1	0			
40	EOL	0,05	0,09	0,04	5	6	1			
41	CO2	0,17	0,21	0,04	3	2	-1	NFPP	0,26	3
41	RC	0,07	0,19	0,12	4	3	-1	PP/cotton	0,45	1
41	Bio	0,07	0,11	0,04	4	5	1	Mono PES	0,29	2
41	Weight	0,28	0,14	-0,14	2	4	2			
41	Cost	0,38	0,30	-0,08	1	1	0			
41	EOL	0,02	0,06	0,04	6	6	0			
42	CO2	0,16	0,16	0,00	3	3	0	NFPP	0,31	2

42	RC	0,06	0,14	0,08	5	4	-1	PP/cotton	0,40	1
42	Bio	0,03	0,11	0,08	6	5	-1	Mono PES	0,29	3
42	Weight	0,17	0,21	0,04	2	2	0			
42	Cost	0,44	0,27	-0,17	1	1	0			
42	EOL	0,15	0,11	-0,04	4	5	1			
43	CO2	0,20	0,20	0,00	2	2	0	NFPP	0,27	3
43	RC	0,20	0,17	-0,03	2	4	2	PP/cotton	0,44	1
43	Bio	0,05	0,08	0,03	5	5	0	Mono PES	0,29	2
43	Weight	0,12	0,19	0,07	4	3	-1			
43	Cost	0,40	0,34	-0,06	1	1	0			
43	EOL	0,02	0,02	0,00	6	6	0			
44	CO2	0,10	0,17	0,07	4	3	-1	NFPP	0,29	3
44	RC	0,25	0,25	0,00	2	1	-1	PP/cotton	0,34	2
44	Bio	0,15	0,13	-0,02	3	5	2	Mono PES	0,37	1
44	Weight	0,07	0,20	0,13	5	2	-3			
44	Cost	0,39	0,17	-0,22	1	3	2			
44	EOL	0,05	0,09	0,04	6	6	0			
45	CO2	0,11	0,18	0,07	3	3	0	NFPP	0,27	3
45	RC	0,08	0,14	0,06	4	4	0	PP/cotton	0,41	1
45	Bio	0,03	0,07	0,04	6	6	0	Mono PES	0,32	2
45	Weight	0,24	0,24	0,00	2	2	0			
45	Cost	0,49	0,28	-0,21	1	1	0			
45	EOL	0,05	0,08	0,03	5	5	0			
46	CO2	0,19	0,15	-0,04	2	3	1	NFPP	0,28	3
46	RC	0,19	0,28	0,09	2	1	-1	PP/cotton	0,38	1
46	Bio	0,03	0,09	0,06	6	5	-1	Mono PES	0,34	2
46	Weight	0,10	0,13	0,03	4	4	0			
46	Cost	0,46	0,26	-0,20	1	2	1			

46	EOL	0,04	0,09	0,05	5	5	0			
47	CO2	0,05	0,16	0,11	5	4	-1	NFPP	0,29	3
47	RC	0,13	0,24	0,11	3	1	-2	PP/cotton	0,35	2
47	Bio	0,04	0,11	0,07	6	6	0	Mono PES	0,36	1
47	Weight	0,25	0,20	-0,05	2	2	0			
47	Cost	0,40	0,17	-0,23	1	3	2			
47	EOL	0,12	0,12	0,00	4	5	1			
48	CO2	0,06	0,11	0,05	5	6	1	NFPP	0,30	2
48	RC	0,08	0,21	0,13	4	1	-3	PP/cotton	0,30	2
48	Bio	0,06	0,18	0,12	5	3	-2	Mono PES	0,40	1
48	Weight	0,33	0,20	-0,13	1	2	1			
48	Cost	0,33	0,17	-0,16	1	4	3			
48	EOL	0,14	0,14	0,00	3	5	2			
49	CO2	0,22	0,20	-0,02	2	2	0	NFPP	0,23	3
49	RC	0,14	0,25	0,11	5	1	-4	PP/cotton	0,36	2
49	Bio	0,08	0,09	0,01	6	6	0	Mono PES	0,41	1
49	Weight	0,15	0,11	-0,04	3	5	2			
49	Cost	0,15	0,16	0,01	3	4	1			
49	EOL	0,25	0,20	-0,05	1	2	1			
50	CO2	0,06	0,11	0,05	5	5	0	NFPP	0,29	3
50	RC	0,13	0,20	0,07	3	2	-1	PP/cotton	0,37	1
50	Bio	0,04	0,11	0,07	6	5	-1	Mono PES	0,34	2
50	Weight	0,24	0,15	-0,09	2	3	1			
50	Cost	0,42	0,28	-0,14	1	1	0			
50	EOL	0,10	0,15	0,05	4	3	-1			
51	CO2	0,02	0,21	0,19	6	2	-4	NFPP	0,24	3
51	RC	0,17	0,35	0,18	3	1	-2	PP/cotton	0,33	2
51	Bio	0,07	0,11	0,04	5	5	0	Mono PES	0,43	1

