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Sustaining aviation: A decision-tree framework for recycling aircraft cabin interiors

Shahrokh Nikou *, Sicco Santema

Delft University of Technology, Faculty Industrial Design Engineering, Department: Design, Organisation and Strategy (DOS), the Netherlands

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ABSTRACT

The aviation industry faces pressure to reduce its environmental footprint while maintaining cost efficiency, regulatory and safety compliance. This research investigates how recyclability, as a key strategy within circular economy principles, can be implemented for aircraft interior parts. Employing a multi-method approach, including literature analysis, field research, stakeholder interviews, and a case study, this research identifies critical enablers and barriers to recycling aircraft interior parts. The findings demonstrate that recycled materials can meet key fire safety standards, supporting their potential for reuse in safety-relevant aircraft applications. A decision-tree framework was developed to assess the recycling potential of interior parts across maintenance, repair, and overhaul (MRO) operations. The research concludes that advancing recyclability within aircraft interiors aligns with circular economy ambitions and is both technically feasible and economically advantageous, offering a scalable pathway to enhance sustainability and operational efficiency in the aviation sector.

1. Introduction

The aviation industry is facing growing pressures both for its environmental footprint and inefficiencies in material use and waste generation (Amankwah-Amoah, 2020; Gopalakrishnan et al., 2012; Sebastian and Louis, 2021). While much attention is given to emissions from aircraft operations, sustainability challenges rooted in the short lifespan and high turnover of aircraft interior parts deserve equal focus. Despite advances in reducing emissions, the aviation sector has yet to address sustainability challenges related to the lifecycle management of interior parts, a critical gap this research aims to fill.

Interior components such as seat parts are frequently replaced due to wear, design updates, or regulatory requirements, resulting in significant waste volumes and ongoing reliance on virgin materials (Guven et al., 2024; Sebastian and Louis, 2021). These parts often consist of high-performance materials, including aluminium alloys, thermoplastics, and composites that are scarce, energy-intensive to produce, and costly to dispose of (Saraçyakupoğlu, 2024). Combined with rising operational costs and increasing sustainability expectations, these challenges emphasis the need for new strategies to balance operational efficiency with environmental impact.

Circular economy (CE) principles, such as reuse, recycling, and remanufacturing, offer promising strategies in different domains to extend the lifecycle of materials and components (Bronsky et al., 2025; Prendeville and Bocken, 2016). When implemented in aircraft interiors, these principles can strategically respond to aviation's material and cost-related pressures by reducing raw material dependency and minimising waste (Zuidberg, 2014; Krauklis et al., 2021; Scheelhaase et al., 2022). CE in aviation industry involves embedding these concepts throughout the lifecycle of aircraft components and systems (Bachmann et al., 2021; Rutkowski, 2022). Closed-loop recycling systems enable returning recycled materials directly to OEMs, and recovered materials are reintroduced into the same production cycle or returned directly to the OEM for reuse, aiming to preserve material utility (Kara et al., 2022; Van Loon and Van Wassenhove, 2017). Closed-loop recycling provides a structured approach to recovering and reintegrating materials, enhancing efficiency while reducing environmental impact (Daube et al., 2024; Dias et al., 2022; Guven et al., 2024; Hyvärinen et al., 2023; Yang et al., 2024).

Specifically, recycling materials such as polymers and composites enables their reintegration into production cycles, reducing waste and procurement costs (Krauklis et al., 2021). For example, plastic seat components, frequently replaced in aircraft interiors, show potential for recycling while maintaining compliance with aviation safety standards (Ateeq et al., 2023; Rahman et al., 2023). In addition, localised recycling and processing facilities can enhance supply chain resilience, reduce

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* Corresponding author. Landbergstraat 15, 2628 CE, Delft, the Netherlands.
E-mail addresses: S.N.Nikou@tudelft.nl (S. Nikou), S.C.Santema@tudelft.nl (S. Santema).

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transportation-related emissions, and improve material availability, thus contributing to both sustainability and operational efficiency (Elsayed et al., 2019).

Traditional linear production models in the aviation industry remain resource-intensive, with many components discarded after a single lifecycle (Rzevski et al., 2016; Pohya et al., 2021). CE principles enable the extension of material lifecycles through refurbishment, remanufacturing, and modular design (Prendeville and Bocken, 2016). For example, modular seat systems allow the replacement of individual parts rather than entire units, significantly reducing material waste and lifecycle costs (Kokorikou et al., 2016). This aligns with the circular cabin design initiative, which emphasises reusing interior components and integrating sustainability into design processes, a critical area still underdeveloped in the aviation industry (Wehrend et al., 2024).

In addition, successful integration of CE principles in aviation also depends on regulatory support and cross-sector collaboration (Salesa et al., 2023). Policy frameworks such as the EU's Circular Economy Action Plan,[1] offer incentives for material recovery and recycling, encouraging stakeholders to invest in CE solutions. Partnerships among airlines, suppliers, Original Equipment Manufacturers (OEMs), and recycling specialists are essential to resolve technical and regulatory barriers and scale implementation effectively (Dias et al., 2022).

Although CE frameworks and assessment tools have been proposed in various industrial domains, their application to the aviation sector, particularly to cabin interiors, remains limited. Several studies show the development of such general frameworks, Ortiz-de-Montellano and van der Meer (2022), for example, present a comprehensive cross-sector framework distinguishing circular processes (e.g. reuse, remanufacturing, recycling) and their environmental and economic impacts. Similarly, Demko-Rihter et al. (2023) develop a readiness-assessment framework to evaluate manufacturers' maturity in adopting circular strategies. While these frameworks provide valuable conceptual foundations, they are not designed for highly regulated contexts such as aircraft interiors, where certification, material consistency, and operational constraints strongly influence feasibility.

In the aviation literature, Khalifa et al. (2024) offer a comprehensive review of circular practices, encompassing sustainable fuels, maintenance operations, and waste-management initiatives, but interior parts are not included in their research. Their findings highlight a gap between strategic ambitions and operational tools. The authors highlight that despite progress in system-level circularity, there is no structured framework in aviation guiding component-level recycling decisions or linking material recyclability with certification, economic, and logistical criteria. Building directly on this gap, this paper offers an empirically grounded decision-tree framework that operationalises CE principles for aircraft cabin interiors. By integrating interview insights, field observations, and pilot testing of recycled components, the framework translates circularity from an abstract principle into a practical decision-support tool that enables maintenance and engineering teams to evaluate recycling feasibility within real-world operational and regulatory constraints, using the recyclability of a seat backrest as a case study.

Building on this identified gap, this research is guided by the following research question, "*How can decision-making in the recycling of aircraft interior parts be facilitated using circular economy principles while ensuring compliance with industry standards*?". This research aims to develop a framework that supports the aviation industry's transition toward more sustainable and resource-efficient operations, addressing both environmental impact and operational cost challenges. The framework guides material recovery efforts that align with CE principles while complying with aviation safety standards. To address the main research question, the following sub-questions are further formulated.

