CIRCULAR ECOSYSTEMS IN THE AEROSPACE SECTOR: A COMPARATIVE ANALYSIS OF BRAZIL AND CANADA

Keywords: circular economy; circular ecosystem; aerospace sector; collaboration; sustainability.

1 INTRODUCTION

The growing environmental crisis has placed unprecedented pressure on industries to reconsider their production and consumption models (Hofmann, 2019). In recent years, the circular economy (CE) has emerged as a prominent alternative to the linear "take–make–dispose" paradigm, offering a systemic approach to reducing waste, regenerating resources, and closing material loops (Barros et al., 2021; Kirchherr et al., 2017). This model emphasizes the creation of value through continuous resource circulation rather than extraction and disposal, and it has been increasingly adopted across multiple sectors of the global economy (Geissdoerfer et al., 2017).

The aerospace sector occupies a unique position in this debate. It is both a symbol of technological advancement and a sector highly dependent on raw materials, energy-intensive production processes, and a globalized supply chain (Bales et al., 2004; Monteiro et al., 2022). Aerospace innovation drives employment and competitiveness, but it also generates significant environmental impacts, particularly in terms of carbon emissions, noise pollution, and end-of-life material waste (Eckelman et al., 2014; Rupcic et al., 2023). The challenge lies in aligning technological progress with sustainability initiatives while responding to international commitments.

Within this scenario, circular ecosystems emerge as collaborative arrangements in which companies, governments, universities, and research institutions come together to foster CE principles (Ferrari et al., 2023; Konietzko et al., 2020). These ecosystems are not isolated initiatives but structured collaborations that aim to generate synergies between diverse actors (Gomes et al., 2024). They provide tangible and intangible resources for accelerating circular practices, as no single firm or institution can effectively transition toward circularity on its own. Instead, it is the interaction between diverse actors that drives innovation, knowledge sharing, and systemic change.

The formation and success of these ecosystems, however, are influenced by regional and institutional contexts. The specific challenges, available resources, and strategic priorities of a country or region shape the nature of the collaborations and the types of circular solutions pursued. Therefore, understanding how these ecosystems function in different national settings is important for developing effective policies and strategies. This study aims to shed light on these dynamics by examining and comparing two distinct circular ecosystems in the aerospace sector: one in Brazil and one in Canada.

2 RESEARCH PROBLEM AND OBJECTIVES

Despite the growing academic and industry interest in the CE, there remains a significant gap in the literature regarding its practical implementation within complex, high-technology sectors like aerospace (Dias et al., 2022). Specifically, the mechanisms and objectives of collaboration between diverse actors to foster circularity in this industry are not well-documented. This leads to several unanswered questions, such as how different types of organizations, from large corporations to government agencies and academic institutions, effectively collaborate to address sustainability challenges.

Consequently, the central research problem for this study is to identify the key actors within these collaborations and understand the specific goals they pursue. The key question this article seeks to answer is: "*Which actors are involved in circular ecosystems in the aerospace sector, and what objectives do they pursue?*" By investigating two distinct national cases, this research aims to provide a comparative perspective on the strategic choices and collaborative models that drive the transition towards CE in the global aerospace industry.

The primary objective of this paper is to evaluate the key collaborations within two circular ecosystem programs in different countries, one in Brazil and one in Canada. This evaluation focus on comparing their innovation priorities, the alignment of their projects with CE principles, and the projected environmental impacts of their initiatives. The comparative analysis aims to identify shared patterns, and context-specific best practices that can be adapted and applied to other regional and industrial contexts. By achieving this objective, the study contributes to the body of knowledge on CE implementation, offering practical insights for policymakers and industry leaders.

3 THEORETICAL FRAMEWORK

CE has been conceptualized as a restorative and regenerative model that seeks to decouple economic growth from resource consumption (MacArthur, 2015). Its guiding principles include minimizing resource inputs, extending product life cycles, and regenerating natural systems (Geissdoerfer et al., 2020). CE emphasizes systemic redesign across the entire value chain, requiring innovation in products, services, processes, and business models (Jesus & Jugend, 2021; Whalen, 2019).