51	Weight	0,22	0,12	-0,10	2	3	1			
51	Cost	0,43	0,08	-0,35	1	6	5			
51	EOL	0,08	0,12	0,04	4	3	-1			
52	CO2	0,11	0,09	-0,02	3	6	3	NFPP	0,32	2
52	RC	0,06	0,15	0,09	4	3	-1	PP/cotton	0,31	3
52	Bio	0,06	0,15	0,09	4	3	-1	Mono PES	0,36	1
52	Weight	0,26	0,30	0,04	2	1	-1			
52	Cost	0,50	0,20	-0,30	1	2	1			
52	EOL	0,03	0,11	0,08	6	5	-1			
53	CO2	0,14	0,29	0,15	3	2	-1	NFPP	0,26	2
53	RC	0,07	0,08	0,01	5	4	-1	PP/cotton	0,49	1
53	Bio	0,08	0,06	-0,01	4	5	1	Mono PES	0,25	3
53	Weight	0,20	0,19	-0,01	2	3	1			
53	Cost	0,48	0,34	-0,14	1	1	0			
53	EOL	0,03	0,04	0,01	6	6	0			
54	CO2	0,16	0,11	-0,05	3	4	1	NFPP	0,31	2
54	RC	0,12	0,15	0,03	4	3	-1	PP/cotton	0,38	1
54	Bio	0,04	0,10	0,06	6	5	-1	Mono PES	0,31	2
54	Weight	0,24	0,26	0,02	2	2	0			
54	Cost	0,40	0,27	-0,13	1	1	0			
54	EOL	0,05	0,10	0,05	5	5	0			
55	CO2	0,05	0,14	0,09	5	4	-1	NFPP	0,29	3
55	RC	0,08	0,18	0,10	3	3	0	PP/cotton	0,37	1
55	Bio	0,08	0,09	0,01	3	6	3	Mono PES	0,34	2
55	Weight	0,29	0,26	-0,03	2	1	-1			
55	Cost	0,47	0,24	-0,23	1	2	1			
55	EOL	0,02	0,10	0,08	6	5	-1			
56	CO2	0,07	0,11	0,04	3	4	1	NFPP	0,30	3

56	RC	0,07	0,11	0,04	3	4	1	PP/cotton	0,38	1
56	Bio	0,07	0,11	0,04	3	4	1	Mono PES	0,32	2
56	Weight	0,36	0,23	-0,13	1	2	1			
56	Cost	0,36	0,31	-0,05	1	1	0			
56	EOL	0,07	0,12	0,05	3	3	0			
57	CO2	0,39	0,15	-0,24	1	5	4	NFPP	0,31	2
57	RC	0,12	0,19	0,07	4	1	-3	PP/cotton	0,38	1
57	Bio	0,15	0,19	0,04	3	1	-2	Mono PES	0,31	2
57	Weight	0,10	0,16	0,06	5	4	-1			
57	Cost	0,05	0,17	0,12	6	3	-3			
57	EOL	0,20	0,13	-0,07	2	6	4			
58	CO2	0,05	0,20	0,15	4	2	-2	NFPP	0,26	3
58	RC	0,05	0,10	0,05	4	5	1	PP/cotton	0,41	1
58	Bio	0,05	0,09	0,04	4	6	2	Mono PES	0,33	2
58	Weight	0,25	0,17	-0,08	2	3	1			
58	Cost	0,49	0,27	-0,22	1	1	0			
58	EOL	0,10	0,17	0,07	3	3	0			
59	CO2	0,17	0,13	-0,04	4	5	1	NFPP	0,36	1
59	RC	0,19	0,19	0,00	2	1	-1	PP/cotton	0,33	2
59	Bio	0,07	0,17	0,10	6	4	-2	Mono PES	0,31	3
59	Weight	0,30	0,19	-0,11	1	1	0			
59	Cost	0,18	0,18	0,00	3	3	0			
59	EOL	0,09	0,13	0,04	5	5	0			
60	CO2	0,17	0,18	0,01	1	2	1	NFPP	0,29	3
60	RC	0,17	0,29	0,12	1	1	0	PP/cotton	0,34	2
60	Bio	0,17	0,15	-0,02	1	4	3	Mono PES	0,37	1
60	Weight	0,17	0,17	0,00	1	3	2			
60	Cost	0,17	0,13	-0,04	1	5	4			

60	EOL	0,17	0,08	-0,09	1	6	5			
61	CO2	0,03	0,13	0,10	6	4	-2	NFPP	0,45	1
61	RC	0,07	0,07	0,00	5	6	1	PP/cotton	0,32	2
61	Bio	0,15	0,08	-0,07	3	5	2	Mono PES	0,23	3
61	Weight	0,17	0,20	0,03	2	2	0			
61	Cost	0,15	0,35	0,20	3	1	-2			
61	EOL	0,44	0,16	-0,28	1	3	2			
62	CO2	0,15	0,17	0,02	3	3	0	NFPP	0,35	2
62	RC	0,14	0,28	0,14	4	1	-3	PP/cotton	0,26	3
62	Bio	0,07	0,08	0,01	5	5	0	Mono PES	0,39	1
62	Weight	0,17	0,13	-0,04	2	4	2			
62	Cost	0,45	0,25	-0,20	1	2	1			
62	EOL	0,02	0,08	0,06	6	5	-1			
63	CO2	0,14	0,16	0,02	3	4	1	NFPP	0,23	3
63	RC	0,24	0,24	0,00	2	1	-1	PP/cotton	0,35	2
63	Bio	0,04	0,10	0,06	6	5	-1	Mono PES	0,41	1
63	Weight	0,10	0,10	0,00	4	5	1			
63	Cost	0,39	0,19	-0,20	1	3	2			
63	EOL	0,10	0,20	0,10	4	2	-2			
64	CO2	0,11	0,21	0,10	3	1	-2	NFPP	0,32	2
64	RC	0,08	0,17	0,09	5	4	-1	PP/cotton	0,40	1
64	Bio	0,07	0,15	0,08	6	5	-1	Mono PES	0,28	3
64	Weight	0,19	0,18	-0,01	2	3	1			
64	Cost	0,45	0,19	-0,26	1	2	1			
64	EOL	0,10	0,10	0,00	4	6	2			
65	CO2	0,05	0,06	0,01	5	4	-1	NFPP	0,35	1
65	RC	0,05	0,05	0,00	5	5	0	PP/cotton	0,34	2
65	Bio	0,07	0,08	0,01	3	3	0	Mono PES	0,31	3