1. What are the key factors influencing decision-making in recycling practices for aircraft interior parts, considering regulatory, safety, economic, and operational constraints?
2. How can the recycling potential of aircraft interior parts be assessed within MRO operations?
3. Which current seat components demonstrate recycling potential?
4. How do the material properties of recycled seat backrests change during the recycling process?

Together, the answers to these questions provide a comprehensive understanding of how CE principles can be effectively integrated into the decision-making around recycling of interior parts. Each sub-question targets a specific aspect of the broader challenge, ranging from identifying enabling factors and assessing recyclability to evaluating material properties. This structured approach enables detailed analysis and supports well-founded conclusions.

This research adopts a qualitative approach, combining a literature review on CE principles in aviation and relevant regulatory frameworks, semi-structured interviews with aviation professionals, material suppliers, and recycling experts, as well as field observations conducted during Maintenance, Repair and Overhaul (MRO) operations. Additionally, to enhance the practical applicability, the case study also incorporated material testing of recycled backrests, assessing their compliance with aviation safety standards and lifecycle performance. A European airline serves as the empirical context and is referred to as the case company throughout this research. By focusing on decision-making in recyclability principles for aircraft interiors, this research contributes to the growing literature by developing a decision-tree framework for recycling aircraft cabin interior parts.

The framework development was guided by (a), existing frameworks found in the literature, (b) insights from the interview analysis, and (c) the pilot recycling trial. The framework provides operational insights and implementation pathways for integrating recyclability principles, specifically through the recyclability of seat components. The findings show the potential for strengthening supply chain resilience, and reducing dependency on virgin materials, while maintaining compliance with the strict aviation standards.

This paper is structured as follows: Section 2 provides the literature on circularity in aviation and the circular cabin model. Section 3 presents the research method, followed by the results in Section 4. The discussion is provided in Section 5, and the conclusion is presented in Section 6.

2. Literature review

2.1. Circularity in aviation

The aviation industry has committed to achieving net-zero carbon emissions by 2050, aligning with the Paris Agreement (Jensen et al., 2023). While technological advancements in propulsion systems and Sustainable Aviation Fuels (SAFs) contribute significantly to emission reductions (Undavalli et al., 2023), aircraft interior parts, which account for a substantial portion of aircraft weight, remain an underexplored area in the aviation industry (Kobenko et al., 2022).

While CE principles prioritise reducing waste, reusing materials, and recycling end-of-life products (Salesa et al., 2023), their application in aviation has primarily focused on high-value components like engines and fuel systems (Guven et al., 2024). Although these focused areas are critical, there remains a lack of knowledge on how to optimise cabin interior parts design through the integration of recyclable materials to create additional pathways to sustainability (Wehrend et al., 2024). Furthermore, adopting CE enhances supply chain resilience (Khalifa et al., 2024; Martínez Leal et al., 2020), while promoting long-term sustainability, allows to mitigate risks from material shortages through the use of emerging digital technologies (Bhawna et al., 2024).

Nevertheless, extending CE principles to aircraft interior parts

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[1] https://environment.ec.europa.eu/strategy/circular-economy-action-plan_en.

requires addressing challenges related to material certification, regulatory and safety compliance, and lifecycle assessments. For example, aviation regulations mandate strict safety and performance standards, particularly for cabin materials (Eisenhut et al., 2021). In this industry, certification processes for recycled components, such as fire resistance testing, are costly and time intensive (Bachmann et al., 2021; Krauklis et al., 2021). These regulatory challenges, alongside the high initial investment required to develop recycling infrastructure, have historically hindered the adoption of CE principles in aviation (Dias et al., 2022).

Efforts such as closed-loop recycling and remanufacturing of aircraft interior parts, focusing on material recovery and modular design, emphasises collaboration among regulators, manufacturers, and airlines to streamline certification processes, supporting broader CE implementation in aviation (Hyvärinen et al., 2023). Within this context, the circular cabin project initiative shows the feasibility of extending CE principles to aircraft interiors (Khalifa et al., 2024). This includes the recycling of high-value materials, such as polycarbonate products, to enable circularity and material reuse (Hyvärinen et al., 2023).

Allred and Salas (2011) argue that some interior parts consisting of polycarbonate demonstrate high recyclability potential and can retain their structural integrity and meet strict aviation safety standards after processing. This highlights the potential for CE implementation to transform traditionally waste-intensive elements of aviation into sustainable, efficient systems (Guven et al., 2024). Moreover, by drawing lessons from the automotive industry successes and adapting similar strategies (Baldassarre et al., 2022), the aviation industry can accelerate the integration of CE principles into its operations. This approach not only addresses environmental challenges but also yields economic and operational benefits, paving the way for a more sustainable future in aviation.

2.2. *Circular aircraft cabin model*

Recent initiatives, such as the circular cabin model represent a transformative approach to integrating CE principles into interior parts, focusing on reducing waste and costs while maintaining compliance with strict safety regulations. Aircraft interiors make up a considerable portion of the total cabin weight and are among the most frequently replaced components due to wear and regulatory updates (Guven et al., 2024; Tsai et al., 2014; Yakovlieva et al., 2021). For example, economy-class seats (Kokorikou et al., 2016), which are widely used across fleets, provide a significant opportunity for material recovery, cost efficiency, and reducing waste (Sebastian and Louis, 2021). In addition, polycarbonate, a thermoplastic known for its durability, impact resistance, and heat resistance, has been identified through prior research as highly recyclable (Ozturk et al., 2024). Reprocessing polycarbonate allows the retention of its essential properties, while meeting aviation-specific and safety standards such as fire resistance and structural integrity (Antonakou and Achilias, 2013).

Moreover, the circular cabin model leverages a systematic approach to material lifecycle management. For instance, Panza et al. (2022) discuss an open product development approach to support CE through a material lifecycle management framework. The authors argued that by implementing closed-loop recycling systems, the aviation industry can ensure that materials recovered from decommissioned seats are reintegrated into new production cycles. This approach reduces reliance on virgin raw materials and significantly reduces waste sent to landfills, thereby aligning with airlines' broader sustainability targets. Furthermore, the model's emphasis on frequently replaced components such as cabin seats enhances both scalability and replicability across diverse aircraft types and fleets.

All in all, the literature findings establish a foundational understanding of recycling in aviation, highlighting technical, regulatory, and economic barriers. It emphasises that recyclability is largely determined during the design stage, where material compatibility, diversity, and purity directly affect recovery feasibility.

2.3. *Factors influencing the adoption of recycling practices for aircraft interior parts*

This section presents the factors influencing the adoption of recycling practices for cabin interior parts in the aviation industry. Understanding these factors is critical to designing effective recycling strategies that align with industry standards, economic realities, and operational constraints. Given the complexity of aircraft maintenance and the regulatory environment, successful integration of recycling practices requires balancing technical feasibility, safety, cost-effectiveness, and sustainability goals.