In the context of the aerospace industry, CE translates into several practices. These include the redesign of aircraft components for reduced weight and higher recyclability, the use of advanced composites that can be reused or reprocessed, the remanufacturing of engines and critical parts, and the adoption of propulsion technologies that reduce carbon emissions and noise pollution (Ranasinghe et al., 2019; Sadeghian, 2020). Maintenance and repair practices are also crucial, as they extend product lifespans and reduce the need for virgin materials.

Building on the literature on business ecosystems, circular ecosystems can be defined as collaborative networks of diverse stakeholders who co-create sustainable solutions (Bocken et al., 2019). Moore (1993) describes business ecosystems as interactive economic communities of organizations and individuals. Applied to circularity, these are collaborative arrangements that foster synergy among diverse stakeholders (Bocken et al., 2019). The effectiveness of these ecosystems lies in their ability to bridge gaps in knowledge, technology, and capital. They facilitate the flow of information and resources, enabling the co-creation of innovative solutions that would be difficult for a single company to develop in isolation.

In the aerospace sector, these ecosystems can accelerate the adoption of circular practices through shared research on new materials, development of advanced remanufacturing technologies, and the creation of more robust and localized supply chains for component repair and reuse. Unlike traditional supply chains, which are often linear and hierarchical, ecosystems are non-linear and interdependent, fostering value creation through partnerships and joint experimentation. Adner (2017) emphasizes that ecosystems should be seen as structures that shape strategic outcomes, which in the case of CE means orchestrating multiple actors to align around environmental objectives.

Circular ecosystems also interact with broader policy and governance frameworks. Government incentives, funding mechanisms, and regulatory requirements play a significant role in shaping collaborative dynamics. For instance, public–private partnerships and industry–academia collaborations often emerge as vehicles for experimentation, enabling firms to share risks and access resources that would otherwise be unattainable. Since circular ecosystems pursue collective objectives to advance sustainability-oriented innovation, they can be particularly interesting to the aerospace sector, due to its capital intensity and technological complexity.

4 RESEARCH METHOD

This study adopts a qualitative, exploratory design based on document analysis. Document analysis is particularly appropriate for investigating institutional arrangements and reported outcomes, as it allows researchers to access detailed information produced by the organizations involved while minimizing researcher intervention.

For Ecosystem A, in Brazil, two documents about a specific collaborative program on sustainability were examined. The first is an 18-page case study report produced by a consulting firm participating in the initiative, which provides insights into the implementation and effects of sustainability practices within the program. The second is a 67-page e-book published in 2025, which consolidates the program results and presents both quantitative and qualitative indicators on environmental, social, and governance (ESG) practices. Together, these documents provide a comprehensive overview of the program's design, implementation, and outcomes.

For Ecosystem B, in Canada, twelve official reports about a specific program on the aerospace ecosystem were analyzed, published between 2012 and 2025. These documents together account 379 pages and were issued at different stages of the project's lifecycle. They detail the project's objectives, activities, technological innovations, and environmental results. Importantly, they also outline the participation of different actors and the evolution of collaborative structures over time, which makes them particularly relevant for the purposes of this study.

All documents were read in full and analyzed according to three analytical dimensions: the actors involved in each ecosystem, the collaborations established, and the circularity-related objectives and results. A comparative approach was then applied to identify similarities and divergences between the two ecosystems. By analyzing data from these multiple documents, the study sought to capture the evolution and outcomes of the ecosystems.

While relying on document analysis entails certain limitations, the breadth, depth, and official nature of the reports examined provide a strong foundation for a comparative assessment of the practices implemented across these different contexts.

5 RESULTS AND DISCUSSION

The documentary analysis of the two programs, Ecosystem A (Brazil) and Ecosystem B (Canada), reveals different strategic approaches to fostering CE in the aerospace sector. While both successfully promoted collaboration between diverse actors, their models, priorities, and long-term goals were shaped by their respective national contexts and industrial objectives.

The Canadian program is an example of a long-term, R&D-driven approach to circularity. Launched in 2010 and continuing into three different phases until 2023, its core purpose was to develop cutting-edge technologies and systems to significantly reduce the environmental footprint of aircrafts. Its structure was a consortium involving major aerospace companies, numerous SMEs, universities, the government, and research centers, reflecting a top-down, project-focused model. The first phase of the program alone had a budget of $150 million.