65	Weight	0,32	0,33	0,01	2	2	0			
65	Cost	0,45	0,43	-0,02	1	1	0			
65	EOL	0,06	0,05	-0,01	4	5	1			
66	CO2	0,16	0,20	0,04	3	3	0	NFPP	0,29	3
66	RC	0,10	0,17	0,07	4	4	0	PP/cotton	0,39	1
66	Bio	0,05	0,10	0,05	5	5	0	Mono PES	0,32	2
66	Weight	0,27	0,22	-0,05	2	2	0			
66	Cost	0,37	0,23	-0,14	1	1	0			
66	EOL	0,05	0,08	0,03	5	6	1			
67	CO2	0,19	0,14	-0,05	2	4	2	NFPP	0,28	2
67	RC	0,11	0,21	0,10	5	2	-3	PP/cotton	0,26	3
67	Bio	0,04	0,08	0,04	6	6	0	Mono PES	0,46	1
67	Weight	0,18	0,21	0,03	3	2	-1			
67	Cost	0,13	0,14	0,01	4	4	0			
67	EOL	0,36	0,22	-0,14	1	1	0			
68	CO2	0,06	0,06	0,00	5	6	1	NFPP	0,32	2
68	RC	0,09	0,17	0,08	4	4	0	PP/cotton	0,27	3
68	Bio	0,15	0,08	-0,07	2	5	3	Mono PES	0,41	1
68	Weight	0,15	0,22	0,07	2	2	0			
68	Cost	0,52	0,28	-0,24	1	1	0			
68	EOL	0,02	0,19	0,17	6	3	-3			
69	CO2	0,11	0,10	-0,01	3	5	2	NFPP	0,25	2
69	RC	0,06	0,20	0,14	4	3	-1	PP/cotton	0,22	3
69	Bio	0,06	0,07	0,01	4	6	2	Mono PES	0,53	1
69	Weight	0,26	0,26	0,00	2	1	-1			
69	Cost	0,48	0,22	-0,26	1	2	1			
69	EOL	0,03	0,16	0,13	6	4	-2			
70	CO2	0,11	0,19	0,08	4	3	-1	NFPP	0,35	1

70	RC	0,05	0,13	0,08	5	4	-1	PP/cotton	0,33	2
70	Bio	0,04	0,07	0,03	6	5	-1	Mono PES	0,32	3
70	Weight	0,43	0,27	-0,16	1	2	1			
70	Cost	0,26	0,29	0,03	2	1	-1			
70	EOL	0,12	0,06	-0,06	3	6	3			
71	CO2	0,19	0,21	0,02	2	2	0	NFPP	0,27	3
71	RC	0,13	0,28	0,15	3	1	-2	PP/cotton	0,38	1
71	Bio	0,13	0,11	-0,02	3	4	1	Mono PES	0,35	2
71	Weight	0,07	0,11	0,04	5	4	-1			
71	Cost	0,44	0,18	-0,26	1	3	2			
71	EOL	0,03	0,11	0,08	6	4	-2			
72	CO2	0,15	0,05	-0,10	3	6	3	NFPP	0,29	3
72	RC	0,08	0,30	0,22	4	1	-3	PP/cotton	0,31	2
72	Bio	0,05	0,18	0,13	5	2	-3	Mono PES	0,41	1
72	Weight	0,24	0,15	-0,09	2	4	2			
72	Cost	0,43	0,18	-0,25	1	2	1			
72	EOL	0,04	0,14	0,10	6	5	-1			
73	CO2	0,16	0,14	-0,02	3	4	1	NFPP	0,28	3
73	RC	0,04	0,29	0,25	4	1	-3	PP/cotton	0,35	2
73	Bio	0,04	0,10	0,06	4	5	1	Mono PES	0,37	1
73	Weight	0,39	0,17	-0,22	1	3	2			
73	Cost	0,33	0,22	-0,11	2	2	0			
73	EOL	0,04	0,09	0,05	4	6	2			
74	CO2	0,46	0,15	-0,31	1	5	4	NFPP	0,33	2
74	RC	0,07	0,25	0,18	3	1	-2	PP/cotton	0,36	1
74	Bio	0,07	0,17	0,10	3	4	1	Mono PES	0,31	3
74	Weight	0,07	0,19	0,12	3	2	-1			
74	Cost	0,31	0,19	-0,12	2	2	0			