In general, recyclability is one of the core principles of CE and is largely determined during the design phase of aircraft interior components. Design decisions influence the compatibility of the materials, the diversity of materials used, and the overall ability to recover pure and valuable recycled materials (Martínez Leal et al., 2020). Ensuring that materials are compatible and minimising material diversity facilitate easier separation and processing, which is essential for maintaining the quality and value of recycled parts. This factor enables effective recycling and compliance with safety regulations, providing a basis for developing practical, context-specific solutions to enhance circularity in aircraft interiors. In the following, we elaborate on the factors which have been identified during the literature review process.

2.3.1. *Regulations and flight safety*

The aviation industry is governed by strict regulations to ensure flight safety and airworthiness. Any material or design change arising from recycling processes must comply with the strict standards (De Florio, 2016). Parts undergoing recycling must often pass through complex certification procedures, particularly when modifications to structural integrity or operational characteristics are affected. These regulatory standards safeguard safety but introduces significant complexity and costs, necessitating early integration of safety considerations within the recycling design process.

2.3.2. *Economic viability*

Economic feasibility influences whether recycling can be sustained in aviation. Recycling offers potential cost savings by reducing raw material consumption and waste disposal expenses (Asmatulu et al., 2013). The high costs associated with certification and compliance, especially for major design changes, impose additional financial burdens (Xie et al., 2019). Closed-loop recycling systems also improve economic viability by reducing investment costs and stabilising part supply (Van Loon and Van Wassenhove, 2017). The availability and demand for parts also impact economic considerations, as shortages can lead to costly grounded aircraft (Chenoweth et al., 2010; McDonald, 2002).

2.3.3. *Supply chain, technology readiness, and partnerships*

An efficient supply chain is critical to support the steady flow of recyclable materials necessary for circular operations. Recycling adds complexity by requiring consistent material flows and technological readiness to handle diverse materials (Lapko et al., 2018). Despite challenges such as increasing use of composite materials that are harder to recycle, advancements in recycling technology and growing industry partnerships are fostering the development of effective closed-loop systems (Hyvärinen et al., 2023). In this regard, collaboration among stakeholders is essential to overcome market immaturity and logistical hurdles.

2.3.4. *Operational considerations*

Operational variability in aircraft maintenance complicates the establishment of reliable recycling processes. The unpredictable demand for spare parts and fluctuating repair schedules limits the ability to forecast material availability (MacLean et al., 2005). Routine maintenance checks, which vary in scope and frequency, provide opportunities for material recovery but require careful coordination to accumulate sufficient volumes for recycling (Deng and Santos, 2021). Aligning recycling efforts with major cabin modifications and redesign projects can improve material collection efficiency and support sustainability initiatives (Niţă and Scholz, 2011).

2.3.5. Public perception, Corporate Social Responsibility, and sustainability goals

Public perception and Corporate Social Responsibility (CSR) commitments play an influential role in motivating companies to adopt recycling practices. Organisations that prioritise sustainability and social responsibility often enhance their reputation and consumer trust, which in turn supports broader environmental goals (Modak et al., 2019). In the aviation industry, achieving ambitious targets like net zero emissions by 2050 depends not only on technological advances but also on sustainable operational practices, including recycling (Bergero et al., 2023). Such initiatives contribute to environmental stewardship and long-term viability.

2.3.6. Social innovation

Implementing recycling practices successfully requires social innovation that fosters collaboration, knowledge sharing, and adaptability within organisations. Multifunctional teams and strong social capital support the development of creative solutions and process improvements necessary for sustainable transitions (Allal-Chérif et al., 2022; Emre, 2012). Given the high workload and stress levels among aviation maintenance personnel, recycling processes must be designed to integrate smoothly into existing workflows without adding extra burden, ensuring acceptance and long-term success (Santos and Melicio, 2019).

2.3.7. Material properties

It is worth mentioning that Martínez Leal et al. (2020) have developed the Recyclability Index to evaluate the recyclability of aircraft interior parts. This index identifies the potential for material recovery while ensuring alignment with aviation safety requirements. The recyclability index provides a structured approach for assessing the feasibility of recycling through three indicators: (i) material compatibility: which determines whether materials can be recycled together without property degradation, (ii) material diversity, where fewer material types simplify separation and improve processing efficiency, and (iii) material recyclability, which measures recovery yield and purity critical for maintaining the value of recycled outputs. By highlighting how material design directly influences recovery potential, the index offers a practical benchmark for evaluating circularity during the design and maintenance of aircraft cabin components.

3. Method

This section outlines the methodological approach used to answer the main RQ and sub-RQs. We specifically focus on recycling processes within MRO operations. The empirical data, comprising semi-structured interviews, field visits, and material testing, were all conducted in the context of the MRO facilities of the case company. This focus reflects the operational reality where interior components such as seat parts are most frequently replaced, repaired, or scrapped during regular maintenance cycles, providing a practical setting for implementing and testing CE principles. A mixed-methods approach, including semi-structured interviews, expert fieldwork consultation (see Section 4.4), and a pilot testing visit aimed at practical testing were adopted to ensure both theoretical depth and contextual applicability. Through this approach, we gained a triangulated perspective on decision-making in the circularity of cabin interior parts.

In total, eight semi-structured interviews were conducted with professionals across the case company's internal ecosystem to gather perceptions about the factors influencing the decision-making in recycling practices for aircraft interior parts. The participants included specialists in maintenance, engineering, customer service, and sustainability operations. The interviews followed a standardised protocol, beginning with questions about participants' background, followed by thematic questions based on six core factors identified during the literature phase: (i) regulations and flight safety, (ii) economic viability, (iii) supply chain, technology readiness, and partnerships, (iv) operational considerations, (v) public perception, CSR, and sustainability goals, and (vi) social innovation.

Each interview lasted approximately 20 min and was conducted in person or via Teams calls. The sessions were recorded (with consent), summarised, and thematically coded to extract actionable insights. Participants were asked to confirm or challenge the completeness of the identified influential recycling factors with an opportunity to provide additional insights related to their area of expertise.

Following the interviews, 11 field research visits were carried out at the case company's facilities across multiple departments involved in the lifecycle of interior parts: from disassembly and repair to disposal and material handling to headquarter sustainability office to in-flight services. The purpose of these visits was to evaluate the technical feasibility of recycling cabin seat backrests, specifically those made from polycarbonate. Moreover, these site visits enabled us to observe operational workflows, material sorting processes, and cross-departmental practices affecting recycling potential. In addition, as a pilot testing activity, a collaborative material testing visit was conducted with external partners.