The program's sub-projects focused on foundational technological advancements. These included developing composite airframe structures, next-generation compressors, and advanced avionics. As the program evolved through its different phases, it tackled new challenges through projects like the development of a hybrid propulsion system, intelligent wings for eco-navigation, and high-reliability photonic modules. The collaborations were highly structured and aimed at achieving specific technological gains. A dedicated “environmental gains committee”, composed of experts from each partner, was established to develop performance indicators and measure the environmental benefits of the new systems throughout their lifecycle. This model successfully led to tangible outcomes, including new patents and the creation of high-quality jobs for researchers and engineers. The program’s goals were not only to create environmental benefits like reduced fuel consumption and resource preservation but also to maintain the region's competitive edge in the global aerospace market.

In contrast, the Brazilian program focused on building operational capacity and implementing sustainable practices within the existing local aerospace ecosystem. This ecosystem involved a governmental agency, a technology park, and two private consulting institution, targeting ten SMEs that supply a major aerospace company. The program was short-term and aimed at engaging and training these companies to adopt ESG (Environmental, Social, and Governance) practices.

The methodology of this program was centered on providing personalized diagnostics and practical training to help companies identify opportunities for improvement and implement tangible actions. The program's objectives were about enhancing operational efficiency, such as waste reduction and material reuse, and fostering a cultural transformation toward sustainability. The collaboration model was less about co-developing new technologies and more about knowledge transfer and support for practical implementation. The success of this program was measured by the companies' progress in integrating sustainable practices, which led to measurable improvements in waste management and resource efficiency.

The comparative analysis between the two cases reveals a clear strategic divergence. Ecosystem B in Canada pursued a proactive, innovation-centric strategy. By investing heavily in multi-phase R&D projects, it aimed to create a new generation of aerospace technologies that would reduce environmental impact from the design stage. This approach is well-suited for a mature, high-tech industry seeking for a global leadership position.

Ecosystem A in Brazil, however, adopted a reactive, implementation-centric strategy. Its focus was on strengthening the existing supply chain by providing the tools and knowledge necessary for SMEs to meet sustainability requirements. This model is effective for an emerging aerospace ecosystem that needs to elevate the standards of its local partners to build more resilient collaboration toward CE goals.

These differences reflect the unique industrial and institutional contexts of each country. The Canadian model, with strong public funding for large-scale research projects, enables a focus on high-risk, high-reward technological innovation. The Brazilian model, prioritizing economic development and local industry growth, opted for a practical and immediate approach that can be implemented across a broad range of companies. Both models, while different in their execution, underscore the role of collaboration in advancing circularity within the aerospace sector.

6 FINAL CONSIDERATIONS

The comparative analysis of the two ecosystems in the aerospace sector provides evidence that the approach to fostering CE is highly context-dependent. It is a strategic choice shaped by national policies, industrial maturity, and regional priorities. While Ecosystem B (Canada) demonstrated a successful model for driving innovation through long-term, collaborative R&D, positioning its industry at the technological forefront, Ecosystem A (Brazil) showcased an effective model for building capacity and operational efficiency within the local supply chain.

These findings contribute to the broader discourse on CE implementation, illustrating how different collaborative mechanisms can lead to valuable, though distinct, outcomes. The study highlights the importance of a coordinated effort among diverse actors to address the complex challenges of sustainability in a high-tech sector. The articulation of these ecosystems, whether driven by a focus on technological breakthroughs or by a commitment to industrial adaptation, is a key determinant of success.

The insights from this comparative study can inform the design of future sustainability programs in the aerospace and other complex industries. For policymakers, the study suggests that a deep understanding of the local context is essential before designing a CE strategy. For industry leaders, it underscores that collaboration is a necessary condition for achieving meaningful progress towards sustainability. Ultimately, the successful transition to CE in the aerospace sector depends on the ability of diverse actors to work together, leveraging their tangible and intangible resources to create shared environmental and economic value.

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