74	EOL	0,03	0,05	0,02	6	6	0			
75	CO2	0,08	0,13	0,05	4	4	0	NFPP	0,13	3
75	RC	0,14	0,19	0,05	3	3	0	PP/cotton	0,46	1
75	Bio	0,05	0,05	0,00	5	6	1	Mono PES	0,41	2
75	Weight	0,25	0,24	-0,01	2	2	0			
75	Cost	0,43	0,31	-0,12	1	1	0			
75	EOL	0,05	0,08	0,03	5	5	0			
76	CO2	0,08	0,20	0,12	4	3	-1	NFPP	0,26	3
76	RC	0,08	0,24	0,16	4	1	-3	PP/cotton	0,36	2
76	Bio	0,14	0,09	-0,05	3	5	2	Mono PES	0,37	1
76	Weight	0,18	0,09	-0,09	2	5	3			
76	Cost	0,45	0,24	-0,21	1	1	0			
76	EOL	0,08	0,15	0,07	4	4	0			
77	CO2	0,12	0,18	0,06	3	3	0	NFPP	0,30	3
77	RC	0,11	0,22	0,10	4	2	-2	PP/cotton	0,38	1
77	Bio	0,04	0,14	0,11	6	4	-2	Mono PES	0,32	2
77	Weight	0,24	0,12	-0,12	2	5	3			
77	Cost	0,43	0,23	-0,20	1	1	0			
77	EOL	0,06	0,11	0,05	5	6	1			
78	CO2	0,07	0,11	0,05	5	4	-1	NFPP	0,34	2
78	RC	0,31	0,32	0,01	2	1	-1	PP/cotton	0,28	3
78	Bio	0,03	0,08	0,05	6	5	-1	Mono PES	0,38	1
78	Weight	0,16	0,15	-0,01	3	3	0			
78	Cost	0,34	0,26	-0,08	1	2	1			
78	EOL	0,09	0,07	-0,02	4	6	2			
79	CO2	0,13	0,21	0,08	5	2	-3	Recycled PP	0,37	1
79	RC	0,15	0,21	0,06	3	2	-1	Bio PP	0,35	2
79	Bio	0,10	0,03	-0,06	6	6	0	Lightweight PET	0,27	3

79	Weight	0,13	0,22	0,09	4	1	-3			
79	Cost	0,21	0,21	0,00	2	2	0			
79	EOL	0,27	0,10	-0,17	1	5	4			

Figure A1

Material alternative preference weights for all ANP results split between the two decision cases.

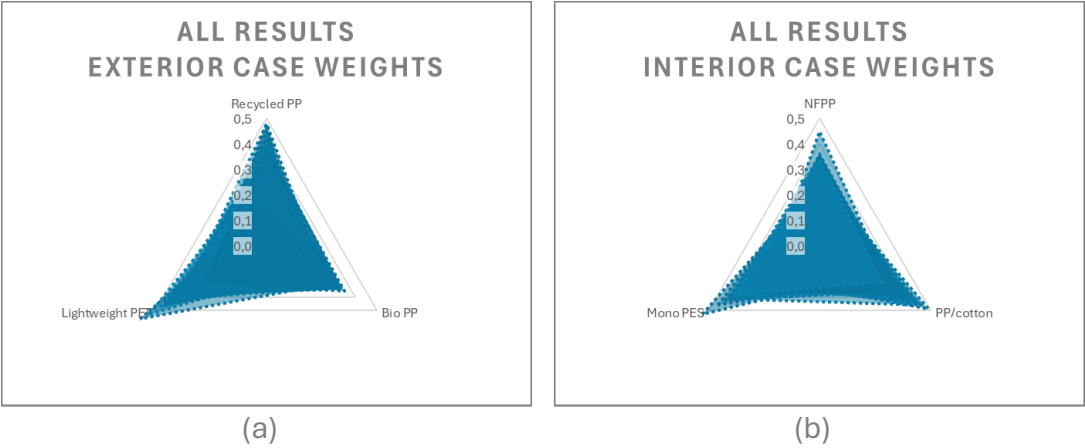


Figure A2

Material alternative preference weights for all ANP results split between the two decision cases and between component level and broad level decision makers.