4. Results

4.1. Interview results

The interview analysis revealed several practical and operational challenges related to recyclability, regulations, economic constraints, and workload management. The interviewees highlighted four overarching aspects shaping the adaptability of recycling processes within the case company's operations: (i) personnel expertise, (ii) availability and proximity of recycling infrastructure, (iii) operational processes, and (iv) collaboration with OEMs. Interviewees further emphasised that success depends on combining these factors with attention to material compatibility and regulatory compliance, which aligns with recyclability assessment principles.

First, well-trained personnel with sufficient recycling knowledge and behaviours are essential to ensure consistent quality and effectiveness. Second, the availability and proximity of capable recycling facilities, alongside committed OEM partners, significantly influence feasibility and efficiency. Third, operational challenges such as high workloads, particularly in logistics and material separation highlighted the need for streamlined workflows to reduce complexity and resource pressure. Finally, OEM engagement in sustainable practices is often driven by airline pressure and broader supply chain dynamics.

Interviewees also emphasised the importance of maintaining fire-retardant properties in recycled materials, requesting certification protocols to guarantee consistent quality and regulatory compliance. This indicates that ongoing research is needed to better understand the effects of recycling on material properties and to develop robust protocols ensuring batch-to-batch consistency. These insights highlight the importance of aligning human, technical, and regulatory factors to successfully scale CE practices within the case company. In addition, regulatory compliance, especially concerning fire safety and structural integrity, adds significant complexity and cost to the certification of recycled materials.

Industry-specific standards from regulatory bodies, e.g. the European Union Aviation Safety Agency (EASA) and the Federal Aviation Administration (FAA) were identified as key constraints (De Florio, 2016). Interview results also support this observation, with multiple participants pointing out that fire safety remains the most critical certification requirement and that maintaining consistent material properties could simplify approval processes. The recyclability of the part and understanding whether material properties change during recycling is crucial. One participant emphasised, "*If the recycled material is identical to the original, it avoids additional certification. Otherwise, fire safety and batch consistency must be ensured*" (Interviewee 6).

To address first sub-question "*What are the key factors influencing decision-making in recycling practices for aircraft interior parts, considering regulatory, safety, economic, and operational constraints?*", we present expert interviews results based on the six factors identified in Section 2.3.

A. ***Regulations and Flight Safety***: In aviation, strict certification regulations ensure flight safety and airworthiness. Any design changes, including the use of recycled materials, must comply with EASA or FAA standards, often requiring extensive testing and approval (De Florio, 2016). Fire safety remains the most critical certification aspect for aircraft interior parts. Participants emphasised fire safety as the foremost consideration for material approval, stating, "*Material must be flame-retardant and maintain structural integrity over its lifespan*" (Interviewee 8*)*, and Interviewee (6) indicated that *"Maintaining consistent material properties simplifies certification".*

B. ***Economic Viability***: The feasibility of recycling depends on economic factors such as return on investment and certification costs. While recycling can reduce environmental impact and potentially lower material expenses through closed-loop processes (Asmatulu et al., 2013), high certification costs and combined with fluctuating and unpredictable demand for parts create significant challenges. Interviewees emphasised the critical role of cost management, noting that "*the financial business case will ultimately determine whether recycling is adopted*" (Interviewee 3). Moreover, an interviewee indicated that "*OEMs prioritise profits but can be influenced by external pressure, particularly from airlines*"*. Or another interviewee indicated that "Financial viability is essential for recycling efforts"* (Interviewee 5).

C. ***Supply Chain, Technology Readiness and Partnerships***: Efficient supply chains and strong partnerships are crucial for implementing closed-loop recycling systems. While proximity to recycling infrastructure can reduce costs and streamline logistics, the actual capability or preparedness of these recycling systems differs (Maaβ, 2020). OEMs play a significant role in determining material use and recycling practices. One participant noted, "*OEMs prioritise their profit models, but airline pressure could drive more sustainable practices*" (Interviewee 5). Another noted, "*Local recycling capabilities are key for efficient operations*" (Interviewee 1).

Moreover, Interviewee (4) confirmed that the role of OEMs should be considered within the broader theme of supply chain and technical readiness partnerships and noted that: "*OEMs do not directly influence how cabin parts are scrapped or recycled at the case company*", emphasising the importance of stimulating OEM collaboration within wider supply chain dynamics. Additionally, Interviewee (7) mentioned that "*Material shortage and OEM pressure are key challenges to recycling*".

D. ***Operational Considerations***: The unpredictable flow of aircraft interior parts, influenced by maintenance schedules and varying repair needs, complicates recycling efforts. Effective maintenance planning depends on consistent material availability to support closed-loop systems (MacLean et al., 2005). Workload was identified as a significant challenge. One participant noted, "*High workloads leave little capacity for additional tasks like material separation, making process simplicity critical*", also the same interviewee mentioned that "*Material separation for complex parts is necessary but difficult under current conditions*" (Interviewee 2). Another interviewee mentioned that "*Proper knowledge and behaviour among colleagues are crucial for recycling success, yet recycling infrastructure and local capabilities are critical*", (Interviewee 1). Interestingly, Interviewee (4) indicated that "While I am not expert, I think the OEMs do not influence how the scrapping or recycling of cabin parts are done".

E. ***Public Perception, CSR and Sustainability Goals***: Sustainability efforts in aviation are increasingly influenced by public perception and CSR initiatives. Recycling practices can enhance company reputation and build consumer trust (Modak et al., 2019). While direct references to public perception and CSR were limited in the interviews, Interviewee (5) highlighted an important indirect connection and noted that "*Although OEMs primarily focus on controlling their supply chains for profit, they are nonetheless responsive to external pressure from airlines to adopt more sustainable practices*". This suggests that the case company can leverage its position to influence supplier behaviour in line with broader sustainability goals, reflecting an implicit role of CSR-driven demand in advancing CE initiatives in aviation. Moreover, one interviewee mentioned that "*The longevity and durability of recycled materials are vital to ensuring their usability and sustainability in the long term*" (Interviewee 8). Also, Interviewee (2) mentioned that "*Resistance arises if sustainability efforts add to existing workloads*". It was also mentioned that "*The business case must balance financial and sustainability impacts*" (Interviewee 3).

F. ***Social Innovation***: Implementing recycling processes depends on employee involvement and social innovation. Collaboration across multifunctional teams fosters creative problem-solving and improves process efficiency (Allal-Chérif et al., 2022). One participant emphasised, "*Knowledge and behaviour of employees are critical to success; proper training is essential to ensure recycling effectiveness*" (Interviewee 1).

4.2. Cross-interview insights

The expert interviews not only validated the relevance of the six identified factors but also revealed nuanced insights that deepen our understanding of their practical implications in aviation recycling. For practitioners, the critical role of regulatory compliance, especially around fire safety, extends beyond technical necessity to shape material innovation pathways, highlighting an opportunity for proactive certification strategies to accelerate adoption. Economic viability emerged as a dynamic challenge influenced by fluctuating part demand, emphasising the need for adaptable business models that can manage market variability while leveraging closed-loop efficiencies.

The variable readiness of recycling infrastructure and the complex role of OEMs, characterised by mixed interests and varying levels of engagement, reveal that supply chain collaboration cannot be taken for granted but requires deliberate relationship-building and strategic leverage from airlines. Operational constraints, particularly workforce capacity and the unpredictability of part flows, emphasise that successful recycling demands not only process redesign but also organisational change and targeted training, pointing to social innovation as a critical enabler. While CSR and public perception were less explicitly articulated, their indirect influence through supply chain pressures suggests a growing space for sustainability-driven procurement policies to catalyse change. Collectively, these insights advance the literature by integrating technical, economic, social, and strategic dimensions, offering holistic knowledge for practitioners aiming to embed circularity within complex aviation maintenance systems.

In the following, we synthesise the overarching themes that emerged across all eight interviews. These cross-interview insights complement the literature and field findings, offering practical considerations for advancing circular practices within cabin interior maintenance. The interviewees broadly confirmed that the proposed list of factors is comprehensive and relevant. This strong validation supports the use of these factors as a foundational framework for developing and implementing recycling strategies at the case company. The following themes provide deeper insights into each of these areas, see Table 1.

Table 1
Cross-interview insights.

Themes	Cross-Interview Insights
Infrastructure and Local Capabilities	Accessible and capable local recycling infrastructure is a foundational requirement. Local recycling and repair of interior components reduce logistical complexity, accelerate turnaround, and improve process reliability, enhancing overall operational efficiency.
Knowledge and Behaviour of Personnel	Employee awareness and behaviour are critical for successful recycling. Lack of knowledge or improper material separation risk material purity and recycling effectiveness, highlighting the need for dedicated training and behavioural change programmes to support staff engagement.
Operational Barriers and Workload	High workloads and limited resources hinder staff's ability to perform complex material separation. Recycling feasibility depends on part complexity and available operational time. Sustainability initiatives that increase workload without sufficient support risk generating resistance among personnel.
Economic Viability	Economic feasibility is essential. Recycling initiatives must balance cost-efficiency with sustainability goals. Interviewees stressed the importance of highlighting additional recycling costs versus traditional processes, as these are often underrepresented in business cases, impacting adoption decisions.
OEM and Supply Chain Influence	The role of OEMs in enabling or constraining recycling is complex. OEMs often prioritise part sales, limiting support for sustainable alternatives. However, external pressure from airlines, especially during material shortages can influence OEM behaviour, suggesting leverage points for driving change.
Certification and Regulatory Constraints	Fire safety is the most critical certification requirement for aviation-grade materials. Maintaining material consistency across batches can simplify certification. Certification challenges vary across industries, with aviation facing strict standards, posing a significant barrier to recycling adoption.
Material Durability and Lifespan	Material lifespan is vital for sustainability. Recycled materials must maintain structural integrity over time to avoid premature failure, cracking, or breakdown, which would undermine both environmental and operational value.

4.3. Development of the decision-tree

This section presents the approach used to answer sub-question 2: "*How can the recycling potential of aircraft interior parts be assessed within MRO operations?*" The outcome of this phase was the development of a decision-tree framework designed to systematically evaluate the recycling potential of interior parts within the MRO environment. The case study served as a pilot for testing and refining this decision-tree framework (Fig. 1). To bridge theoretical insights with practical application, field research was conducted to gather firsthand information from industry experts and observe decision-making processes related to recycling within the case company's cabin maintenance operations. This included a pilot study and consultations with practitioners involved in disassembly, materials handling, and repair workflows. These activities provided valuable contextual understanding of the challenges and operational realities faced when applying the decision-tree framework. Based on these observations, the initial assessment criteria embedded in the decision-tree were refined and iteratively validated with experts to ensure their accuracy, relevance, and applicability within real-world airline maintenance contexts.

The decision-tree integrates decision points such as part repair frequency, replacement cost, material composition, and current scrappage practices to guide recycling decisions systematically. For example, parts that are frequently repaired or have replacement costs exceeding €1000 are flagged for repair consideration. Components made of multiple materials are identified as requiring additional separation efforts, potentially impacting recycling feasibility. The decision-tree also incorporates the willingness of OEMs to participate in closed-loop systems, suggesting partnerships with third-party recyclers when OEM collaboration is limited. This structured framework was piloted in the case study to validate its practicality and refine its applicability.

Findings show that economic and logistical viability depend on a consistent flow of materials and steady demand. Parts with irregular availability or limited volumes are less likely to support cost-effective recycling within the decision-tree framework. Close collaboration with OEMs and engineering teams is essential to verify material composition and evaluate technical suitability, ensuring the decision-tree's recommendations align with practical recycling capabilities.

Designed for simplicity and flexibility, the decision-tree framework is suitable for broad application across cabin maintenance operations. It facilitates cross-departmental alignment by enabling informed and consistent recycling decisions that support CE objectives and enhance operational sustainability. To maximise usability, the decision-tree follows the design principle, featuring straightforward language and a clear, visually appealing layout. This approach ensures the tool is easily understood and readily shareable across all Engineering and Maintenance departments.

The decision-tree is designed to guide recycling decisions in a sequential manner. The first step is to gather the part name, number, and a visual representation of the component. This information is essential for accurately identifying the part and ensuring a smooth and reliable evaluation. Typically, the part number is found on the component and can be cross-referenced in systems such as SAP or the part's manual.

The next step involves answering the question: "Does the part require frequent replacement rather than on-aircraft repair, and is its replacement cost significant?" This decision node evaluates whether the part is frequently replaced and economically relevant within MRO operations. Parts that are replaced at least ten times per year and whose replacement cost exceeds €1000 are prioritised for further assessment within the recycling pathway. For lower-cost components, recycling is considered only when reprocessing is more cost-effective than producing new parts. This step distinguishes between components that can still be repaired or refurbished and those that are removed from service and potentially suitable for material recovery. The evaluation relies on historical part data and expert input to ensure both operational and economic feasibility.

The subsequent question, "Is the part non-reusable and non-repairable and therefore will be scraped?" ensures that recycling is considered only for components that have reached the end of their service life. Parts that remain suitable for repair, refurbishment, or are covered under warranty are excluded, as they can be restored or replaced without entering the recycling pathway. In this way, recycling is reserved exclusively for parts that are beyond further use.

Following this step, the decision-tree assesses "Is there a planned modification or a consistent flow of scrapped material sufficient to enable batch recycling?". This node defines a practical scope boundary for recycling within MRO operations. Successful recycling requires either planned modifications (e.g. cabin redesigns) that generate predictable volumes of scrapped parts, or a steady flow of parts removed during routine maintenance that is sufficient to enable recycling. In the absence of both, recycling is considered out of scope at this stage, as low-volume scrappage does not justify the fixed costs associated with collection, sorting, transport, and processing. In such cases, the part is not excluded permanently from recycling but deemed currently unviable within the operational scope of the framework.