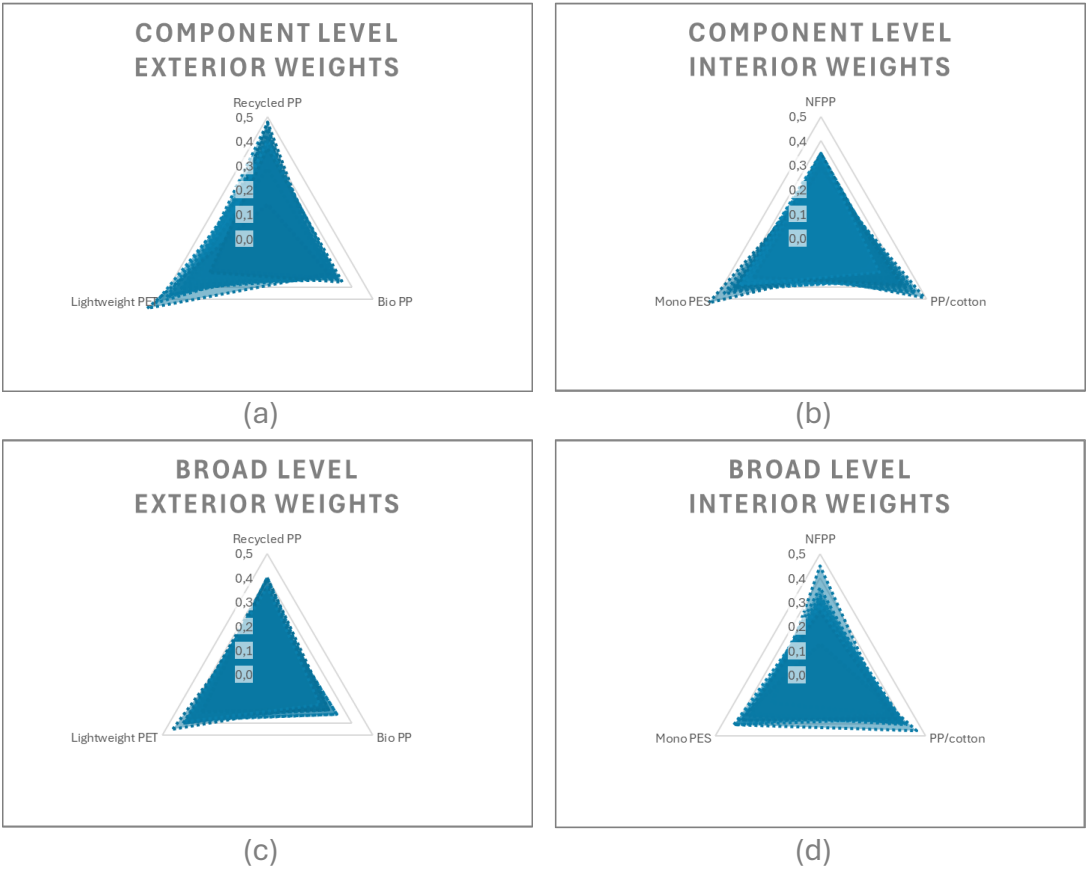


Figure A3

Material alternative preference weights for all ANP results split between the two decision cases and between team level, department level, unit level and complete vehicle level decision makers.

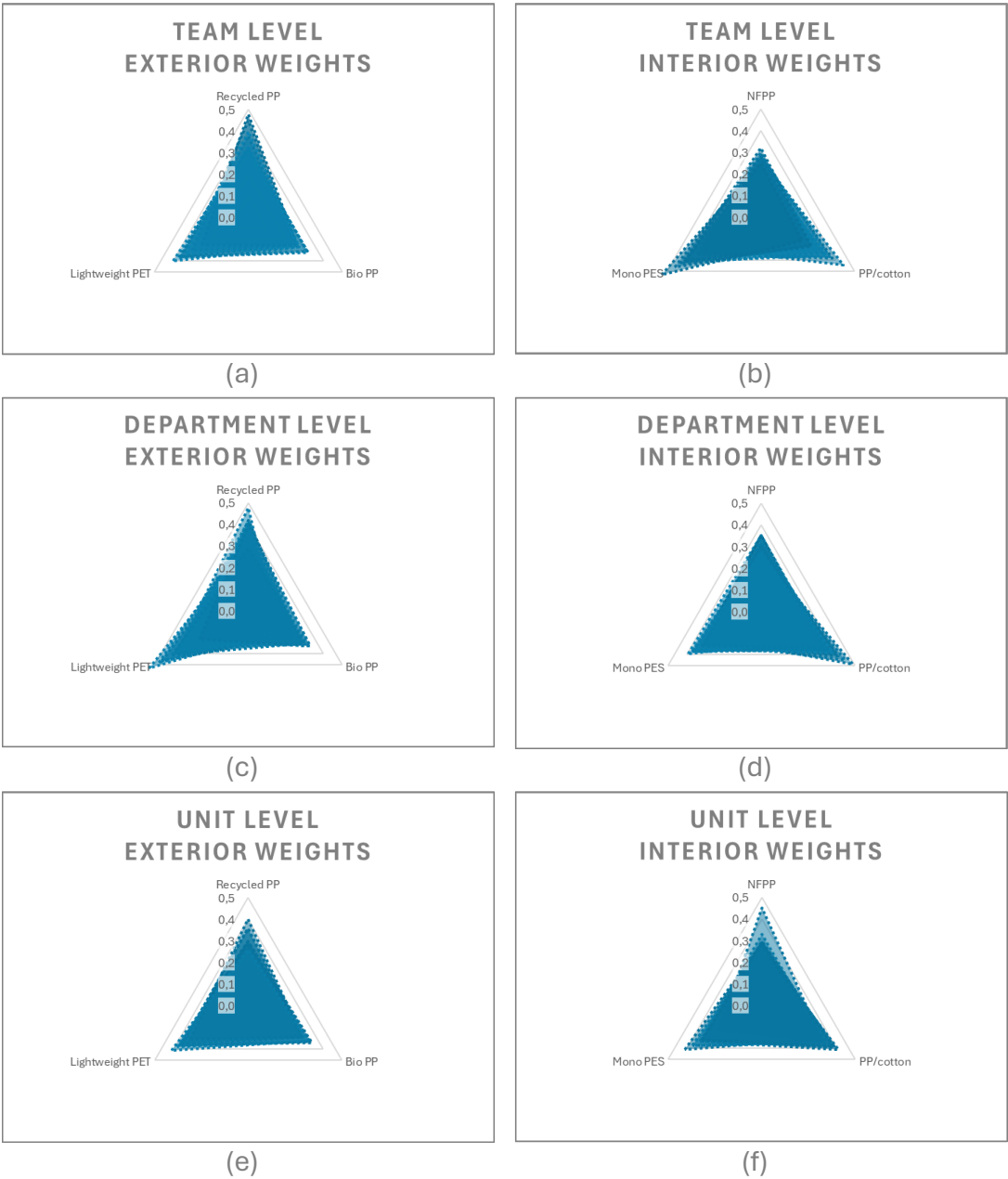




Figure A4

Material alternative preference weights for all ANP results split between the two decision cases and between decision makers working in the line organization and decision makers working in specific car programs.