The subsequent step asks: "Does the part consist of multiple materials?". For optimal recyclability, parts should ideally be made from a single material feature a simple design (Martínez Leal et al., 2020). When parts contain multiple materials, additional separation steps are required. In these cases, external support, such as social workshops, may be utilised to facilitate material separation.

Next, the material's recyclability is evaluated by asking: "Is the material recyclable?". This process involves identifying the specific

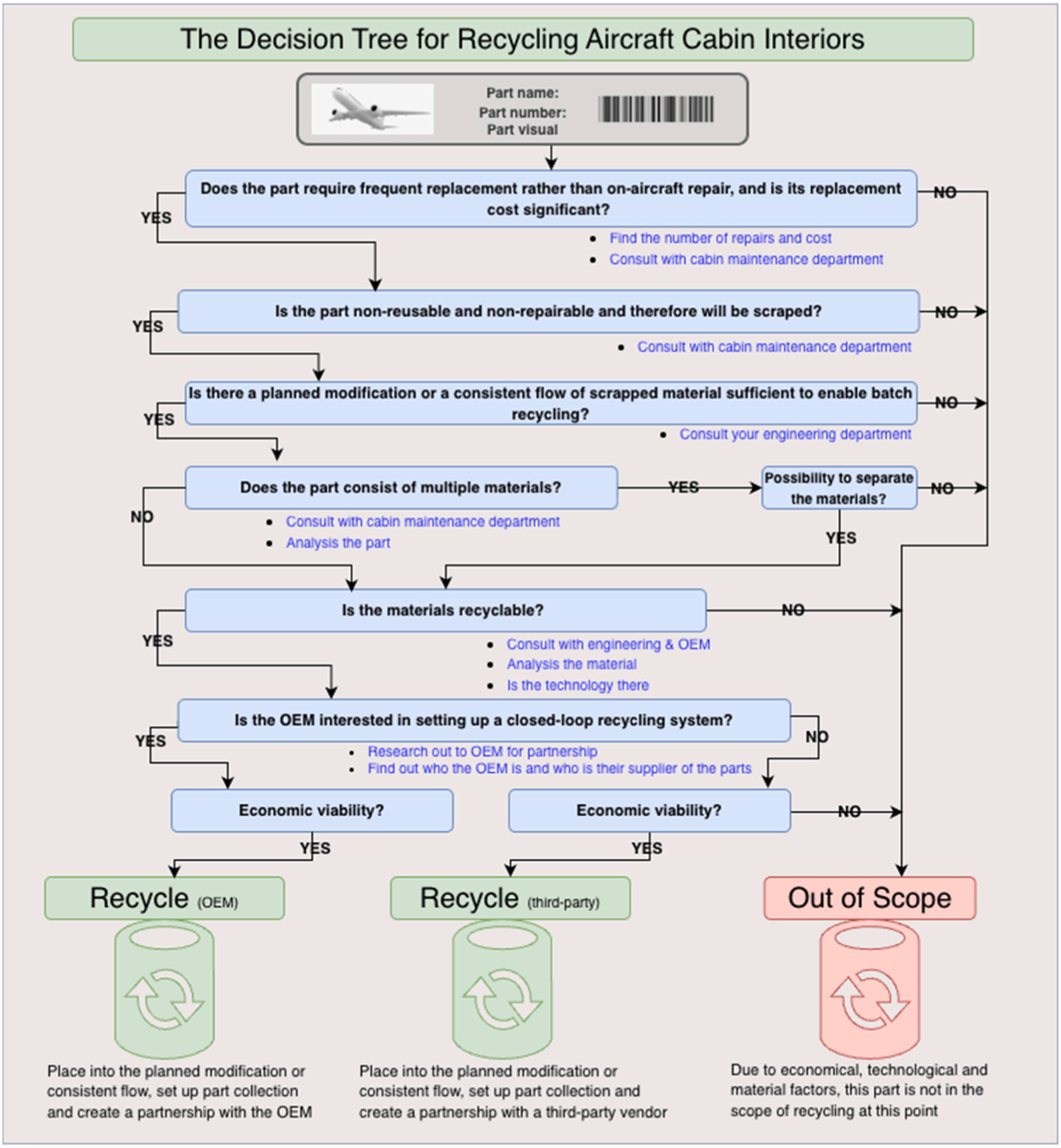

Fig. 1. The decision-tree for recycling aircraft cabin interiors in MRO operations.

material through consultations with engineering teams and OEMs. The material's suitability for recycling is then assessed collaboratively with industry experts.

The subsequent decision node, “Is the OEM interested in setting up a closed-loop recycling system?”, determines the engagement strategy for recycling. If the OEM expresses interest, a partnership for closed-loop recycling is pursued. If not, collaboration with certified third-party recyclers is explored as an alternative pathway for material recovery. Importantly, a lack of OEM interest does not exclude recycling but redirects it toward an external recycling model.

Following either pathway, the final decision node assesses “Is there economic viability?”. This step evaluates whether recycling is cost-effective compared to replacement, taking into account material recovery value, certification costs, and process feasibility. By applying this economic assessment to both OEM-led and third-party recycling options, the framework ensures that recycling decisions within MRO operations are based on financial feasibility as a final determining criterion. Parts that meet this criterion proceed to recycling, while those that do not are considered out of scope at this stage.

The decision-tree was evaluated and tested through a case study with practitioners at the case company to validate its usability without requiring prior specialised knowledge. Minor language adjustments were made based on their feedback. Additionally, the framework was reviewed by company experts to verify its accuracy and clarity, with no discrepancies reported. This thorough evaluation demonstrates that the decision-tree is both practical and accessible, providing confidence in its applicability across the case company's operations.

4.4. *Identifying seat components with recycling potential*

The third sub-question “*Which current seat components demonstrate recycling potential?*” was addressed through a combination of field visits, desk analysis, and collaboration with internal departments and external partners. The goal was to identify interior seat parts with significant recycling potential and substantiate these findings with operational and financial data. The identified components served as key inputs for validating and testing the decision-tree framework introduced earlier.

The field visits began with visiting the department responsible for sorting scrapped aircraft cabin interior parts based on technical inspections. This department plays a key role in deciding whether parts should be repaired, returned to stock, or scrapped. Observations at this department, supported by discussions with handlers, helped identify parts frequently deemed irreparable and thus suitable for material recovery. This site visit facilitated coordination for part collection during the pilot phase of the decision-tree validation.

Further fieldwork with maintenance personnel provided vital insights on components most prone to damage and replacement, ensuring the decision-tree's assessment criteria were tested against practical wear patterns across the fleet. Desk research was conducted to cross-reference frequently scrapped part numbers with company systems and technical manuals. This approach aimed at validating repair frequency, replacement costs, and material characteristics relevant for the decision-tree's application. Collaboration with the seat manufacturer offered detailed material specifications, enabling grouping of components by plastic type for potential bulk processing within the decision-tree framework. Plastic economy seat parts (i.e. backrests) emerged as high-potential candidates for recycling, small in size but frequently replaced, making them ideal for validating scalable recycling loops through the decision-tree.

Findings from this phase strongly support the financial and environmental case for targeted recycling efforts. The high replacement volume and significant procurement costs of these parts underline the opportunity for cost reduction, supply chain resilience, and waste minimisation through closed-loop recycling practices. This data-driven identification of recyclable components provided essential input for prioritising parts during the decision-tree validation, laying the groundwork for effective recycling initiatives across aviation maintenance operations.

4.5. *Assessing material properties of recycled seat backrests*

The sub-question four “*How do the material properties of recycled seat backrests change during the recycling process?*” was addressed through collaborative field research and practical testing, conducted with internal teams and external partners, a local aircraft part supplier. The goal was to assess whether recycled polycarbonate materials from seat backrests retained the performance characteristics required for reuse in safety-critical aviation applications, with a focus on fire resistance.

The investigation began with a pilot initiative aiming to develop a minimal viable proof of concept for closed-loop recycling. Site visits and consultations within cabin maintenance operations departments supported the identification and collection of used backrests due to their polycarbonate composition and potential for material recovery. The repair department provided complementary insights, especially on how certification requirements and repair processes influence material reuse. Parts Manufacturer Approval (PMA) is often sourced from third-party suppliers or repaired in-house to reduce OEM dependency. This reinforces the need for dual approvals, Design Organisation Approval (DOA) and Production Organisation Approval (POA) to certify any modified or recycled components.

The interviewee analysis also indicated and emphasised that material consistency across batches could simplify certification procedures. Material selection and part frequency data were also analysed using the case company's maintenance records and stock planning systems. These were used to identify high-turnover components and assess the financial feasibility of recycling. While fire resistance was confirmed, further tests on material degradation are necessary to meet full certification criteria under aviation regulations. A local company specialising in the manufacturing and recycling of plastic aircraft parts collected the backrests, and the recycling process was started by cleaning, disassembling, and shredding backrests into granulate were cleaned and then injection-moulded into test plates. This phase uncovered key operational challenges. Non-polycarbonate elements such as embedded adhesives and repair patches had to be manually removed to ensure material purity. Eventually, 10 kg of clean polycarbonate granulate were produced and used to injection-mould test plates.

Next, a local aircraft part supplier tested the recycled plates for fire resistance of the recycled plates to assess compliance with the aviation safety standards for polycarbonate. This testing phase provided critical data on material behaviour, performance consistency, and the influence of embedded contaminants, offering real-world evidence of the recyclability of aviation plastics.

The samples met three core aviation fire safety criteria: no flaming drips that ignite the cotton indicator, a flame length not exceeding 20.32 cm (8 inches), and self-extinguishing within 15 s after flame removal. These results demonstrate that recycled polycarbonate can meet key fire safety standards, supporting its potential for reuse in safety-relevant aircraft applications.

Moreover, collaboration with the seat manufacturer further highlighted the challenge of OEM compliance. Although recycled backrests showed technical potential, OEM material specifications for polycarbonate seat backs remain strict. Nonetheless, recycled material could be repurposed for non-critical parts such as cable plates. These findings stress the need for OEMs to revise material standards and incorporate non-virgin alternatives, particularly under pressure from sustainability-oriented airline partners.

The results of the pilot testing demonstrate that seat backrest recycling is both technically feasible and cost-effective under specific conditions. By managing part collection, cleaning, and logistics internally while collaborating with certified processing and testing partners, airlines could build a closed-loop recycling model aligned with CE principles (Daube et al., 2024; Dias et al., 2022; Guven et al., 2024; Hyvärinen et al., 2023; Van Loon and Van Wassenhove, 2017; Yang et al., 2024). As such, this pilot testing can be considered a crucial step in operationalising circularity in aviation interiors.

While further research and broader certification coverage are needed, this initiative shows clear potential for scale and industry impact. Additionally, addressing OEM resistance and aligning regulatory requirements with material reuse opportunities are key enablers for broader adoption. With sustained effort, this model can drive significant environmental and economic gains while reinforcing the airline's leadership in sustainable aviation.

5. Discussion

Existing CE frameworks provide valuable conceptual foundations for implementing circularity across industrial systems. However, these models remain largely generic and do not consider the safety, certification, and operational constraints that define aviation. Building on these foundations, the decision-tree developed in this paper translates high-level circular principles into component-level decision nodes directly applicable within MRO operations. In this sense, it operationalises the value-retention logic proposed by Ortiz-de-Montellano and van der Meer (2022) but grounds it in empirical evidence from the aviation domain. Furthermore, while Khalifa et al. (2024) highlight the growing importance of circular practices in aviation, their review emphasises the lack of practical frameworks guiding component-level decision-making. This paper addresses this gap by providing an empirically validated tool that links circular principles with real-world recycling decisions for aircraft cabin interiors. Building on this conceptual grounding, the empirical results show the feasibility and strategic value of recycling interior parts in the aviation industry.

The case on recycling polycarbonate shows that the material retains its critical fire resistance properties, meeting aviation safety requirements. This finding aligns with existing studies such as Martínez Leal et al. (2020) and Dolganova et al. (2022), who highlight the importance of material consistency and regulatory compliance in enabling CE adoption in highly regulated sectors. These results support the usability of the framework for recycling aircraft cabin interiors.

From an economic perspective, the findings emphasise the potential of closed-loop recycling systems to reduce costs associated with raw material procurement and waste management. The developed framework facilitates the identification of highly recyclable materials by assessing material compatibility and re-processability. Enhancing the recyclability of aircraft interior parts can reduce dependence on scarce materials and support a more stable, cost-efficient supply chain. This insight supports earlier findings by Hyvärinen et al. (2023), who identify cost savings as a key driver of sustainability transitions in capital-intensive industries. Furthermore, recycling offers a compelling alternative to disposal, as landfill and incineration of aviation materials entail high financial and environmental costs (Elsayed et al., 2019; Keivanpour et al., 2013).

By reprocessing interior parts such as seat backrests, airlines can avoid environmental penalties and align with evolving sustainability regulations, including the Federal Aviation Administration[2] (FAA), guidance promoting recycling and material recovery. This research emphasises the strategic value of localised recycling infrastructure to reduce transport-related emissions and costs, while improving operational turnaround. Establishing regional material recovery hubs enhances supply chain resilience and creates opportunities for secondary markets in recycled aviation-grade plastics, offering airlines potential new revenue streams.

Despite the operational feasibility demonstrated in this research, there are some broader system-level barriers which constrain the adoption of circular recycling practices in aviation. For example, regulatory constraints and OEM requirements remain significant challenges, as current certification standards often mandate the use of virgin materials for safety-critical components. These requirements limit the approval and large-scale integration of recycled materials in aircraft interiors, even when technical performance can be demonstrated. Addressing these barriers will require the development of clearer regulatory pathways and certification frameworks that explicitly support circular innovation while maintaining aviation safety standards.