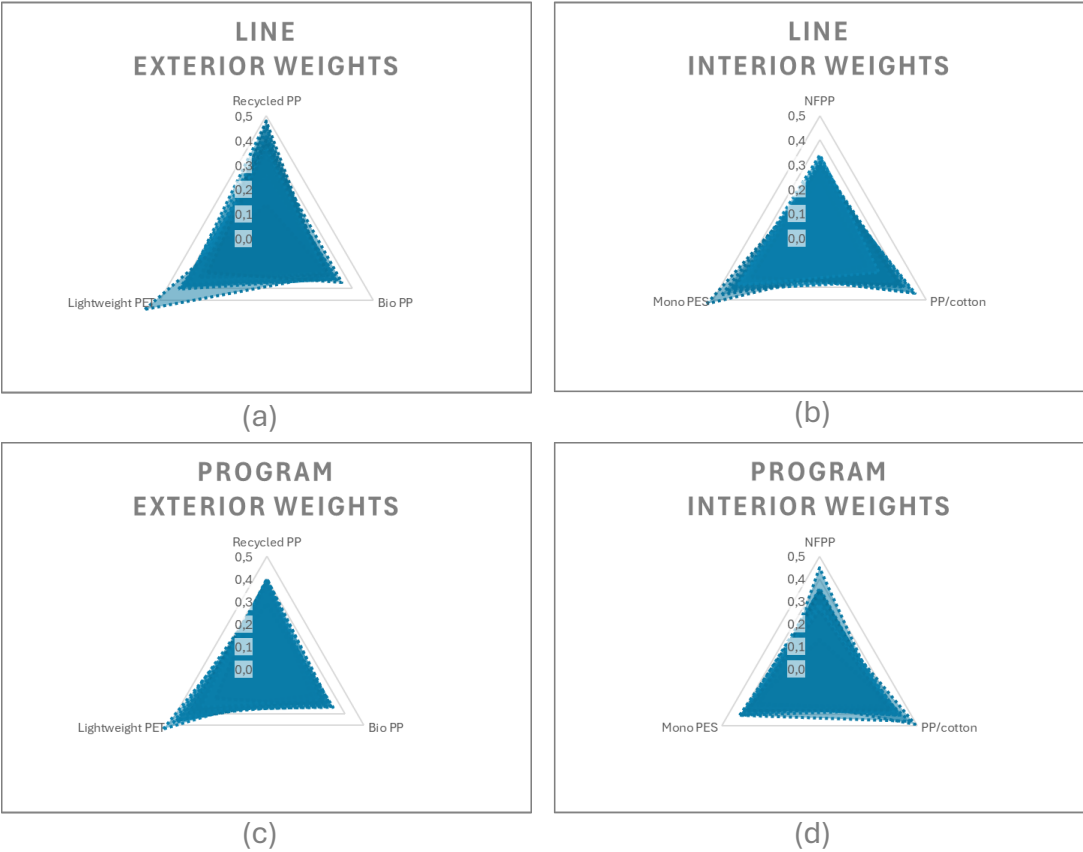


Figure A5

Material alternative preference weights for all ANP results split between the two decision cases and between decision makers working in the early phase of the product development cycle, in the late phase of the product development cycle and in the line organization.