5.1. *Theoretical contributions*

This research contributes to the growing body of literature on decision-making in implementing CE principles by extending its application into a specific context, e.g. aviation cabin interiors. While previous CE studies have primarily focused on aircraft engines, fuel systems, or high-value technical components, this research shifts the focus toward cabin interior parts, highlighting a new frontier for sustainability innovation in aviation, and offers a practical tool to advance this effort through the developed decision-tree framework.

By integrating material testing, we introduce a multi-method approach to operationalising CE in a highly regulated and safety-critical environment and contribute to theoretical discussions on how CE can be embedded into complex industrial systems where compliance, performance, and cost must be simultaneously balanced. The framework offers a novel, practice-informed contribution to CE literature, showing how structured tools can bridge the gap between strategic vision and operational execution.

Moreover, the findings advance our understanding of the socio-technical enablers and barriers to circularity, highlighting the role of workforce knowledge, OEM influence, and local infrastructure, factors often overlooked in CE theory. These findings offer a more holistic understanding of CE implementation by emphasising not only material flows and design but also human behaviour, organisational culture, and ecosystem collaboration. In fact, we demonstrate that circularity is both a material and institutional transformation by showing that the recyclability potential of aircraft interior parts can be scaled beyond pilot projects into systemic change, enriching theoretical debates on sustainable innovation, systems thinking, and cross-sector integration.

5.2. *Practical implications*

A practical contribution of this research is the application of a decision-tree framework for assessing and evaluating the recyclability of cabin interior parts. This framework provides practitioners with a clear, structured pathway to assess the recycling potential of each cabin interior part. The questions formulated in the framework guide practitioners and decision-makers through key considerations, such as cost-effectiveness, material composition, and repair frequency. This enables practitioners to make informed decisions about which parts can feasibly be recycled. With its simple design and clear language, the framework is intended for easy application across departments, supporting and fostering interdepartmental knowledge sharing.

Additionally, this framework supports data-driven decision-making by systematically evaluating key criteria such as repair frequency, cost thresholds, material composition, and certification feasibility against recycling requirements. In doing so, it simplifies complex evaluations and promotes consistency across departments. Furthermore, the flexibility of the framework enables customisation for various cabin interior parts and operational contexts. This adaptability supports faster implementation of recycling principles and allows for tailored engagement with suppliers and regulators. By offering a transparent, structured process, the framework improves interdepartmental coordination and external stakeholder collaboration, essential for scaling circular initiatives within a highly networked industry.

Moreover, the implementation of the framework into recycling practices of aircraft cabin parts supports cost reduction and enhances supply chain resilience. By recovering and reusing materials, airlines can reduce their dependence on volatile raw material markets and lower waste management expenses. Additionally, our suggestion to develop local recycling networks and closed-loop systems highlight the potential for operational efficiency and long-term cost stability in aviation. The case company's circular approach could serve as a practical model for integrating sustainability with business performance. The findings also show CE decision-making in aviation offers tangible benefits for airlines, positioning them as leaders in sustainable aviation.

The case company's proactive adoption of CE principles such as recycling polycarbonate and implementing structured decision-making, signals a strategic commitment to innovation and environmental responsibility. Aviation companies could gain competitive advantages, including strengthened stakeholder trust, improved customer loyalty, and increased regulatory alignment. CE is not only an environmental necessity but also a strategic opportunity, showing how innovation and responsibility can converge to drive competitive and sustainable growth in the aviation industry. In an era where passengers and corporate clients are prioritising environmental performance, sustainable practices could make an airline a preferred choice for eco-conscious passengers. Still, alignment with global goals such as the Paris Agreement and the European Green Deal enhances the potential to participate in public-private partnerships and regulatory incentives aimed at decarbonising aviation.

5.3. *Limitations*

While this research provides valuable insights into decision-making for recycling aircraft cabin interiors, several limitations should be acknowledged. First, the decision-tree framework was developed and tested within a single case study and focused specifically on polycarbonate seat backrests, which limits the generalisability of the findings to other cabin interior components and materials.

Future research should apply and validate the framework across a

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[2] https://www.faa.gov/sites/faa.gov/files/airports/resources/publications/reports/RecyclingSynthesis2013.pdf.

broader range of materials and interior parts, particularly those subject to different aviation-specific performance requirements such as toxicity, heat release, and smoke emission.

Second, data availability and traceability within the case company's internal systems constrained the full visibility of component flows. For example, some parts routed through repair facilities were not consistently logged as scrapped, limiting the ability to establish a fully traceable recycling loop. This affected the empirical assessment of material volumes and process continuity.

Third, organisational structures and coordination mechanisms within the case organisation influenced access to information and cross-departmental alignment. While this reflects common challenges in complex MRO environments, it may have shaped the scope and depth of the empirical insights obtained.

6. Conclusion

This research develops a decision-tree framework to embed recycling principles into aircraft cabin interiors, with a particular focus on the recyclability of polycarbonate seat backrests. The decision-tree offers a systematic, practical tool to support recycling decisions, facilitating the operationalisation of CE strategies in the aviation industry and delivering both environmental and economic benefits.

A key contribution of this research is the demonstration of technical feasibility: recycled polycarbonate backrests retained essential properties such as fire resistance and thus passed critical aviation safety tests. This pilot testing marks a significant step towards closed-loop recycling in aircraft cabin interiors.

Beyond feasibility, this research highlights the economic and operational advantages of recycling initiatives. Material recovery can reduce reliance on virgin raw materials, lower disposal costs, and mitigate supply chain disruptions. The integration of the framework into recycling practices further supports practical implementation, guiding practitioners in identifying recyclable parts and prioritising actions aligned with CE goals. By aligning CE principles with regulatory and operational requirements, this research shows that sustainability and compliance are not mutually exclusive but can be jointly achieved.

Moreover, this research shows that integrating CE principles into aircraft cabin interiors is both achievable and beneficial, laying the groundwork for a more sustainable and efficient aviation industry. Through collaborative design, informed material selection, and structured decision-making, circularity can become a practical and scalable solution in even the most highly regulated sectors.

CRediT authorship contribution statement

Shahrokh Nikou: Writing – review & editing, Writing – original draft, Supervision, Investigation, Formal analysis, Conceptualization. **Sicco Santema:** Writing – review & editing.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the author(s) used AI tool in order to check the language, typos, and grammar. After using the tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

Conflict of interest statement

The authors declare that there are no conflicts of interest related to the content of this manuscript. All co-authors have reviewed and approved this statement and confirm their agreement.

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The authors confirm that this manuscript is original, has not been published previously, and is not currently under consideration for publication elsewhere.

Data availability

Data will be made available on request.

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