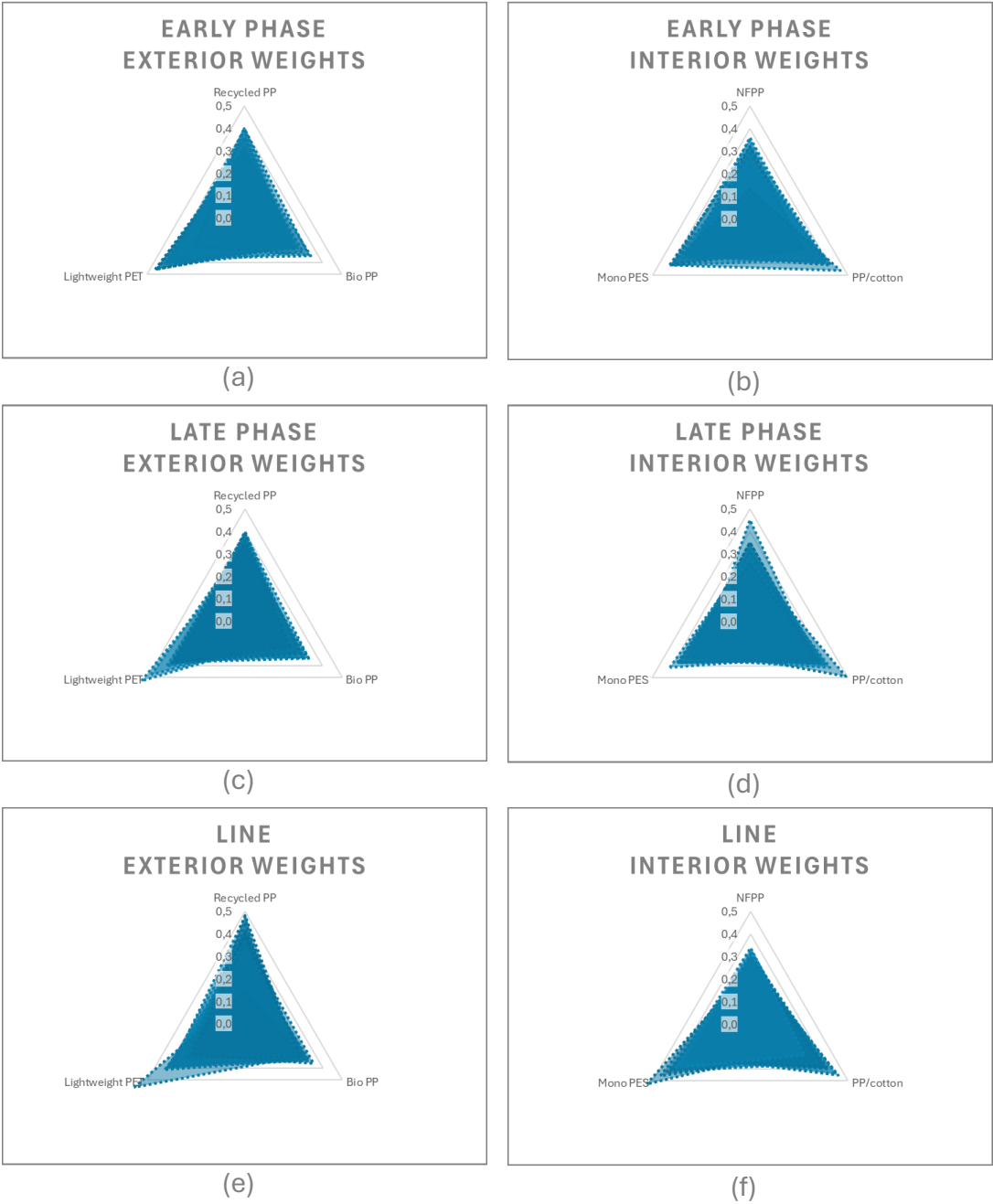
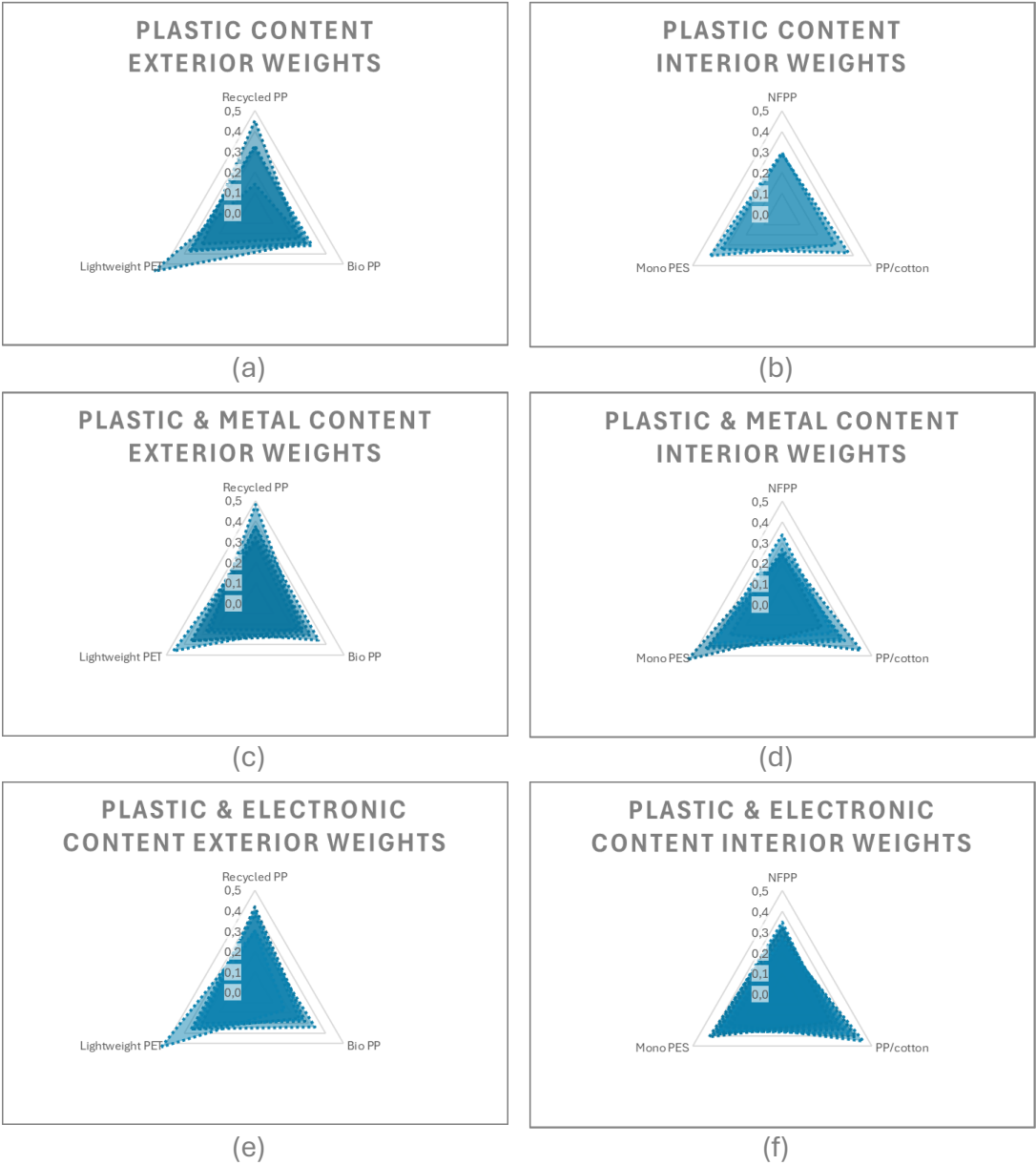
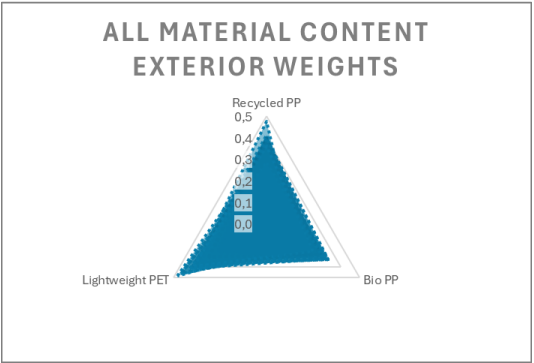


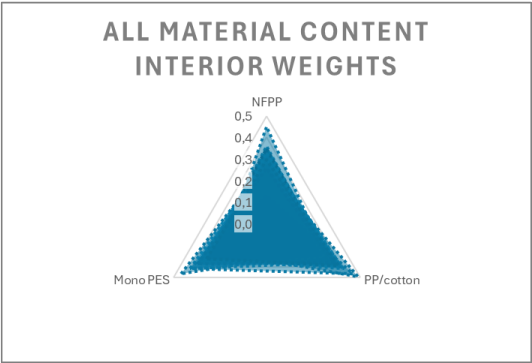
Figure A6

Material alternative preference weights for all ANP results split between the two decision cases and between decision makers working with mainly plastic content, mainly plastic and metal content, mainly plastic and electronic content, and all kinds of material content.





(g)



(h)

Figure A7

Material alternative preference weights for all ANP results split between the two decision cases and between decision makers working with mainly Full Service Supplier content, mainly Build-to-Print content and mixed Full Service Supplier and Build-to-Print content.

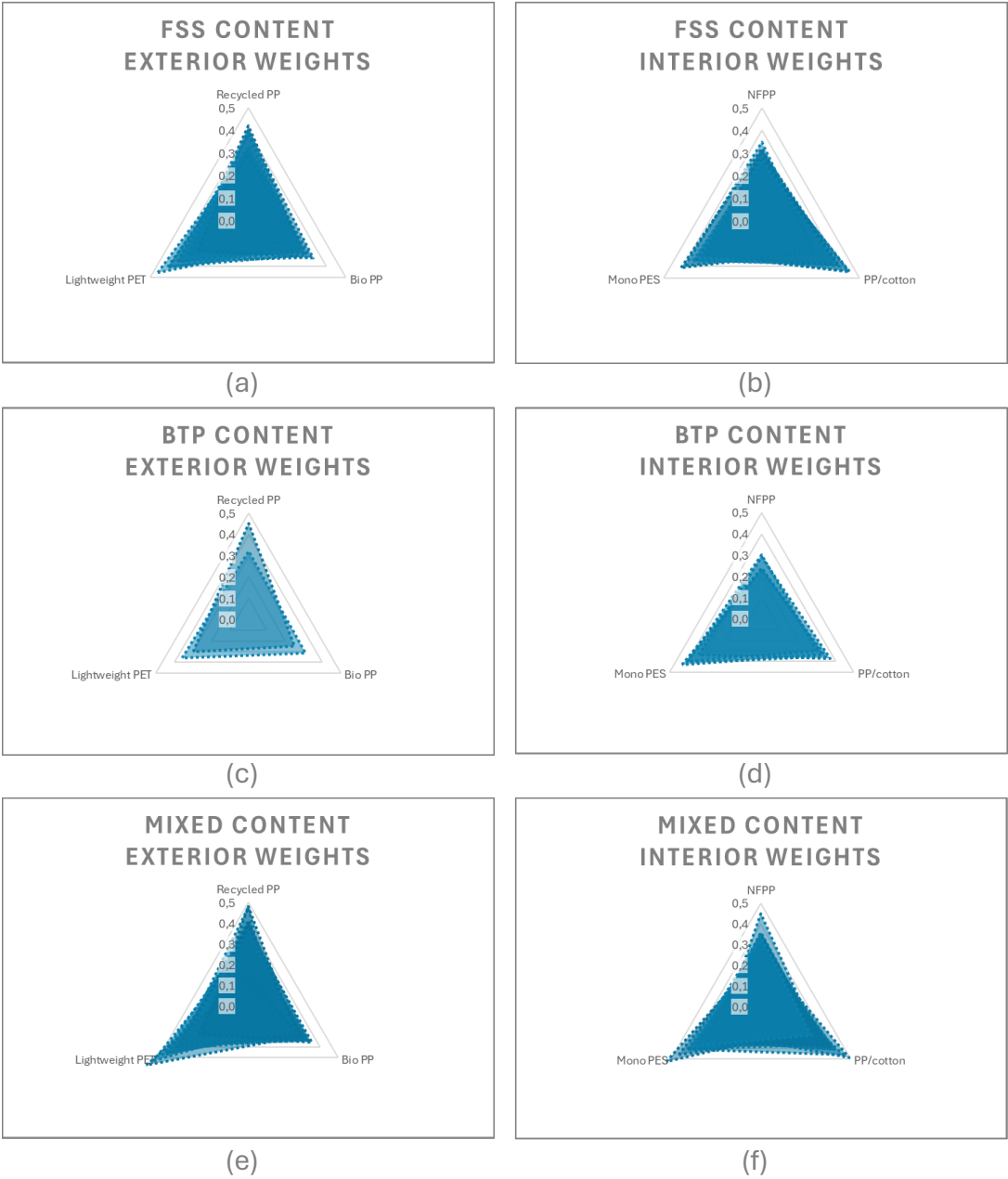


Figure A8

Supplementary questions form

Supplementary Questions

Please respond to this form after completing the Excel form.

* Required

* This form will record your name, please fill your name.

1. Which decision case did you do? *

Exterior case (Frunk system)

Interior case (Luggage trim)

Criteria

2. Do you usually consider all six criteria (CO2, recycled content, biobased content, cost, weight and end of life circularity/recyclability) when making material choices? *

Yes

No

3. Are there any other criteria that you usually consider in these kinds of decisions? *

4. Which criteria do you usually consider? *

CO2

Recycled Content

Biobased content

Cost

Weight

End Of Life circularity/recyclability

Other

Target/status

6. When responding to the Excel form, did you consider the department target/status background information? *

Yes

No

7. Please explain how you considered the department target/status background information when responding to the Excel form? *

8. Is this the same way that you usually consider target/status information when making these kinds of decisions in your work? *

Yes

No

9. Please explain how you usually consider department target/status information when making these kinds of decisions? *

XXVIII

